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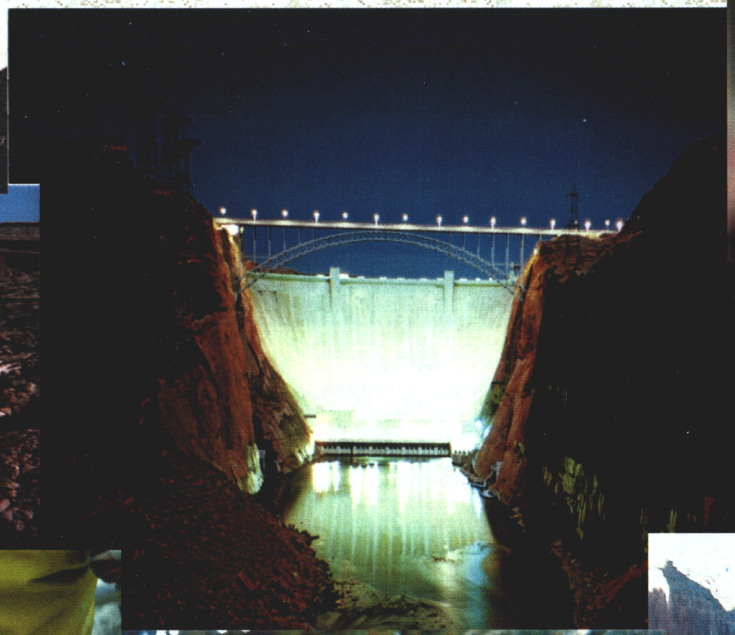
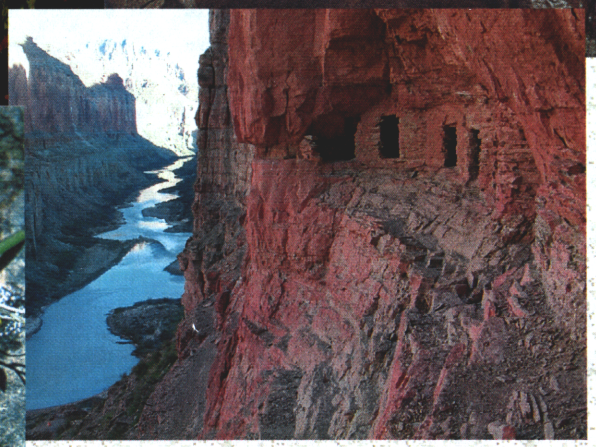
# Grand Canyon Monitoring and Research Center

## Science Advisors River Trip

## Briefing Book

## Sept. 29 – Oct. 8, 2001





USGS
science for a changing world

Note: River trip was originally scheduled for Sept/Oct 2001. Postponed due to 9/11/01 event.
This trip actually took place April 6-13, 2002 (same briefing book used.)

## Purpose and Layout of this Booklet

The intent of this booklet is to provide an overview of the programs currently funded through Grand Canyon Monitoring and Research Center (GCMRC), the mechanisms at hand at GCMRC to facilitate data collection, management and delivery, and an idea of the processes involved in data collection associated with resource monitoring.

As you travel downstream, you will be exposed to sites that are associated with different monitoring or research projects. The staff from GCMRC will be on hand to provide you information about the research, but you are encouraged to read the summary documents for a better understanding of the overall goals of the monitoring or research projects. By doing so, you will gain a better understanding of why particular areas in the Grand Canyon may be monitored more intensively than others.

As you float down the river, you should also remember to have fun, relax and enjoy yourself, and remember that the AMP was established as a consensus-based program to study the "...effects of the Secretary's actions" on the downstream resources. The intent is that managers could use this information to recommend appropriate changes in dam operations, if needed.

## Acknowledgements

Many thanks to Carol "Fritz" Fritzinger (GCMRC Logistics Coordinator), and Jacob "Jake" Tiegs (GCMRC Warehouse Tech) for handling the logistics and gear needs of this trip. Also, thanks in advance to the Humphrey Summit Support crew: Jeff Behan, Kirk Burnett, Steve Jones, Lynn Roeder, Rachel Schmidt, and Harlan Taney for getting us down the river safely and cooking up some great meals.

Photo credits include: Helen Yard (Flycatcher), Bill Vernieu (Anasazi Granary), Larry Stevens (Kanab Ambersnail), Lisa Kearsley (beaches). Other photographs were obtained from GCMRC holdings.

# Science Advisors River Trip
# Briefing Book

## Table of Contents

**Purpose and Layout of Book**

**SECTION 1: TRIP AGENDA and OVERVIEW**
- A. Participant List
- B. Daily Agenda
- C. Archaeological Site Etiquette & Information

**SECTION 2: BACKGROUND**
- A. A Brief History of the Colorado River Ecosystem
- B. History of Dam-Related Science in the Grand Canyon
- C. GCDAMP and the GCMRC Program
- D. GCMRC Mission Statement
- E. Program Activities
- F. Library Overview

**SECTION 3: BRIEFING PAPERS**
- A. Terrestrial Ecosystem Activities
- B. Aquatic Ecosystem Activities
- C. Integrated Terrestrial and Aquatic Ecosystem Activities
- D. Information Technology

**SECTION 4: STRATEGIC PLANNING**
- A. AMP Strategic Plan, Mission, Vision, Goals and Objectives
- B. Information Needs
- C. AMP Narrative of Desired Future Resource Conditions

*Cover Photos (clockwise from top left): Owl Eyes – before 1996 BHBF (RM 134.6L); Southwestern Willow Flycatcher; Humpback Chub; Anasazi Granary; Kanab Ambersnail; Rainbow Trout; Owl Eyes – after 1996 BHBF; Glen Canyon Dam*

# Section 1
# Trip Agenda and Overview

# PARTICIPANT LIST

## GCMRC SCIENCE ADVISORS – 2001

DR. JILL S. BARON (Riparian Ecology) – US GEOLOGICAL SURVEY, BRD

DR. VIRGINIA H. DALE (Statistics) – OAK RIDGE NATIONAL LABORATORY

DR. LANCE H. GUNDERSON (Adaptive Management) – EMORY UNIVERSITY

DR. DAVID HULSE (Geographic Information Systems) – UNIVERSITY OF OREGON

DR. JAMES F. KITCHELL (Fisheries) – UNIVERSITY OF WISCONSIN

DR. JOHN B. LOOMIS (Socio-Economics) – COLORADO STATE UNIVERSITY

DR. RANDOLPH S. PARKER (Hydrology) – U.S. GEOLOGICAL SURVEY, WRD

DR. DALE M. ROBERTSON (Limnology) – U.S. GEOLOGICAL SURVEY, WRD

DR. DOUGLAS W. SCHWARTZ (Archaeology) – SCHOOL OF AMERICAN RESEARCH

DR. JOE WATKINS (Anthropology) – BUREAU OF INDIAN AFFAIRS

**Currently Unassigned Resource Areas:**

**Aquatic Ecology**

**Geomorphology**

**Science Advisors Resource Orientation River Trip**
**September 26 - October 8, 2001**

**Daily Agenda**

**Tuesday, 9/25**

| | |
|---|---|
| A.M. - 8:00: | Crew loads gear at GCMRC warehouse |
| P.M. - 12:00: | Truck departs for Lee's Ferry to rig boats |

*(Participants starting the trip at Lee's Ferry arrive in Flagstaff, spend the night at Amerisuites)

**Wednesday, 9/26**

| | |
|---|---|
| A.M. - *6:00: | Participants starting the trip at Lee's Ferry leave Flagstaff in van (pick-up at Amerisuites) |
| *8:30: | Van arrives at Lee's Ferry, finish loading boats |
| 9:00: | Boats depart downriver |
| P.M. - 12:00: | Lunch |
| 5:30: | Arrive at camp (North Canyon - 24 ½ Mile) |
| 6:30: | Dinner |
| 7:30: | Evening discussion around the campfire |

**Thursday, 9/27**

| | |
|---|---|
| A.M. - 6:00: | Coffee |
| 6:30: | Breakfast |
| 7:30: | Boats depart downriver |
| P.M. - 12:00: | Lunch |
| 5:30: | Arrive at camp (Buck Farm - Saddle Canyon) |
| 6:30: | Dinner |
| 7:30: | Evening discussion around the campfire |

*schedule for participants starting trip at Lee's Ferry
**schedule for participants starting trip at LCR

**Friday, 9/28**

| | |
|---|---|
| A.M. - 6:00: | Coffee |
| 6:30: | Breakfast |
| 7:30: | Boats depart downriver |
| P.M. - 12:00: | Lunch |
| 5:30: | Arrive at camp (LCR - 60 Mile) |
| 6:30 | Dinner |
| 7:30: | Evening discussion around the campfire |

**(participants starting the trip at LCR arrive in Flagstaff, dinner on your own, spend the night at Amerisuites)

**Saturday, 9/29**

| | |
|---|---|
| A.M. - 6:00: | Coffee |
| **6:00: | Vans pick up participants starting the trip at LCR at Amerisuites<br>Drive to Salt Trailhead (continental breakfast in vans) |
| 6:30: | Breakfast |
| 7:30: | Boats depart downriver (to LCR) |
| **8:00: | Helicopter meets vans at Salt Trailhead for shuttle to Boulders Camp on LCR |
| **10:00: | All participants shuttled to Boulders Camp, hike to confluence to meet boats |
| 10:00: | Discussions at LCR: Native Fish, Tribal Perspectives, Tributary Debris Flows in LCR and Access to Spawning Habitat |
| P.M. - 12:00: | Lunch at LCR |
| 12:30: | Continue Discussions at LCR if more time is needed |
| 2:00: | Depart downriver for Palisades |
| 2:30-4:30 | Discussions at Palisades: Erosion and Mitigation, Arroyo Cutting, Cultural Sites and the Possible Effects of a BHBF |
| 4:30: | Depart downriver |
| 5:00: | Arrive at camp (Palisades -Tanner) |
| 5:30: | River/Camp Orientation |
| 6:30: | Dinner |
| 7:30: | Evening discussion around the campfire: Sediment Storage and Budget |

*schedule for participants starting trip at Lee's Ferry
**schedule for participants starting trip at LCR

**Tuesday 10/2**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart Downstream |
| | 10:15-11:00: | Shinumo Creek |
| P.M. - | 12-12:30: | Lunch |
| | 2:00-3:30: | Elves Chasm, discuss Kanab Ambersnail |
| | 5:00-5:30: | Arrive at camp (Forester) |
| | 6:30: | Dinner |
| | 7:30: | Evening Discussion around the campfire: Vegetation/Integrated Terrestrial Resource Monitoring, Channel Margin Surveys |

**Wednesday, 10/3**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart downstream |
| | 10:30: | Randy's Rock, Discussion: Humpback Chub Issues |
| P.M. - | 12-12:30: | Lunch at Stone Creek |
| | 1:00-3:00: | Tapeats Creek |
| | 5:00-5:30: | Arrive at camp (Owl Eyes) |
| | 6:30: | Dinner |
| | 7:30: | Evening discussion around the campfire: Experimental Flows |

**Thursday 10/4**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart downstream |
| P.M. - | 12:00-3:30: | Lunch at Kanab Creek, discussion: Native Fish and Aquatic Foodbase |
| | 3:30: | Depart downstream |
| | 5:00-5:30: | Arrive at camp (Ledges) |
| | 6:30: | Dinner |
| | 7:30: | Evening discussion around the campfire: Native Fish |

**Sunday, 9/30**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart downstream |
| | 10:30-11:00 | Discussion at Cardenas: Remote Sensing |
| | 11:00: | Depart downstream |
| | 11:30-2:30: | Lunch and Tour of Unkar Delta |
| P.M. - | 2:30: | Depart downriver |
| | 5:00-5:30: | Arrive at camp (Grapevine - Cremation) |
| | 6:30: | Dinner |
| | 7:30: | Evening Discussion around the campfire: Remote Sensing |

**Monday, 10/1**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 7:30: | Early departure for Phantom Ranch |
| | 9:00: | Arrive Phantom Ranch |
| | 9-11:30: | Discussion: Brown Trout and Native vs. Non-native Issues at Bright Angel Creek |
| | 11:30: | Depart downstream |
| P.M. - | 12-12:30: | Lunch |
| | 5:00-5:30: | Arrive camp (Bass - 110 Mile) |
| | 6:30: | Dinner |
| | 7:30: | Evening Discussion around the campfire: Camping Beaches and Recreational Issues |

**Friday 10/5**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart downstream |
| | 11:30-2:30: | Lunch and hiking at Havasu |
| P.M. - | 2:30: | Depart downstream |
| | 5:00-5:30: | Arrive at camp (Fern Glen) |
| | 6:30: | Dinner |
| | 7:30: | Free social evening around the campfire |

**Saturday, 10/6**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart downstream |
| P.M. - | 12:00-1:00: | Scout, run, pictures at Lava Falls |
| | 1:00-2:00: | Lunch below Lava Falls |
| | 2:00: | Depart downstream |
| | 5:00-5:30: | Arrive camp (194 Mile) |
| | 6:30: | Dinner |
| | 7:30: | Evening discussion around the campfire: Debris Flows, Integration and Ecosystem Science Perspectives |

**Sunday, 10/7**

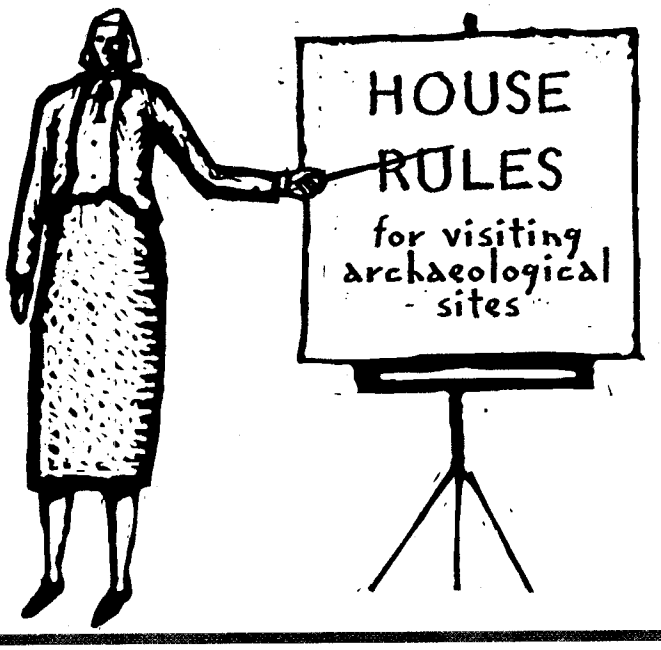
| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 8:00: | Morning discussion (optional) |
| | 10:00: | Depart downstream |
| P.M. - | 12-12:30: | Lunch (Goodding's Willow, 209 Mile) Discussion: Traditional Cultural Properties (TCPs); Co-management of Resources |
| | 5:30: | Arrive camp (220 Mile) |
| | 6:30: | Dinner |
| | 7:30: | Closing Comments and discussion around the campfire: AMP Process, Strategic and Science Planning, Adaptive Management |

**Monday, 10/8**

| | | |
|---|---|---|
| A.M. - | 6:00: | Coffee |
| | 6:30: | Breakfast (packed black bags required) |
| | 7:30: | Depart for Diamond Creek |
| | 9:00: | Arrive at Diamond Creek, Take-out vehicles meet trip, unload and de-rig Boats, load trucks |
| | 11:30-12:00: | Lunch @ Diamond Creek |
| P.M. - | 12:00: | Depart Diamond Creek |
| | 3:00: | Arrive Flagstaff, clean-up trip at GCMRC Warehouse |

# VISITING ARCHAEOLOGICAL SITES

## at Grand Canyon National Park




As you hike in the Grand Canyon you may be lucky enough to come across remnants of cultures from long ago. You may see evidence left by people early in this century, miners perhaps, or remnants of prehistoric and historic Native American inhabitants, dwellings for example, or pictographs, petroglyphs, and potsherds.

These ruins and artifacts are a precious legacy. It is the mission of the National Park Service to preserve these special places. You can help us by observing our House Rules.

Thank you! The Management

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**1. Keep your feet off the furniture.**

Due to their age, archaeological sites are very fragile. Walls crumble and topple easily. Walk carefully and avoid stepping on walls, artifacts, and easily eroded slopes.

**2. Don't eat in the living room.**

Avoid picnicking in archaeological sites. Crumbs attract rodents who may then nest in the site. Pick up and carry out all of your trash and garbage.

**3. No slumber parties.**

Do not camp in ruins or on archaeological sites. These sites are extremely fragile. Your inadvertant activities will damage these wondrous places.

**4. Don't touch the paintings.**

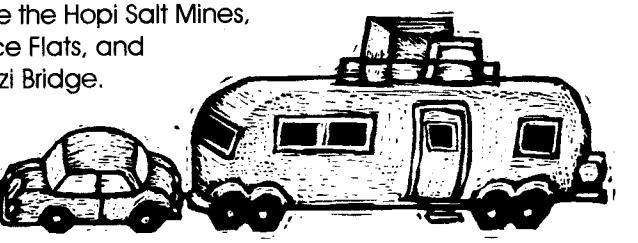
Oils from human skin damage pictographs and petroglyphs. Never deface this artwork by adding your own. These irreplaceable masterpieces are easily destroyed. (And besides that, it's illegal!).

**5. Don't pee in the parlor—or any other room.**

Pa-leese! I mean really! Why would anyone think this was acceptable behavoir? Your mom would be REALLY mad if you did this at home.

**6. Don't go if you're not invited.**

Due to their extreme fragility and their importance to Native Americans, a number of archaeological sites along the Colorado River are closed to visitation. These include the Hopi Salt Mines, Furnace Flats, and Anasazi Bridge.



**7. Don't rearrange the furniture or mess with the knicknacks.**

Leave everything right where you found it. Out of context, artifacts mean little to archaeologists. Leave artifacts for others to enjoy just as you have. (Remember, it's illegal to collect any artifact or natural object from a National Park. And we wouldn't want you to get in trouble with your mom.)

**8. Tell mom if you see anything wrong.**

Contact a ranger if you find archaeological sites defaced or if you witness someone removing artifacts. Call (520)-638-7767 to report an incident.

# NOTES ON CULTURE AND HISTORY ALONG THE COLORADO RIVER THROUGH GRAND CANYON

| Mile | Comments |
|---|---|
| 0 | Lees Ferry Historic District; site of original ferry crossing - 2 sites, upriver during high water, downriver during low water (winter). Numerous buildings reflect many different uses from a trading post (referred to as Lees Fort) to USGS buildings (mainly from the 1920's). Upstream and underwater are the remains of the Charles Spencer, the only boat in Arizona listed on the National Register. This area is administered by Glen Canyon NRA. GRCA begins at the confluence of the Colorado River and the Paria.<br><br>Just downstream of the launch ramp, note the cable across the river. It marks the official dividing line between the Upper and Lower basins for water allocations.<br><br>River left, at the rim, is Navajo Nation land (DOI and Navajo have ongoing dispute as to the location of the boundary). |
| 12 | Just below Soap Creek on the left, at Salt Water Wash, is a small inscription pecked into the rock face just above the river in a small eddy. The inscription reads: FMBrown, Pres DCC&PRR was drowned, July 10 1889 opposite this point. Frank Mason Brown, President, Denver Colorado Canyon and Pacific Railroad Company, ... Brown was the financier for an ill-fated expedition directed by Robert Brewster Stanton who was surveying for the construction of a railroad along the river. The man who carved the epitaph, Peter Hansbrough, drowned 2 days later, with Henry Richards, in 25-Mile rapid. |
| 31.5 | South Canyon: Series of Puebloan ruins on terrace above river. Rooms first noted in 1953 by Walter Taylor. Occupation ca. A.D. 800 - 1050. One large ss boulder containing numerous petroglyphs adjacent to largest habitation room. Many of the glyphs are recognizable as Hopi clan symbols. Trails lead visitors to most of the rooms. Access onto limestone terrace is through notches in 2 separate locations. Just look for footprints up through the sand (or mud). The skeleton shown in the river guide was likely an Anglo. The skull was taken in 1934; other parts taken over the years so that virtually nothing remains. |

Just downstream of South Canyon is Stanton's Cave, famous for considerable research conducted on the split-twig figurines. The figurines, dates ca. 2500 B.C., were found in this cave, and many others in the Redwall limestone throughout the park. Excavations in the 1960's by RC Euler recover over 100 figurines, primarily on the surface of the cave. Under the surface, however, were the remains of driftwood and extinct animal bones dated to 43,000 BP. The cave is called Stanton's Cave because Stanton purportedly hauled his boats and equipment up into the cave after the first 3 men died on his 1889 trip. He returned to the canyon in early 1890 to resume his survey efforts.

32 Vasey's Paradise, a spring which flows out from the Redwall. Watch out for poison ivy. Also an endangered snail lives here so stay at river level. Vasey's shows up in Hopi history as the place the Spanish priests forced some Hopi men to travel to for fresh water.

40 Marble Canyon Dam site: the beginning of the modern environmental movement after the loss of Glen Canyon and the saving of Echo Park. One of the few places Reclamation planned to build a dam and didn't. Everything you have come through would have been underwater had the dam been built.

43 Look high up on the right for the remains of a wooden bridge across a crevice in the limestone. Part of a cross-canyon route. The bridge is made of driftwood logs of cottonwood, C-14 dates 770/850 AD. Sites located across from the bridge on river left at the talus top and above the bridge along the route to the top of the Redwall. The route on the other side of the river is through Eminence Break, located just downstream on river left.

43.8 Two Anglo graves located on beach just below rapid on left; Peter Hansbrough of the Stanton survey and a boy scout, David Quigley, who drowned in Glen Canyon in 1951. Why both bodies washed up here is a mystery.

52 Nankoweap, one of the most beautiful places along the river. Considerable Puebloan occupation, PI-PII, both on the delta and up the canyon all the way to the North Rim. The view from the granaries is spectacular. They have been stabilized; one room rebuilt after visitors destroyed the front wall in 1980.

56 Kwagunt, another lovely place. A fault, the Butte fault, connects Nanko and Kwagunt up the drainage. Great place to live 1000 years ago. Both places named for Paiutes by John Wesley Powell.

61.5 Little Colorado; TCP for Hopi, Zuni and Navajo for various reasons. The Hopi place of emergence, the Sipapu, is located 5 miles up the LCR. They believe that not only did they as a people emerge from the Sipapu, but their spirits return there upon death. Also, part of the migration path to the Salt Mines, located just downstream on river left.

For the Navajo, the confluence represents the joining of the sacred male and female beings that mark the boundary of Navajo ancestral lands.

For Zuni, the rivers, along with the Zuni River, form an umbilical cord which connects them to their place of origin.

Just upstream on the leftbank of the LCR is a stone cabin attributed to a miner named Ben Beamer. The cabin is built of materials from an earlier dwelling, which is built on a midden which dates back to the Archaic. Over 2 meters of midden exist underneath the cabin. You'll note considerable manipulation of the trails and erosion channels in an attempt to preserve the deposits. Faint pictographs visible on cliff/overhang on downstream side of cabin.

64.5-65.5 Carbon Creek to Lava Canyon; really nice hike up one canyon and down the other. Connected by the Butte fault. Really interesting geology.

65.5 Palisades Delta; Remains of the Tanner-McCormick mine visible from the river (tailings); old cabin site also. Very fragile sediment deposits.

71 Cardenas Creek/Camp; high on the ridge above the camp is a structure referred to as Stanton's Fort or Cardenas Fort (AZ C:13:2). First photographed by Stanton in 1890, the structure has been interpreted by Hopi as a men's society room. No archeo-astronomy at the site (we've checked). The few sherds located suggest A.D.1175 date.

72.5 Unkar Delta (see brochure)

76.5 Hance! Big ride and the beginning of the gorge. Note the fire damage on the terrace above the river from a campers fire this past May. We lost

most of the original Hance camp. Hance also had an asbestos mine just downstream and up; you can see the tailings from the river.

87.5 Just above the boat beach at Phantom, Bright Angel Site, excavated by School of American Research in late 1960's. See wayside exhibit. Lots of archaeology up Bright Angel Canyon up to the North Rim, primarily Puebloan (PII).

107.4 On river left, remains of metal boat, the Ross Wheeler, abandoned in 1915. We had to chain it to the rocks after someone tried to steal it about 8 years ago. Downstream, on river left, you can see the remains of the original cable car Bass had across the river which delivered his tourists from the south side to the north side. See photo of the hanging horse in the Belknap guide.

108.5 Shinumo Creek enters just downstream of the camp. The terraces above the camp contain numerous archaeological sites, all probably connected with the occupation sites in the creek and up to the North Rim. Additionally, the terrace above the river was to be the switchyard for Stanton's railroad. Also, Wm Wallace Bass had a tourist camp up the drainage, most of the remnants are still visible a few miles up Shinumo Creek. Great place for a layover so you can dayhike in Shinumo (the North Bass trail). Trails lead from the camp up and over the ridgeline into the drainage. Bass also had an asbestos mine in the next canyon downstream (Hakatai).

116.5 Elves Chasm; beautiful waterfall and pools

120 Blacktail; beautiful, quiet slot style canyon

132 Stone Creek, just below Deubendorf rapid on the right. Lovely side canyon with 4 main water falls. Great place for a layover.

133.8 Tapeats Creek; nice hike up to Thunder River. Lots of water and you can hike all the way to Deer Creek if you want across Suprise Valley.

136.3 Deer Creek; great hike up above the falls; watch out for the poison ivy (you'll see it). Once on top of the Tapeats ss, the trail will take you into Deer Creek narrows. Watch for hand-prints, both positives and negatives, along the cliff on both sides of the drainage. Once the canyon opens up above the "jacuzzi", no more prints. Nice hike up to the spring also.

| | |
|---|---|
| 148 | Matkatamiba Canyon; if you can get in, well worth it. Quiet, fluted, etc... |
| 156.5 | Havasu. Worth the stop even if lots of boats there. |
| 178 | Vulcan's Anvil; basalt plug that sticks up from the river is considered to be sacred to Hualapai and Southern Paiute. Just above Lava Falls |
| 188 | River right, pictographs at talus top just above river along with historic graffiti from the dam building era (Bridge Canyon Dam). |

Culture and History Notes courtesy of: Jan R. Balsom
Cultural Resource Manager
Grand Canyon National Park

# Section 2
# Background

# A BRIEF HISTORY OF THE COLORADO RIVER ECOSYSTEM

**Lawrence E. Stevens**

## Geography and Impoundment History

The Colorado River is the primary river system in the American Southwest, draining one twelfth of the coterminous United States. It has the highest ratio of reservoir storage to mean annual flow of any large river basin in North America, making it one of the most thoroughly controlled American rivers. It is dammed by more than 40 large flow regulation structures. The river flows 472 km through northern Arizona between Glen Canyon Dam and Lake Mead, including lower Glen Canyon and all of Grand Canyon. River locations are designated by distance from Lees Ferry, Arizona (river kilometer, km 0), which lies 24.5 km downstream from the dam. The river descends from an elevation of 947 m at Lees Ferry to 404 m elevation at Diamond Creek (km 363), with a mean gradient of 1.52 m/km and with most of its descent occurring in more than 165 whitewater rapids. The river is deeply incised into the uplifted Colorado Plateau, and it flows through Sonoran and Mohave desert scrub vegetation. Mean annual precipitation on the canyon floor is 215 mm/yr, bimodally distributed between winter and summer.

## Geomorphology

The Colorado River is a debris fan-dominated river constrained by talus slopes and cliffs of Proterozoic and Paleozoic bedrock strata, including resistant sandstones, limestones, igneous and crystalline strata, as well as softer shales and siltstones. Variation in bedrock hardness causes variation in channel width-to-depth ratio, channel slope, and valley width. These characteristics allowed Schmidt and Graf (1990) to divide the Grand Canyon into 11 geomorphic reaches. The characteristic channel unit in eddy-dominated rivers is the debris-fan eddy complex.

Channel width is intermittently narrowed by debris fans, rockfall or landslides, and most of the river's drop in elevation occurs in these sections. Immediately downstream from constrictions, channel width abruptly increases and large recirculating eddies exist. Downstream from this expansion, the channel narrows slightly and depth decreases over a gravel or cobble bar creating distinctive wide-shallow and narrow-deep geomorphic reaches. The uppermost Glen Canyon reach is wide (mean width >85 m); 2 wide and 2 narrow (<85 m wide) reaches occur in Marble Canyon between the Paria River (km 1) and the Little Colorado River (km 98) confluences; and the Grand Canyon section between km 98 and Lake Mead contains 3 wide and 5 narrow reaches. The number of sandbar deposits and fluvial marshes, and the percent cover of soft *versus* firm substrata on the channel bed, are positively correlated with reach width. Debris-fan eddy complexes exist at more than 530 tributary confluences, each creating spatially fixed and geomorphically distinctive pool, riffle and sometimes *return current channel* (RCC; backwater) habitats.

## Fine-grained Alluvial Deposits in Eddy-dominated Rivers

Fine-grained (less than 2 mm) alluvial deposits develop at sites where velocity is lowest, particularly in eddies and at channel margins adjacent to wide, low-gradient reaches. Channel constrictions, especially tributary debris fans, control flow separation and thereby control velocity and fine-grained sediment deposition. As a result, sand bars and other intermittent patches of fine sediment in eddy-dominated rivers do not migrate in the Colorado River as they do in alluvial rivers.

Fine-grained eddy deposits include *separation bars* that form near the upstream end of an eddy, *reattachment bars* that form beneath the primary recirculating eddy cell, and *channel-margin deposits* distributed along through-flowing reaches. The reattachment bar, which is commonly colonized by marsh vegetation, is a sand platform that projects upstream as a spit. The upstream portion of the reattachment bar is separated from the bank by an RCC, a scour feature formed by concentrated, recirculating flow when the bar is inundated. Many reattachment bar platforms are emergent after flood recession, and the RCC becomes an area of stagnant flow. Under normal flows, suspended fine sand and silt derived from tributary flows aggrade in RCC's and are deposited as veneers over coarser mainstream flood deposits. The distribution and characteristics of fine-grained deposits are greatly affected by flow regulation, and sediment transport--including suspended sediment concentrations and particle size distribution.

**The Pre-dam Colorado River**

The unregulated Colorado River was flood-prone, turbid, and warmed during summer. The mean daily pre-dam flow from 1922 through 1962 was 470.4 $m^3/s$, with a mean annual flood peak of 2,450 $m^3/s$, a 10-yr flow return frequency of 3,540 $m^3/s$, an historic peak flow of 8,500 $m^3/s$, and a paleoflood peak flow of 14,000 $m^3/s$. The river transported a highly variable mean sediment load of $6.0 \times 10^{10}$ kg/yr past Lees Ferry and was virtually always turbid. Pre-dam water temperature ranged from freezing in winter to 29.4°C in the summer at Lees Ferry, and the river supported a largely endemic, warm-water fish assemblage. Numerous pre-dam photographs reveal little riparian vegetation and little benthic algal cover on rocks during low flows, suggesting that scouring floods limited the colonization and growth of shoreline vegetation and benthic macroalgae. Virtually no data are available on the fish community structure or benthos in the river prior to impoundment.

**The Post-dam Colorado River**

The 200 m-high Glen Canyon Dam was completed in 1963, creating Lake Powell reservoir and regulating the Colorado River. Lake Powell reservoir is the second largest reservoir in the United States. It is estimated that the reservoir with be filled with sediment in 640 years. Construction of this hypolimnetic release dam did not greatly alter the mean daily flow (412.2 $m^3/s$), but impoundment greatly reduced flood frequency and magnitude, increased hourly varying flow, decreased sediment transport, and created cold-stenothermic conditions. Post-dam river flows from 1965 to 1991 fluctuated widely on an hourly basis but little seasonally. During normal inflow years, the maximum range of daily flows exceeded 750 $m^3/s$ every month of the year. This large range in daily flow approximated the post-dam annual discharge range, and exposed the benthos along the shoreline to daily desiccation. However, flood control has stabilized the river's shorelines, allowing profuse riparian vegetation to develop. This vegetation supports a great diversity of terrestrial vertebrates and invertebrates.

The regulated Colorado River is characterized by "normal flow years" with mean annual flood peaks less than 892 $m^3 \cdot s^{-1}$ and annual flow volumes less than $1.22 \times 10^{10} \cdot m^3$. In "normal flow" years from 1963 to 1991, the range of daily flows sometimes exceeded 790 $m^3 \cdot s^{-1}$ in response to hydroelectric peak power generation, equalling the annual discharge range. Extreme daily discharge fluctuations created "tides" of more than 3 m. Flows two to three times greater than

powerplant capacity, and larger annual flow volumes, have occurred during occasional "high flow" years. In high flow years, instantaneous peak discharge at Lees Ferry typically exceeded powerplant capacity but daily discharge variability decreased. High releases occurred in 1965 and during 5 years after Lake Powell filled (1980), but only in 1983 has an annual post-dam flood peak reached mean pre-dam stage. Flows from 1991 through the present have a daily range restricted to between 6,000 and 8,000 cfs/d, and prescribed annual range of 5,000 to 25,000 cfs.

Impoundment reduced sediment transport at Lees Ferry to <1% of pre-dam levels, and mainstream turbidity is now largely determined by tributary-derived suspended sediment contributions. More than 290 ephemeral and 40 perennial tributaries join the Colorado River in Grand Canyon, but only 6 perennial tributaries have mean flows >1 $m^3/s$. Although the base flow of the Paria River (the most upstream perennial tributary) is only 0.2 $m^3/s$ (<0.002% of the mean mainstream flow), it contributes an average of $2.75 \times 10^6$ metric tons of suspended sediment/yr, with concentrations of up to 780,000 mg/L. The Little Colorado River annually supplies 3 times more suspended sediment than the Paria River, and Kanab Creek (km 230) provides additional sediment in the lower Canyon. Turbid inflow from the Paria River reduces maximum benthic light availability between km 1 and 98 approximately 70% of the time on an erratic, seasonal basis. Cumulatively, the Paria River, Little Colorado River and subsequent tributaries reduce maximum light availability in the middle and lower Grand Canyon 80% of the time.

Sediment retention by Glen Canyon Dam and the locations of sediment-contributing tributaries have created 3 mainstream turbidity segments: the clearwater segment (the Glen Canyon reach) lies between Glen Canyon Dam and the Paria River confluence; the variably turbid segment includes the 4 reaches between the Paria River and the Little Colorado River in Marble Canyon; and 3) the usually turbid middle and lower Grand Canyon segment includes the seven reaches between the Little Colorado River and Diamond Creek.

The mean and annual variability of Colorado River water temperature at Lees Ferry was reduced from a pre-dam annual range of 0 to 29.4°C to 8 to 12 °C today, through hypolimnetic releases.

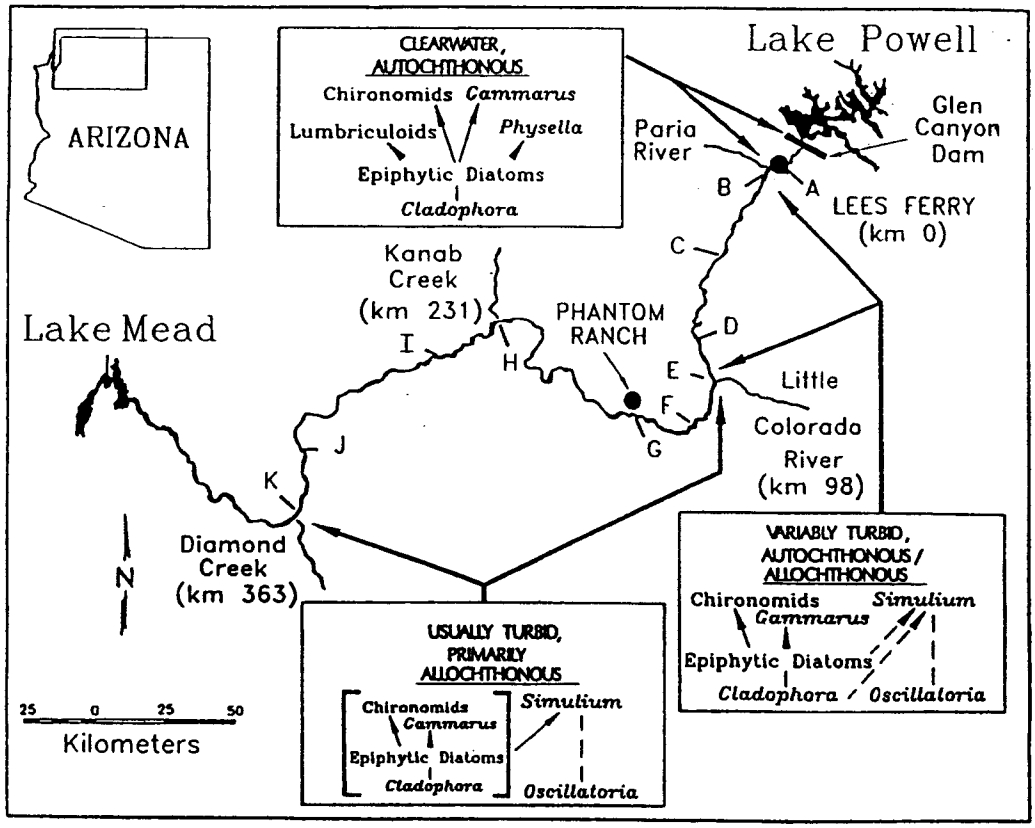
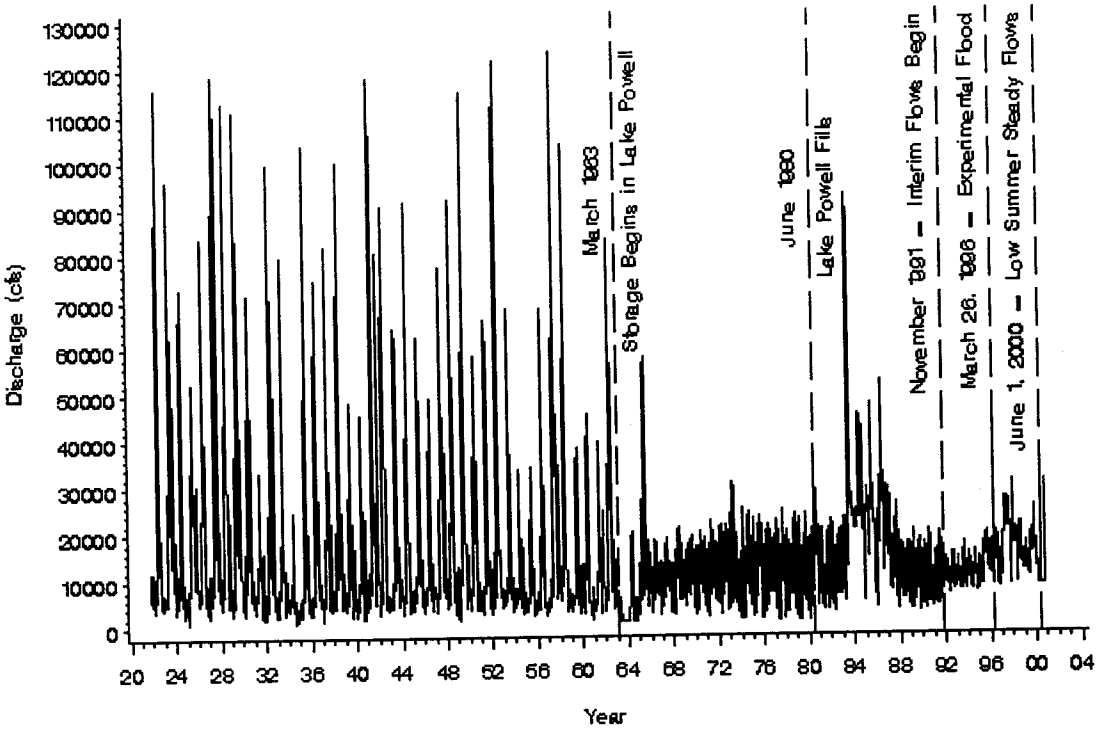



Table 1. Study sites in the Colorado River in the Grand Canyon. Study site letters pertain to Figures 1 and 8. Distance (km) is measured from Lees Ferry, Arizona which lies 24·6 km downstream from Glen Canyon Dam. Turbidity segments include the clear water (CW), variably turbid (VT) and usually turbid (UT) segments. Reach names have been modified from Schmidt and Graf (1990) and reach width was measured at 680 $m^3/s$ by Schmidt and Graf (1990). Sample size is six for all water quality parameters at each site

| Site | Distance from Lees Ferry (km) | Turbidity segment | Reach number (Figure 8) and name | Mean reach width (m) | Elevation (m AMSL) | Mean DO (mg/l) (mg/l; SD) | Mean specific conductivity (μS; SD) | Mean temp. (°C; SD) | Mean pH (SD) | Mean Secchi depth (m; SD) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | CW | 1. Glen Canyon | 85·3 | 947 | 8·1 (1·16) | 0·91 (0·02) | 9·2 (2·20) | 7·7 (0·19) | 5·35 (1·01) |
| B | 3 | VT | 2. Permian Gorge | 70·0 | 940 | 8·3 (1·38) | 0·90 (0·04) | 9·6 (2·17) | 7·8 (0·34) | 4·30 (2·12) |
| C | 50 | VT | 4. Redwall Gorge | 67·1 | 871 | 10·2 (1·18) | 0·79 (0·35) | 10·0 (2·92) | 7·6 (0·47) | 1·02 (1·01) |
| D | 83 | VT | 5. Marble Canyon | 106·7 | 842 | 10·7 (0·66) | 0·92 (0·04) | 10·5 (2·38) | 8·0 (0·26) | 1·05 (1·15) |
| E | 98 | VT | 5. Marble Canyon | 106·7 | 821 | 10·5 (0·42) | 0·94 (0·05) | 10·8 (2·07) | 7·9 (0·28) | 1·38 (1·04) |
| F | 110 | UT | 6. Furnace Flats | 118·9 | 810 | 10·6 (0·82) | 1·00 (0·06) | 10·5 (2·37) | 7·9 (0·21) | 0·97 (1·36) |
| G | 142 | UT | 7. Upper Granite Gorge | 57·9 | 734 | 10·9 (0·20) | 1·02 (0·05) | 10·8 (2·34) | 8·1 (0·13) | 1·15 (1·80) |
| H | 232 | UT | 10. Muav Gorge | 54·9 | 568 | 10·7 (0·77) | 1·01 (0·06) | 11·4 (2·42) | 8·1 (0·13) | 0·37 (0·42) |
| I | 240 | UT | 11. Lower Canyon Reach | 54·9 | 540 | 11·0 (0·77) | 0·99 (0·05) | 10·2 (1·97) | 8·2 (0·12) | 0·15 (0·03) |
| J | 329 | UT | 11. Lower Canyon Reach | 94·5 | 450 | 10·8 (0·28) | 0·98 (0·03) | 11·6 (3·03) | 7·9 (0·30) | 0·85 (0·77) |
| K | 352 | UT | 12. Lower Granite Gorge | 73·2 | 409 | 11·2 (0·37) | 1·00 (0·05) | 12·7 (3·97) | 8·0 (0·23) | 0·20 (0·10) |

# Historical Flows at Lees Ferry




## Recent Glen Canyon Dam Releases

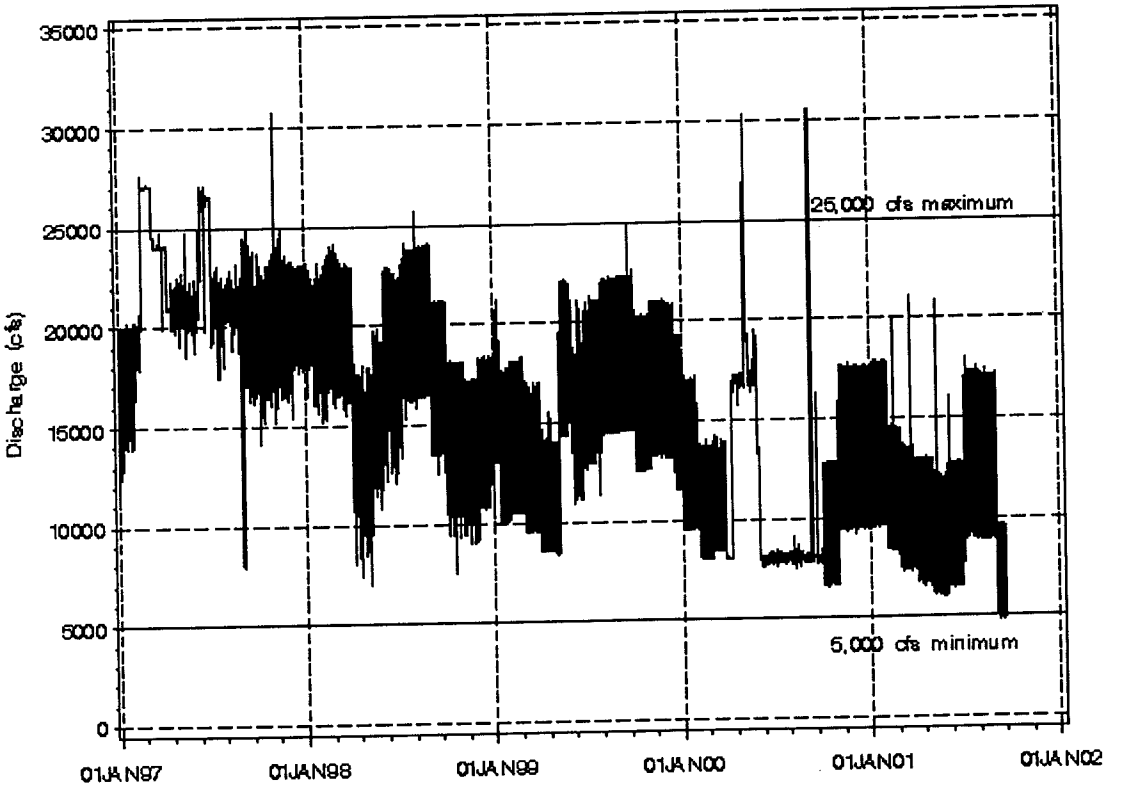


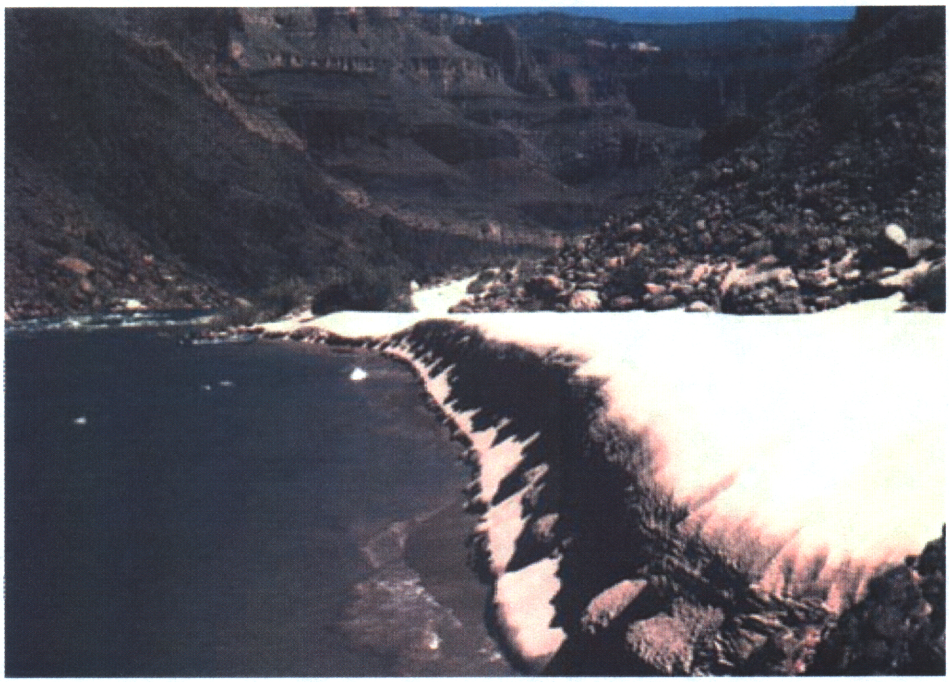
Figure 1. Side canyon flashfloods replenish some of the sediment in the Colorado River through Grand Canyon. (RM14.5.)

Figure 2. Flashflood at 6-Mile Wash.

Figure 3. Flashflood at 6-Mile Wash reaches mainstem Colorado.

Figure 4. Debris fan from flashflood (RM158).

Figures 5 and 6. Owl Eyes camp **before** (3/10/96, above) and **after** (4/28/96, below) the Beach/Habitat Building Flow (BHBF) of 1996.



# HISTORY OF DAM-RELATED SCIENCE IN GRAND CANYON

The Colorado River ecosystem that exists within the scope of monitoring and research for the Grand Canyon Monitoring and Research Center (GCMRC) covers approximately 300 river miles and extends from the fore bay of Glen Canyon Dam to the upper reach of Lake Mead. The environments covered include the aquatic environment, the marsh and riparian communities and the terrestrial communities up to the 300,000 cfs stage line. It is a treasury of unique biological and cultural resources and physical processes.

The ecosystem is known to support more than 200 plant and animal species, including 4 fish species that are endemic to the Colorado River, resident and migratory raptors and waterfowl. The corridor also represents the longest undeveloped stretch of riparian habitat in the United States, further adding to the uniqueness of the river corridor. Historic and cultural sites are found in association with biotic communities and geomorphic structures representing past occupation sites, sites of ceremonial importance, or that represent biological or physical resources traditionally used by the tribes.

Since 1983, the Colorado River ecosystem has been the focus of study relating ecosystem change to the operations of Glen Canyon Dam. The principle concern has been dam operations, and specifically, the effects of high fluctuating daily releases to downstream resources including sediment supply, habitat stability, and cultural resource preservation. The Glen Canyon Environmental Studies Phase I found significant impact on the downstream resources as a result of the high daily fluctuations (up to 25,000 cfs) associated with dam releases.

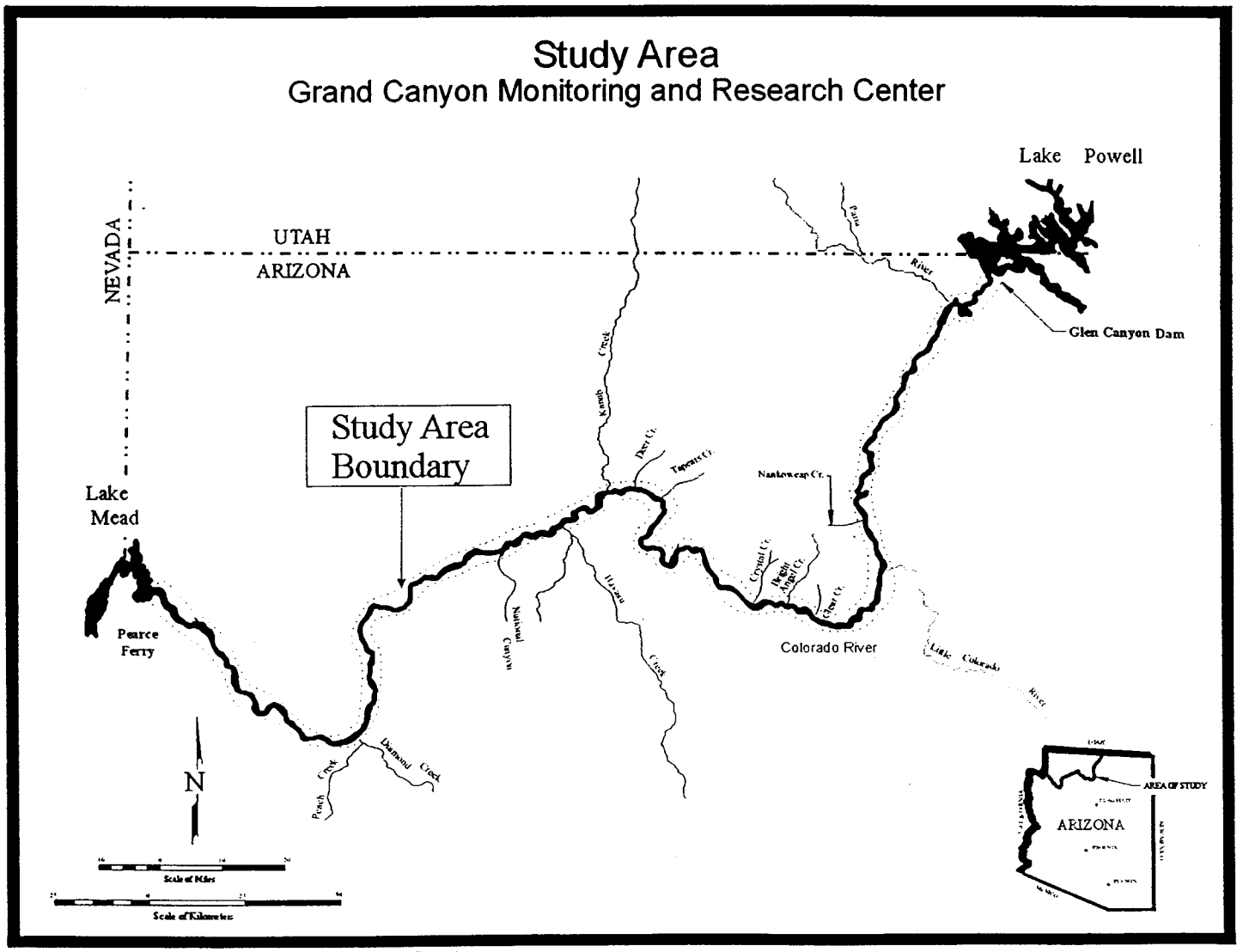
Glen Canyon Environmental Studies (GCES) Phase II (1989-1995) efforts were focused on determining the effects of alternative flow criteria on downstream resources. Associated with this phase was the implementation of research flows in 1990-1991, the signing of the Grand Canyon Protection Act (1992), and the initiation and completion of the Glen Canyon Dam Environmental Impact Statement (1995), and the Beach/Habitat Building Flow in March 1996. These research efforts resulted in the implementation of the modified low fluctuating flow alternative when the Record of Decision was signed by the Secretary of the Interior in May 1996.

Both GCES Phase I and II were programs that were administered by the Bureau of Reclamation. The program was multi-agency in scope, involving tribal, state, federal, university and private interests and investigators. The GCES initiated efforts to develop an integrative science program including geomorphic reach based monitoring sites that included multiple resource monitoring, the development of a GIS database, and the establishment of a library and database to house tabular and hardcopy data.

The record of decision and the GCD-EIS also implemented an Adaptive Management Program for the Colorado River Ecosystem. Included in this program was the institution of a long-term monitoring and research center, called the Grand Canyon Monitoring and Research

Center (GCMRC). The purpose of the GCMRC is to monitor the downstream resources and determine how changes in the quality of these resources may be affected by dam operations. GCMRC is an independent Department of Interior unit that reports directly to the Assistant Secretary for Water and Science. Monitoring and research is funded by the GCMRC through a competitive, peer-reviewed process, with the objective for monitoring projects developed from the stakeholder's management objectives and the Grand Canyon Protection Act. The GCMRC was established in May 1996.

The GCMRC provides information obtained from monitoring and research projects to the Adaptive Management Work Group (AMWG). The AMWG consists of federally appointed representatives of "stakeholders." This "body" uses information provided by the recommendations concerning operations of Glen Canyon Dam to the Secretary for consideration and possible implementation.




Map of Grand Canyon Monitoring and Research Center Study Area

# GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM AND THE GRAND CANYON MONITORING AND RESEARCH CENTER

**Barry Gold**

## Introduction

The Grand Canyon Protection Act of 1992 (GCPA) and the Operation of Glen Canyon Dam – Final Environmental Impact Statement (GCDEIS) directed the Secretary of the Interior to establish and implement long-term monitoring programs and related research and scientific activities that will ensure that GCD is operated in a manner consistent with Section 1802 of the GCPA. The Grand Canyon Monitoring and Research Center was established to facilitate these activities. The mission of the GCMRC is to develop monitoring and research programs and related scientific activities that evaluate short- and long-term impacts of ". . . the effects of the Secretary's actions . . ."[1] on the biological, cultural, and physical resources of the Colorado River ecosystem. The GCMRC is guided in its scientific efforts by the management objectives and information needs specified by the Adaptive Management Work Group (AMWG).

Long-term monitoring of resources of concern has been implemented to detect and quantify changes related to dam operations. Research efforts focus on interpreting and explaining trends, determining causal relationships, and defining inter-relationships among physical, biological and cultural processes. In addition to monitoring and research activities, the GCMRC has developed an information management program to ensure information archiving and transfer to managers, stakeholders, and science organizations.

The physical scope of the research area investigated by the GCMRC is the Colorado River ecosystem, defined as the Colorado River mainstem corridor and associated riparian and terrace zones, located primarily from the forebay of GCD to the western boundary of Grand Canyon National Park, a distance of 293 river miles. The research scope includes limited investigations into some tributaries (e.g., the Little Colorado and Paria Rivers). All projects supported or implemented by GCMRC address determined or potential resource impacts primarily in the Colorado River ecosystem related to dam operations. It also includes, in general, cultural resource impacts of dam operations for inundation levels associated primarily with flows up to approximately 300,000 cubic feet per second (cfs) as addressed in the Programmatic Agreement,[2] and for physical, biological, recreational and other resources, impacts of dam operations for inundation levels associated primarily with flows up to 100,000 cfs. In between these levels, stakeholder concerns with respect to relict vegetation, endangered species, and cultural resources may require activities by the GCMRC.

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[1] As specified in the 1992 Grand Canyon Protection Act, the GCD Environmental Impact Statement (1995), and the Record of Decision (1996). The "Secretary's actions" include dam operations or alternative dam operating criteria as well as other authorized actions; and will be referred to in this document as "dam operations."

[2] The Programmatic Agreement is a legal agreement between federal and state agencies and tribal groups that specifies the responsibilities of the parties to comply with federal historic preservation legislation.

# *GRAND CANYON MONITORING AND RESEARCH CENTER (GCMRC)*

## MISSION

To provide credible, objective scientific information to the Adaptive Management Program on the effects of opening Glen Canyon Dam on the downstream resources of the Colorado River ecosystem, utilizing an ecosystem science approach.

## ROLES AND RESPONSIBILITIES OF GCMRC

1. Advocate quality, objective science and the use of that science in the adaptive management decision process.

2. Provide scientific information for all resources of concern identified in the "Operation of Glen Canyon Dam Final Environmental Impact Statement."

3. Support the Secretary's designee and the Adaptive Management Work Group in a technical advisory role.

4. Develop research designs and proposals for implementing, by GCMRC and/or its contractors, monitoring and research activities in support of information needs identified by the Adaptive Management Work Group.

5. Coordinate review of the monitoring and research program with independent review panel(s).

6. Coordinate, prepare, and distribute technical reports and documentation for review and as final products.

7. Prepare and forward technical management recommendations and annual reports, as specified in Section 1804 of the Grand Canyon Protection Act to the Technical Work Group.

8. Manage all data collected as part of the Adaptive Management Program. Serve as a repository (source of information) for others (stakeholders, students, public, etc.) in various formats (paper, electronic, etc.) about the effects of operating Glen Canyon Dam on the downstream resources of the Colorado River ecosystem and the Adaptive Management Program.

9. Administer research proposals through a competitive contract process, as appropriate.

10. Manage GCMRC finances and personnel efficiently and effectively.

# GCMRC MONITORING AND SCIENCE PROGRAMS

Monitoring and research activities are grouped into terrestrial, aquatic and integrated activities. Remote sensing and information technologies are programs intended to support monitoring and research efforts. Information is provided for resources that have long-term monitoring projects associated with them.

I. TERRESTRIAL ECOSYSTEM ACTIVITIES – terrestrial ecosystem activities include biological and cultural resources, and to some extent, physical resources along the Colorado River ecosystem. For the most part, physical resource data are collected simultaneously for both terrestrial and aquatic resources and appear as integrated activities. Resources of concern with the terrestrial ecosystem are archaeological sites, habitat (vegetation), invertebrates and vertebrates, including socio-cultural components. Long-term goals are to integrate data from these resources with data from sediment budget and transport to understand these interactions.

- Monitoring and inventory of terrestrial resources
- Monitoring Kanab ambersnail populations and habitat at Vaseys Paradise
- Evaluation of cultural resource monitoring and mitigation strategies
- Development of a river corridor research design to evaluate the significance of cultural resource data

II. AQUATIC ECOSYSTEM ACTIVITIES – aquatic ecosystem activities involve primarily biological resources. Many of the programs are undergoing review and long-term monitoring programs are not fully implemented for this area of the research and monitoring program.

- Monitoring the phyto-benthic community
- Monitoring the status and trends of downstream fish community
- Monitoring the status and trends of Lees Ferry trout
- Integrated water quality monitoring

III. INTEGRATED TERRESTRIAL AND AQUATIC ECOSYSTEM ACTIVITIES – integrated activities primarily involve data collection associated with physical components of the Colorado River ecosystem. These activities provide data to other areas with respect to habitat availability and habitat change as it relates to silt, clay, sand, gravel and larger grain sizes.

- Long-term monitoring of fine-grained sediment storage throughout the main channel
- Long-term monitoring of streamflow and fine-sediment transport in the main channel Colorado, Paria and Little Colorado Rivers
- Long-term monitoring of coarse-grained sediment inputs, storage and impacts to physical habitats
- Long-term monitoring of recreational camping beaches

IV. INFORMATION TECHNOLOGY ACTIVITIES – Extensive data and information currently exist in the GCMRC collections relating to the Colorado River ecosystem, resource conditions, quality, and relationships to other resources. Potential equal amounts of data and information exist within museums, universities, agencies, etc. However, much of this information has not been organized, managed or integrated into an analysis of the interrelationship among various resources and dam operations.

The following areas will be implemented in the Information Management Program:

- Development of metadata elements for data collection, processing and use.
- Continued development of extensive multidisciplinary databases and a database management system.
- Development of a geographic information system (GIS) to accommodate multiple layers associated with all resources of interest to stakeholders, including river base map development.
- Development of databases associated with remotely sensed data not presently incorporated in the Glen Canyon Environmental Studies (GCES) database system.
- Development of selected stakeholder interface mechanisms to access data and information in the database management system and GIS.
- Development of an outreach program, including identification and quantification of user needs, to transfer GIS data and information to stakeholders.
- Evaluate remote sensing technologies relative to less intensive and more cost effective methods of monitoring Canyon resources.

The following areas are included in the Information Management Program:

TECHNICAL SUPPORT SERVICES – REMOTE SENSING

- Data Base Management
- Geographic Information System
- Remotely Sensed Data Collection

# GRAND CANYON MONITORING AND RESEARCH CENTER LIBRARY OVERVIEW

The purpose of the Grand Canyon Monitoring and Research Library is to collect, archive and deliver materials collected on the Glen Canyon Dam and its effects on the surrounding environment. These efforts assist the center in its charge to administer long-term monitoring and research. This information could very well be the template and comparative data that will aid in the protection and management of river systems around the world.

The primary purpose of the library is to ensure that these materials are available to researchers funded through GCMRC. The secondary purpose is to provide non-funded researchers and the general public access to documents that are unique to GCMRC. Incorporated with this second purpose is the education and promotion of the use of materials unique to the GCMRC. An underlying management goal associated with the library is to consolidate, preserve, and organize materials to facilitate effective information delivery.

The GCMRC library holdings include information about resources associated with Glen and Grand Canyons. All of this information is contained in a variety of media types ranging from documents to videotapes to slides. All of this information, no matter what media type, is an invaluable resource to the researchers who work in Glen and Grand Canyons, as well as the general public.

**Holdings**

Hard copies and electronic copies of final funded research reports.
Reprints of articles resulting from funded research.
Books resulting from research efforts associated with GCMRC.
Books and articles related to Grand and Glen Canyons.
Books and articles related to natural and controlled rivers and environments.
Photographs and slides developed by GCMRC staff (aerial and field documentation).
CD-ROM versions of aerial photographs and slides.
Videotapes (over-flights, and programs related to Glen and Grand Canyons).
Maps (topographic, flight-line maps, Arc/Info Coverages, orthophotographgy).

# Section 3
# Briefing Papers

# Terrestrial Ecosystem Activities

# Kanab Ambersnail at Vaseys Paradise, Grand Canyon National Park: 1998 Monitoring and Research

Dr. Vicky Meretsky, Indiana University, and Dave Wegner, Ecosystem Management International, Inc.

## History and Conceptual Basis

Kanab Ambersnail (KAS) is a federally endangered terrestrial snail. Two extant populations are known to occur: one on private land in Three Lakes, near Kanab, Utah, and the other at Vaseys Paradise in Grand Canyon National Park. The species was proposed for emergency listing as an endangered species in 1991 and was listed in 1992. Of the two remaining populations, only the Vaseys Paradise population can be studied easily as the other one exists on private land.

The Endangered Species Act of 1973 (ESA) requires federal agencies whose activities affect endangered species to make protection of existing populations and recovery of the species primary management goals. Since discovery of the snails through the Glen Canyon Environmental Studies (GCES) program (1991), the KAS at Vaseys Paradise have been the subject of extensive study of the snails' habitat, population size, predation and impacts related to the operations of Glen Canyon Dam. The primary habitat utilized by the snails is directly impacted by the operations of Glen Canyon Dam.

Through a Section 7 consultation process, the Bureau of Reclamation and the U.S. Fish and Wildlife Service (USFWS) have included the KAS in both the Glen Canyon Dam EIS (1996) and the ongoing Grand Canyon Monitoring and Research Center program. A Kanab Ambersnail Working Group, consisting of members of the USFWS, Reclamation, Arizona Game and Fish Department, National Park Service, academia (Indiana University) and private consultants (previous GCES associate) are presently coordinating related to the research and monitoring.

## Habitat Data Collection

Data are collected at Vaseys Paradise with respect to vegetation area and composition. Habitat is divided into patches that are composed of dominant species (e.g., *Mimulus cardinalis, Nasturtium officanale, Carex aquatilus*). Habitat is mapped for all patches up to 100k cfs. Surveys are conducted in Spring and Fall and coincide with surveys for snails in these patches.

**Habitat Data Collection (continued)**

Habitat patches are influenced by the discharge of the springs, rainfall events and river discharge. The spring's discharge define upper wetted areas and influence the extent of plant growth and distribution. Drier years may result in reduced patches over the growing season or may provide an opportunity for plant species adapted to drier environments to become more representative in a patch for some period of time. Warm winters may also affect growth at the springs particularly with respect to *Nasturtium*, an annual plant. The species may go through several reproductive cycles given warmer conditions and expand in area covered. Patches immediately near the spring discharge show the most change in area covered (6, and 8U) as well as patch 7L which is likely most influenced by mainstem volumes.

**Snail Population Estimates**

Population estimates for Kanab Ambersnail at Vaseys Paradise based on extrapolations from samples, vary from calculated means of 6,300-7,100 individuals in April/May to 18,000-34,000 in October. Snail numbers increase over the season representing reproductive effort for that year, while spring numbers represent over-winter survival. Snail length is more equally spread out by October with higher frequencies of occurrence, while April lengths are recorded at lower frequencies and for numbers in snail length between 3.5-9.5mm.

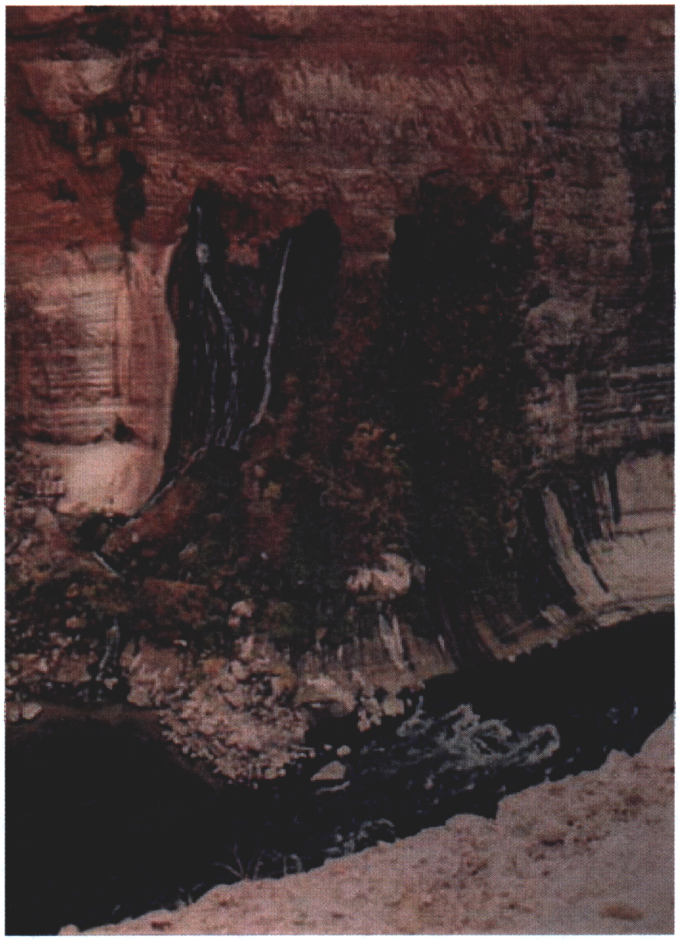


Figure 1. Vasey's Paradise- home of the only population in Grand Canyon of the endangered Kanab Ambersnail.

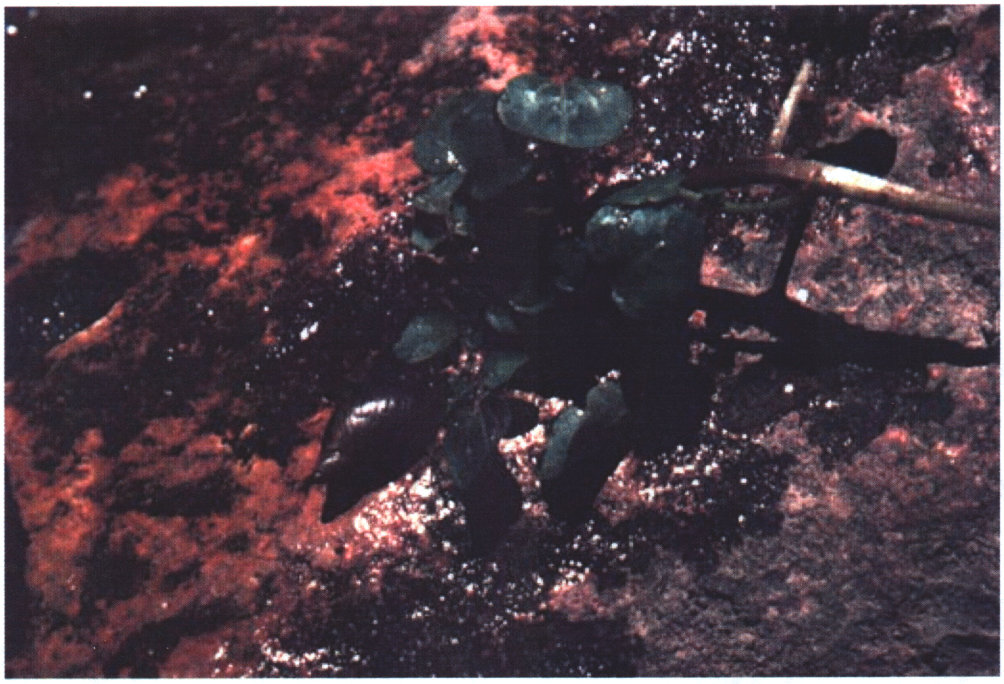
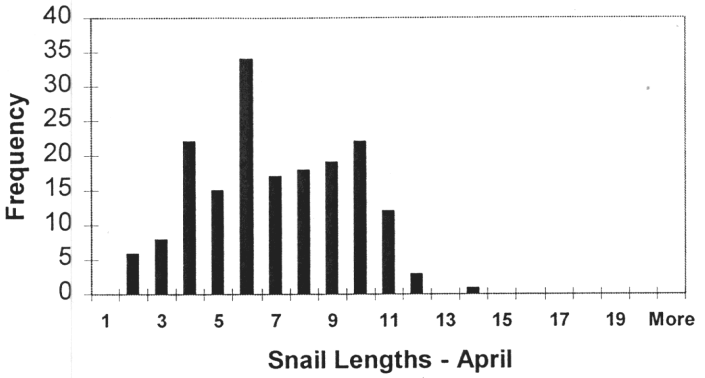
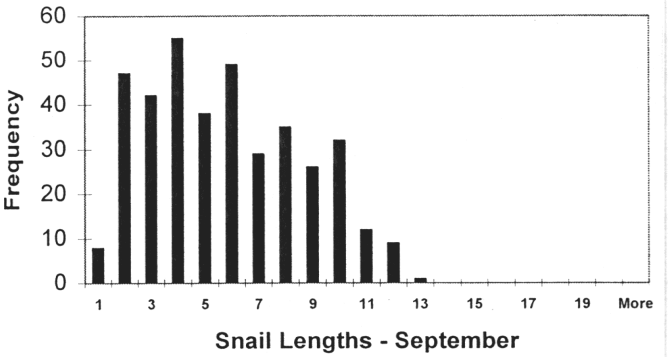


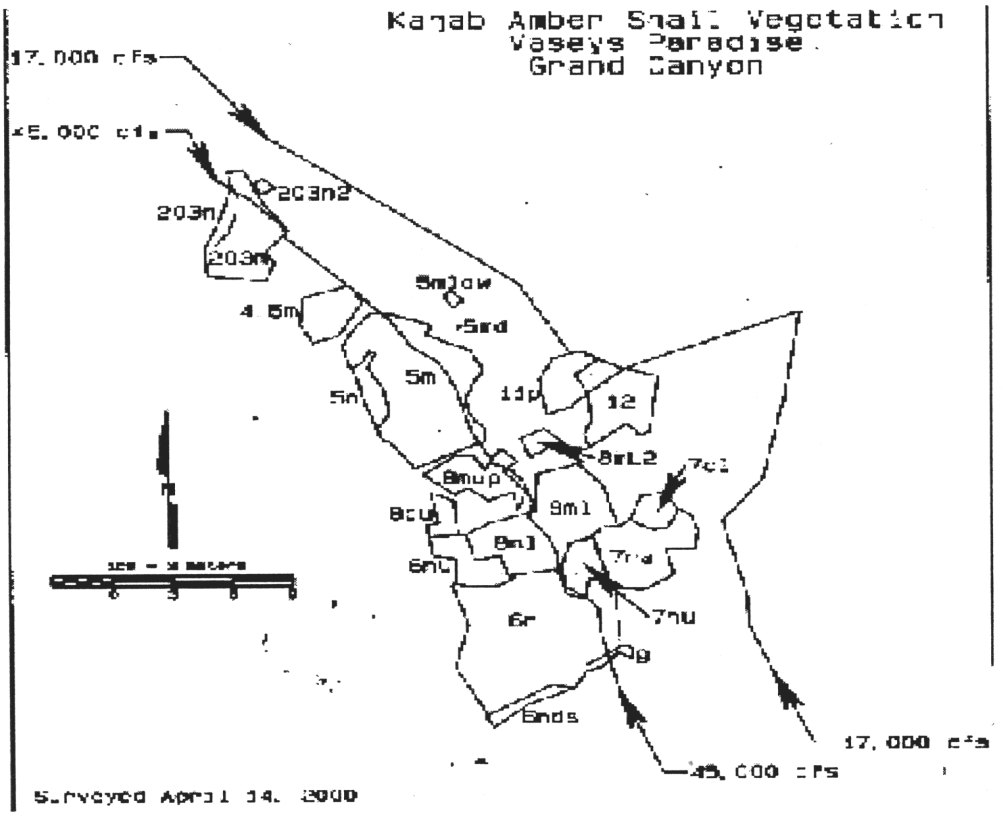
Figure 2. The Kanab Ambersnail, a relict Pleistocene species.

Figure 1. Comparison of snail lengths and frequencies between the months of April and September



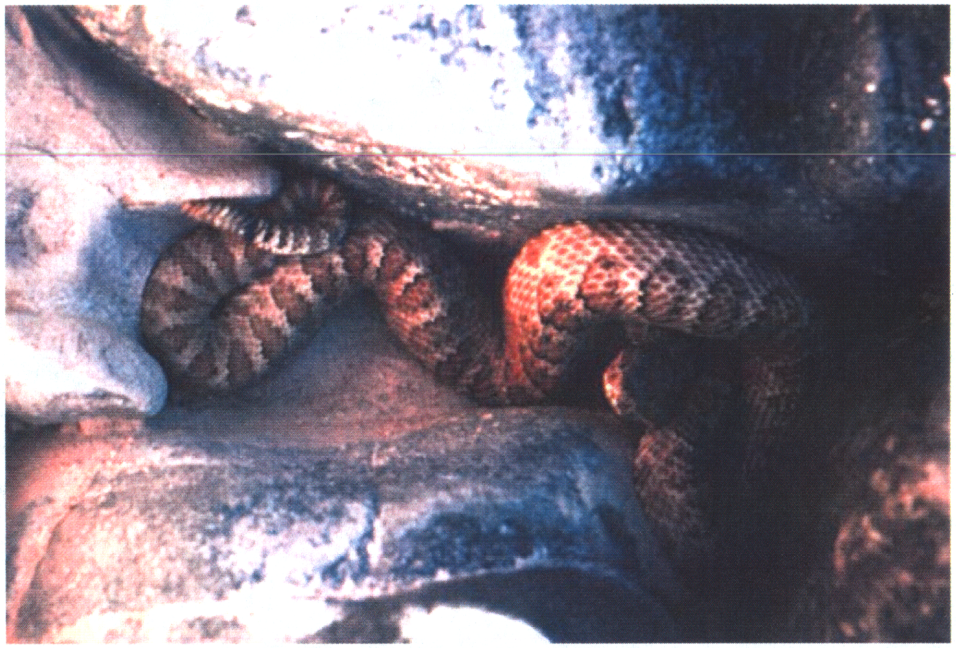

(Figures from SWCA report October, 2000. Meretsky, V. J. and D. Wegner. 2000. Kanab Ambersnail at Vaseys Paradise, Grand Canyon National Park. 1989-99 Monitoring and Research. SWCA, Inc. Environmental Consultants, Flagstaff, AZ.)




Area of habitat above and below 45K cfs and total area of habitat surveyed in April 2000.

**Above 45K cfs** 161.67 $m^2$ **Below 45K cfs** 93.82 $m^2$ **Total area** 255.49 $m^2$

Figure 1. Desert Bighorn sheep (the smallest and least common of the 4 North American species) inhabit steep canyon slopes.



Figures 2. Grand Canyon Pink Rattlesnake, a subspecies of the Western Rattlesnake.

Figure 3. The Grand Canyon is a *refugium* for one of the largest populations of peregrine falcons in North America.

## Riparian Vegetation

Riparian vegetation represents a range of plant species that exists along the river corridor and in the tributaries. In general, riparian communities or associations are dominated by perennial woody species. Germination requirements for plant species influences their occurrence and the present, post-dam assemblage is reflective of the changes in the hydrology. Pre-dam riparian vegetation like mesquite and acacia require scour for germination and a receding hydrograph typical of the pre-dam Colorado River. The Sonoran Desert plants have long tap roots that withstand long periods of dryness on the upper surface of the soil. Other species associated with pre-dam river include Gooddings willows and some cottonwoods. These species are more often found along alluvial floodplains or in large areas susceptible to flooding, sedimentation and slow hydrologic recession like the area around Lees Ferry, Cardenas or in the western portion of Grand Canyon (RM 209) and river reaches further south near Yuma. The roots of these plants are shallower than those of mesquite and acacia, so the plants are more dependent on water being more consistently available. Taking these variables into account, one can begin to predict where and what types of riparian vegetation will be encountered along the river corridor.

The spatial pattern of plant species distribution is dependent on time since disturbance, magnitude of disturbance and availability of water and seed bank availability. Riparian plants able to withstand high scour velocities and whose seeds need to be scarified are likely to be deposited in high velocity environments (like mesquite in the old high water zone) and elevations higher than most beach faces (e.g., channel margins or debris fans), while species that germinate in lower velocity, high sediment accumulation habitats may be found along the lower end of reattachment bars and closer to the zone where water is available on a daily basis rather than periodically available. The lower elevation sandbars are currently colonized by coyote willow, seep willow, tamarisk, desert broom, and arrowweed. Most of these are resistant to burial, where those species associated with the old high water dynamics are more susceptible to burial effects, primarily because they have reduced abilities for vegetative propagation (cloning).

### Monitoring Riparian Vegetation

Riparian vegetation serves as habitat for riparian breeding birds and other faunal elements (insects, herps mammals) and is a concern for encroachment on camping beaches. Rather than measuring vegetation in and of itself, the monitoring program has taken an approach that collects data across trophic levels at sites that are initially linked to that resource for which we have the most continuous data set: birds. With respect to riparian vegetation, structure and composition are measured at each bird patch (64/year: 57 downstream and 7 upstream of Lees Ferry). Linkages between hydrology and vegetation density take place independent of bird surveys and involves random transects along the river corridor. Measurements are made from the river's edge to stage discharge levels of 60k cfs.

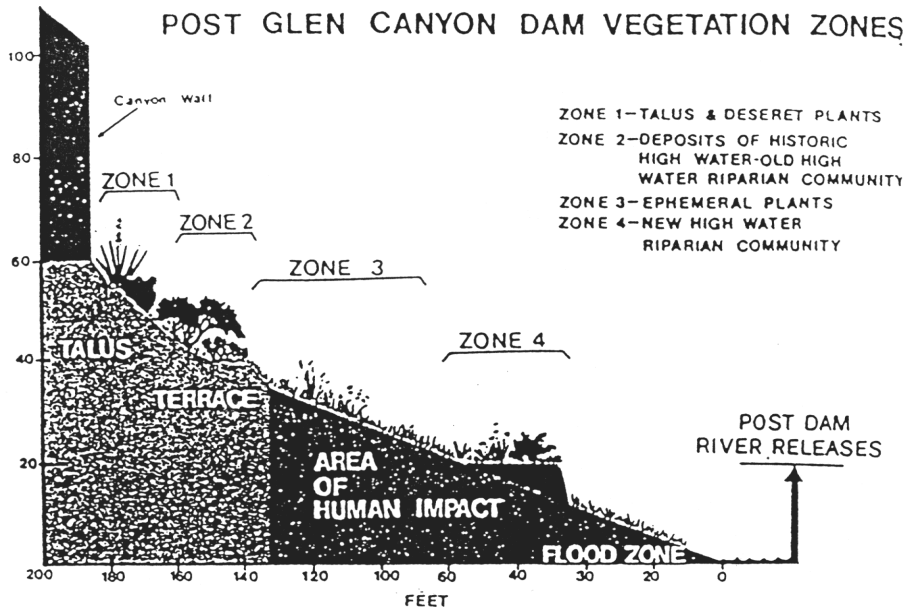



Diagram of Post-Dam vegetation zones. Zone 4 includes marsh, beach and woody riparian plant communities.

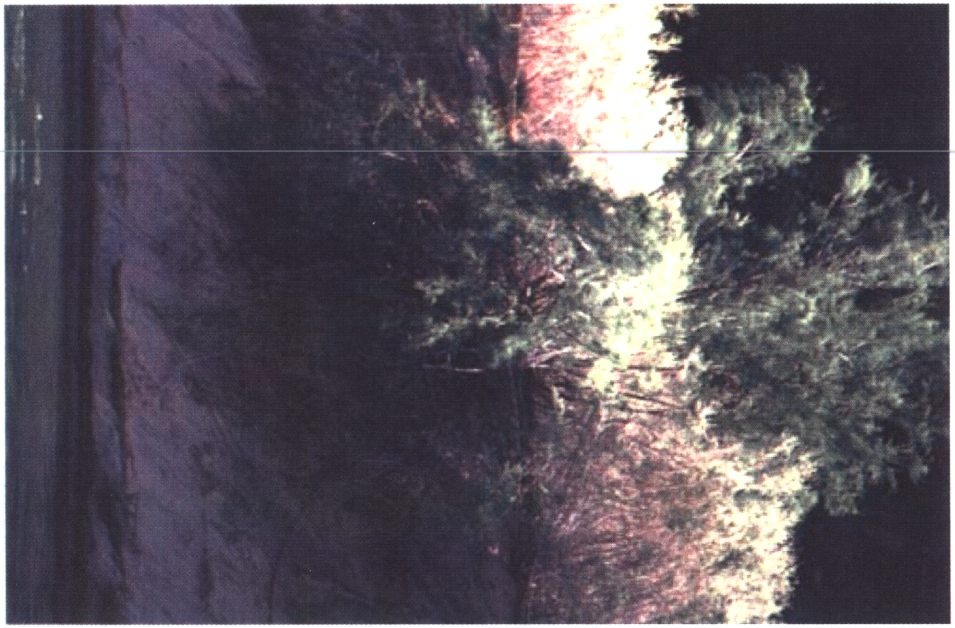


Figure 1. Arroyo cutting can expose cultural resources, causing archaeological information to be lost.

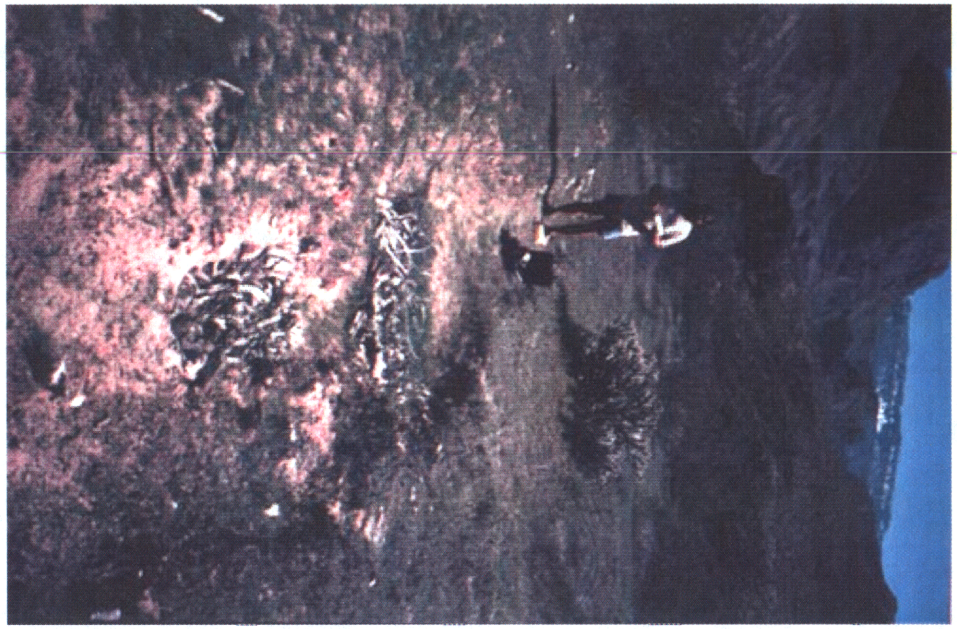


Figure 2. Non-intrusive brush checks capture sediment and help stabilize the drainage.

Figure 3. Prehistoric fire-pit eroding from cutbank. Valuable cultural information would have been lost without excavation actions.

Figure 4. Ceramic vessels recovered from an eroding terrace slope.

# CULTURAL RESOURCE RESEARCH DESIGN IN THE COLORADO RIVER CORRIDOR

## Introduction

Cultural resource investigations have been on-going in the Colorado River corridor for the last four decades. Beginning in 1990, efforts to monitor cultural resources have become more systematic and detailed. In 1994, the Bureau of Reclamation, the National Park Service (Grand Canyon National Park and Glen Canyon National Recreation Area) and several tribal groups executed a Programmatic Agreement to assess the effects of Glen Canyon Dam operations on important cultural resources. While efforts to assess resources have been considerable, a research design has not been completed to direct the overall efforts.

Long-term research goals and domains form a framework that determines the types of data that should routinely be collected through monitoring, data recovery, and remedial actions. Research domains also determine how these data should be collected in order to address specific questions. All archaeological work must be done in an overall research framework that complies with the minimum requirements set forth in the Secretary of the Interior's Standards for Archaeology and Historic Preservation. The research design addresses areas of research potential, treatment, and application for cultural resources along the Colorado River from Glen Canyon Dam to the to the western boundary of GCNP for preservation decision making.

## Project Objectives

The objectives of this project are to: 1) Provide research domains and research questions that are relevant to river specific research with links to larger regional contexts. Research domains may include theoretical and methodological concerns. Issue areas may include archeology, history, ethnography, engineering, architecture, and geomorphology, paleoclimate, and geoarcheology; and 2) Provide a framework for treatment of all cultural resources. The treatment framework should include: 1) evaluation of NR eligible and other resources for purposes of property type evaluation and treatment; and 2) prioritization criteria that includes property type and significance, condition and integrity, and threats. Provide recommendations for incorporating new resource discoveries within this framework.

This project was awarded in September 2001. An orientation with the cultural representatives will be held by November 2001 to outline work tasks and schedules. The project is expected to be completed about December 2002.

# EVALUATION OF CULTURAL RESOURCE MONITORING AND MITIGATION STRATEGIES

## General Project Description

Numerous cultural resources have been identified within the Colorado River ecosystem. These resources are defined as archaeological resources (prehistoric and historic) and traditional cultural resources of importance to Native American groups and other stakeholders. The cultural resources extend from Glen Canyon Dam to the western boundary of Grand Canyon National Park, approximately 293 river miles. The lateral extent of the area is approximately 256,000 cubic feet per second (cfs) stage level which generally approximates the extent of terrace deposits containing cultural materials.

Monitoring data on cultural resources within the area have been collected by the National Park Service (NPS) and tribal groups for several years. These monitoring efforts have identified areas where erosion and gullying have damaged archaeological sites. In an effort to mitigate loss to archaeological sites, the NPS and the Zuni Conservation Program have installed numerous rock and brush check dams at approximately 29 archaeological sites. These dams have been in place for varying lengths of time with differing amounts of maintenance. The purpose of the dams is to slow or arrest erosion through the accumulation of sediments behind the dams. The utility of these measures has not been thoroughly investigated to date.

## Project Goals and Objectives

The goal of this project is to employ remote sensing technologies utilized by GCMRC to study check dam mitigation measures. Additional goals include 1) the evaluation of these technologies for long-term monitoring efforts, and 2) the evaluation of the effectiveness of the check dam mitigation strategies at selected archaeological sites along the Colorado River corridor. Specific objectives of the project are: 1) investigate check dams installed at archaeological sites along the river corridor using existing and on-going remotely sensed data (such as photogrammetric applications to aerial photography and other technologies currently being utilized by GCMRC), Evaluate these technologies for the study of these mitigation measures; 2) evaluate the effectiveness of the check dams and identify geomorphic and other processes that operate at the sites to promote or hamper their utility; 3) provide recommendations on the utility of the remote sensing techniques to study these mitigation measures for long-term monitoring efforts and; 4) provide recommendations on the utility of these mitigation measures and suggest modifications to these efforts, if necessary.

Twelve sites have been selected to be investigated during this study. Eight of the sites have erosion control features in place and four of the sites will serve as controls. The work is in the preliminary stages with field visits for ground checks scheduled in Spring and Fall of 2002.

## Erosional Effects on Cultural Resources at Terrace Locations

**Major Questions:**

1) Are the erosional processes identified at cultural sites related to dam operations or are they natural? Can this be determined?
2) What can be done to help protect cultural sites that are experiencing erosional effects?

Past studies (Hereford, 1993; Thompson & Potochnik, 2000) argue that erosion has increased in the post-dam period and that this is due to: (1) the presence of the dam which withholds sediment and eliminates high flood events, and (2) the operations of the dam which regulate flows within a narrow range relative to pre-dam unregulated conditions. This situation results in a lower main stem base level that has changed the equilibrium conditions at the mouths of gullies and arroyos, resulting in the accelerated rates of gully erosion. The erosion along channel margins and the headward cutting gullies impact deposits that contain cultural materials causing loss of cultural materials and their context. Recent work (Thompson& Potochnik, 2000) concludes that, (1) gully erosion of terraces has been severe during the past 20 years due to unusually high precipitation, (2) sediment deprivation coupled with a lack of large annual floods has caused a reduction in restorative (depositional) factors, (3) beach-habitat-building flows (BHBF) are essential for initiating natural restorative processes, (4) aeolian reworking of newly deposited flood sands onto higher terraces may be one of the most important gully mitigation processes and, (5) gully-deepening and river/wind depositional processes were in dynamic equilibrium prior to dam construction allowing preservation of cultural sites. At selected gully sites, sediments were deposited in arroyo mouths following the 1996 spike flood (Yeatts, 1996) suggesting that BHBFs maybe used as a management tool to temporarily stabilize cultural resources. The duration that deposits remain in arroyos may vary with subsequent flow regimes, climatic conditions, geomorphic setting, and amount of deposit. A modeling project (Wiele, 2001) predicts certain channel margin deposits, given selected flow levels and sediment availability.

In contrast, a recent program evaluation (PEP Report 2000) recommended addressing broader geomorphic questions and less emphasis on distinguishing dam effects from natural processes. They argue that erosional processes are long-term and will continue to affect the cultural resources. Attempts to quantify dam related versus natural effects is not a cost-effective research endeavor. A new suite of geomorphic questions that are tied to the future research design should be developed for the corridor resources. These questions should link the prehistoric fluvial and sedimentary environment to the resources and provide a basis for understanding site location and occupation and site preservation processes.

## Managing a Limited Sediment Supply to Achieve In-Situ Preservation of Cultural Sites Within Pre-Dam River Terraces

Closure of Glen Canyon Dam reduced the available fine-sediment supply of Glen, Marble and Grand Canyons by about 90 percent. This highly limited sediment-supply condition, combined with the drastically reduced annual flood frequency, makes the challenge of achieving in-situ preservation of cultural resources within pre-dam river terraces great. Unless active nickpoints within terrace gullies are buried, and remain isolated from rainfall-runoff processes, active head-ward erosion of the gullies will continue upstream. Gullies with nickpoints that have already migrated upstream to terrace elevations above the maximum stage of controlled floods (BHBF's) will continue to erode through terraces. Burial of gully reaches below the nickpoint elevation can temporarily isolate sites from environmental processes, but such deposits will not arrest rapid head-ward advancement of active gullies.

Where terrace gullies can be completely inundated and buried with fine-sediment by the maximum stage of controlled floods, terrace erosion might be arrested for longer periods; assuming that site burial can be maintained through repeated managed bar-building floods. The overall effectiveness of such strategies is limited by the degree to which controlled-flood magnitude is constrained by dam operations, and by the limitations of the post-dam fine-sediment supply within the river channel. Temptation on the part of managers to increase the magnitude of controlled floods to achieve in-situ preservation must be balanced with the fact that multi-year accumulation of tributary fine-sediment is not occurring under current dam operations. If multi-year inputs of fine-sediment are not able to accumulate throughout the channel at lower elevations, then implementation of controlled floods needs to capitalize on periods when the channel is newly recharged with fine-sediment. Higher fine-sediment supply conditions result in higher suspended-sediment concentrations, and higher sand-bar deposition rates. By timing controlled floods of any magnitude with periods when the channel is recharged with new fine-sediment inputs, the potential for bar-building success is increased.

Recently obtained suspended-sediment data (see Attachment 1) collected during summer 1999 through spring 2000, support the fact that most ROD operations do not allow annual fine-sediment inputs to accumulate within the Colorado River ecosystem. The preliminary conclusion of sediment researchers is that most recent, new sand inputs to Marble Canyon were transported past Phantom Ranch within several months, and that erosion of sand from the upper reaches of the ecosystem occurred once the new inputs were exported. The latest paradigm for fine-sediment resources related to the impact of dam operations is more complex than originally thought during completion of the Glen Canyon EIS. Perhaps more important than near-elimination of the spring snowmelt-runoff flood, is the fact that regulation has now limited the frequency of flows below 8,000 cfs from about 50 percent of the time (pre-dam), to less than 15 percent of the time during the 1990's. Raising the base of lower flows has created nearly optimal sand export conditions most of the year (see Attachment 1), relative to the average grain-size of sands input from Marble and Grand Canyon tributaries.

The potential for achieving in-situ preservation of cultural resources within Glen Canyon terraces is likely nil without drastic measures, such as sediment augmentation. Achieving such a goal in reaches below the Paria and Little Colorado Rivers may be feasible without sediment augmentation, but may still require additional flexibility in dam operations beyond that which is allowed under the current ROD.

# Assessment and Treatment of Gullies
Andres Cheama, Zuni Conservation Program

## Purpose

The purpose of the treatment is to help stabilize a gullies within the vicinity of archeology sites and to reduce the velocities through the affected site by placing check dams and other structural treatments, such as a "rocks lining" to provide roughness to the channel.

## Assessment

The Archeology Section of the Park Service does the initial assessment of the sites. Once a site is identified, a determination is made to either treat the site or not and if it is to be treated, how? If structural treatment is needed, then staff from the Zuni Conservation Program will accompany the Park Service to assess the site for the proposed treatment.

In assessing the site, there are several variables that are looked at in determining the feasibility of treatment. The first parameter is the size of the gully. Since the work is limited due to manpower and time constraints, any work that will require an extensive amount of time and movement of a large volume of rock is deemed unfeasible. The second is the developmental stage of the gully. It makes little sense to treat a gully that is stabilizing. More benefit can be gained by concentrating on gullies that are in the incision stage of development. The last two parameters are the gradient at the proposed location, and the soils. In areas where the slope is steep and the soils are loose, other variables are looked to determine if treatment will work; i.e., a solid control and a chance of vegetation to get established. In areas where the soil deposits are coarse fluvial sediment or wind blown deposits, one problem is sub-surface flow that undermines the structure through piping and de-stabilization of the soil due to saturation. Another form of treatment is vegetative, and if it can be used to either augment the structural treatment or as a stand-alone treatment.

## Treatment

Structural treatment will consist of check dams, rock lining, headcut treatment, and bank protection. The spacing of the checks is done to allow the built up sediment to reach the next check. Structures can be rock and brush, basket weave, or log jams. Rock lining of the channel is done to prevent scouring of the channel bed. Bank protection consists of armoring the banks with rock, and in some sites deflectors were put in to help keep the water away from the banks and promote deposition on the downstream side of the structure. The construction of these checks and any type of structural treatment is labor intensive because rocks must be carried from nearby slopes in five-gallon buckets. For example, in 1995, seventy-three structures were built in two days at Palisades using buckets and rock litters.

## Monitoring and Maintenance

The Park Service and the Zuni Conservation Program do monitoring. If maintenance is required, then the Park Service and the Conservation Program will perform the work. Most of the work involves the installation of a low flow channel and re-enforcement of the banks. This type of maintenance was done at Palisades in 1998, and at other sites, using the same procedure.

# Aquatic Ecosystem Activities

# GCMRC Water Quality Monitoring Program

**Bill Vernieu**
**Susan Hueftle**
**Nick Voichick**

## Introduction

Water quality monitoring conducted by the Grand Canyon Monitoring and Research Center is focused on defining the physical, chemical, and biological characteristics of the water in Lake Powell and the Colorado River in Grand Canyon. This information is used to develop an understanding of how natural processes and dam operations affect trends and variability in these parameters and in linkages with other downstream resources. The program is designed to address established information needs and management objectives related to Lake Powell and downstream resources affected by water quality.

Inflow hydrology and composition, internal mixing processes, and operational effects of Glen Canyon Dam determine the water quality released downstream to the Colorado River in Grand Canyon. Downstream changes are due to the effects of instream processes, tributary inputs, and biological effects of the aquatic ecosystem.

## Program Components

The GCMRC Integrated Water Quality Monitoring Program is undergoing revision following external panel review. In it present form, it consists of four components: (1) quarterly lake-wide reservoir monitoring on Lake Powell, (2) monthly forebay monitoring in Lake Powell; (3) continuous monitoring of the Glen Canyon Dam tailwater below the dam and at Lees Ferry; and (4) thermal monitoring at a network of mainstem and tributary sites in Grand Canyon.

The reservoir-wide and forebay monitoring on Lake Powell was established in 1991 and continued to the present. Information from this program is integrated with the twenty-five-year period of record (1965-1990) from the Bureau of Reclamation's previous Lake Powell water quality monitoring program to provide a continuous coverage of Lake Powell's water quality history.

**Susan Hueftle**

## Results of Lake Powell-Tailwater monitoring:

### The Hydrograph:

The August water quality monitoring trip found the reservoir at a steady elevation of 3680 ± 0.1 ft (1121 m). The hydrograph reflects the drought conditions that pervaded the Colorado river basin for water year 2000 (WY00-Oct. 1999-Sept. 2000). By September, the basin was still 83% of normal precipitation. Lake Powell inflows totaled 8,134,423 af or about 71% of damera average, while releases totaled 9,378,000 af or about 96% of post dam releases (USBR Hydromet database).

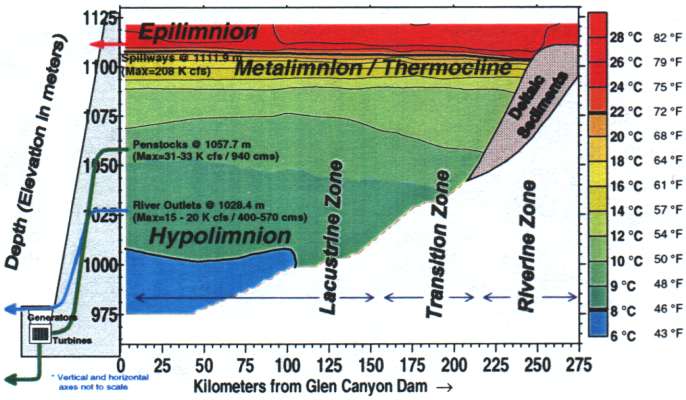
Typically the spring inflow begins in February and peaks in early June. This year inflows didn't increase significantly until May and the bi-modal peak was on May 12th and June 3rd (30,600 cfs and 40,600 cfs, respectively, figure 1).

### The Profiles:

Figure 2 provides orientation for some of the terminology and general characteristics of the reservoir. There, and in the main channel isopleths for the reservoir (figure 3), the effect of the depressed inflows is apparent. These profiles demonstrate physical conditions (temperature, conductivity (or salinity), pH, etc.) along the thalweg of the Colorado river in the reservoir. The dimensions of the spring flood plume, as observed by the fresher water extending across the top of the lake (figs. 3c & 3d) in the conductivity plots, is less extensive than in past years which had greater inflow. Further, the specific conductance of the base inflow near Hite Marina was over 1100 µS, as opposed to the low of 470 µS at the peak of the spring runoff last May '00. By contrast, May of 1997, reflecting one of the highest inflow years in the last 14 years, had a minimum conductance of 356 µS, and the fall of that year had a maximum inflow conductance of 960 µS. The conductance of the inflow is dictated by the volume of runoff combined with other seasonal characteristics including irrigation runoff and temperature. Long-term trends near the dam are demonstrated in figure 4.

Winter mixing drove the thermo-/ chemo-cline (zones of steepest change gradient) to the depth of the penstocks (~50-60 m from the lake's surface) in January. By the peak of summer warming in August, the upper boundary of the thermocline started at 10-12 m and extended to the depth of 30-40 m throughout the lake (figures 2, 3a-3d, 4). Because of the reduced inflow volume, this year's thermocline is shallower than in recent years' (fig.4).

Figure 2: Temperature profile for the main channel of Lake Powell, Aug. '00, including some terminology.




Lake-wide dissolved oxygen content is decreasing after last spring's lake-wide enrichment which reached a 15 year high. This was a result of 2 processes last spring and winter. For the 2nd consecutive winter Lake Powell experienced a late winter oxygenated underflow plume (figures 3a-3c). As a result of high inflows since 1993 and continuing dilution of overall ion concentrations, the density gradient separating the epilimnion from the hypolimnion has weakened, allowing the penetration of cold, well-oxygenated water into the deepest layers of the lake. This process was significantly enhanced by the use of the jet-tubes in 1996 for

Figure 1: Hydrograph for Lake Powell elevation, inflow and outflow for Oct 1, 1999 to September 30, 2000.

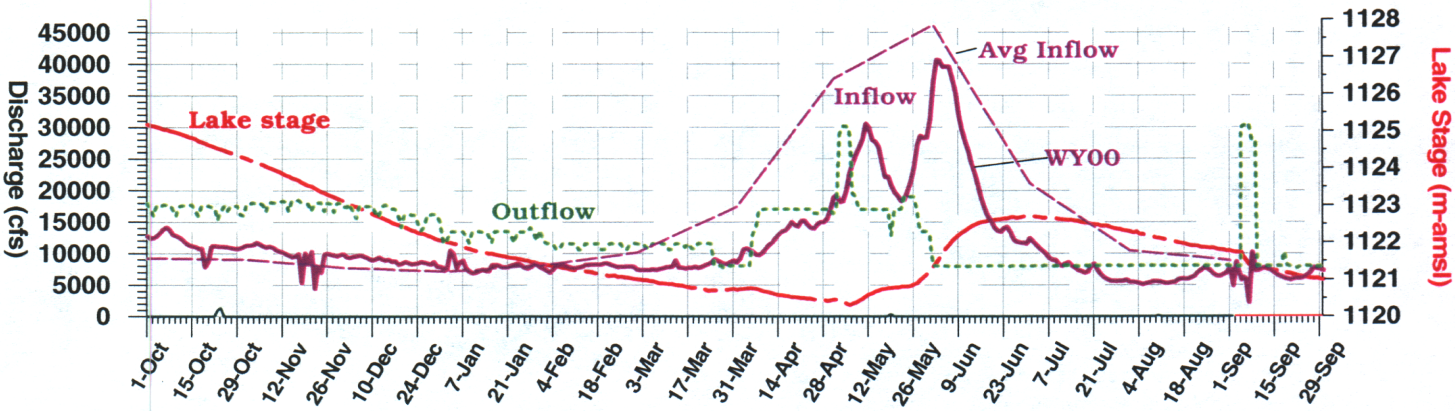
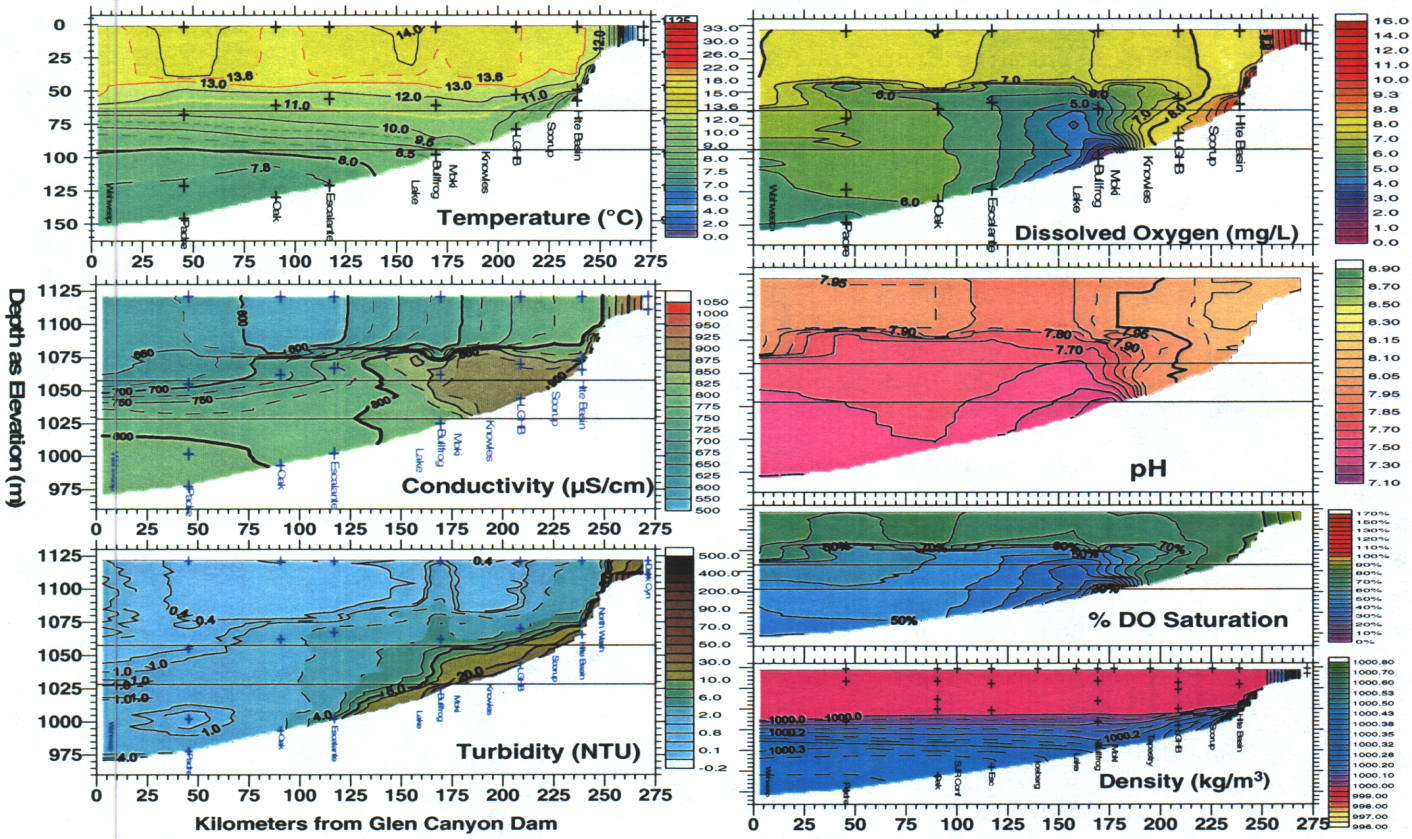
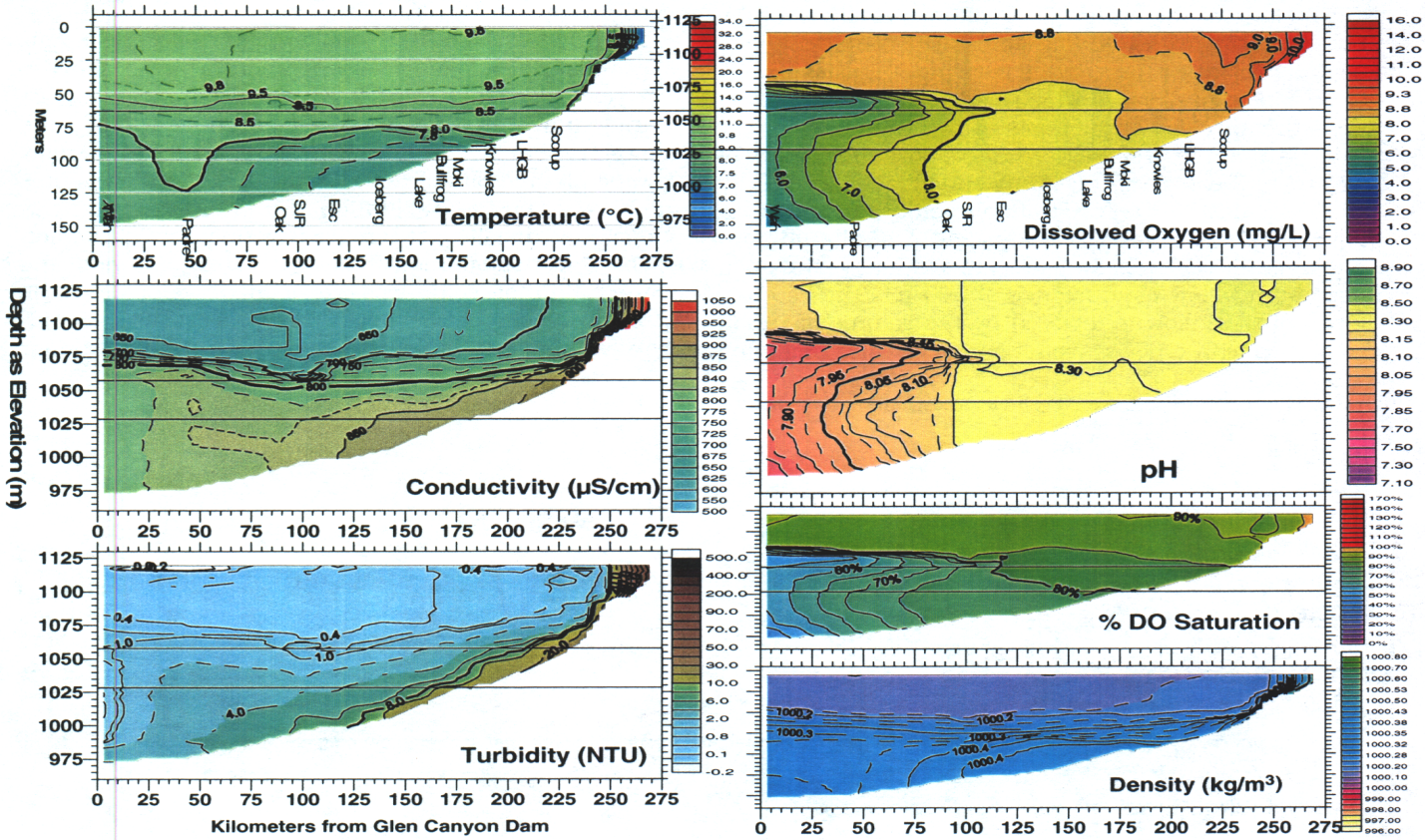


**Figure 3. Isopleths of the Colorado channel of Lake Powell.**

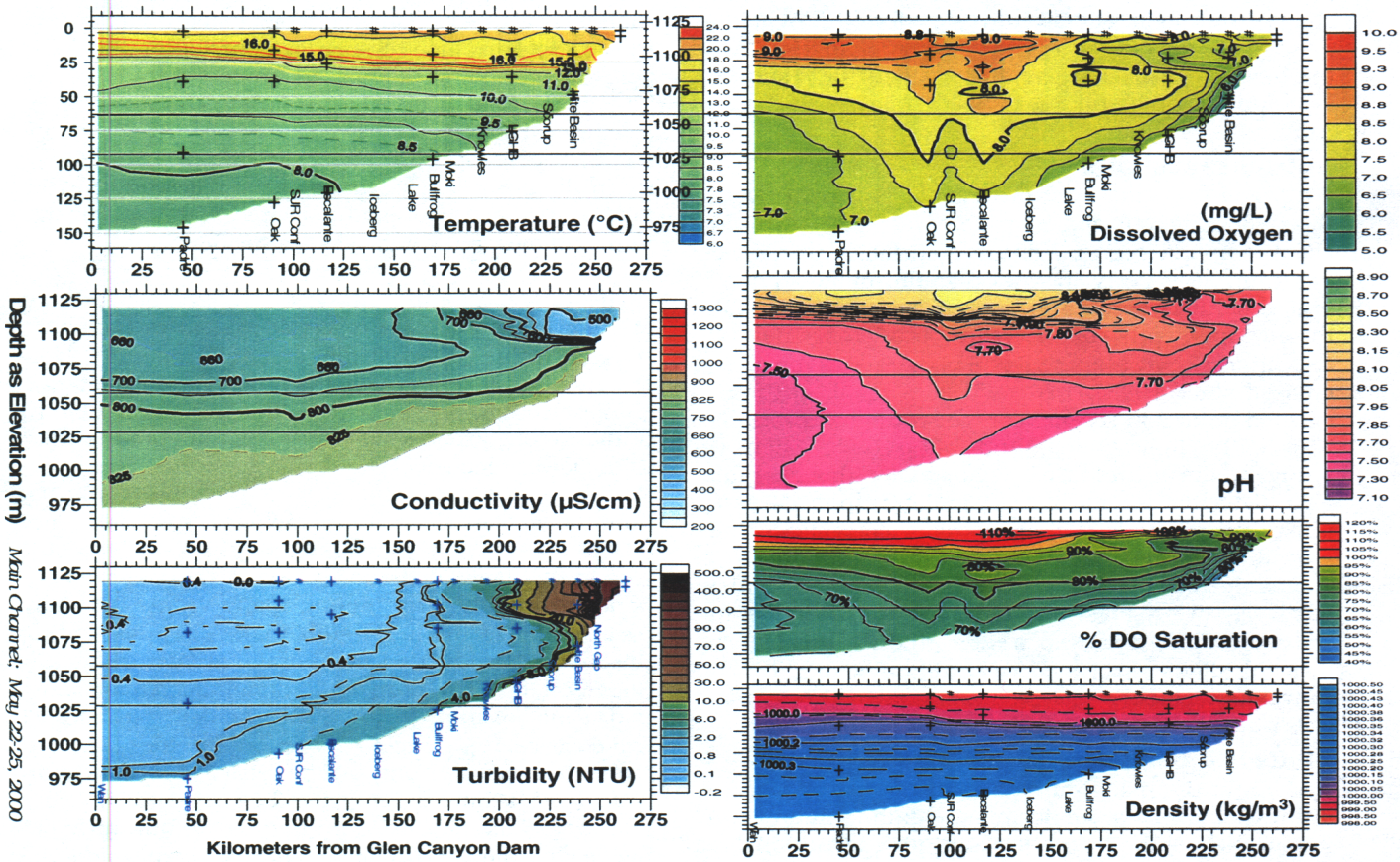
3 A. December 6-11, 1999, Lake elevation 1122.9 m (3684 ft)



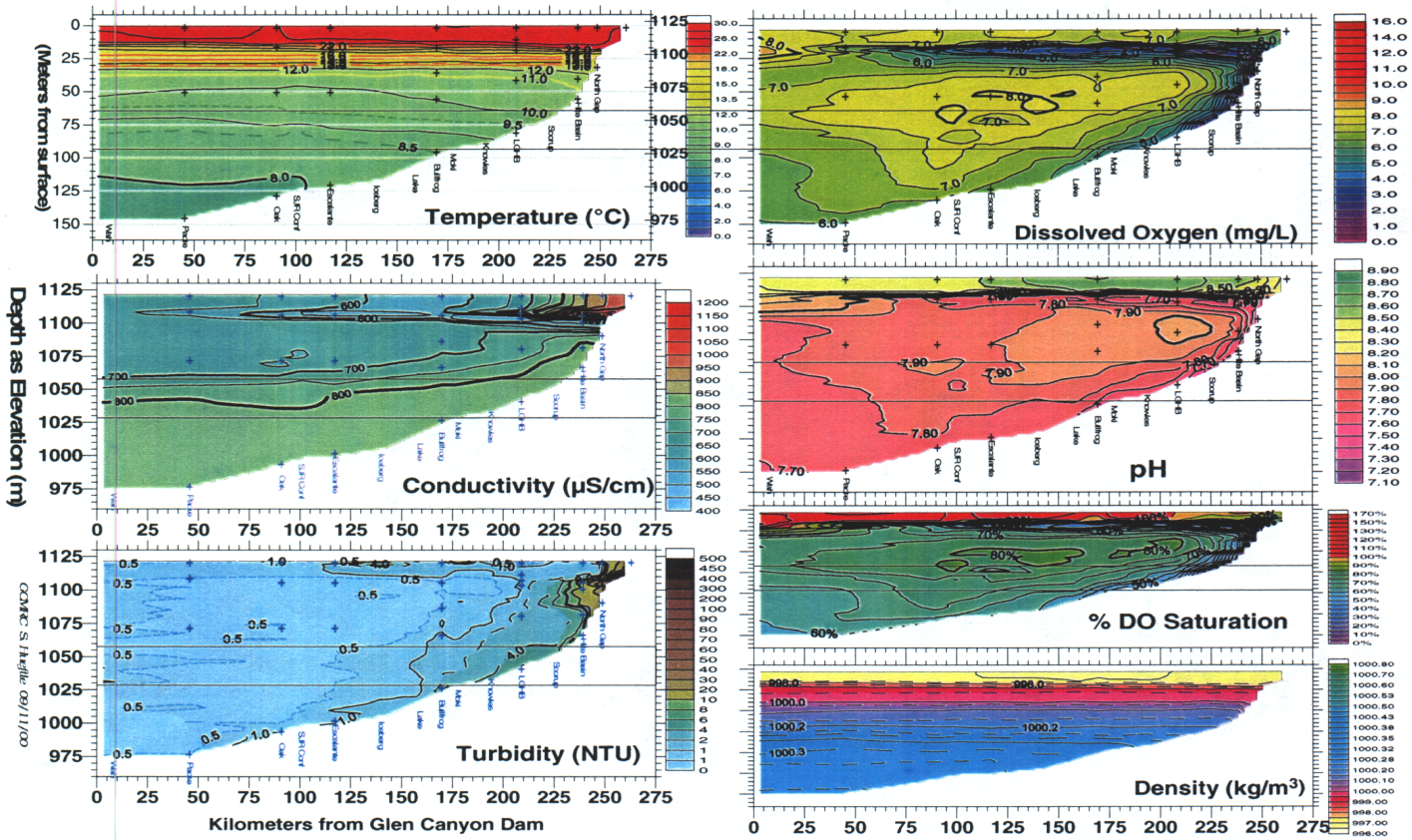

3 B. February 25-29, 2000, lake elevation: 1121.1 m (3678 ft)



3 C. Main Channel; May 22-25, 2000. Lake elevation =1120.8 m (3677.1 ft)




3.D. Main Channel; August 25-28, 2000. Lake elevation = 1121.8 m (3680.5 ft)



the experimental flood, as well as high steady discharges that followed. Given the low levels of hypolimnetic dissolved oxygen that existed prior to 1997 and the hazards of discharging low oxygen, this may offer a tool for managing hypoxia (low $O_2$) levels in the future.

**Nutrient results:**

Although results are provisional, nutrient levels throughout Powell demonstrate a response to recent climatic trends. Figure 7 displays surface nutrient values from Lees Ferry to the Colorado inflow stations, and generally represents or even exaggerates trends throughout depths of the reservoir. Across the lake and in the tailwaters, phosphorus values have increased since 1993. This could be a result of the increased inflows in recent years, or could be associated with biotic interactions, and will receive extensive study in the future. Ortho-phosphate, though often near detection limits, shows similar results. Nitrate-nitrite nitrogen alone demonstrates consistently decreasing concentrations paralleling conductance trends on the reservoir. As would be expected, nutrient levels are highest at the inflow and decrease toward the dam. Seasonal trends produce the highest concentrations associated with the inflow event, with nutrients metabolized, mixed and diluted through fall and winter.

**Biological results:**

Much of the plankton data is in the early stages of analysis. Figure 7 summarizes the data from an aerial perspective, showing the levels of phytoplankton biovolume and zooplankton biomass present in the reservoir and tailwaters for the last year. It shows that productivity for both peak in spring and summer. Primary productivity increases as early as February resulting in the high spring saturation levels of oxygen in the lake. Blooms of algae and zooplankton often follow winter turn-over. Increasing nutrients and warmer temperatures continue to favor productivity until predation and excessive heat drive productivity lower in the water column by late summer and fall.

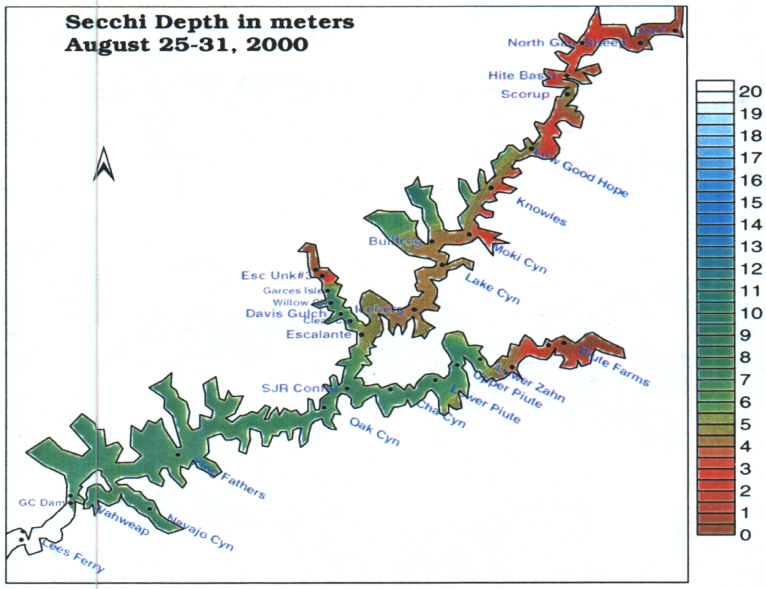
For August, secchi depths (table I, map 1) reflected heightened productivity from phytoplankton (see chlorophyll levels, table I, fig.6), suspension of sediments from the spring flood (a minor contributor this year with lower inflows), as well as some "whiting" of the lake in the lacustrine zones from super-saturation of calcium carbonate, a fairly common occurrence in late summer. Chlorophyll values ranged from 0.5 to 3 mg/m$^3$ in the down-lake portions of the reservoir, 2 to 10 mg/m$^3$ in the transitional portions, and 5-10 mg/m$^3$ in the inflows, reflecting seasonal peaks.

The ranges of nutrients and primary productivity are indicative of a large reservoir system with distinct zones (riverine to lacustrine) and this generally demonstrates a system which transitions from moderate or mesotrophic productivity in the transition zone to primarily oligotrophic (low nutrient, low productivity) in the lower reaches of the lake.

Findings on the reservoir included some unusual events on-shore. In May, the appearance of mosquitoes in two bays at the lower end of the lake was experienced for the first time in many years. This may be an effect of the fairly stable lake elevation during this spring. On the first night of the August trip, Mark Anderson of Glen Canyon National Recreation Area had a misadventure with a rattlesnake. "I thought I kicked a cactus". A sound bite on the toe lead to a midnight helicopter out, but he returned to the trip in a day and a half, gaining the Trooper Award. Other unusual wildlife included an impressive but fairly benign giant hairy scorpion *Hadrurus spadix*, and the rarest sighting, a freshwater jellyfish, *Craspedacusta sowerbyi*. The jellyfish was found by a park visitor in Oak Canyon. This is the only known species of freshwater jellyfish in the U.S., but though seen on rare occasions, it appears not to be documented in Lake Powell.

**Acknowledgments:**

The Integrated Water Quality Program wishes to thank Glen Canyon National Recreation Area for assistance of personnel and equipment. Appreciation is extended to GCMRC staff and the many supporters of the IWQP and volunteers who assisted in collections.

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Map 1: August '00 secchi depths across Lake Powell with map of stations sampled in WY2000. Lake length along the main channel is 272 km (154 miles) from dam to Dark Canyon.

Figure 4: Wahweap (forebay station above dam) profiles from Jan 1993 to September 13, 2000. Penstock and jet tube depths indicated.

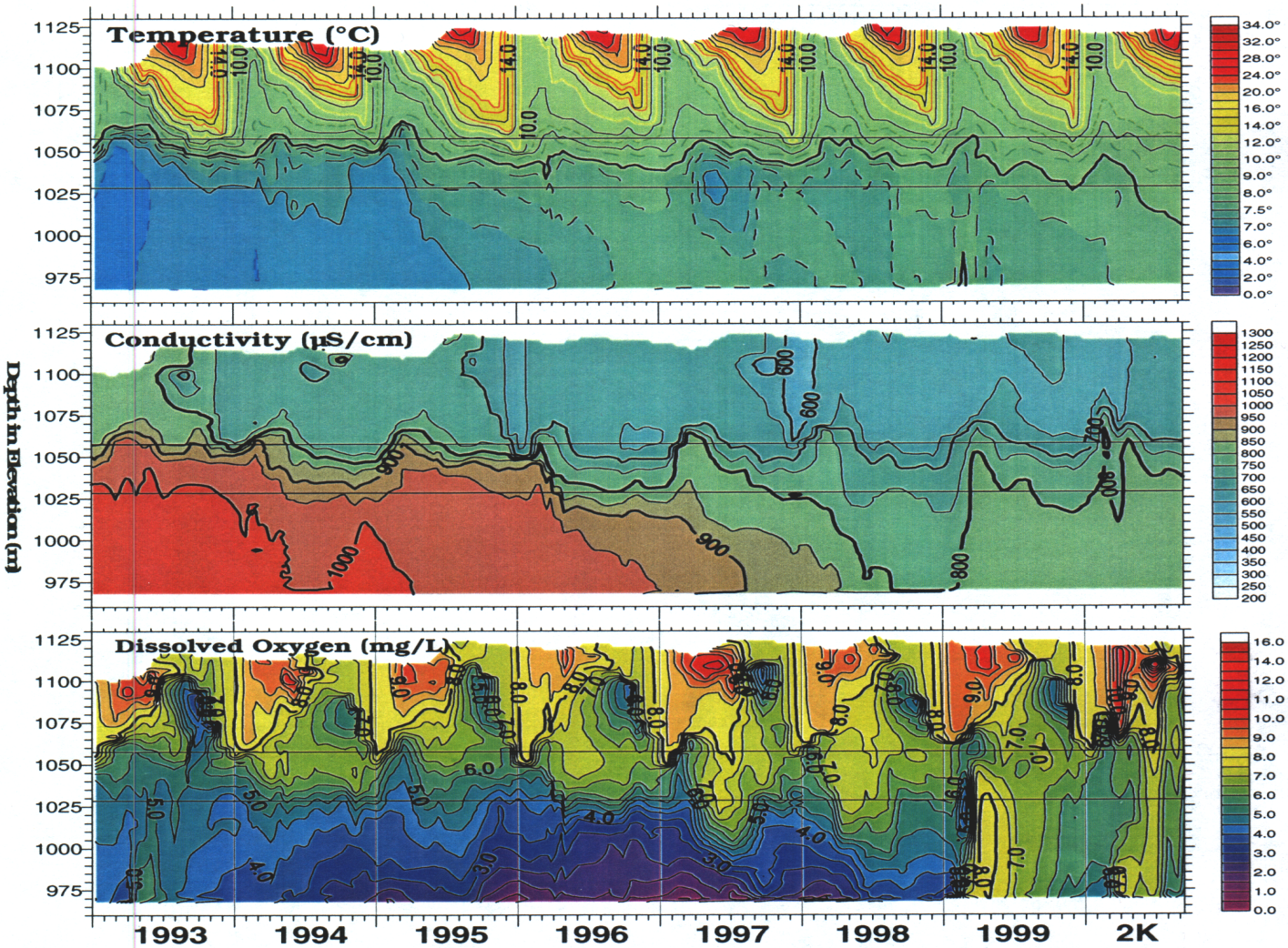



Table 1: Secchi depth (m) and surface chlorophyll-a (mg/m3) values for Feb '92 through August 2000. Storet numbers refer to Lake Powell stations, reach (CR= Colorado River, ESC=Escalante, SJR= San Juan, NVC= Navajo Cyn.; and river kilometer from Glen Canyon Dam.

| Site Name | Storet# ↓ | Maximum Secchi Disk readings (m) for Feb '99 to August '00 | | | | | | | Surface Chlorophyll-a (mg/m^3) for WY99-00 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quarter → | 9902 | 9906 | 9909 | 9912 | 2K02 | 2K05 | 2K08 | 9902 | 9906 | 9909 | 9912 | 2K02 | 2K05 | 2K08 |
| Lees Ferry | LPCR-249 | | | | | | | | 2.16 | 1.43 | 1.13 | 1.24 | 0.66 | 0.69 | 0.41 |
| GC Dam | LPCR-001 | | | | | | | | 0.15 | 0.06 | 0.14 | 0.31 | 0.03 | 0.04 | 0.10 |
| Wahweap | LPCR0024 | 16.7 | 11.2 | 10.8 | 7.9 | 15.5 | 12.7 | 7.6 | 0.46 | 0.45 | 0.98 | 0.40 | 0.31 | 0.44 | 0.91 |
| Xing Fathers | LPCR0453 | 15 | 9.3 | 8.3 | 16.1 | 18.3 | 10.25 | 7.9 | 0.96 | 0.37 | 0.89 | 0.42 | 0.41 | 0.28 | 1.08 |
| Oak Cyn | LPCR0905 | 12.95 | 9.4 | 7.9 | 15.5 | 15.7 | 12.5 | 7.9 | 0.49 | 0.46 | 1.68 | 0.28 | 0.51 | 0.12 | 1.29 |
| SJR Confluence | LPCR1001 | 13.5 | 8.6 | 6.5 | | 14.15 | 11 | 7.4 | 0.45 | | 1.86 | | 0.46 | 0.70 | 1.67 |
| Escalante Confluence | LPCR1169 | 15.1 | 7.9 | 7.4 | 15.1 | 15.8 | 12.1 | 4.7 | 1.47 | 0.86 | 1.6 | 0.95 | 0.41 | 0.26 | 1.81 |
| Iceberg | LPCR1395 | 14.9 | 6.5 | 6.7 | | 15.8 | 11.4 | 4.1 | 1.43 | 0.909 | 1.64 | | 0.44 | 0.40 | 3.40 |
| Lake Cyn | LPCR1587 | 13 | 7.3 | 6.7 | 11.1 | 16.2 | 9.7 | 4.3 | 2.49 | 2.064 | 1.98 | 0.39 | 0.39 | 0.18 | 2.95 |
| Bullfrog | LPCR1692 | 10.8 | 5.4 | 6 | 8.3 | 13.5 | 6.8 | 4.15 | 1.45 | 1.94 | 2.83 | 0.75 | 0.32 | 0.41 | 1.84 |
| Moki Cyn | LPCR1772 | 8.6 | 4 | 8 | 8.8 | 11.8 | 4.2 | 3.95 | 2.55 | 1.84 | 2.39 | 0.54 | 0.62 | 0.61 | 1.72 |
| Knowles | LPCR1933 | 12.3 | 3.2 | 7.3 | 9.5 | 12.5 | 2.5 | 4.2 | 1.56 | 1.22 | 3.69 | 0.18 | 0.75 | 0.30 | 4.15 |
| Low Good Hope | LPCR2085 | 12.9 | 2.3 | 7.4 | 7.4 | 12.3 | 2.7 | 5 | 1.53 | 1.15 | 4.43 | 1.21 | 0.70 | 1.04 | 3.29 |
| Scorup | LPCR2255 | 10 | 3.2 | 6 | 4.4 | 7.8 | 0.55 | 4.8 | 1.44 | 1.53 | 4.285 | 0.70 | 0.40 | 2.25 | 3.41 |
| Hite Basin | LPCR2387 | 10.4 | 0.9 | 2.73 | 3.9 | 9 | 0.35 | 3.4 | 2.14 | 2.75 | 6.97 | 1.17 | 0.52 | 2.31 | 4.94 |
| North Gap | LPCR2483 | 10.45 | 0.34 | 3.8 | 3.1 | 7.2 | 0.25 | 3.4 | 0.81 | 2.16 | 6.88 | 0.11 | 0.12 | 3.95 | 9.57 |
| Sheep | LPCR2626e | 0.45 | 0.2 | | | | 0.2 | 0.35 | 1.31 | 0.81 | | | | 3.08 | 5.27 |
| Dark Canyon | LPCR2713e | | | 0.28 | 0.47 | 0.28 | | | | | 2.6 | 0.93 | 1.02 | | |
| Clear Ck | LPESC072e | 7.95 | | 5.2 | | 14.2 | 12.1 | 6.4 | 1.08 | | 1.61 | | 0.26 | 0.69 | 1.48 |
| Davis Gulch | LPESC119 | 9.6 | 10.4 | 6.1 | | 14.15 | 12.1 | 6.5 | 1.1 | 0.24 | 1.13 | | 0.21 | 0.21 | 1.20 |
| Willow Ck | LPESC200 | 12 | 10.6 | | | 7.6 | 11 | 7.5 | 0.55 | | 1.13 | | 0.20 | 0.27 | 0.97 |
| Garces Isle | LPESC273e | | 10.5 | 5.15 | | 4.8 | 8.8 | 7.1 | 0.4 | | 2.42 | | 0.24 | 0.43 | 1.00 |
| Esc Unk#3 | LPESC347e | | 0.9 | 0.08 | | 0.48 | 0.35 | 0.28 | 1.18 | 0.32 | 3.67 | | 7.11 | 2.22 | 6.10 |
| Navajo Cyn | LPNVC124 | 5.8 | | 10.1 | | 9.7 | 12.7 | 7.5 | 5.84 | | 0.89 | | 0.66 | 0.16 | 0.30 |
| Cha Cyn | LPSJR193 | 11.6 | 7.7 | 7.3 | 10.35 | 10.3 | 10.8 | 6.9 | 1.009 | 0.55 | 1.28 | 0.97 | 0.84 | 0.53 | 1.16 |
| Lower Piute | LPSJR329 | 12 | 9.7 | 6.9 | 6.7 | 11.3 | 10.8 | 7.2 | 0.91 | | 1.48 | 0.77 | 0.55 | 0.40 | 1.25 |
| Upper Piute | LPSJR431 | 13.3 | 7.5 | 4.7 | 6.3 | 10.3 | 8.7 | 9.2 | 0.87 | 0.39 | 3.755 | 0.46 | 0.30 | 0.51 | 0.52 |
| Lower Zahn | LPSJR625 | 11.4 | | 2.45 | 5.5 | 8.3 | 5.5 | 6.6 | 1.49 | | 4.46 | 1.56 | 0.71 | 1.07 | 0.50 |
| Mid Zahn | LPSJR686 | | 0.25 | | | 2.05 | 5.8 | | 0.91 | 2.135 | | | 1.47 | | 4.37 |
| Piute Farms | LPSJR850e | | | 0.45 | 0.8 | 0.4 | 0.15 | 0.12 | | | 3.82 | 1.00 | 0.96 | 3.64 | 5.94 |

Figure 5: Chlorophyll values (mg/m³) for WY00 for Lake Powell and tailwaters. Samples were collected at 1m depth.

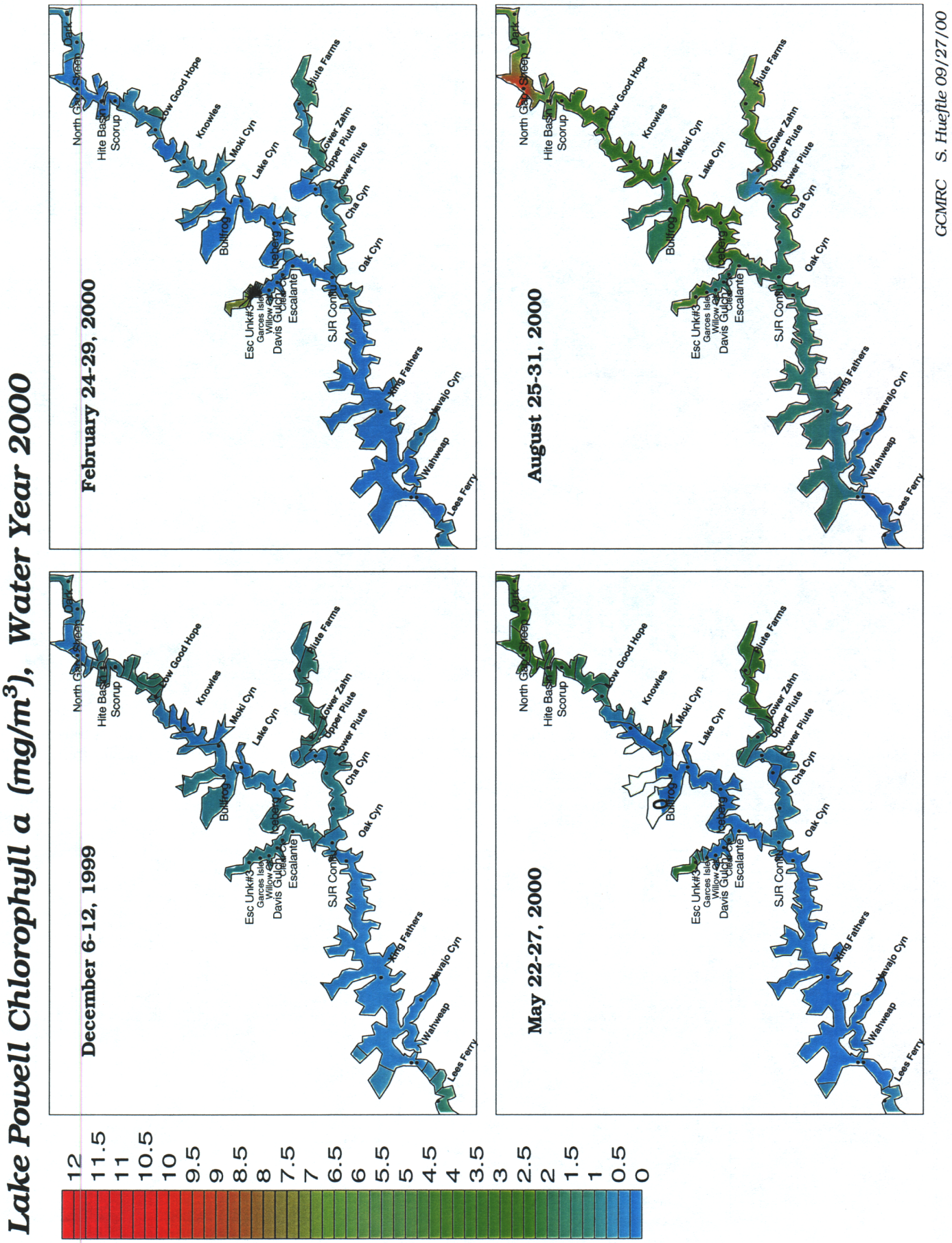


Figure 6: Phytoplankton biovolume (µm³/L) and Zooplankton biomass (µg DW/cm² —analogous to µg/L) estimates for Sept '99 to May '00 quarterly trips. Zoop samples compiled for 0-30m & 30-60m tows.

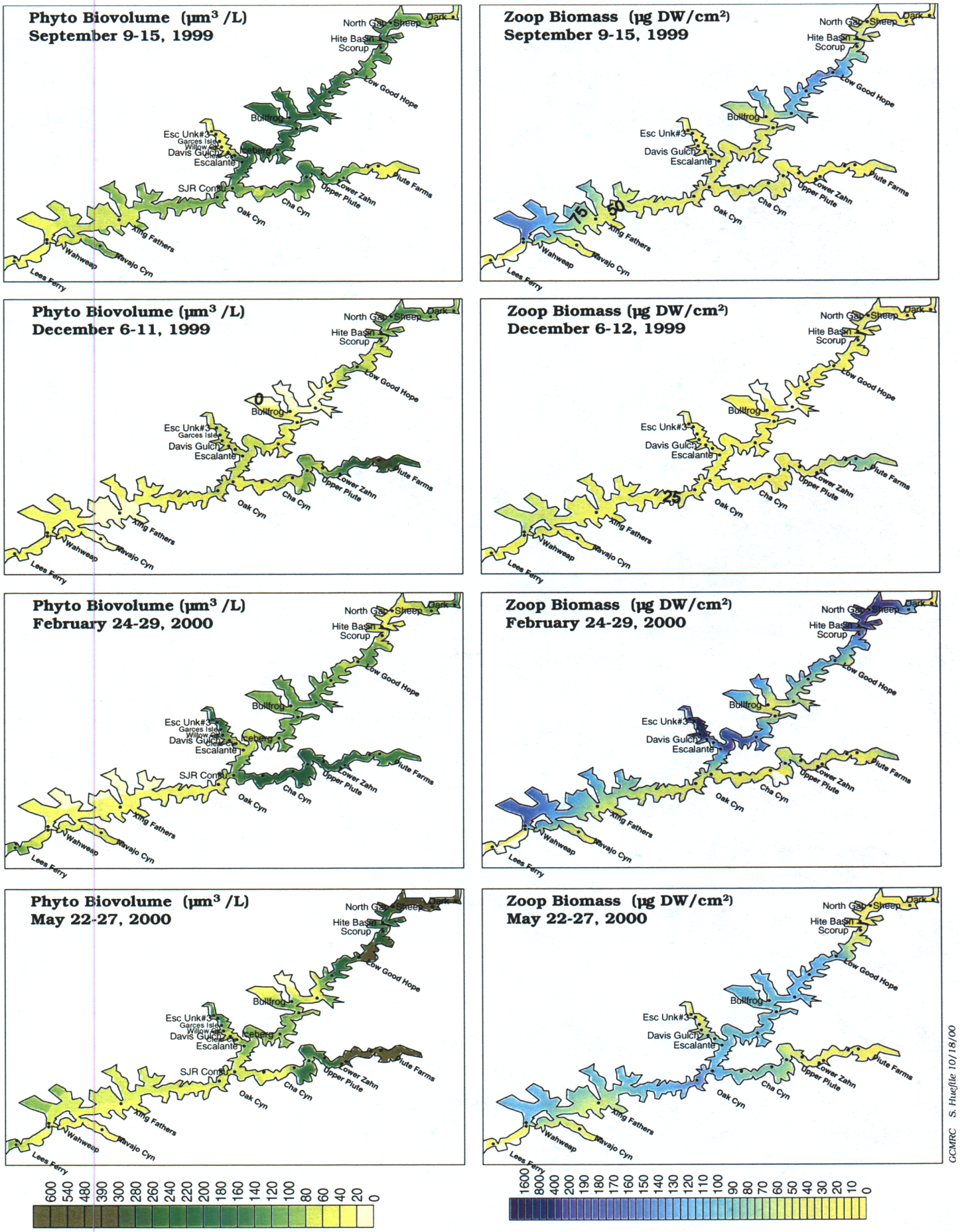
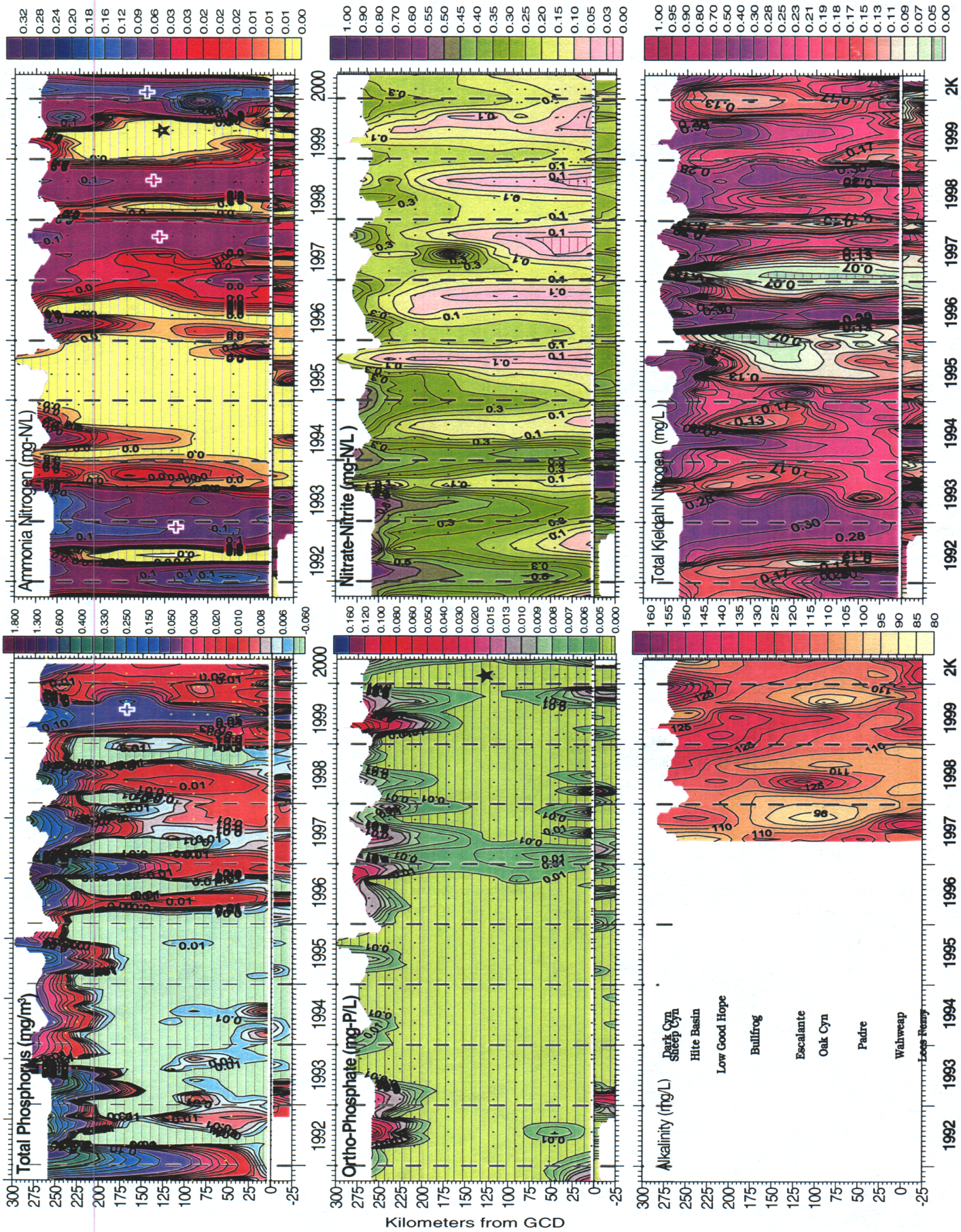


Figure 7: Surface Nutrient Values in the Main Channel and tailwaters of Lake Powell, Sept. 1991 to May 2000 (0 to -2m). Values below detection levels indicated by striped areas. PROVISIONAL DATA: Stars indicate low suspect values; crosses indicate high suspected values. Ammonia values are particularly variable.



# Salmonid Population Size in the Colorado River, Grand Canyon, Arizona

Fishery Fact Sheet
Arizona Game and Fish Department
Grand Canyon Monitoring and Research Center
June 2001

## INTRODUCTION

Over the past decade, considerable research and monitoring has been conducted on the effects of varied flow regimes on aquatic biota of the Colorado River below Glen Canyon Dam (GCD). Management recommendations for native fish assume that physical habitat features (seasonality of flow, habitat morphometry, temperature) are the primary limiting factors for native fish populations. However, much less is known of population size and dynamics of exotic fish and, in particular, the risk of predation that salmonid populations pose to native fish. The objective of this study was to estimate population size and distribution of non-native salmonids rainbow trout (*Oncorhynchus mykiss;* RBT) and brown trout (*Salmo trutta;* BNT) in Grand Canyon for use in assessing predation risks to native fishes.

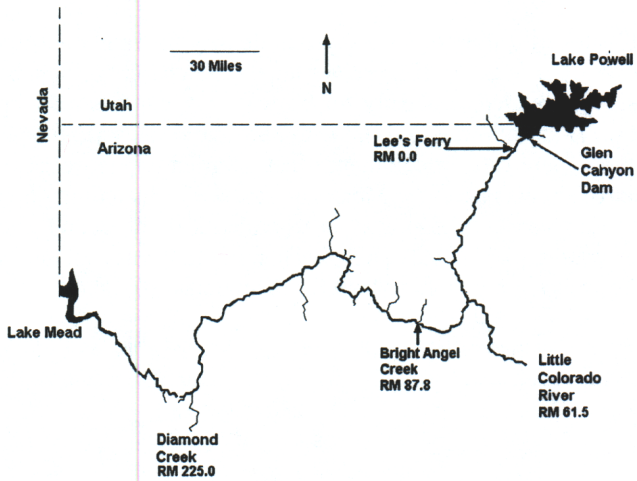



**Figure 1. Study area.**

## METHODS

### *Population Estimate Approach and Assumptions*

We estimated system-wide (RM 18-225) population size for rainbow and brown trout by calibrating single-pass electrofishing (EF) catch-per-effort (CPE) values to absolute, local estimates of fish density ($N_o$). The latter were obtained by a series of spatially and temporally discrete depletion and/or mark-recapture (M/R) electrofishing experiments conducted over a range of fish densities. The focus of this report is on results from depletion experiments. We have no observational model for M/R data at this time, but hope to evaluate them using mark-rate techniques in the coming year.

Relation of depletion estimates to index samples (single-pass CPE) was made assuming

$$CPE = q\,(N_o)$$

where catchability coefficient q is some fraction of absolute fish abundance removed per unit of effort (Hilborn and Walters 1992). In this manner, single-pass index EF samples collected throughout the river system can be "translated" into absolute fish numbers, which are then expanded and plotted longitudinally against river mileage. The resulting curve is then integrated to provide a system-wide population estimate.

The theory behind depletion electrofishing is illustrated in Figure 2, whereby increases in cumulative numbers (K) of fish over a consecutive series of electrofishing passes is plotted against the accompanying decline in CPE with each pass (Leslie and Davis 1939). The value of the x-axis intercept of the regression line in figure 2 (98, or estimated K at CPE = 0 after multiple passes) is the estimate of fish present prior to electrofishing. In our analysis, we used a maximum binomial likelihood routine to search for $N_o$ estimates (Walters, unpublished; Hilborn and Walters 1992) while also accommodating occurrences of zero CPE values.

We treated all depletion data as originating from closed populations (see *Field Methods*). We restricted our inferences on $N_o$ to areas effectively sampled by EF (within ca. 15 m of the shoreline; AGFD, unpublished March 2001 data). Fish with capture probability (q) of near zero (fish inhabiting deep, offshore areas) were modeled indirectly by extrapolating near shore estimates across river length and width.

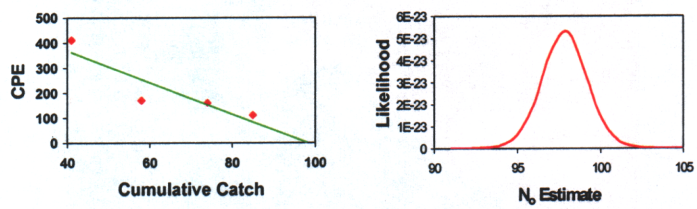


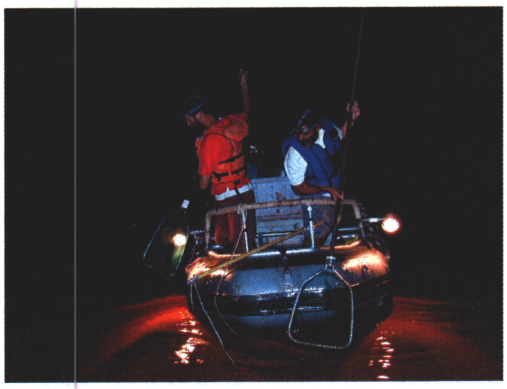

**Figure 2. A typical RBT depletion sample (left, RM 22.3, 6/2/2000) and associated likelihood profile on $N_o$ = 98 fish (right).**

### *Field Methods*

We collected electrofishing data during five mainstem Colorado River trips in Grand Canyon National Park during 2000 (table 1). Samples were collected by Arizona Game and Fish Department (AGFD) and SWCA, Inc., Environmental Services (SWCA). Discharge from GCD was relatively constant at 8,000 cfs during the entire study period. An additional mainstem trip was conducted during December

2001, but mark-rate and distributional data from that trip are pending analysis.

All data used in population estimates were collected by electrofishing at night. We used a 16' Achilles inflatable sport boat outfitted for electrofishing, applying an average output of 310 volts and 14 amps to a 35 cm spherical electrode. All salmonids were measured (maximum total length, mm). We clipped adipose fins of all fish larger than 100 mm. As relatively little is known of brown trout population parameters (growth rates, survival, movement), we implanted all BNT >120 mm with passive internal transponder (PIT) tags. We also clipped adipose fins of all PIT tagged brown trout to allow evaluation of tag loss.



We selected experimental depletion electrofishing transects according to availability of shoreline structural features to minimize immigration and/or emigration from the study area between multiple EF passes (Figure 3). We found that sandbars usually provided the best barrier to immigration and emigration from the transect, because trout generally do not utilize such areas. Debris fans, rapids and rock outcrops also served as barriers, but they were not as effective as sandbars (Speas and Rogers, personal observations). In most cases, few fish were captured at the extremities of the EF transects, and we believe effects of immigration and emigration were minimal. Transects averaged 0.13 miles in length.

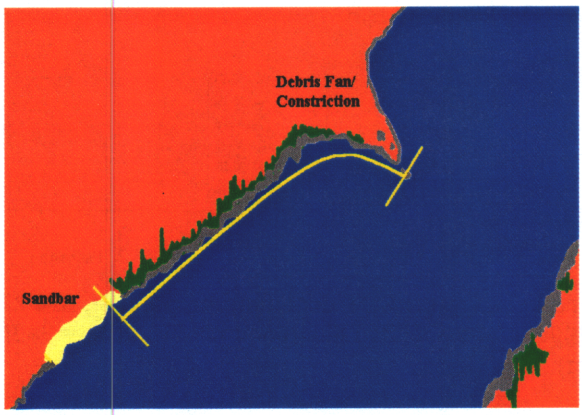



**Figure 3. Schematic of a typical depletion/mark-recapture experimental transect.**

Each depletion experiment was conducted over a period of 2-3 hours each night. We electrofished depletion transects repeatedly until the catch was reduced to about 20% of the first-pass catch. Fish were processed between passes and retained in a mesh live well until the experiment was concluded. At select locations, depletion transects were revisited 24 h later to collect recapture observations using the same amount of effort applied during the previous night.

## RESULTS AND DISCUSSION

Combined efforts between AGFD and SWCA resulted in over 500 EF samples collected between river miles (RM) 0 and 225 during June-September, 2000 (table 1). AGFD conducted 77 depletion experiments. Gastrointestinal tracts were collected from almost 900 fish and are currently being analyzed by Grand Canyon Monitoring and Research Center (GCMRC).

**Table 1. Size and type of electrofishing samples collected on the Colorado River in Grand Canyon, 2000**

| Agency | Trip Dates (2000) | N Index CPE | N Depletion[1] |
|---|---|---|---|
| AGFD | 6/4-5/18 | 83 | 21 |
| AGFD | 7/21-8/3 | 53 | 37 |
| AGFD | 8/25-9/6 | 26 | 19 |
| SWCA | 6/7-6/23 | 174[2] | - |
| SWCA | 8/7-8/22 | 50 | - |
| SWCA | 9/14-9/28 | 43 | - |
| Total | - | 429 | 77 |

[1]First pass from these samples also functioned as index CPE
[2]Not included in population estimate due to EF power output differences

### *Catchability coefficients*

Estimates of q did not vary by fish density for rainbow trout (slope of q was 0) (Figure 4, left). Catchability may be positively related to density for brown trout, but this bias did not preclude calibration of CPE to absolute density (Figure 5, right). There was little evidence that q varied with successive electrofishing passes. Mean q for RBT including first depletion passes (0.52) was nearly identical to second and later passes (0.51), but q for BNT from first pass inclusion (0.16) was slightly greater than for second pass (0.11).

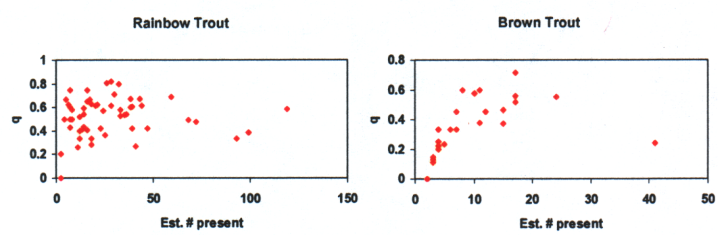



**Figure 4. Catchability coefficient (q) in relation to estimated fish density for RBT (left) and BNT (right).**

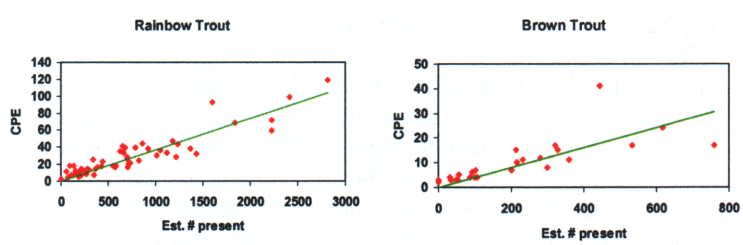



**Figure 5. Calibration of local fish density (RBT, left, and BNT, right) estimates to observed first pass CPE from depletion experiments.**

The usefulness of CPE calibration for long-term monitoring will depend on variability of q with water clarity and seasons, because such variation will affect the slopes of CPE on $N_o$ (Figure 5). Catchability for RBT in samples collected from turbid water conditions was 0.58, compared with 0.51 from clear water. Catchability of brown trout, by contrast, was only 0.10 in turbid water, compared to 0.18 from clear water. Only 13 depletion experiments were conducted under turbid water conditions, and we consider variance of q with water clarity an information need to further refine the monitoring program.

Also, preliminary observations from samples collected during December 2000 and March 2001 (analysis in progress) suggest that behavioral changes in fish distribution associated with reproduction may also result in different estimates of q (Walters, personal communication).

### *Salmonid population estimates and longitudinal distribution*

For both rainbow (figure 6) and brown trout (figure 7), mean fish/RM were modeled longitudinally by a cubic polynomial regression, in which all terms were significant (RBT $R^2$ = 0.60; BNT $R^2$ = 0.24; P<0.0001 for each) except for 2nd and 3rd order coefficients for RBT. These terms were retained, however, to obtain the best approximation of longitudinal variation and minimize negative fish density estimates.

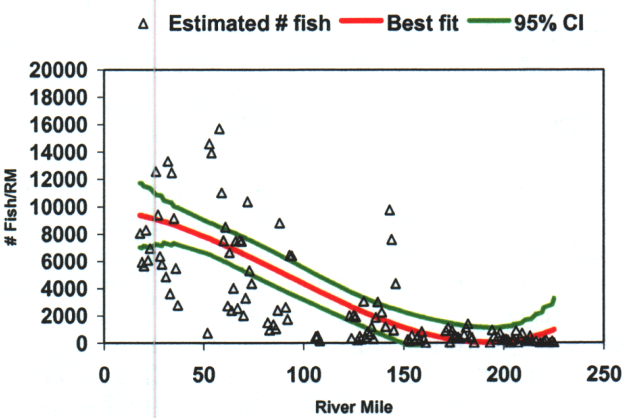



**Figure 6. Estimated rainbow trout/river mile, best fitting line and 95% confidence intervals.**
**RBT/RM=0.0025(RM)^3 - 0.6929(RM)^2 - 9.6464(RM) + 9744.1**

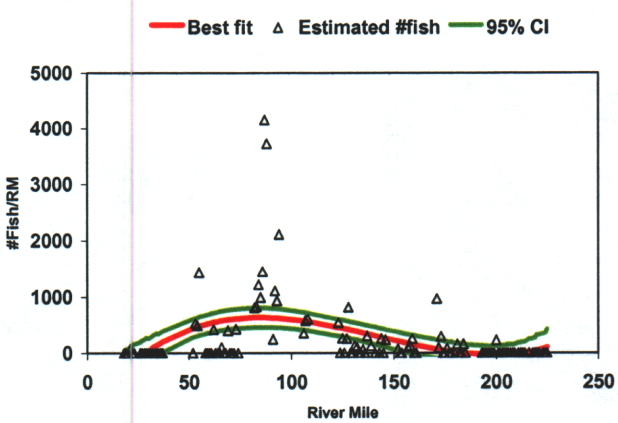



**Figure 7. Estimated brown trout/river mile, best fitting line and 95% confidence intervals.**
**BNT/RM=0.0009(RM)^3 - 0.3786(RM)^2 + 44.767(RM) +-990.38**

Integration of the polynomial curves yield an estimated 743,000 RBT (95% CI: 500,000-1,000,000 RBT) occurring in the Colorado River between RM 18 and 225 (figure 6). Estimated brown trout population size was 56,000 (95% CI: 20,000-100,000 BNT). Rainbow trout occurred predominantly in the first 100 river miles below Lees Ferry, whereas maximum brown trout numbers occurred between RM 50 and 150, especially in the vicinity of Bright Angel Creek (figure 7).

### *Length Frequencies*

Modal length frequencies for adult RBT and BNT were 315 and 282 mm, respectively (figure 8). Juvenile model length frequency for RBT was 160 mm, and 120 mm for BNT. Given these distributions, it is likely that at least a portion of the salmonid populations exert predation pressure on small-bodied fish, but frequency of occurrence and composition of fish in salmonid diets are unknown at this time.

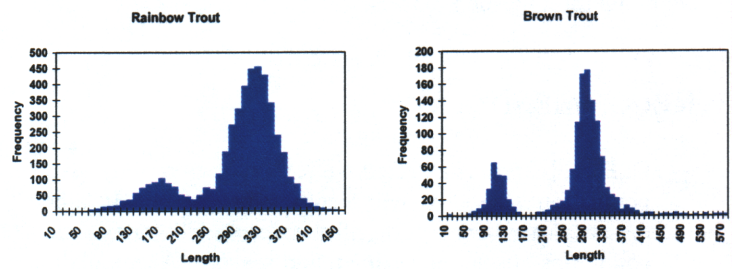



**Figure 8. Length frequencies of rainbow trout (left) and brown trout (right) in the Colorado River, Grand Canyon during 2000.**

### *Error Sources*

We feel that depletion samples were conducted on highly discrete spatial (delimited transects ca. 0.1 mile in length) and temporal (consecutive EF removal passes) scales. Error associated with immigration, emigration, and within-experiment variance in capture probabilities is likely negligible in comparison to error introduced by cross-sectional extrapolation from the local to the system-wide level. While variance in fish numbers along the longitudinal axis of the river is captured by our method, very little is currently known of fish density gradients along the cross-section of the channel.

Fish in areas inaccessible to electrofishing—primarily deep (ca. > 2 m), offshore areas--are effectively invulnerable to depletion estimators in that their catchability approaches zero. Theoretically, however, such fish should be at least partially accounted for in mark-recapture estimates. For comparative purposes, we calculated M/R estimates for RBT and BNT using the same assumptions as we used with depletion estimates[3].

---

[3] M/R estimates of $N_o$ were calculated by maximizing the binomial likelihood for $N_o$ in the formula

$$\Pr\{m|n,n/N_o\} = [n!/m!(n-m)!](n/N_o)^m(1-(n/N_o))^{(n-m)}$$

where $n$ is total fish marked and $m$ is total fish recaptured in an experimental transect 24 h after marking (Hilborn and Walters 1992).

For rainbow trout, estimates of absolute fish numbers ($N_o$) from fish recaptured 24 h after marking in depletion transects were about 2.9 times larger than depletion estimates. Brown trout M/R estimates of $N_o$ were only 1.5 times larger than depletion estimates. While these estimates of bias are admittedly crude, they do suggest that depletion estimates of local fish abundance are negatively biased. In practice, biases of 30-50% in depletion estimates are not uncommon (Hilborn and Walters 1992). It is very possible, however, that such negative biases may be overwhelmed by positive biases introduced by extrapolation.

We are confident that depletion-derived estimates will be useful in evaluating relative risk of predation for native fish because they are relatively precise estimates of population orders of magnitude. Use of such estimates in conjunction with estimates being developed for native fish in a predator-prey model framework should reveal the degree of relative risk salmonids pose to native fish at the population level. Evaluation of stomach samples from summer 2000 should also aid in interpreting such models.

## RECOMMENDATIONS

- CPE calibration is an effective technique to rapidly assess population size, but we recommend continued—albeit opportunistic—estimation of q under varied water clarity conditions, discharge regimen and seasons. Accumulation of such data should facilitate future population estimates despite effects of diverse sampling conditions.

- To facilitate independent estimators of population size, we recommend continued tagging of all salmonids on all mainstem Colorado River fish monitoring trips.

- The primary source of uncertainty in generating population estimates at the system level is making inferences of fish density in areas inaccessible to electrofishing. We recommend research on the cross sectional distribution of fish density in the Colorado River in Grand Canyon. At present, we are investigating use of snorkel surveys to quantify cross-sectional distribution in the Glen Canyon reach (Lees Ferry), and these data may prove useful in estimating fish densities downstream as well.

- Mark-recapture information is at present distributed over both diel and seasonal time scales. We feel that there is more information in the M/R data than just estimates of q, which warrants more comprehensive assessments than we can provide at this time.

## ACKNOWLEDGEMENTS

Grand Canyon Monitoring and Research Center funded the present study under Cooperative Agreement No. 1425-98-FC-40-22690 and provided logistical support. We are grateful to Dr. Carl Walters for his invaluable input in developing the longitudinal population size approach, and his authorship of the maximum likelihood routine for depletion experiments. We also thank the personnel of SWCA for obtaining considerable amounts of longitudinal trout CPE data during 2001.

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Leslie, P.H. and D.H.S. Davis. 1939. An attempt to determine the absolute number of rats on a given area. Journal of Animal Ecology 8:94-113.

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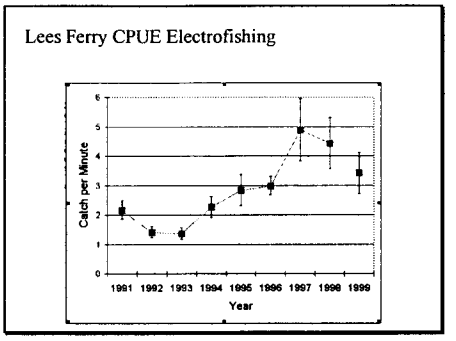
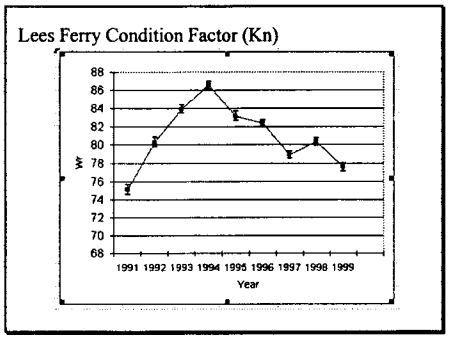
# LEES FERRY TROUT FISHERY STATUS AND TRENDS
# TECHNICAL WORK GROUP MARCH 23, 2001



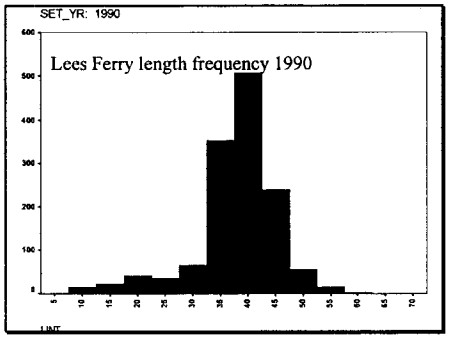

Catch per minute electrofishing at standard sites declined somewhat during 1999, from 4.4 fish per minute to 3.4 fish per minute. Difference was not statistically significant (error bars are 95% Confidence Intervals).

December 2000 Update: Mean CPE = 3.5 fish/ minute

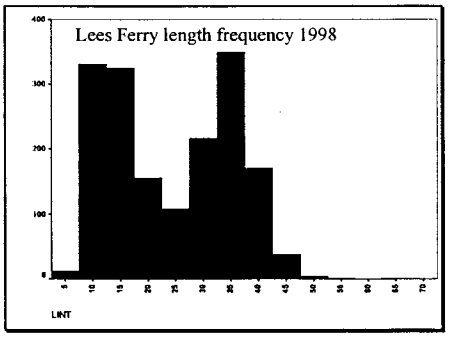



Kn (Wr) during 1999 was 77.5, down from 80.3 during 1998

December 2000 Update: Mean Kn = 73.9




Size composition of fish collected by electrofishing during 1990 shows an absence of small fish (< 150 mm) in the catch.




Size composition of fish collected by electrofishing during 1998 shows an abundance of small fish (< 150 mm) in the catch indicating successful natural reproduction.

Angler Use

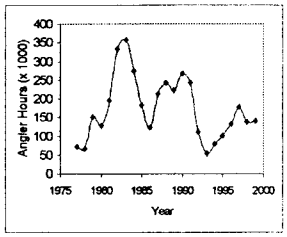



Figure 7. Annual use (angler hours), Lees Ferry 1977-1999.

Angler use remained fairly stable from 1998 to 1999 at 140,000 angler hours.

Angler catch per hour

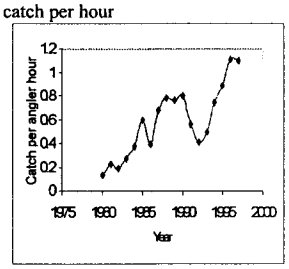



Figure 6. Mean catch of rainbow trout per angler hour, Lees Ferry 1980-1998.

Catch per angler hour remained stable from 1998 – 1999 at approximately 1.1 fish per angler hour. Stable angler use and catch rates suggest stability in the trout population.

Downstream emigration?

- > 400,000 hatchery stocked fish marked with coded wire tags 1991-1997
- 2021 trout examined in downstream reaches (1992-1999)
- 3 tested positive for cwt (or hook).
  - .14%

Downstream emigration of hatchery stocked fish from Lees Ferry to downstream reaches appeared to be negligible during 1991-1999.

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## Fisheries Monitoring: Native & Non-native Fish in Grand Canyon

Grand Canyon Monitoring and Research Center: Biological Program

At present, very few reliable trend data (Meretsky, 2000) are available for native and non-native fish in the Colorado River. Most studies were primarily focused toward characterizing the life history characteristics; as well as directed toward understanding effects relative to Glen Canyon Dam operations. Although this information is very valuable it has not allowed us to reconstruct fish population dynamics. For this reason, in the last year we have restructured and changed the emphasis of the overall monitoring approach. Currently FWS, AGF and SWCA are conducting a joint sampling effort in monitoring and analyzing native and non-native fish population dynamics in the downstream sections of the Colorado River. This integrated effort is scaled back from previous years so that an alternate analytical method or model can be developed that incorporates disparate data sets in combination with ongoing data collection efforts. This year's monitoring program is directing its efforts toward:

1. Determining densities and distributional patterns of non-native fish by sampling with electrofishing gear. Sampling efforts include a combination of depletion and mark-recapture methods to develop catchability coefficients for population estimates of rainbow and brown trouts.

2. Development of stock assessment program for the LCR to provide seasonal estimates of abundance, over-wintering and post-monsoon survival/retention, age-size class structure, spawning abundance, and an index of recruitment strength.

3. Efforts will be coordinated with stock assessment activities in the Colorado River mainstem based on subsequent recapture and mark rates to estimate the relative proportion of mainstem to LCR populations. Secondly, this will be used to make inferences on various size class movement patterns and their survival in the river.

4. Data from this year's joint data collection effort combined with historical data will support the observational data for developing the stock synthesis model and evaluating catch-rate to indexed fish abundance data. This approach integrates a population model with an observational model to estimate key parameters of a population with respect to recruitment, abundance, and survival, so that we are capable of inferring how the population has responded through time.

Recognize that presently we have reduced the overall spatial scale and focus of this sampling and synthesis effort, directing it specifically to humpback chub and flannel-mouth suckers in the LCR tributary and inflow area (RM 58 to 65). This approach will provide a means to reconstruct observational data in order to infer historical population dynamics. Depending on our success, we intend on adapting this same approach and expanding it spatially to include other peripheral aggregations. For this reason, it is critical that we have access to the entire historical data in order to construct and develop the stock synthesis model. Data compilation and quality control efforts are ongoing for GCMRC, FWS and AGF. We expect to have received the source and synthesized historical data from these collaborators by early summer to populate the age-structured model being developed.

## CPUE

Catch-per-unit-effort (CPUE) is an index used as a measure of relative fish abundance. Theoretically, the use of different gear types should be directly proportional to the abundance of fish locally caught. Yet, numerous environmental variables as well as fish behavior influence capture efficiency. Depending on the species, it has become apparent that this type of index does not provide an accurate estimate of abundance. However, it does seem to work quite effectively for monitoring non-natives, specifically trout. For the purpose of contrasting gear effectiveness (Gorman and Coggins 2000) we have been included a number of graphs to provide an example of CPUE variability for specific gear types and fish species. It is notable that CPUE variability for humpback chub is prevalent for all previous fish sampling efforts, which is the reason we are moving away from this conventional monitoring index.

## Population Estimates

Population estimates for humpback chub (HBC) caught in the Little Colorado River are graphically represented by month (lower and upper 95% confidence intervals) (Douglas and Marsh 1996; Coggins 2001). The monthly estimates are not continuous for the period of record, and the break point reflects a nine-year gap from the most recent estimate (Oct-2000). To provide some semblance of trend, we have highlighted population estimates (red) that are similar in sampling date. However, recognized that population estimates are problematic since the LCR is not a closed population. Therefore, monthly population estimates will vary through time due to effects from immigration and emigration of spawning adults and juveniles moving locally or at great distances within the LCR and Colorado River ecosystem. Also, the accompanying histogram represents the distribution of abundance estimates by size class at intervals of 10 mm total length that were calculated for the LCR population during the 2000-fall sampling trip. Future monitoring efforts scheduled for this spring and fall will utilize this same stock assessment approach to provide seasonal population estimates (spring and fall) for HBC. Alternately, the stock syntheses model scheduled for development will provide us with a method to reconstruct demographic trends by size class for the period of observation.

## References

Meretsky, V.J., R.A. Valdez, M.E. Douglas, M.J. Brouder, O.T. Gorman, and P.C. Marsh. 2000. Spatioteomporal variation in length-weight relationships of endangered humpback chub: implications for conservation and management. Transactions of the American Fisheries Society. 129:419-428.

Douglas, M.E., P.C. Marsh. 1996. Population estimates/population movements of Gila cypha, an endangered cyprinid fish in the Grand Canyon region of Arizona. Copeia. 1996(1): 15-28.

Gorman, O., and L. Coggins. 2000. Status and trends of native and non-native fishes of the Colorado River in Grand Canyon. U.S. Fish and Wildlife Report, Arizona Fishery Resources Office, Flagstaff. 24p.

Coggins, L. 2001. Fisheries monitoring activities in the Little Colorado River within Grand Canyon during 2000. Draft-Report. U.S. Fish and Wildlife Report, Arizona Fishery Resources Office, Flagstaff. 102p.

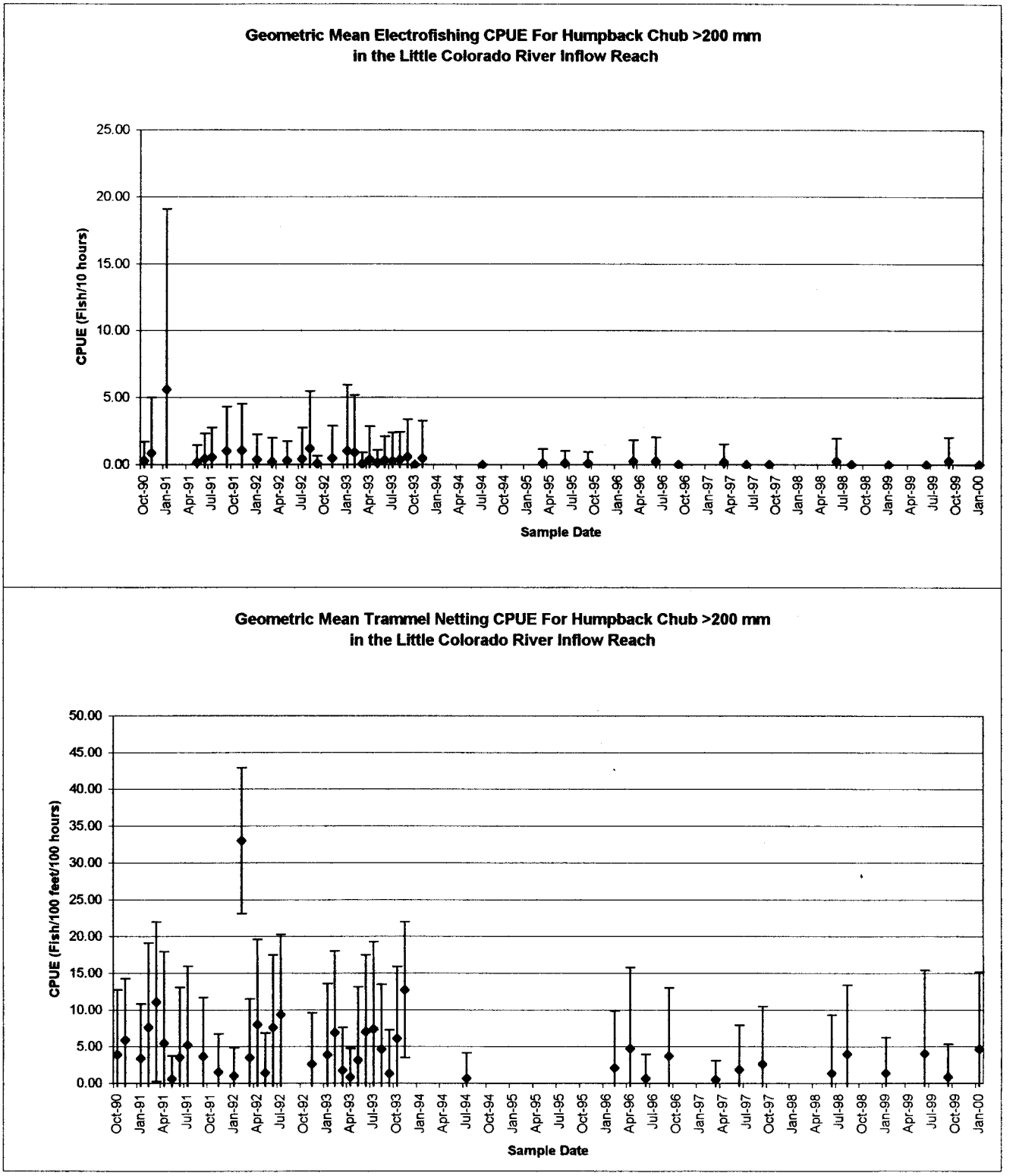



Figure 6. Electrofishing and trammel netting CPUE for humpback chub > 200 mm within the Little Colorado River Inflow Reach. Error bars are one standard error.

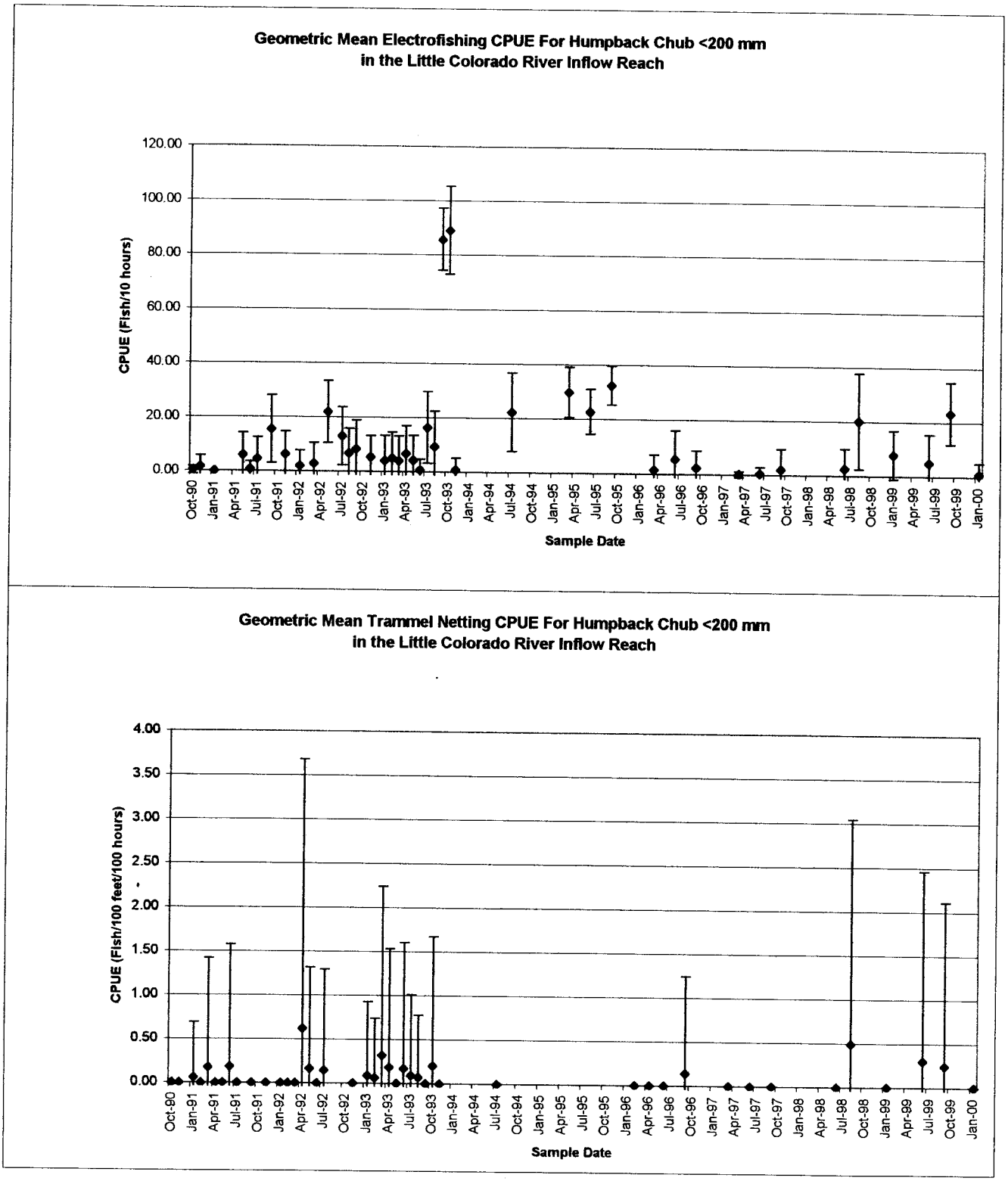
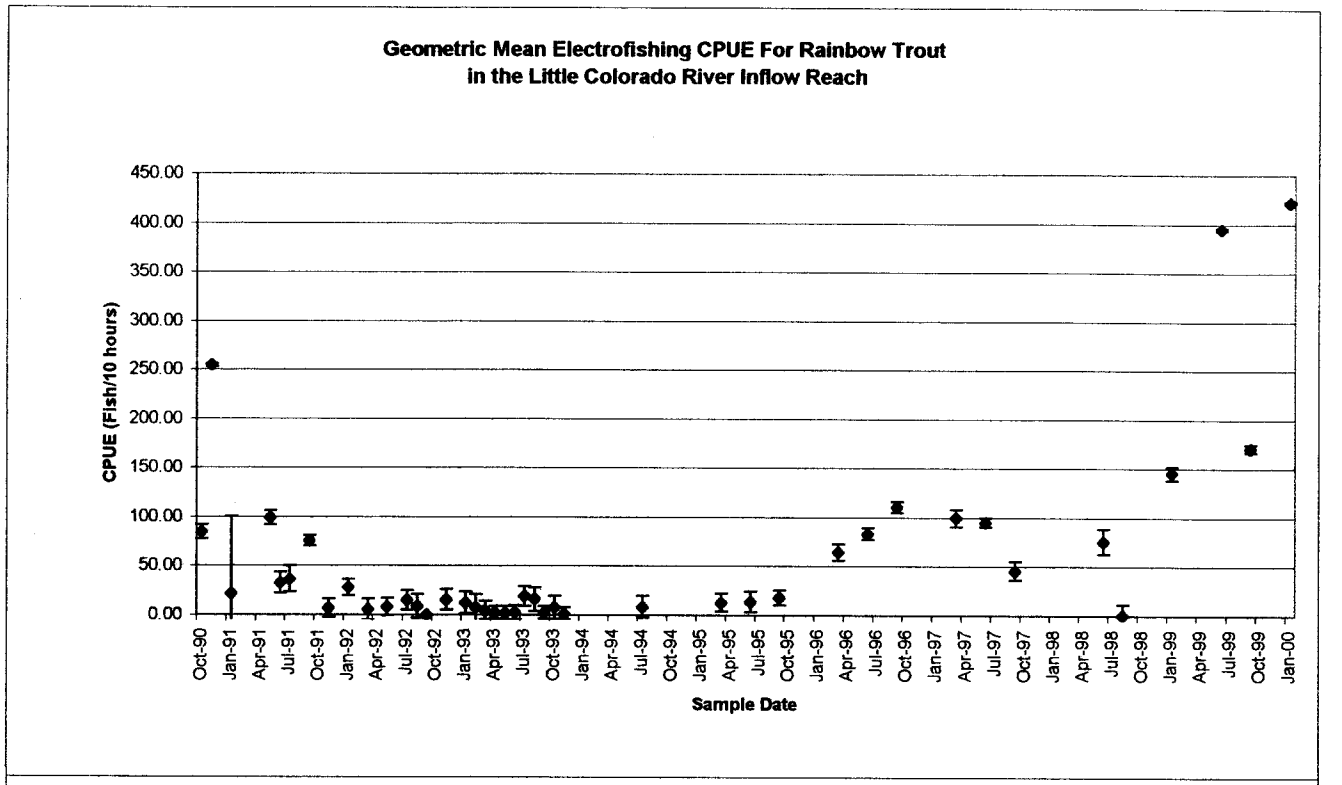



Figure 1. Electrofishing and trammel netting CPUE for humpback chub < 200 mm within the Little Colorado River Inflow Reach. Error bars are one standard error.



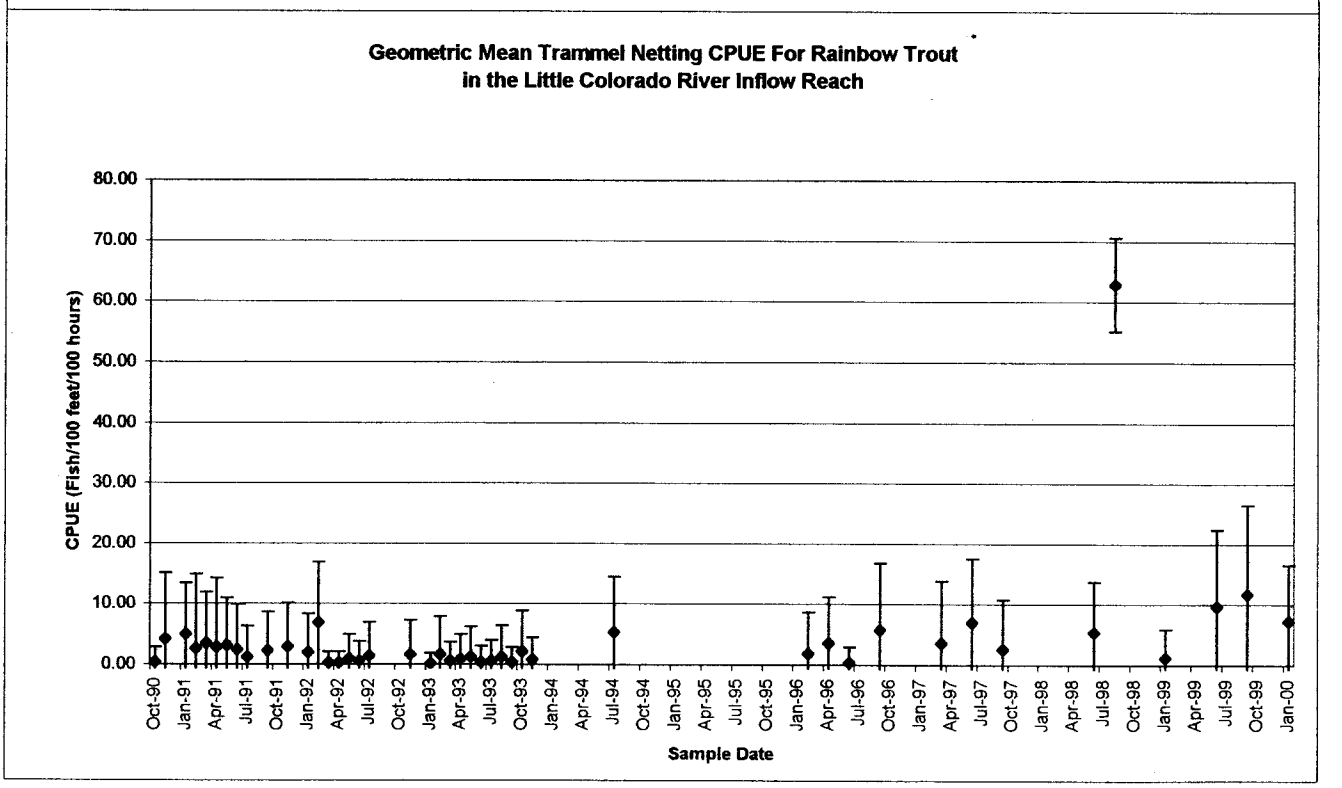
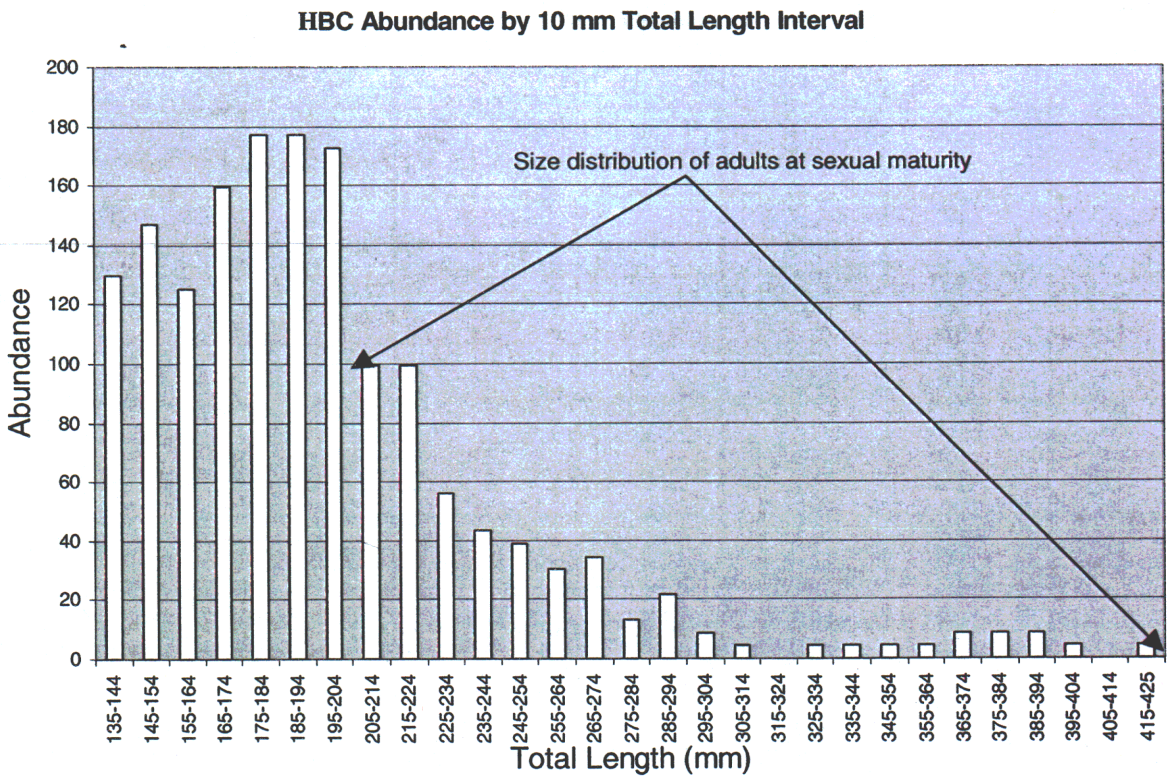




Figure 12. Electrofishing and trammel netting CPUE for rainbow trout within the Little Colorado River Inflow Reach. Error bars are one standard error.


HBC Abundance by 10 mm Total Length Interval
Size distribution of adults at sexual maturity
Abundance
0
20
40
60
80
100
120
140
160
180
200
135-144
145-154
155-164
165-174
175-184
185-194
195-204
205-214
215-224
225-234
235-244
245-254
255-264
265-274
275-284
285-294
295-304
305-314
315-324
325-334
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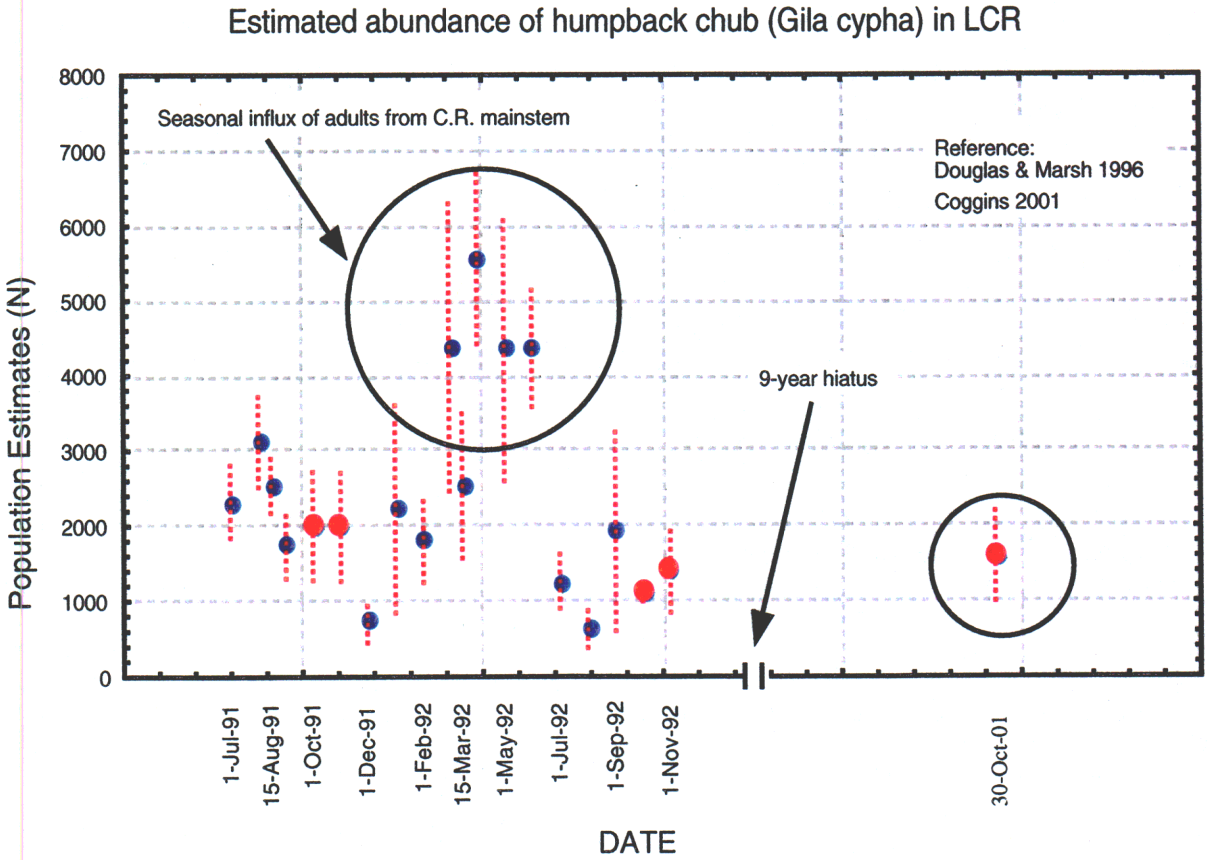
345-354
355-364
365-374
375-384
385-394
395-404
405-414
415-425
Total Length (mm)


Estimated abundance of humpback chub (Gila cypha) in LCR
Seasonal influx of adults from C.R. mainstem
Reference:
Douglas & Marsh 1996
Coggins 2001
9-year hiatus
Population Estimates (N)
0
1000
2000
3000
4000
5000
6000
7000
8000
1-Jul-91
15-Aug-91
1-Oct-91
1-Dec-91
1-Feb-92
15-Mar-92
1-May-92
1-Jul-92
1-Sep-92
1-Nov-92
30-Oct-01
DATE

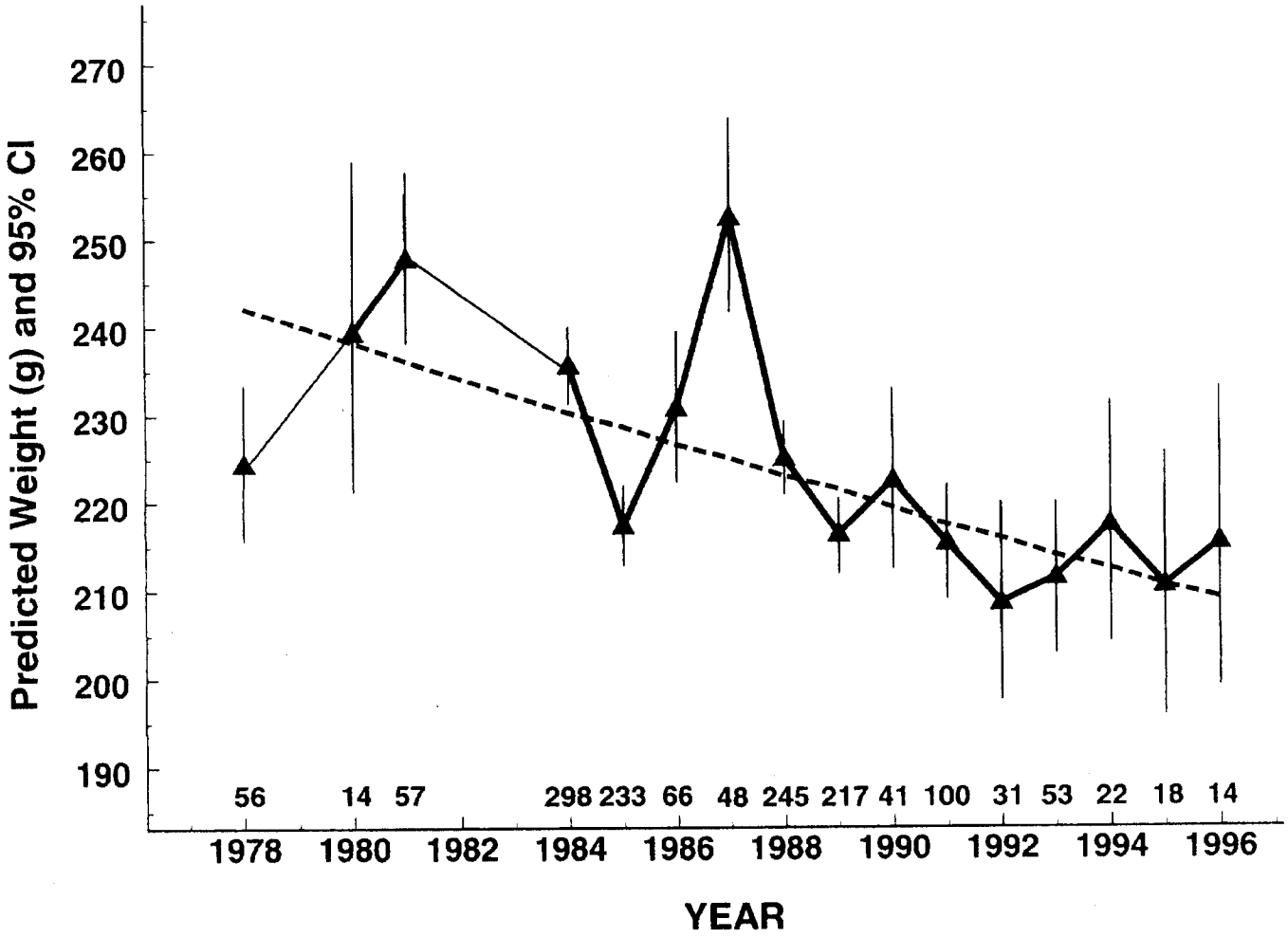



Figure 3. – Predicted weights and 95% confidence intervals (CI) of 300-mm TL adult male humpback chub from data collected at the Little Colorado River—Colorado River confluence, 1978-1996. The broken line shows the linear trend from a log-log analysis, back-transformed into the original units. Predictions are back-transformed output from a log-log analysis. Sample sizes are shown above the abscissa.

Figure 1. A specimen of the endangered Humpback Chub (Gila cypha)

Figure 2. Razorback Sucker (Xyrauchen texanus)

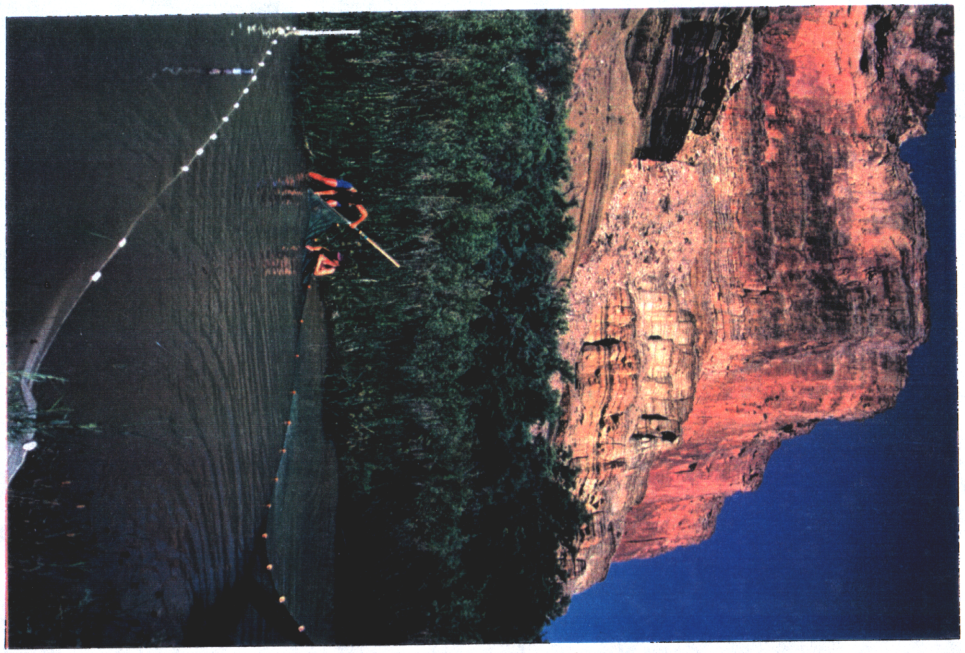


Figure 3. Seining for native fish, Kwagunt backwater, RM55. Warmer backwaters may provide breeding habitat

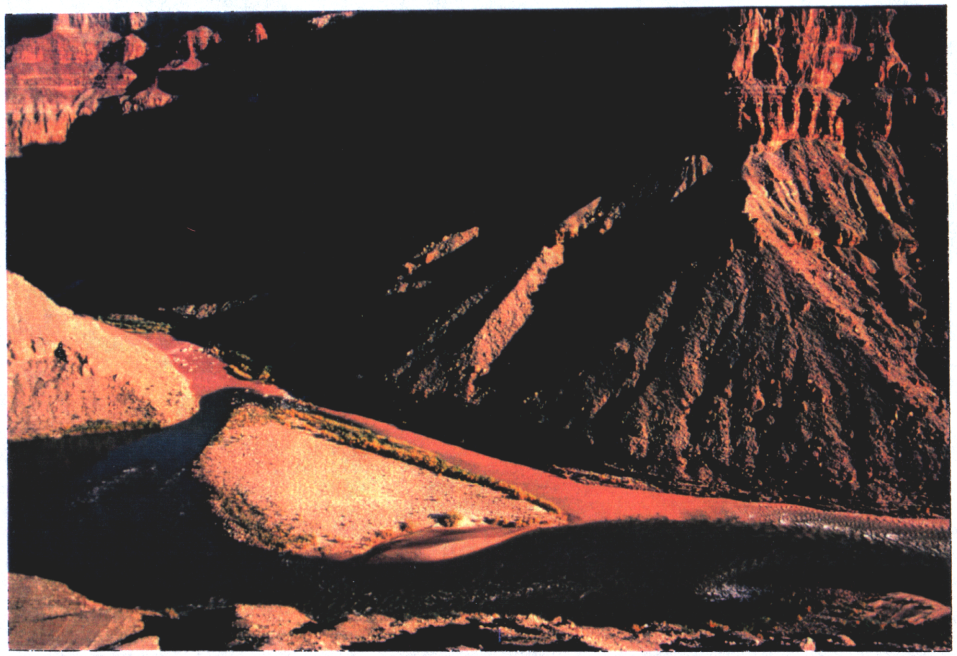


Figure 4. View up LCR. Higher mainstem flows push cold water into chub Fingerling habitat below LCR island

# Integrated Terrestrial and Aquatic Ecosystem Activities

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GCMR-700

September 18, 2000

# MEMORANDUM

**To:** Kathleen Wheeler

**From:** Barry D. Gold BG

**Subject:** Summary of Recent Sediment related Research Findings

A few months ago I sent you five published scientific papers that presented the results of recent sediment-related research sponsored or conducted by GCMRC. At that time you asked that we prepare a summary of those papers for your information. I asked Ted Melis, the GCMRC Program Manager for Physical Resources and the sediment researchers whose work we were citing to develop a summary memo. While the attached memo was reviewed by myself and Randy Peterson it represents the researcher's own perspectives on their recent findings.

Their conclusions could have important implications for the Glen Canyon Dam Adaptive Management Program. They challenge the two hypotheses on which the EIS and ROD were based. First they challenge the notion that sand can be stored in the channel bed over a number of years and then once sufficient accumulation has occurred it can be redistributed through a Beach/Habitat-Building Flow. Rather, they argue that the sand which enters the system from tributary events is transported downstream relatively rapidly. Second, they postulate that the fraction of sand that is remaining will not be sufficient to build bars and provide a positive sand balance.

The implications for their findings for sediment resources only are: (1) that releases above peak-power-plant discharge may need to be conducted immediately after substantial inputs of sand from tributaries; and (2) flows following sand inputs from tributary events should be maintained at 8,000 to 10,000 cfs to maximize sediment storage until peak power-plant discharges can be implemented.

Their findings also suggest two hypotheses that will need to be evaluated based on the data collected from the GCMRC long-term monitoring program. One is that the system will exist in the post-dam era in some sort of degraded equilibrium as compared to the pre-dam sediment balance. The other is that the system will continue to experience a long-term loss of sediment.

# United States Department of the Interior

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University of California at Santa Cruz
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MEMORANDUM

August 29. 2000

To: Barry D. Gold, Chief, Grand Canyon Monitoring and Research Center

From: David M. Rubin DMR and David J. Topping, U.S. Geological Survey
John C. Schmidt, Utah State University
Joe Hazel, Northern Arizona University

Re: Summary and Discussion of Recent Research Findings Related to Dam Operations and Sand Bar Resources of the Colorado River Ecosystem

## Background

Sand bars are an essential component of the Colorado River ecosystem downstream from Glen Canyon Dam. They create habitat utilized by endangered fish; they contain and protect an array of Native American cultural resources; they provide campsites used by recreational boaters; and they are a distinctive attribute of the pre- and post-dam river landscape. Improving and maintaining sand bars below the dam is a fundamental long-term management objective of the Grand Canyon Protection Act, the Operation of Glen Canyon Dam Final Environmental Impact Statement, and the Glen Canyon Dam Adaptive Management Program (See Attachment 1).

Sand bars and sandy banks of the Colorado River in Grand Canyon are maintained by the sand that is transported through the canyon. The high-elevation parts of these sand bars (those parts at elevations above peak power-plant discharge) can be constructed only by flows that exceed peak power-plant discharge (i.e. flows greater than 31,000 cfs); in the absence of such high flows, these high-elevation areas are eroded by lower flows or canyon winds or are rapidly colonized by both native and exotic vegetation. Flows above peak power-plant discharge are necessary to maintain these high-elevation sand bars, but are effective only when the river contains sufficient sand resources.

Evaluating restoration and sustainability of sand resources is a complicated problem that involves sand storage on the Colorado River's bed, tributary resupply of sand, sand deposition induced by flows above peak power-plant discharge, erosion and transport of sand during normal power-plant operations, and recolonization by vegetation. Improving or sustaining sand resources is a difficult challenge because Glen Canyon Dam traps all of the sediment from the upper Colorado River, resulting in an approximate 94% reduction (relative to pre-dam inputs) in the amount of sand supplied to the Colorado River at the upstream boundary of Grand Canyon National Park.

With respect to restoration and sustainability of sand bars, the Secretary of the Interior's 1996 Record-of-Decision (ROD) for operations of Glen Canyon Dam is based primarily on two hypotheses:

(1) that much of the sand introduced to the Colorado River by tributaries downstream from Glen Canyon Dam can accumulate in the channel over multiple years if dam releases do not exceed average volume, and


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(2) that flows above peak power-plant release (such as the 45,000 cfs flow in 1996) can effectively move that accumulated sand from the channel bed to bars, thereby rebuilding sand bars that are eroded by typical dam releases.

Recent Findings

Work conducted since the 45,000 cfs release in 1996 has shown that the first hypothesis on which the 1996 ROD was based is false and that the second hypothesis is only partially true. The 45,000 cfs release in1996 increased the amount of sand at high elevations (Figure 1), but the sand that was deposited at high elevations came largely from the lower portions of the sand bars (Schmidt, 1999) and not from the channel bed as originally hypothesized.

Under the dam operations imposed by the 1996 ROD, most newly input sand is not stored on the channel bed for long periods of time (Topping et al., 2000a; Topping et al., 2000b). Flows above peak power-plant release cannot take advantage of multiple years of sand accumulation, because substantial multi-year accumulation of sand does not occur. Instead, this sand is transported downstream relatively rapidly. The time required to export (transport downstream past the Grand Canyon gage) one-half of a 500,000 metric ton input of tributary sand (the contribution of a typical, moderate, Paria flood) varies from less than one week (for dam discharges of 25,000-30,000 cfs) to roughly one year (for discharges of 10,000 cfs), as illustrated in Figure 2.

The time required to export the second half of a tributary input is greater than for the first half (for a constant water discharge), because the second half is coarser, as a result of winnowing of the bed (Topping et al., 2000b; Rubin and Topping, in press). The remaining half, however, is not necessarily sufficient to enable both bar-building and a positive sand balance. For example, the 45,000 cfs release in 1996 exported 700,000 metric tons of sand from Marble Canyon in one week. Thus, a release above peak power-plant discharge is a double-edged sword: high discharges are indispensable for rebuilding high-elevation parts of bars, but high discharges deplete sand resources rapidly (Figure 2). Conducting a release above peak power-plant discharge when recent tributary sand inputs are greatest will tend to minimize the negative impact on the sand resources.

Since the 45,000 cfs release in 1996, six kinds of sediment and topographic data have been examined: sediment input and output, changes in grain size of sand on the river bed, changes in sand-bar size, geomorphic mapping, and changes in channel cross-sections. Some of these studies document rapid export of tributary sand (transport past the Grand Canyon gage), whereas others demonstrate a lack of substantial multi-year accumulation of sand, especially in upper Marble Canyon:

• Both measurements and calculations of sediment input and output have shown that most fine sediment (sand, silt, and clay) introduced by tributaries is exported within a few months (Topping et al., 2000a; Topping et al., 2000b). For example, field measurements show that most sediment introduced by floods on the Paria River in September, 1999, was exported within 6 weeks. On a longer time scale (August 11, 1999 to May 14, 2000), the Paria supplied approximately 0.8 million metric tons of sand to the Colorado River, while roughly twice this amount of sand (1.5-2 million metric tons) was exported past the Lower Marble Canyon gage.

• Changes in grain size of sand on the river bed also demonstrate rapid export of tributary sand. The bed was measurably enriched in finer sand as a result of Paria floods in September, 1998 (median grain size of Paria River sand is 0.11 – 0.13 mm). When sampled next (May, 1999), most of the new fine-grained sand on the bed had been winnowed (Topping et al., 2000b). The

remaining sand in the channel was generally too coarse to be transported onto the high-elevation areas of sand bars.

• Topographic surveys of 11 sand bars in the first 76 miles downstream from the dam document a continuing depletion of sand-bar area from 1991 to 1999 (Figure 1A). High flows in 1996 and 1997 temporarily reversed this trend but did not halt the continuing decrease in sand-bar area. The sand bars (above 20,000 cfs) were 22% smaller in surface area in 1999 (Figure 1A), although they contained 2-3% more sand than in 1991 (Figure 1B).

• Topographic surveys of 35 sand-bar sites documented scour of sand during the 45,000 cfs release in 1996, followed by net accumulation (J. Hazel, personal communication). Comparison with tributary-input data for the same time, however, indicates that most of the observed accumulation occurred when there was no substantial tributary sand input.

• Repeated surveys of channel cross-sections from 1991 to 1999 have shown relatively large and rapid fluctuations in the amount of sediment present (M. Flynn and N. Hornewer, personal communications). These fluctuations are interpreted to represent temporary storage and subsequent down-river transport of sediment. These studies have not detected multi-year accumulation of sediment.

• Analysis of bed-elevation data at the historical Marble Canyon dam sites suggests considerable loss of sediment from the 1950's to the present. Not only does the post-dam river contain less sand than the pre-dam river, but the remaining sand is generally coarser (Rubin and Topping, in press).

• Geomorphic mapping indicates that deposition of the 45,000 cfs release in 1996 was least near Lees Ferry and was greatest downstream from the Little Colorado River (Schmidt et al., 1999; H. Sondossi, personal communication). The magnitude of "improvement" is greatest further downstream where more tributaries have delivered fine sediment to the channel. Thus, the "improvement" caused by any specific release above peak power-plant discharge differs both temporally and spatially, depending on how enriched or depleted a particular reach is at the time.

## Implications for Current Management Actions

The features listed above characterize a system where increases in sand abundance result not from incremental multi-year accumulation but rather from temporary storage of individual tributary inputs. In such a system, where increases in sand abundance are temporary, the goal for building sand bars should be to exploit tributary inputs as soon as possible, because the volume of sand available for bar-building is greatest immediately after large tributary inflows. To be effective in rebuilding sand bars, releases above peak power-plant discharge should occur soon after these tributary inflows, before the new sand is lost downstream (Figure 2).

Large Paria tributary inflows typically occur during late summer and early fall. Under the rules of the 1996 ROD, however, releases above peak power-plant discharge cannot be implemented on a schedule that takes advantage of such inputs. If a release above peak power-plant discharge cannot be scheduled immediately following a tributary input, another option might be to maintain low flows until a release above peak power-plant discharge could be implemented; the low flows would reduce the amount of sand lost downstream. The magnitude of an acceptable low flow that limits the rate of sand export depends on the volume of sand introduced by tributary flooding, the length of time following the tributary input, and what loss of sand downstream is considered acceptable. At dam releases that are typical of recent years, half of the sand introduced by a tributary flood can be exported within days or weeks (Figure 2). Retention of sand for more than a few months

requires sustained dam releases at the lower discharges currently permitted under the ROD (8,000 - 10,000 cfs).

## Recommendations for Future Management Actions

Even if rules for releases above peak power-plant discharge are revised to allow scheduling during or shortly after periods of sand inputs, the objectives of improving or sustaining the desired abundance, form, and function of sand bars may still not be possible because the long-term sand supply from tributaries in critical reaches may be too small. The 76-mile reach downstream from Glen Canyon Dam has but one large sand source: the Paria River. The supply of sand from the Paria River is only about 6% of the sand that was supplied to this reach prior to the construction of Glen Canyon Dam. Natural floods from the Paria River may be too infrequent and too small to restore sand resources in this critical upstream reach, which includes the 60-mile length of Marble Canyon within Grand Canyon National Park.

Altering the timing of releases above peak power-plant discharge (or drastically reducing the dam's discharge until such flows can be released) may be insufficient to rebuild sand resources above existing levels or to achieve sustainability at present levels; additional monitoring will be required to see if these options are successful. If alternative timing of releases above peak power-plant discharge proves to be insufficient for sand-bar management goals, then other more effective alternatives should be evaluated.

One approach would be to selectively add sand downstream of the dam. This alternative ("sediment augmentation") was considered and eliminated during the Operations of Glen Canyon Dam EIS process. We are unaware of engineering feasibility studies of such a program, but sediment by-pass is an attribute of some recently built dams, as well as harbors and estuaries. A review of sediment pipeline technology is included on the EPA web site, http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch5.html. Addition of enough sediment (continuously, seasonally, or perhaps only during releases above peak power-plant discharge) would offer greater flexibility in dam operations, and it is conceivable that such an approach might cost less than imposing new constraints on dam operations. It is possible that sediment augmentation, substantial seasonal modification of flows released from Glen Canyon Dam, or both, might be able to restore the sand resources in the Colorado River ecosystem in Grand Canyon National Park without more extreme actions.

## Conclusions

The post-dam Colorado River is depleted in sand resources relative to the pre-dam river. The existing management strategy permitted under the ROD is failing to restore sand resources in the ecosystem in Grand Canyon National Park. The bars are continuing to decrease in surface area, and no long-term retention of tributary sand has been detected.

Our opinion, based on the information presented in this summary, is that any of the following approaches will have a significantly greater likelihood of success in restoring or retaining sand resources in the Grand Canyon ecosystem:

(1) Implement releases above peak power-plant discharge immediately after substantial inputs of sand from tributaries.

(2) Maintain low flows following sand inputs until releases above peak power-plant discharge can be implemented.

(3) Add sediment downstream from the dam.

Dam operations of the last decade must have caused one of the following possible effects on sediment resources in the Colorado River ecosystem: sediment resources were enhanced or replenished relative to conditions in the early-to-mid 1990's, sediment resources were maintained in a degraded (post-dam) condition, or long-term export and loss of sediment resources is continuing. Distinguishing between such possibilities has been—and should continue to be—an important function of the GCMRC Adaptive Monitoring Program. The research reviewed above demonstrates that current operations are failing to increase sediment resources. At least one significant measure of sediment resources, surface area of sand bars above 20,000 cfs, documents continuing depletion of sand resources.

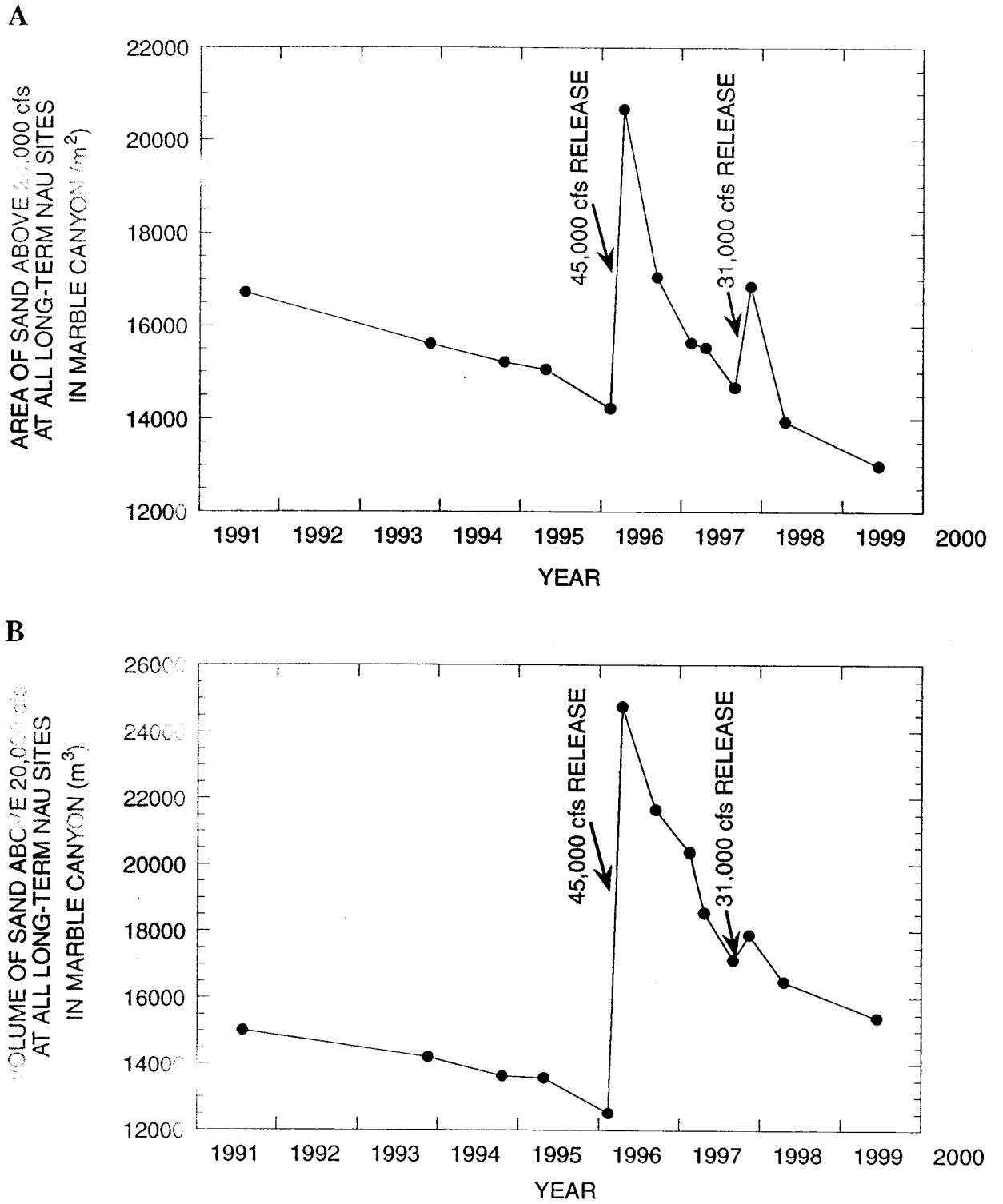


**Figure 1.** Changes in sand-bar surface area and volume at all 11 long-term Northern Arizona University study sites in Marble Canyon. **A.** Surface area of sand bars decreased by 22% from 1991 to 1999 despite temporary increases caused by high releases in1996 and 1997. **B.** Volume of sand bars in 1999 was 2-3% greater than in 1991.

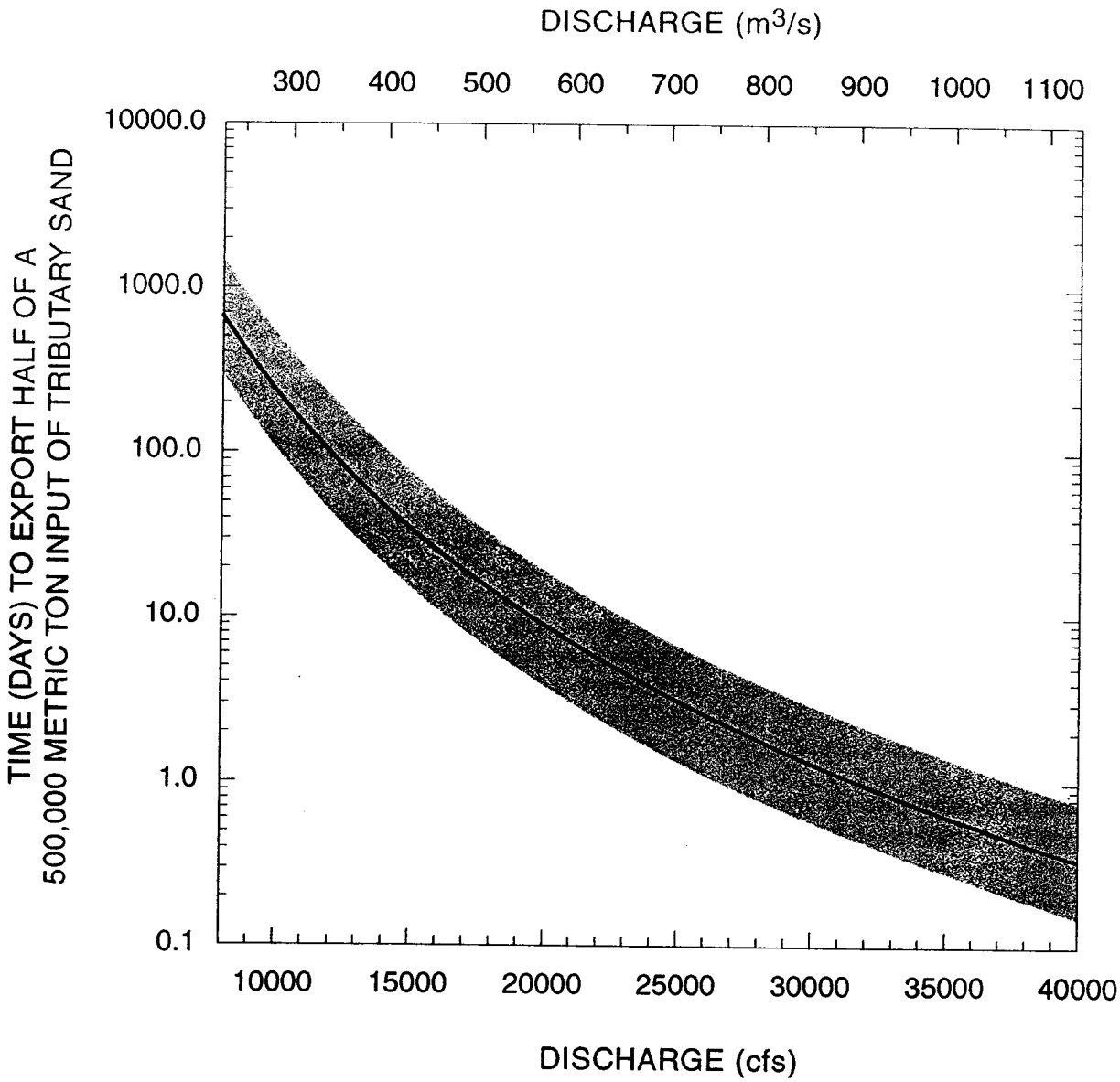


**Figure 2.** Calculated time to export one-half of a 500,000 metric ton input of tributary sand past the Grand Canyon gage. Calculations are based on sediment-transport data collected at the Grand Canyon and above LCR gages during the 1990's. The upper limit of the shaded area (slowest export) is calculated using the average suspended-sediment concentration for each specified discharge; the lower limit of the shaded area (most rapid export) is calculated for high concentrations of suspended sediment at each discharge; the solid line in the center of the shaded band is calculated using concentrations that decrease through time from high values (during and immediately following tributary inputs) to mean concentrations (after half of the tributary sand has been exported). At the upper range of dam operations, half of the sediment is exported within a few days; multi-year accumulation is only likely to occur if discharge is restricted to less than 8,000-10,000 cfs. To maximize the benefit of sand supplied by tributaries, releases above peak power-plant discharge should be implemented as soon as possible after tributary input events.

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**Attachment 1.** Management objectives for sediment resources within the Glen Canyon Dam Adaptive Management Program are stated as follows in the June 10, 1998 Management Objectives document adopted by the Adaptive Management Work Group.

## SEDIMENT RESOURCES

Goal: to maintain a range of sediment deposits over the long-term, including an annually flooded bare-sediment (unvegetated) active zone, a less frequently flooded vegetated zone, terraces (within the 45,000 cfs river stage), and backwater channels. Managing sediment resources will be on a reach-scale basis. Should significant and localized adverse impacts occur, site-specific mitigation would be considered.

Definition: Sediment resources include a broad array of material, ranging from suspended fines to coarse gravels. Primary interest relates to both material in suspension, which affects benthic capability, as well as stored sediment in beaches and channel margins, which affects recreation.

## MANAGEMENT OBJECTIVES

**MO 1:** Maintain a long-term balance of river-stored sand to support maintenance flow (in years of low reservoir storage), beach/habitat-building flow (in years of high reservoir storage), and unscheduled flood flows. Maintain system dynamics and disturbance by annually (in years which Lake Powell water storage is low) redistributing sand stored in the river channel and eddies to areas inundated by river flows between 20,000 cfs and maximum power plant capacity.

**MO 2:** As a minimum for each reach, maintain the number and average size (area and thickness) of sandbars and backwaters between the stages associated with flows of 8,000 and 45,000 cfs that existed during the 1990/91 research flows.

**MO 3:** Periodically increase the average size of sandbars above the 20,000 cfs river stage and number and average size of backwaters to the amounts measured during the high period of 1990/91 or the 1996 test of the beach/habitat-building flow in as many years as reservoir and downstream conditions allow.

**M) 4:** Maintain system dynamics and disturbance by redistributing sand stored in the river channel and eddies to areas inundated by river flows up to 45,000 cfs in as many years as possible when BHBF hydro logic and resource criteria are met.

# RECREATION

## MANAGEMENT OBJECTIVES

**MO 2:** Maintain flows (under approved operating criteria) and sediment processes that create an adequate quantity, distribution and variety of beaches for camping, as long as such flows are consistent with management of natural recreation and cultural resource values (other natural resource values).

# DEVELOPMENT OF A DYNAMIC SEDIMENT BUDGET FOR THE COLORADO RIVER ECOSYSTEM

**David J. Topping, USGS**

This research is intended to develop predictive methods for determining the real-time inputs of sand, silt, and clay to Colorado River ecosystem and the spatial and temporal evolution of the sediment supply in the Colorado River. Because the grain size of sediment in the Colorado River evolves as functions of tributary activity and dam operations, mainstem sediment-transport rates evolve by over an order of magnitude. Thus, static sediment budgets using stable sediment-rating curves (as done in the 1995 Glen Canyon Dam Environmental Impact Statement) cannot be constructed. Our approach is to use a process-based methodology to develop a dynamic sediment budget for the Colorado River ecosystem. The methods that we are developing will allow managers to design dam releases to maximize the retention of fine sediment in the Colorado River ecosystem under very different sediment-supply conditions.

Analysis of sediment budgets suggests that both before and after completion of Glen Canyon Dam in 1963, the Colorado River in Grand Canyon was annually supply limited with respect to fine sediment (i.e., sand, silt, and clay). During each year, between 80 and 120% of the supply of fine sediment to the reach between the Lees Ferry and Grand Canyon gages was exported. In both the late pre- and early post-dam periods, storage of fine sediment in this reach was typically for 1-2 years. Completion of the dam decreased the supply of fine sediment to this reach by 83% , decreased the seasonal storage of sediment by about 50%, and radically altered the seasonal patterns of sediment storage and erosion. In the pre-dam era, during lower flows, the san-transport capacity of the Colorado River at the Lees Ferry gage was lower than that at the Grand Canyon gage, with the opposite being true during higher flows. Because of these differences in transport capacity, in the pre-dam era, storage of sediment in Marble and upper Grand Canyons increased rapidly during mid-July through October, the season of dominant tributary sediment input. Following this rapid increase, the volume of sediment stored in Marble and upper Grand Canyons continued to increase at a slower rate as sediment was supplied from the Colorado River above Lees Ferry. Finally, during the snowmelt flood, sediment would be eroded from Marble and upper Grand Canyons. In the post-dam era, storage of sediment in Marble and upper Grand Canyons only increases during the time of large sediment inputs form the Paria and Little Colorado Rivers. During the rest of the year in the post-dam era, the tendency is for erosion of sediment from Marble and upper Grand Canyons. Thus, Glen Canyon Dam has converted a system in which sediment would generally accumulate over 8 months of a year to one in which sediment is generally eroded over 8 months of a year.

As a result of the mismatch in the timing of maximum sediment supply and transport, the grain-size distribution of sediment both on the bed and in suspension in the Colorado River evolves over time. This grain-size evolution occurs as a function of changes in the upstream supply of sediment caused by both tributary activity and dam operation. Systematic changes in bed elevation also occur as functions of the discharge of water and upstream sediment supply. Sediment input to the Colorado River during tributary floods

travels down the mainstem as elongating "sediment waves," with the finest sizes (because their lower settling velocities) traveling the fastest. As the front of these sediment waves pass a given location, the concentration of suspended sediment first increases as the grain size in the system fines, then subsequently decreases as the grain size in system coarsens. In the post-dam era, changes in sand-transport rates as high as a factor of 15 have been observed in connection to sediment fining during large tributary floods. As the finest sizes of sediment are winnowed form the bed, the bed and suspended sediment coarsen, causing the formation of inversely graded deposits. Because the grain size of sediment changes over time, sediment rating curves are unstable. Therefore, sediment budgets in a supply-limited river like the Colorado River cannot be constructed through use of stable sediment rating curves. We are developing predictive methods to determine the spatial and temporal evolution of the sediment supply in the Colorado River. These methods can be used by managers to design dam releases (both within powerplant capacity and above) to maximize the retention of sediment in the Colorado River ecosystem.

# STATUS OF FINE-SEDIMENT IN THE COLORADO RIVER ECOSYSTEM PRIOR TO THE MAY 2000 31,000 cfs RELEASE

David J. Topping, David M. Rubin, and Nancy J. Hornewer (USGS)

## Summary

Analysis of the intensive August 1999-April 2000 suspended-sediment dataset collected by the USGS - Arizona District at the Lower Marble Canyon Gage (a.k.a. the "above LCR gage") and the Grand Canyon Gage indicates that **at least as much sand was exported past these 2 gages as was supplied by the upstream tributaries during this period**. Moreover, analysis of the data from the Lower Marble Canyon Gage suggests strongly that sand was eroded from the Colorado River in Marble Canyon during August 1999-April 2000. Analysis of the suspended-silt and clay data indicates that about as much silt and clay was exported past these 2 gages as was supplied by the upstream tributaries during this same period. Thus, the fine-sediment mass balance in the Marble Canyon and upper Grand Canyon portions of the Colorado River Ecosystem was slightly negative at the beginning of the 2000 LSSF Experiment. These results are shown in Figure 1.

Computations of $\beta$ values (Rubin and Topping, 2001) from the August 1999-April 2000 suspended-sand data indicate that, at both gages, the upstream supply of sand coarsened as it became depleted prior to the May 2000 31,000 dam release (Figure 2). As defined in Rubin and Topping (2001), $\beta$ is a nondimensionalized measure of the grain size of the bed sediment that is accessed by the flow, and is computed from the suspended-sediment data. Comparison of the 1999-2000 $\beta$ values from the Grand Canyon gage with $\beta$ values computed from pre-dam and pre-1999 post-dam suspended-sand data indicates that the sediment supply was coarser and more depleted in April 2000 than at any other time except during the fall of 1985 (a period following 3 years of sustained high dam releases).

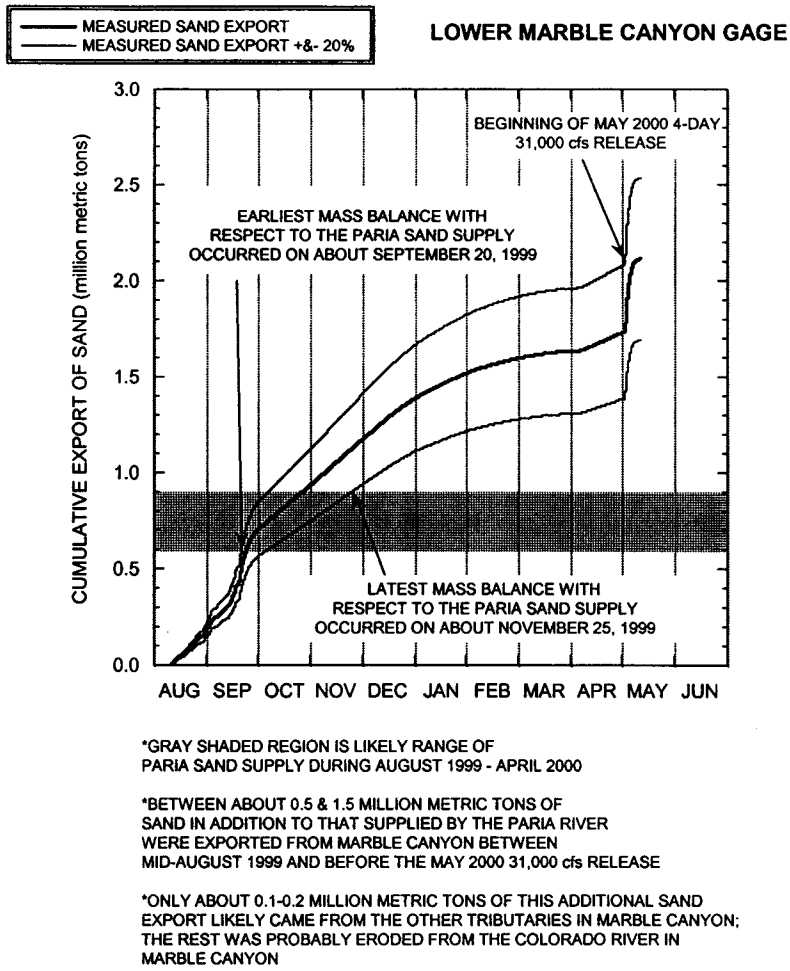


**Figure 1a:** Sand mass balance plot for the 98-km long reach from Lees Ferry to the Lower Marble Canyon gage for August 1999-early May 2000. The sand budget for this period becomes negative (indicating net erosion of sand from the canyon) when the export curves exceed the gray box by more than 0.1-0.2 million metric tons (the likely contribution of sand from the smaller tributaries). Estimates of the sand contribution from the smaller Marble Canyon tributaries based on Webb et al. (2000) and the results from the current monitoring program on these tributaries.

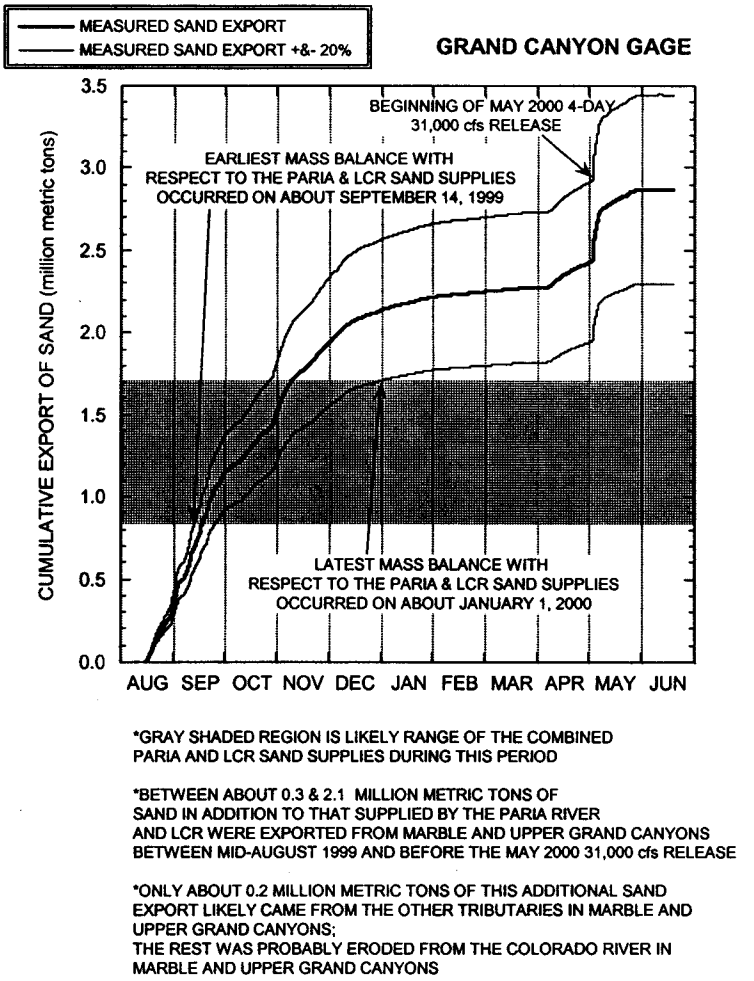


**Figure 1b:** Sand mass balance plot for the 141-km long reach from Lees Ferry to the Grand Canyon gage for August 1999-June 2000. The sand budget becomes for this period becomes negative (indicating net erosion of sand from the canyon) when the export curves exceed the gray box by more than about 0.2 million metric tons (the likely contribution of sand from the smaller tributaries).

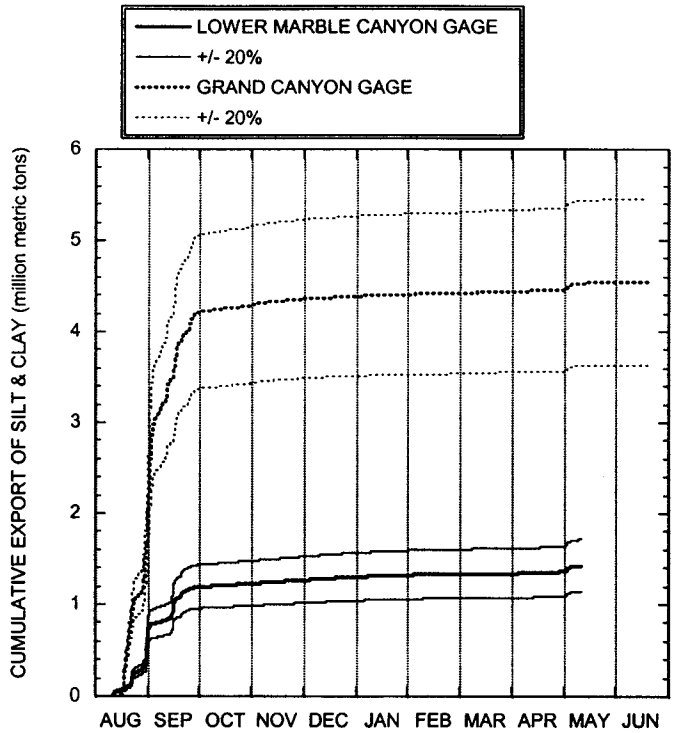


**Figure 1c:** Measured silt and clay exports past the Lower Marble Canyon and Grand Canyon Gages during August 1999-June 2000. During this period, the Paria River supplied about 0.8 million metric tons of silt and clay to the Colorado River, and the Little Colorado river supplied about 3 million metric tons of silt and clay to the Colorado River.

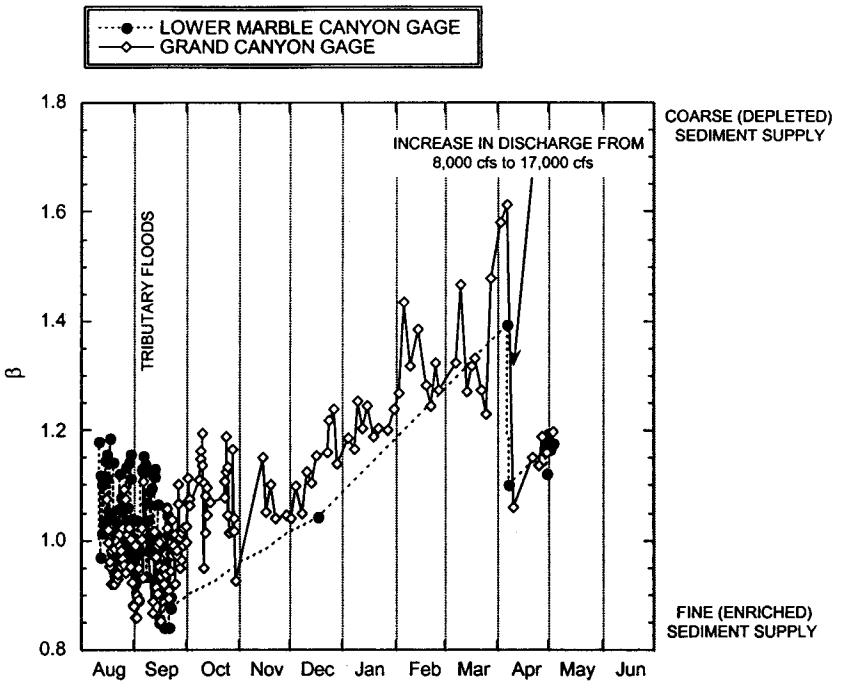


**Figure 2a:** Computed β values from the suspended-sand data collected at the Lower Marble Canyon and Grand Canyon Gages. At both gages, the upstream supply of sand: (1) first fined as it became enriched during the August-September 1999 period of tributary floods; (2) then coarsened as it gradually became depleted from October 1999 through March 2000; (3) then fined abruptly as the dam releases increased from 8,000 cfs to 17,000 cfs; and (4) finally coarsened again during the period of steady 17,000 cfs before the May 2000 31,000 release (values during the May high release not shown). The abrupt fining during the increase in discharge from 8,000 to 17,000 cfs occurred in response to finer sources of sand at higher elevations being accessed/eroded by the higher flow.

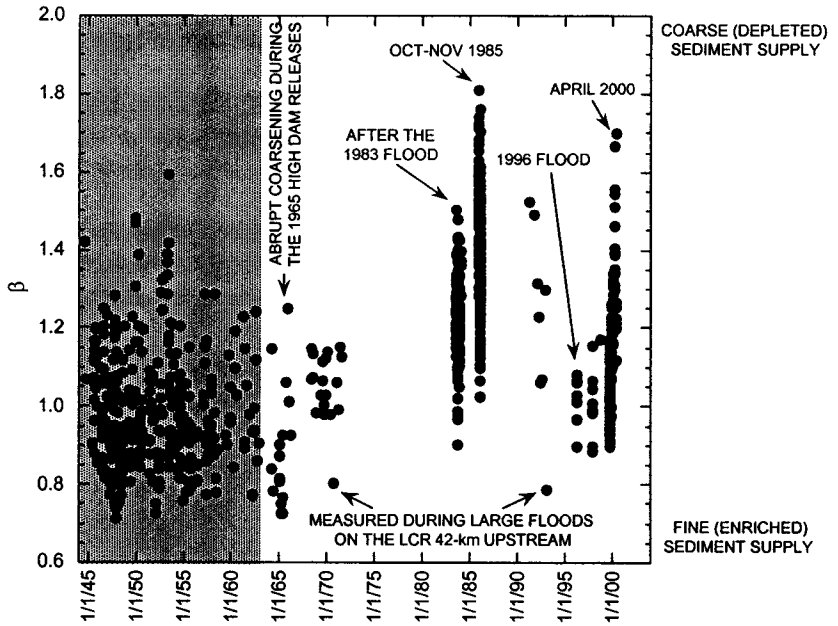


**Figure 2b:** Computed β values from all 1944-2000 suspended-sand data collected in flows of 8,000 cfs or higher at the Grand Canyon Gage. The shaded region indicates the pre-dam era. During April-June 1965, the first period of high flows following closure of Glen Canyon Dam in March 1963, the sand supply at the Grand Canyon Gage coarsened as 16 million metric tons of fine sediment (mostly sand) were eroded from the reach between Lees Ferry and the Grand Canyon Gage (Rubin and Topping, 2001). The sand supply at the Grand Canyon Gage never fully recovered from the 1965 event. After 1965, the sediment supply became as enriched as it was seasonally in the pre-dam era only during large tributary floods upstream. [During the pre-dam era, up to 13 million metric tons of sand would accumulate in the reach between Lees Ferry and the Grand Canyon Gage between July and March. This stored sand would then be depleted during the higher snowmelt flows during April-June (Topping et al., 2000).] The sediment supply at the Grand Canyon Gage was the coarsest and most depleted during the fall of 1985, following 3 years of sustained high dam releases. The second most depleted period for the sediment supply occurred during April 2000, just prior to the May 2000 4-day 31,000 cfs release. As shown in Figure 1, the fine-sediment mass balance between Lees Ferry and the Grand Canyon Gage was slightly negative during August 1999-April 2000. Interestingly, the sand supply was coarser and more depleted during April 2000 than it was immediately following the 97,000 cfs 1983 flood.

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# Monitoring Fine-Sediment Storage of the Colorado River Ecosystem below Glen Canyon Dam, Arizona

Sand Bar Studies Fact Sheet
Department of Geology
Northern Arizona University

December 1999

The distribution of fluvial sediment downstream of Glen Canyon Dam is of fundamental importance to the Colorado River ecosystem in Glen, Marble, and Grand Canyons. Sand deposited along the channel margins creates the foundation of the ecosystem by providing substrate and habitat for aquatic and terrestrial species. Sand bars deposited within eddies are also the primary campsites for rafting and hiking groups. Glen Canyon Dam has transformed the once sediment-laden Colorado River into a sediment-limited system. The only remaining sources of fine-sediment (sand and finer) input are tributaries, primarily the Paria and Little Colorado Rivers.

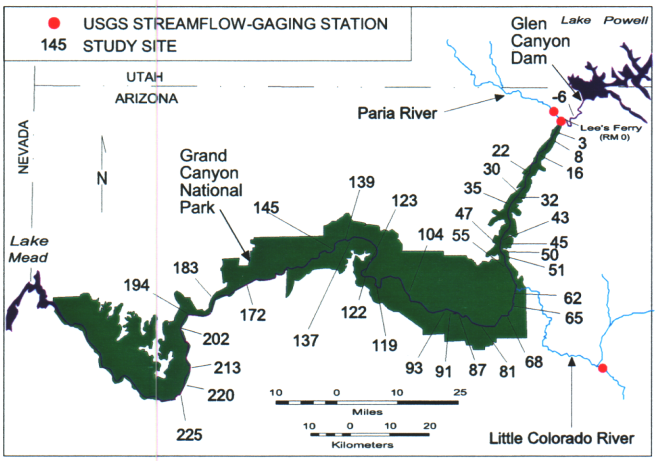



**Figure 1. Location of NAU study sites and streamflow gaging stations. River miles after Stevens (1983).**

In cooperation with the Glen Canyon Environmental Studies and the Grand Canyon Monitoring and Research Center, we have monitored the movement and accumulation of fine-sediment throughout the Colorado River ecosystem since 1990. Our approach is to conduct repeated topographic and hydrographic surveys at 35 long-term study sites and to use these data to estimate reach and system-wide responses of sediment to changing dam operations (Figure 1; see Kaplinski et al., 1995; 1998; or Hazel et al., 1999, for an extensive description of our methodology and study sites). In our analysis, we divide the river corridor into the Glen, Marble, and Grand Canyon reaches to describe sediment storage changes above and below the Little Colorado River. For each site, the volume of sediment stored within main channel, eddy, and sand bar environments are measured (Figure 2). These values are compared to previous surveys to determine site-specific changes, then averaged or summed over the entire reach to assess reach-scale effects. While these 35 sites are not wholly representative of the entire fluvial system, they provide the most accurate and complete time-series available to date for medium-term, volumetric and area changes in sediment storage. Furthermore, volumetric data from these monitoring sites, in conjunction with reach-scale aerial photogrammetric mapping (Schmidt et al., 1999a), flow modeling (Wiele et al., 1999), and suspended sediment sampling (Topping et al., 1999), is critical to the development of a Colorado River ecosystem sand budget (Schmidt, 1999; Hazel et al., in prep.). In this fact sheet, we briefly summarize our monitoring and stress the importance of tributary floods and controlled flood flows in conserving sediment and rebuilding eroded sand bars.

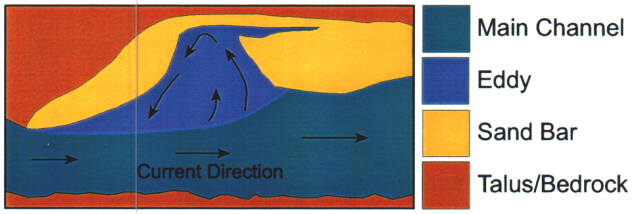



**Figure 2. Cartoon map view of typical Colorado River sand bar showing areas where volumes are calculated.**

Discharge data shown in Figure 3a summarizes the pattern for Glen Canyon Dam operations from 1991-1999. Interim flows, released during completion of the Glen Canyon Dam EIS (DOI, 1995), occurred from 1991 through 1996, and were intended to minimize sand bar erosion and export of sand, as well as to maximize potential fine-sediment storage in the river channel. Despite the reduced peak daily flows,

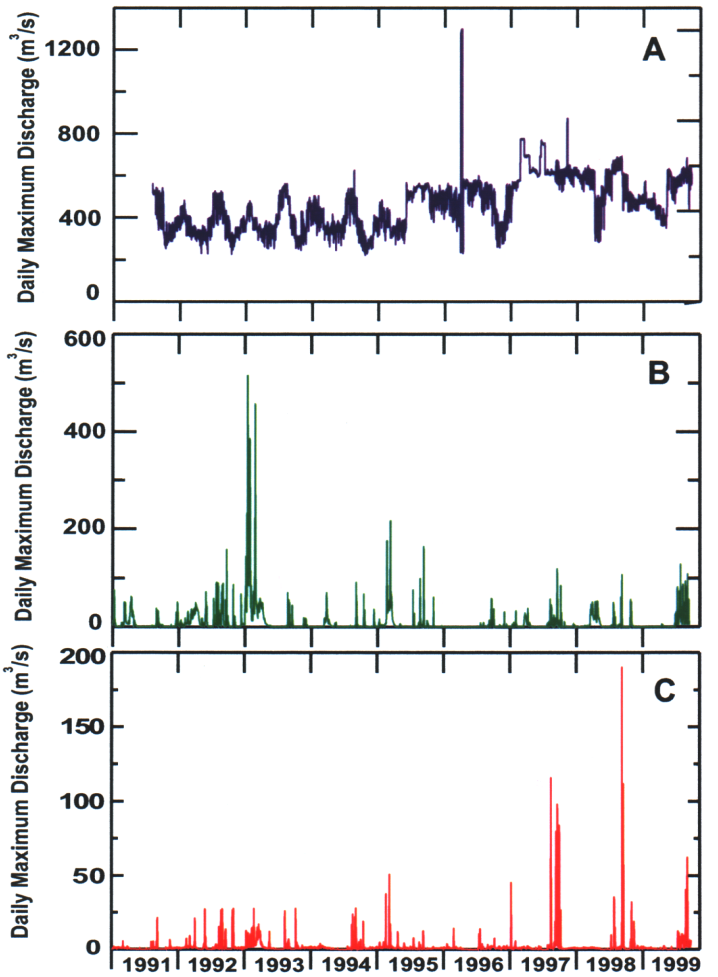



**Figure 3. Daily maximum discharge hydrographs from U.S.G.S. gaging stations. A) Colorado River near Lee's Ferry (09380000), B) Little Colorado River near Cameron (094020000), C) Paria River near Lee's Ferry (9382000).**

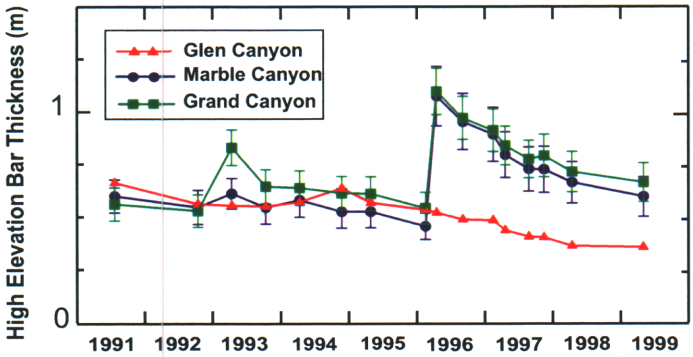



**Figure 4. Average sand thickness of high-elevation sand bars in Glen, Marble, and Grand Canyons.**

limited hourly ramping rates, and fluctuation range characteristic of interim flows, high-elevation (above the 556 $m^3/s$ [20,000 $ft^3/s$] stage elevation) sandbars were progressively eroded (Figure 4).

Sand bars aggraded during tributary flood events from the Paria and Little Colorado Rivers in 1993 and 1995. Floods from the Little Colorado River during the winter of 1993 raised mainstem flows to over 950 $m^3/s$ (33,000 $ft^3/s$) (Figure 3b). Following these floods, we measured a substantial increase in high-elevation sand bar thickness downstream of the Little Colorado River confluence. The observed bar building demonstrated that flows in excess of power plant capacity were a viable mechanism to aggrade high elevation sand bars.

In the final EIS, it was hypothesized that controlled flooding could transfer sediment from the channel bed to the channel banks and re-build eroded sand bars (Schmidt et al. 1999b). Aggraded sandbars would potentially provide more area for riparian habitat development, camping, and prolong the residence time of sediment within the system by removing it from direct downstream transport. A controlled flood would also re-introduce a "disturbance" to the ecosystem; much like controlled burns are used in forest ecosystems. Short-duration dam-released floods, in excess of powerplant capacity, were included as an integral part of the preferred alternative in the final EIS on operations of Glen Canyon Dam (DOI, 1995) and the Record-of-Decision (DOI, 1996).

The 1996 controlled flood, released on March 26, 1996, was designed to test these hypotheses (Figure 3a). The hydrograph consisted of a seven day, sustained high discharge of 1,274 $m^3/s$ (45,000 $ft^3/s$), preceded and followed by three days of a constant low discharge of 227 $m^3/s$ (8,000 $ft^3/s$). The data summarized by Webb et al. (1999) indicate that the 1996 controlled flood achieved many of the intended goals. The high-elevation parts of sand bars accumulated a significant volume of sand (Figures 4 & 5). Even the site in Glen Canyon was aggraded, where sand supply is thought to be most limited. Hazel et al. (1999) correlated the magnitude of deposition to space available for deposition and stressed the importance of antecedent conditions in the prediction of future floods intended to aggrade sand bars. In contrast to high-elevation deposition, sediment was scoured from low-elevation storage areas in the main channel and large eddies (Figure 5 & 6). Significant scouring of sand from the low-elevation parts of large eddies suggests that eddy systems can store as much, or more sand than the adjacent main channel pool. The 1996 experiment demonstrated that controlled flooding could transfer fine-sediment from the bed to the channel margin.

Perhaps more important than the deposition during the 1996 controlled flood was the longevity of the newly aggraded bars. Subsequent monitoring from 1996 to 1999, showed that sand bars eroded rapidly during the first six months of "normal" dam operations following

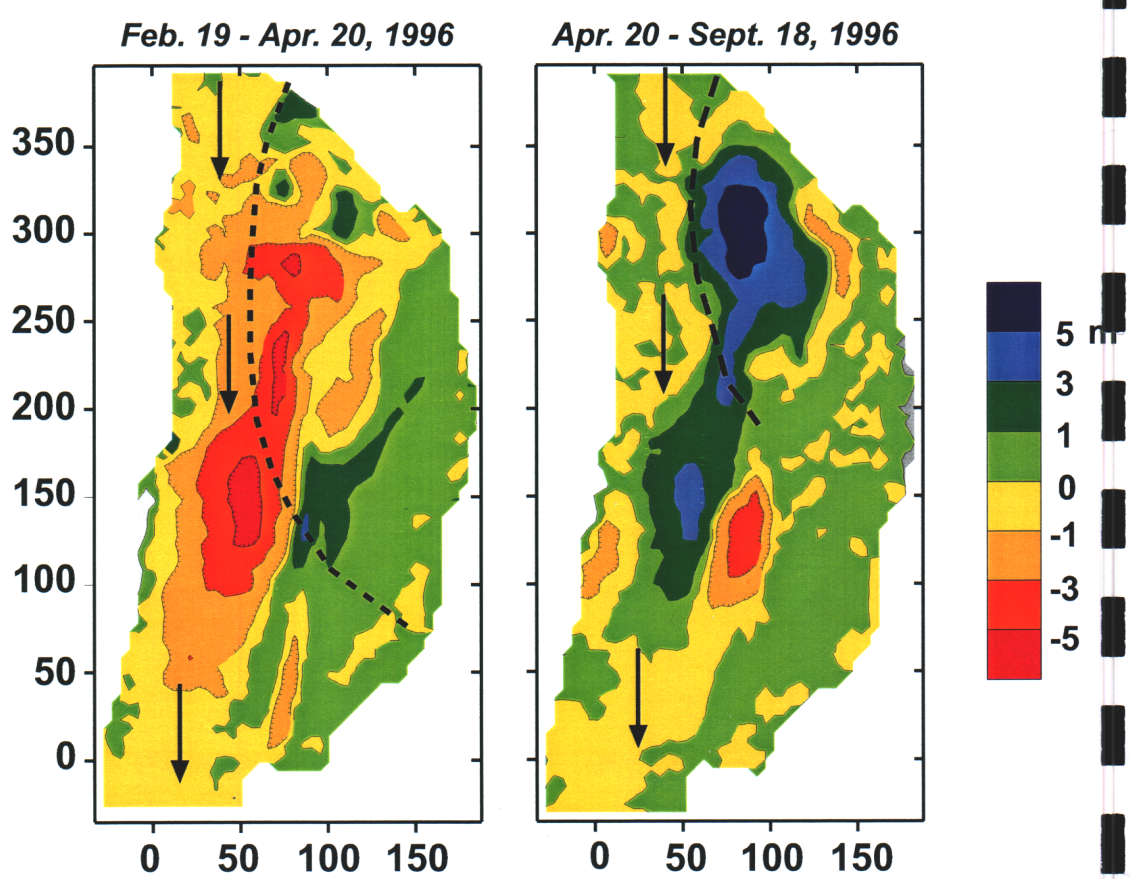



**Figure 5. Topographic changes at the 51 mile study site. Areas of deposition are shown in greens and blues, and areas of erosion are shown in yellows and reds. Arrows indicate the direction of the main current. A) Changes from before and after the 1996 controlled flood. Approximate location of the eddy fence at a discharge of 1,274 $m^3/s$ is shown by the dashed line. Note the low-elevation scour within the eddy and main channel, and high-elevation deposition along the sand bar. B) Changes six months after the 1996 controlled flood. Approximate location of the eddy fence at 556 $m^3/s$ eddy fence is shown by the dashed line. Note the low-elevation deposition within the eddy and the main channel, and high-elevation erosion of the downstream end of the sand bar exposed to direct downstream current.**

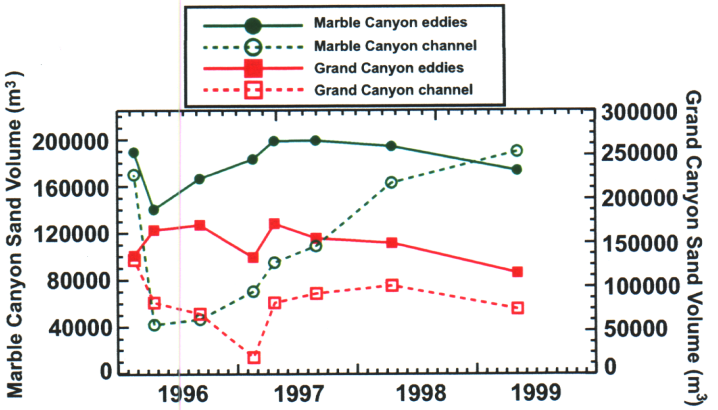



**Figure 6. Total cumulative eddy and channel sand volume in Marble and Grand canyons.**

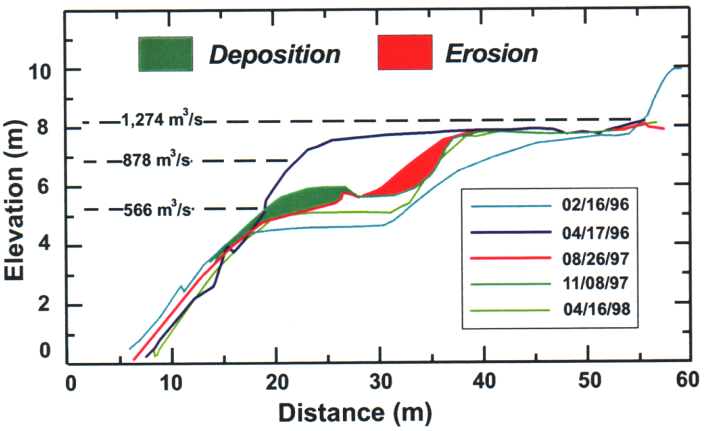


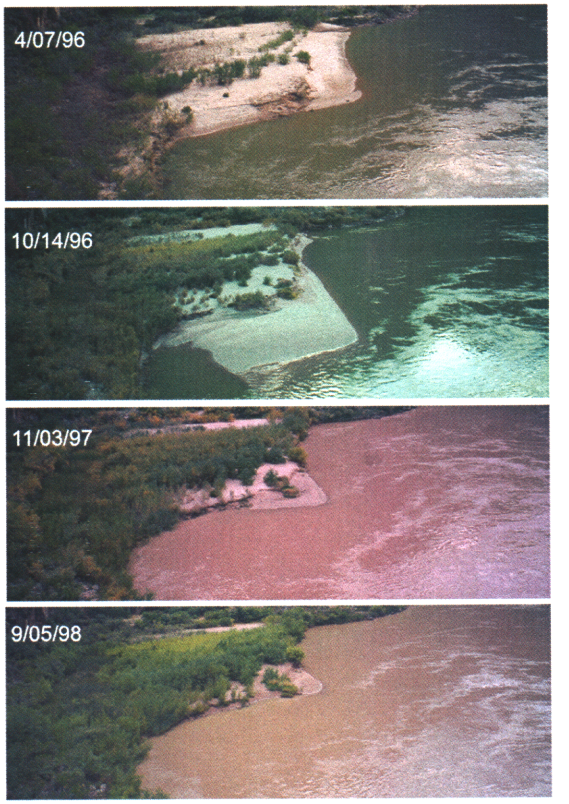

**Figure 7. Topographic cross-sections of the 30 mile sand bar in upper Marble Canyon. Flow stage elevations for thehigh-elevation volume calculations (556 m³/s, 20,000 ft³/s), the 1996 controlled flood (1,274 m³/s, 45,000 ft³/s),and 1997 test flow (878 m³/s, 31,000 ft³/s) are shown.**

the controlled flood, but erosion rates then decreased with time (Figure 4). In contrast, low elevation eddy and main channel environments aggraded (Figures 5 & 6). Sand eroded from high-elevation bars was gradually transferred back to low elevation storage environments in eddies and the main channel (Figures 4 & 6).

Beginning in 1995, and continuing into 1999, dam releases were generally high to prevent spills from Lake Powell (Figure 3a). In 1997, four closely-spaced floods from the Paria River in August and September 1997, delivered an estimated 770,000 m³ of sand to the Colorado River (Figure 3c). Following these inputs, the Glen Canyon Dam adaptive management program recommended that a short-duration, powerplant capacity test flow be released in Fall 1997. The 1997 test consisted of a constant flow of 878 m³/s (31,000 ft³/s) for 48 hours. The 1997 test flow examined the hypothesis that a shorter-duration, lower magnitude dam release could mimic the results of the 1996 controlled flood and transfer Paria-supplied sediment from the channel bed onto channel margin sandbars before the sand was transported downstream from Marble Canyon.

Our monitoring shows that the 1997 test flow only temporarily and partially achieved this objective. The 1997 test flow did not reverse the trend of high elevation erosion following the 1996 controlled flood (Figure 4). Net high-elevation sand bar thickness did not increase because deposition of sand on the bar was offset by erosion of the deposit above the stage elevation reached by the 878 m³/s (31,000 ft³/s) flow (Figure 7). These results suggest that the stage elevations reached by the 1997 test flow were not high enough to result in deposits that could escape rapid erosion by the dam releases that followed.

Our latest monitoring data show that, as of April 1999, fine-sediment has accumulated within the channel and eddies and eroded from the sand bars to levels at, or near those measured before the 1996 flood (Figures 4 & 5). In 1998 and 1999, the Paria River continued to input a significant amount of sediment into the Colorado River (Figure 3c). Our monitoring does not indicate that these inputs increased storage at our sites, but the inputs may have been retained elsewhere in the ecosystem (Figure 5). This suggests that low-elevation storage areas scoured by the 1996 controlled flood had filled with sand eroded from the channel margin and from the 1997 tributary inputs. These results support the conclusion of Topping et al. (in press) that the amount of sand storage is limited in the Colorado River, and that when eddy and main channel environments are full, new sediment inputs are rapidly transported downstream because Record-of-Decision flows are relatively higher, on average, than pre-dam flows, and little space is available for deposition. Our latest measurements in April 1999, indicate that, at our monitoring sites, space is available for high elevation deposition and low elevation sediment is available for redistribution. In general, these data imply that a controlled flood, at the present time, will likely result in high-elevation deposition.




**Selected Photographs from the 194 mile study site. Main channel flow is from bottom to top. Note the colonization of the 1996 controlled flood deposit by riparian plants.**

**Topographic surveys determine the amount of sediment stored on sand bars.**

**Hydrographic surveys determine the amount of sand stored in the channel.**

## Conclusions

As of April 1999, sand storage levels measured at our study sites are near those measured before the 1996 controlled flood. High- elevation sand bars have eroded to levels slightly higher than pre-flood measurements. Low elevation storage environments in eddies and in the main channel have recovered to approximately equal to pre-flood measurements.

The 1996 controlled flood resulted in widespread high-elevation sand bar deposition.

The 1997 test flow resulted in some high-elevation deposition of sand, however most of these sand deposits were rapidly eroded under high dam releases by April 1998.

In addition to sediment availability, the volume of sand occupying depositional sites prior to flooding is an important factor in determining the magnitude and persistence of flood related deposition.

The most efficient way to conserve fine sediment in the system is to release controlled floods that redistribute sand to higher elevations along the channel margins where it will remain in storage for relatively long periods.

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**Sand bars built by flood flows and used as campsites are continually being eroded by flows from Glen Canyon Dam.**

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NORTHERN ARIZONA UNIVERSITY
Department of Geology
Sand Bar Studies Fact Sheet

# Monitoring the Effects of the 1997 Glen Canyon Dam Test Flow on Colorado River Ecosystem Sand Bars

July 2000

***Controlled floods of appropriate stage and duration have important potential for resource management of the Colorado River ecosystem in Grand Canyon National Park. High releases from Glen Canyon Dam can be used to scour sand-sized sediment on the channel bottom and redistribute it to the banks and bars along the channel margin. New and existing deposits are valued components of the riverine ecosystem. They provide habitat for native and non-native fish, the substrate for riparian vegetation, erosion-protection for archeological sites, and are used for camping by river runners. The first opportunity to study physical processes during controlled flooding occurred in spring 1996, with a seven day release of 1,274 $m^3/s$ (45,000 $ft^3/s$) (Webb et al., 1999). The 1996 flood was considered a short-term success but several studies demonstrated the importance of decreasing river sand concentrations on transport and deposition (Schmidt, 1999). The possibility that a shorter duration and lower magnitude release than the 1996 flood (i.e., a non-spill release) could achieve some level of sediment conservation was of interest to the Glen Canyon Dam adaptive management program. Following significant sand inputs from the Paria River in late summer 1997, and before the sand was lost downstream to Lake Mead, a test flow was released to transfer some of this sediment to the channel margin. Termed the 1997 Test Flow, the release started on November 3, and consisted of a constant flow of 878 $m^3/s$ (31,000 $ft^3/s$) for 48 hours.***

## Sand Delivery by the 1997 Paria River Floods

Most of the sand supplied to the Colorado River ecosystem comes from the Paria River, about 25 km below Glen Canyon Dam, and the Little Colorado River, about 125 km below the dam (Fig. 1). In August-September 1997, the Paria River produced four large floods that delivered approximately 2.0 million Mg of sand to the Colorado River (Fig. 2a) (Topping et al., 2000). This sand input was nearly twice the mean-annual input from this tributary and ranked among the top 20% during the 75 years of gage record on the Paria River (Topping et al., 2000). The Little Colorado River was also active during this period.

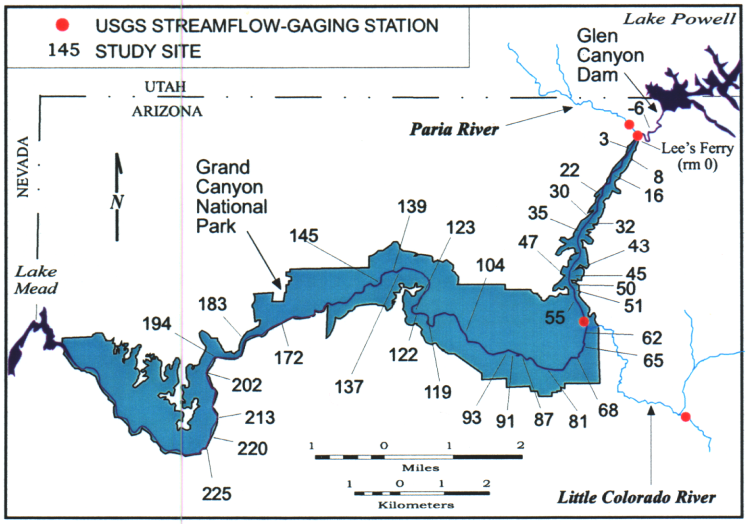


**Figure 1. Location of study area, major sand supplying tributaries, USGS streamflow-gaging stations, and sand bar monitoring sites.**

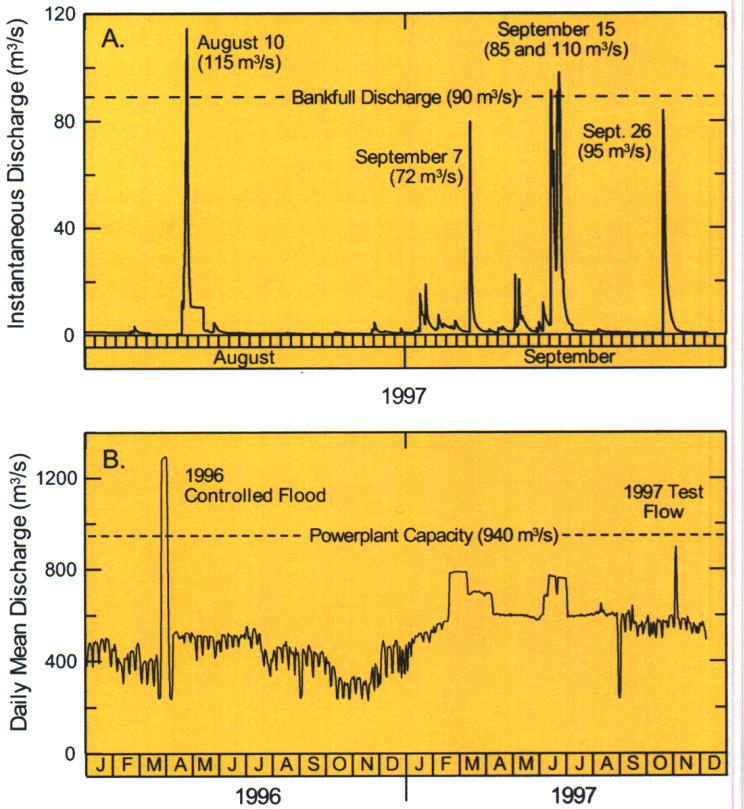


**Figure 2. Discharge hydrographs. A, Instantaneous discharge at USGS streamflow gaging station Paria River at Lee's Ferry, Arizona, August and September 1997. B, Daily mean discharge at the USGS streamflow-gaging station, Colorado River above Little Colorado River near Desert View, Arizona, January 1996 to December 1997.**

## High-Elevation Sand Bars Were Monitored at 35 Long-Term Study Sites Before and After the 1997 Test Flow

Thirty-five long-term study sites are located throughout the Colorado River ecosystem (Fig. 1). Each site contains one or more sand bars. Ground points were collected with electronic total stations and topographic surface models created using the triangulated irregular network method of contouring with surface modeling software [study site locations, descriptions, and methods are provided by Kaplinski et al. (1995) and Hazel et al. (1999)]. At each site, the volume and thickness of sand stored at high elevation within the bar was calculated and then compared to previous surveys to determine site-specific changes. These values are then averaged or summed to assess reach-scale effects. We define the high-elevation sand bar as bedforms deposited in eddies occurring above the 566 $m^3/s$ (20,000 $ft^3/s$) stage elevation. Above this topographic level sand bars are considered campsites because the campable area is greatest and more substrate is available for riparian vegetation, marsh and wetlands. Areas below this level are regularly inundated and reworked by dam releases and typically are not available for camping or colonization by plants.

## The 1997 Test Flow Did Little to Offset Erosion of the 1996 Flood Deposits

We examined the net high-elevation change in sand thickness at the sites by producing a time series from data collected since 1996 (Fig. 3). The sample population is divided into sites in Marble Canyon, upstream from the Little Colorado River; and those in Grand Canyon, downstream from the Little Colorado River (Fig. 1). The time series demonstrate that sand was successfully redistributed to high-elevation by the 1996 Controlled Flood. Following the 1996 Flood, adjustment of the newly aggraded bars to lower, sustained high flows led to rapid but declining rates of erosion (Fig. 2b). The 1997 Test Flow did not result in aggradation great enough to compensate for the erosion that had occurred between April 1996 and November 1997. Net high-elevation bar thickness did not increase at the sites because deposition of sand on the inundated part of the bar was offset by erosion of high-elevation parts of the pre-existing deposits (Hazel et al., 2000; Kaplinski et al., 1999). In general, erosion resulted from cutbanks that retreated horizontally as much as 5 m. The base of the cutbanks developed at the stage elevation reached by the 878 $m^3/s$ flow.

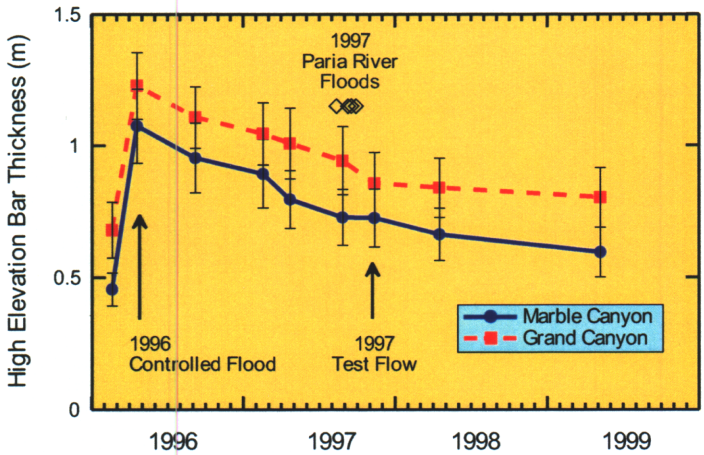


**Figure 3. Average high-elevation sand thickness changes in Marble and Grand Canyons versus time. Diamond symbols indicate dates of the 1997 Paria River floods. Error bars are standard error about the mean.**

## The Stage Change of Controlled Floods is Important for Net Bar Deposition

The 1997 Test Flow did not completely inundate the sand bars in this study. As a result, the stage change was not high enough to redistribute sand to areas where depositional sites were open. The erosional trend following the 1996 Flood, however, suggests that potential depositional area was open in late 1997 (Fig. 3). Hazel et al. (1999) showed that the magnitude of stage change caused by the 1996 Flood was an important factor in net deposition. The stage change during the 1997 Test Flow was roughly half that of the 1996 Flood at the study sites. There was no significant correlation between bar thickness change and stage change during the 1997 Test Flow (Fig. 4). In contrast, a positive correlation was observed as a result of the 1996 Flood ($r^2$=0.59, significant at the 95% confidence level). It is possible that the 2-day duration of the 1997 Test Flow was too short and a longer test may have resulted in net deposition. However, suspended- and bed-sediment measurements at USGS streamflow-gaging stations indicate that the 1997 Test Flow depleted a major portion of the supply of finer sand throughout the Colorado River ecosystem (Topping et al., 2000). The sand export rate from Marble Canyon was twice that observed during the 1996 Flood. These observations suggest that 1997 Test Flow was high enough to transport large amounts of sand supplied to the Colorado River channel but the new sand was not effectively redistributed to the channel margin.

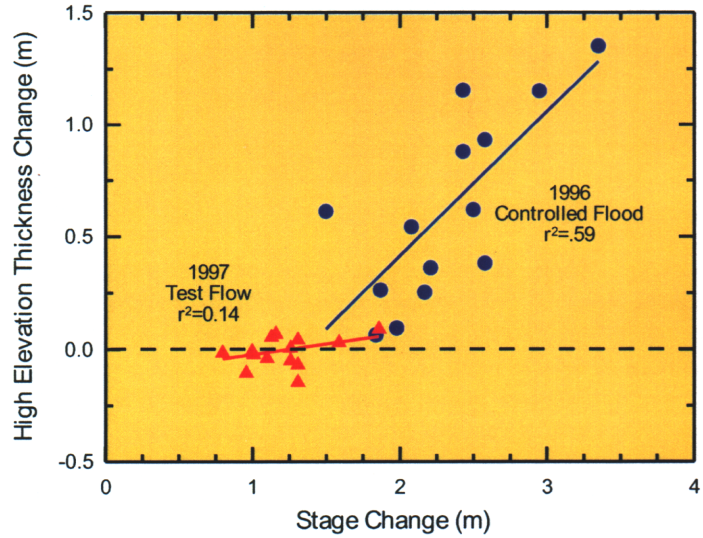


**Figure 4. The relation between stage change and high-elevation thickness change in Marble Canyon. The stage change is based on the elevation difference from 566 to 878 $m^3/s$ (1997 Test Flow) and from 566 to 1,274 $m^3/s$ (1996 Controlled Flood) at each study site.**

The results of this study suggest that in order to prolong the residence time of tributary-supplied sand in the Colorado River ecosystem, a greater stage increase is required to access high elevation areas available for deposition. Even the largest floods on the Paria River do not raise mainstem discharge high enough and for sufficient duration to result in deposition above stage levels reached by normal dam releases. Timing controlled high releases to coincide with or shortly follow the summer and fall sediment input season may improve the likelihood that inputs are conserved, especially within upstream reaches closest to the dam.

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NORTHERN ARIZONA UNIVERSITY

Department of Geology
Sand Bar Studies Fact Sheet

# Monitoring the Effects of the Spring 2000 Habitat Maintenance Flow on Colorado River Ecosystem Sand Bars

January 2001

***The magnitude and timing of controlled floods required to distribute large amounts of sand into eddies and rebuild eroded sand bars is a critical objective of research and monitoring in the Colorado River ecosystem, downstream from Glen Canyon Dam. Aggradation of sand bars at higher elevations is dependent on the size and abundance of sand temporarily stored on the channel bottom and the duration and stage of the high release. New and existing deposits are valued components of the riverine ecosystem. They provide habitat for native and non-native fish, the substrate for riparian vegetation, erosion-protection for archeological sites, and are used for camping by river runners. The 1995 Glen Canyon Dam Environmental Impact Statement recommends scheduled high releases of short duration be implemented for environmental purposes (U.S. Department of Interior, 1995). Habitat maintenance flows (HMF) are within powerplant capacity (~940 m³/s), whereas those above this discharge are beach/habitat-building flows (BHBF). The former were intended to maintain existing camping beaches and wildlife habitat and the latter to more extensively modify and create sand bars, and thus restore some of the dynamics that result from flooding in the ecosystem.***

## Flood Experiments in the Colorado River Ecosystem

In this study we evaluate the effects of three intentional, controlled floods that were released in 1996, 1997, and 2000. We compare the results to a natural flood that occurred in 1993. The first test of a BHBF occurred in spring 1996, with a 7-day release of 1,274 $m^3/s$. A HMF test occurred in November 1997, following large sand inputs from the Paria River in late summer 1997. The objective of the 1997 HMF was to transfer some of the tributary supplied sand to the banks and bars before it was transported downstream. This release had a 2-day duration of 868 $m^3/s$. A second HMF experiment occurred as part of the Low Summer Steady Flows (LSSF) in 2000 (Fig. 1). The LSSF was designed to test the benefits of low flows on native fishes of the Colorado River below Glen Canyon Dam. The LSSF was preceded in May by a 4-day spike of 858 $m^3/s$, partly intended to improve aquatic habitat by rebuilding and restructuring sand bars. In addition, an unregulated January 1993 flood on the Little Colorado River delivered large amounts of sand and increased the discharge of the Colorado River to a peak of approximately 950 $m^3/s$ (Wiele et al., 1996). Together, these four floods of near powerplant capacity or greater provide an opportunity to measure sand bar response to flow magnitude and the timing relative to tributary sediment supply.

## High-Elevation Sand Bars Were Measured Before and After the Spring 2000 HMF

In 1990, a project monitoring sand bars in the Colorado River ecosystem was initiated by Northern Arizona University. Since then, the study sites have been monitored annually and before and after flood events. Site locations, methods, and results can be found in Hazel et al. (1999). The sites are representative of the different types of eddy sand bars and are spatially distributed throughout the Colorado River ecosystem.

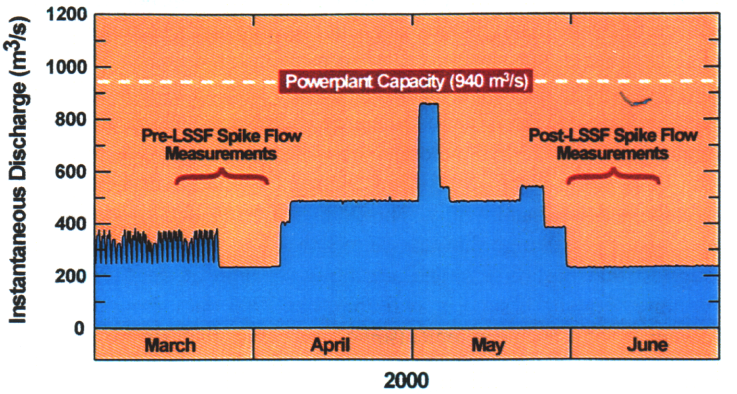


**Figure 1. Instantaneous discharge at USGS streamflow gaging station Colorado River at Lees Ferry, Arizona, March-June, 2000. The timing of measurements made before and after the spring 2000 HMF are shown.**

We calculate the area, volume and thickness of sand stored at high elevation at each bar. We define high-elevation as the area that is emergent at a flow of 566 $m^3/s$, a moderately high flow in the post dam era (Hazel et al., 1999). Areas below the stage elevation reached by this flow are regularly inundated and reworked by dam releases and typically are not available for camping or colonization by plants.

## Long-Term Trends in High Elevation Sand Bar Storage

To identify long-term trends, our approach is to develop a time series of average high-elevation change (Fig. 2). The sample population is divided into sites in Marble Canyon (upstream from the Little Colorado River) and those in Grand Canyon (downstream from the Little Colorado River). One site is located in Glen Canyon, the reach closest to the dam. Figure 2 indicates that the 1993 Little Colorado River flood and the 1996 BHBF were the only high flows to significantly replenish sand in high elevation bars. Although rapid adjustment of newly-aggraded bars to normal dam releases led to high rates of erosion following these events, the rates decreased with time. After more than a year, on average, the sand bars were still larger than they had been before either the 1993 flood or the 1996 BHBF.

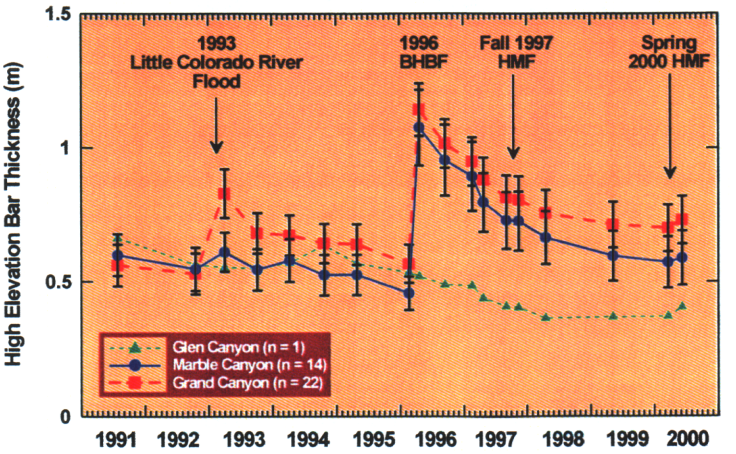


**Figure 2. Average high-elevation sand thickness changes versus time. Error bars are standard error about the mean.**

## Controlled Flood Magnitude

One reason the 1997 HMF and the 2000 HMF did not replenish high-elevation bars is that the flow magnitude was not great enough. In Figure 3, photographs illustrate this pattern of change. Higher stages increase the accomodation space available for deposition (Hazel et al., 1999). Average area and volume changes for the three controlled floods, and for the 1993 Little Colorado River flood, are shown in Figure 4. At discharges below powerplant capacity the changes are not significantly different from 0, suggesting that HMF-type flows are stage-limited. The changes downstream of the Little Colorado River in 1993 show large positive values at a discharge of 950 $m^3/s$, a flow only slightly higher than a HMF. Note that the area increase in 1993 is greater than that of the 1996 BHBF, whereas the volume increase is about half of the 1996 value. The 1993 flood created large deposits because of a greatly increased sand supply. The 1996 BHBF resulted in larger volume deposits, even though the sand supply was lower. While these results suggest that high discharges are more efficient at producing larger volume deposits if sand is available, the 1993 data show that lower discharges are capable of replenishing sand bars during tributary flooding.

## Controlled Flood Timing

Timing deliberate floods to coincide with or closely follow tributary sand inputs, typically in late summer for Marble Canyon tributaries, may provide more effective results than when following periods of prolonged high discharge (U.S. Department of Interior, 1995). The 1993 flood and 1997 HMF were associated with large tributary inputs of sand. The 1996 BHBF and the 2000 HMF occurred in the spring, when suspended sand measurements suggest that tributary sand inputs have been mostly exported from the system (Topping et al., 2000). As a result, during the 1993 flood, sand concentrations in Grand Canyon ranged from 3 to 6 times higher than those during the 1996 BHBF (Rote et al., 1997). During the HMF tests in 1997 and 2000, sand concentrations in Marble Canyon were about the same (D. Topping, USGS, pers com., 2001), and only slightly lower than those of the 1996 BHBF (Topping et al., 2000). Unfortunately, the 1997 HMF occurred more than a month after cessation of Paria River flooding, otherwise the sand supply would have been considerably greater (Hazel et al., 2000). There was little

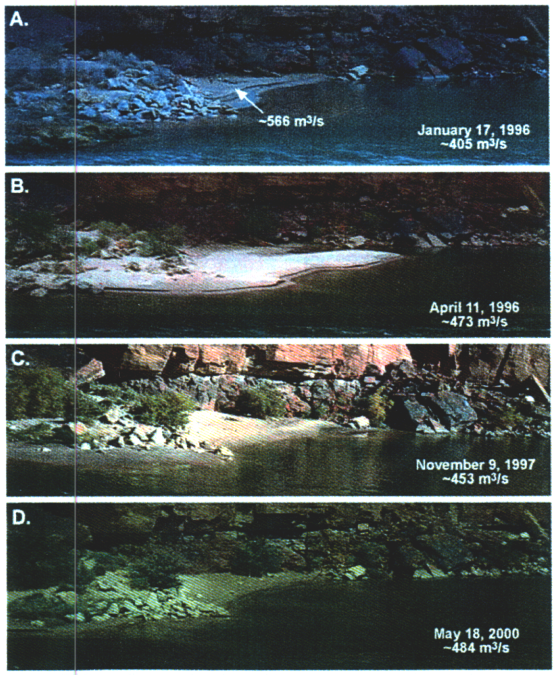


**Figure 3. Selected photographs from the study site located at river mile 16.4 in Marble Canyon. A. Pre-1996 BHBF. B. Post-1996 BHBF. C. Post-1997 HMF. D. Post-2000 MHF. Flow in main channel is from left to right.**

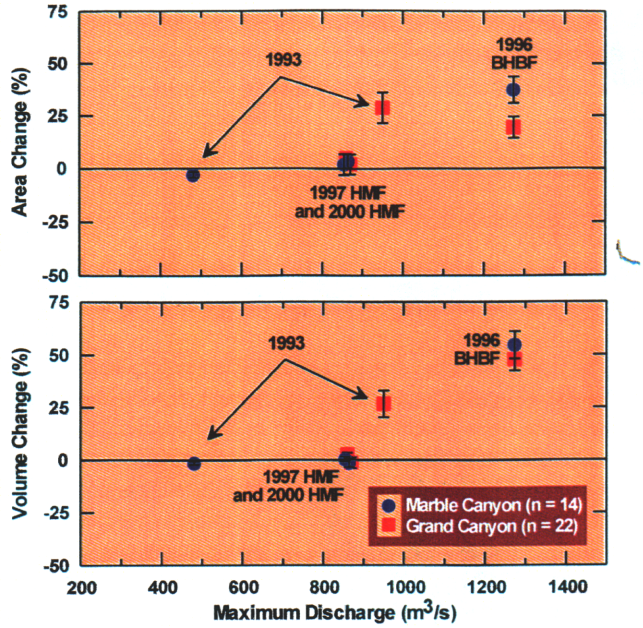


**Figure 4. Average high-elevation area and volume changes plotted as a function of the maximum daily mean discharge. The change between two successive surveys was scaled by the maximum area or volume observed at each site. Error bars are standard error about the mean.**

difference in bar response between the HMF tests in 1997 and 2000 (Fig. 4). In contrast, the 1993 flood built large bars, showing that if sand concentrations are high enough, net deposition will result from HMF-type flows.

Our data demonstrate that sedimentation in eddies is at least as sensitive to flow magnitude as sand supply, because of the major role of accomodation space in determining depositional volume and rate. The effect of lower sand supply can be offset by higher stages. The duration of high flows is considered less important because suspended-sand concentration decreased rapidly during each of the controlled releases (Topping et al., 2000), and deposition rates were highest during the first day or two (Wiele et al., 1999). Flows greater than powerplant capacity may be the only means by which eroded bars can be maintained or rebuilt, especially if HMF releases cannot be scheduled closely with newly input, tributary-supplied sand.

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# SAND TRANSPORT AND BED EVOLUTION MODELING APPLICATIONS IN THE COLORADO RIVER, GRAND CANYON

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## INTRODUCTION

The closure of Glen Canyon Dam in 1963 shut off the mainstem sand supply and altered the natural flows in the Colorado River through the Grand Canyon. The effect of these alterations to the natural river has been the subject of ongoing research, including studies of the changes in sand supplies and sedimentary processes, with an emphasis on the erosion and restoration of sand bars. One component of these studies has been the development and application of unsteady flow models (Wiele and Smith, 1996; Wiele and Griffin, 1997), 1-dimensional sand transport models (Randle and Pemberton, 1987; Bennett, 1993), and multi-dimensional models of flow, sand transport, local erosion and deposition (Wiele and others, 1996; Wiele, 1997; Wiele and others, 1999; Wiele and Franseen, 1999). This paper is a brief overview of the multi-dimensional model and outlines modeling applications to date.

## BACKGROUND

Prior to the closure of Glen Canyon Dam (Fig. 1), approximately 57 million metric tons of sediment, 40% sand, was delivered to the Grand Canyon in the mainstem annually (Topping and others, 2000a). Two main tributaries continue to supply sand. The Paria River, located about 24 km downstream from the dam, delivers about 3 million metric tons of sediment annually, 50% sand (Topping and others, 2000a), and the Little Colorado River, located about 120 km below the dam, supplies about 8.6 million metric tones of sediment annually, 30 to 40% sand (Topping and others, 2000a). Ungaged tributaries deliver about 0.70 million metric tons of sediment, 75% sand, between the dam and the Little Colorado River confluence (Webb and others, 2000). Peak discharges, which typically exceeded 2800 $m^3/s$ during spring flows prior to the dam, currently rarely exceed the 900 $m^3/s$ maximum that can used for power generation at the dam.

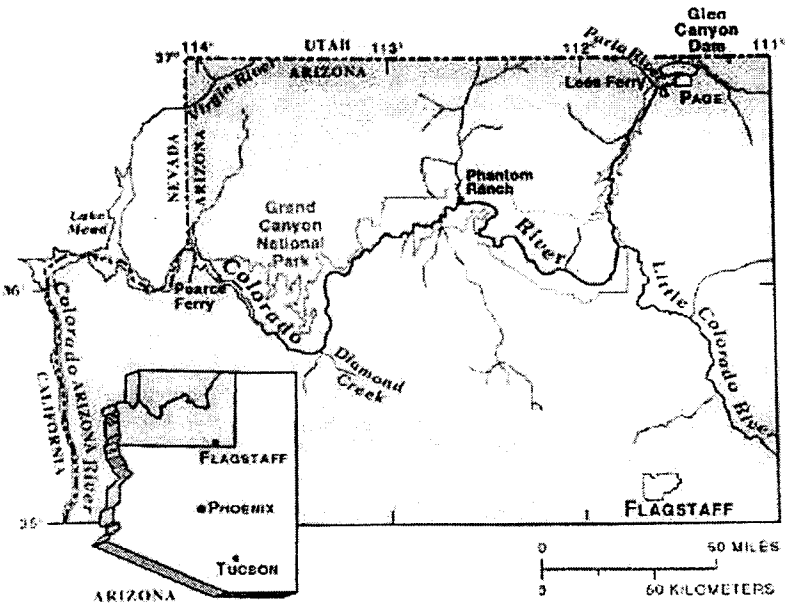


Figure 1. Map of the Colorado River below Glen Canyon Dam.

Maintenance and restoration of sand deposits has focused on distributing the sediment supplied by tributaries to near-shore sites by releasing high discharges in excess of power-plant capacity (Bureau of Reclamation, 1994). Optimum use of tributary-supplied sediment would require high flows to coincide with or shortly follow tributary activity (BOR, 1994). Timing releases with Little Colorado River flows was recommended by Lucchita and Leopold (1999). Careful analysis of suspended sediment measurements and the implications for sand transport processes by Topping and others (2000b) led to their recommendation that high releases instead be triggered by Paria River flows. They concluded that this would produce maximum deposition in the critical Marble Canyon reach, which is upstream from the confluence with the Little Colorado River and has a relatively small sand supply.

A controlled release from the dam in 1996 of 1270 $m^3/s$ for 6 days, although not closely following major tributary activity, rejuvenated many of the near-bank sand bars, especially below the confluence with the Little Colorado River (see Schmidt, 1999, for a summary of monitoring and research results). This release demonstrated that judicious high releases from Glen Canyon Dam can be effective in mitigating some of the deleterious effects of the dam on the downstream river corridor. The model described below is designed to provide a predictive capability of the effects of sand supply and dam operation on sand deposits.

## OVERVIEW OF THE MODEL

The multi-dimensional model is an extension of a model initially developed to study bank erosion and bar formation and stability in gravel-bed rivers (Wiele, 1992). For Grand Canyon applications, suspended-sand transport was added. The flow field is calculated with the vertically averaged momentum and continuity equations for open channel flow. A 3-dimensional advection-diffusion equation that governs the suspended sand field is solved using a parabolic eddy viscosity related to the local shear velocity to quantify the turbulent mixing. A sand concentration near the bed (Smith and McLean, 1977; Wiberg and Rubin, 1985) is used for the lower boundary condition. The sand fall velocity is calculated using the method of Dietrich (1982). The vertical variation in velocity is estimated using a logarithmic velocity profile consistent with the parabolic eddy viscosity. The product of the velocity and suspended sand concentration is integrated vertically to calculate the local suspended sand discharge. The sand transported as bedload is calculated using a bedload function (Meyer-Peter and Mueller, 1948) including the effect of local bed slope on transport rates (Nelson and Smith, 1989). In areas with sufficient sand thickness, local roughness and skin friction are calculated using the method of Bennett (1995) that relates bedform dimensions to flow conditions and sand size. In areas with little or no sand, local channel roughness is calculated as a function of the spatial variability in the bathymetric measurements that form the basis for the gridded channel topography. Local change in bed elevation is then calculated for a small time step with a sediment continuity equation. More detailed descriptions of the model can be found in Wiele and others (1996, 1999).

The bathymetry used to generate the gridded topography in the model was measured by the U.S. Geological Survey (USGS) and the Grand Canyon Monitoring and Research Center. Sand flux into the reaches was taken from measurements (Konieczki and others, 1997) or rating curves for specific events (G.G. Fisk, USGS, personal communication, 1994), or from a model that predicts sand flux as a function of discharge for specified sand supplies (Topping, 1997).

## MODEL APPLICATIONS

The model has been used to examine processes during a tributary flood, compare the effects of natural and dam-generated high flows on sand deposits, predict the effects of variations in water discharge and sand supply on deposition rates and magnitude, and examine the effect of channel shape on locations of deposition and scour and changes in deposit volume. Applications to other disciplines include predictions of sand bar response in reaches containing archeological artifacts (Wiele and Franseen, 1999) in which preservation has been linked to the size and persistence of sand bar deposits (Hereford and others, 1993; Thompson and Potochnik, 2000). The flow component has been used to examine the effect of discharge on endangered fish habitat.

A comparison of natural and artificial events and the effect of sand concentration on sand deposition was examined by Wiele and others (1999) by comparing the results of a flood on the Little Colorado River (LCR) in 1993 and the 1996 controlled release from Glen Canyon Dam. The LCR flood transported about 4 million metric tons of sand into the main channel and increased the mainstem water discharge to a peak of about 950 $m^3/s$. Massive sand deposits

were observed after the LCR flood receded, especially in the 20 km below the confluence. The USGS measured 3 to 5 channel cross sections in 4 reaches ranging from 1/4 to about 1 km in length before and after the LCR flows. The reaches are typically bounded upstream and downstream by riffles or rapids that are formed by debris flows that partially constrict the channel. Recirculation zones form in the lee of the debris fans and can act as effective sand traps. Sand input into the mainstem estimated from gage records (G.G. Fisk, USGS, personal communication, 1993) was used to set the upstream sand boundary-condition for the reaches.

In the reach known colloquially as the Salt reach (Fig. 2a), about 129 km below the dam, model predictions agree well with the measured cross sections (Wiele and others, 1996). Both the model and the measured cross sections show deposition in the main channel, filling a deep hole scoured into the bedrock downstream from the reach inlet, as well as extensive deposition within the recirculation zone during the LCR flood (Fig. 2b). This result contrasts sharply with the deposition pattern during the 1996 controlled release (Fig. 2c) during which sand concentrations were much lower than during the LCR flood and the water discharge was higher. During the 1996 controlled release, which had a discharge of 1270 $m^3/s$, the main channel was scoured. Deposition in the recirculation zone was focused at the reattachment point. Sand was carried in suspension into the recirculation zone and initially deposited rapidly. Once the initial accommodation space (defined by Hazel and others, 1999, as the underwater volume of potential deposition sites) was filled, the model shows that further deposition could proceed only at the rate at which sand was redistributed within the recirculation zone as bedload. Model predictions are compared to bathymetric measurements during the 1996 controlled release (Andrews and others, 1999). The model accurately predicts the general deposition and scour patterns recorded by the bathymetric measurements (Wiele and others, 1999). A disparity exists, however, downstream from the main channel scour zone where deposition was documented by the bathymetric measurements in a high-stress zone. This discrepancy is likely a result of the transport and deposition of coarser material than is represented in the model.

In reaches in which deposition is dominated by recirculation zones, model predictions of sand deposition as a function of water discharge and sand supply follow a consistent pattern. A reach designated the Palisades reach (Fig. 3) by Hereford and others (1991, 1993), at 134 km below the dam, was modeled with 2 discharges, 1270 and 2800 $m^3/s$, and with 3 different sand supplies (Topping, 1997). The sand conditions represent sand supplies during historically high measurements (high); during the 1996 controlled release, which is representative of the post-dam conditions (intermediate); and a relatively depleted state resulting from prolonged high discharges approaching 2800 $m^3/s$ after the closure of the dam (low). At the highest flows modeled, 2800 $m^3/s$, with the lowest sand supply, modeled deposit volume exceeds the volume deposited predicted at lower discharges even with the highest sand supply (Fig. 4). This result demonstrates the importance of the magnitude of the accommodation space in determining deposit volume and the effect of the hydraulic isolation from the main channel on the accumulation of sand in the recirculation zones.

Recirculation zones have tended to be the focus of sediment research due to the effectiveness with which they retain sand. While reaches dominated by recirculation zone show a consistent pattern, other reaches can show considerable variability in response to discharge and sand supply. The reach designated the Above Lava-Chuar (ALC) reach (Fig. 5a), about 133 km below the dam, contains a relatively constrained recirculation zone, but also has a gradual expansion with a sand deposit just downstream from the reach inlet. At 1270 $m^3/s$ and the intermediate sand supply, this bar is partially eroded (Fig. 5b), but at 2800 $m^3/s$ with the intermediate sand supply, the bar is scoured out (Fig. 5c). This modeling result is consistent with the conclusions of Melis (1997) that the slope of the channel side at constrictions plays an important role in determining whether scour or deposition occur in the lee of the constrictions. Increased scour at the higher discharge for a given sand supply is opposite to the response in recirculation zones. Overall, the response of sand deposits in reaches such as the ALC reach is likely to be far outweighed by deposition in recirculation zones, but the response is of particular interest in some reaches, such as those containing archeological artifacts.

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Prepared in cooperation with the Grand Canyon Monitoring and Research Center

# Sediment Delivery by Ungaged Tributaries of the Colorado River in Grand Canyon

## Introduction

Sediment supply and transport in Grand Canyon is an important management issue because of the presence and operation of Glen Canyon Dam on the Colorado River (U.S. Department of the Interior, 1995). Most of the fine-grained sediment that formerly entered the canyon from upstream is trapped in Lake Powell; this sediment once replenished beaches and provided substrate for the riverine ecosystem in Grand Canyon. With the closure of the dam in 1963, sources of fine-grained sediment have been limited to major tributaries, such as the Paria and Little Colorado Rivers and Kanab and Havasu Creeks, and numerous small tributaries. Small tributaries are also the source of coarse-grained sediment (cobbles and boulders), which forms debris fans and rapids, defines pools and eddies that trap and store fine sediment, and provides substrate for aquatic and terrestrial habitats throughout the river channel. Between Glen Canyon Dam and the Grand Wash Cliffs (fig. 1) 768 small tributaries were designated, most of which range from 1 through 5 $km^2$ in area. All of these tributaries produce streamflow, but only the 736 tributaries between Lee's Ferry and the Grand Wash Cliffs produce debris flows (fig. 2). With the exception of Bright Angel Creek and the major tributaries, these small tributaries between Glen Canyon Dam and the Grand Wash Cliffs were ungaged before 1999.

A combination of fluvial and hillslope processes occurs in small tributaries in Grand Canyon, making estimates of sediment yield complicated. Sediment-yield estimates must consider the contributions of both streamflow, which occurs annually in all tributaries, and debris flow, which occurs rarely. Debris flows are slurries of clay- to boulder-sized sediment with sediment concentrations of 70 to 90 percent by volume. In contrast, streamflow typically has a sediment concentration by weight of less than 40 percent. A total of 12,072 $km^2$ in 736 tributaries produces debris flow, and 12,900 $km^2$ produce streamflow. The tributaries were organized into seven sediment-yield reaches that correspond to river segments between major tributaries with gaging records or other estimates of sediment input (fig. 1).

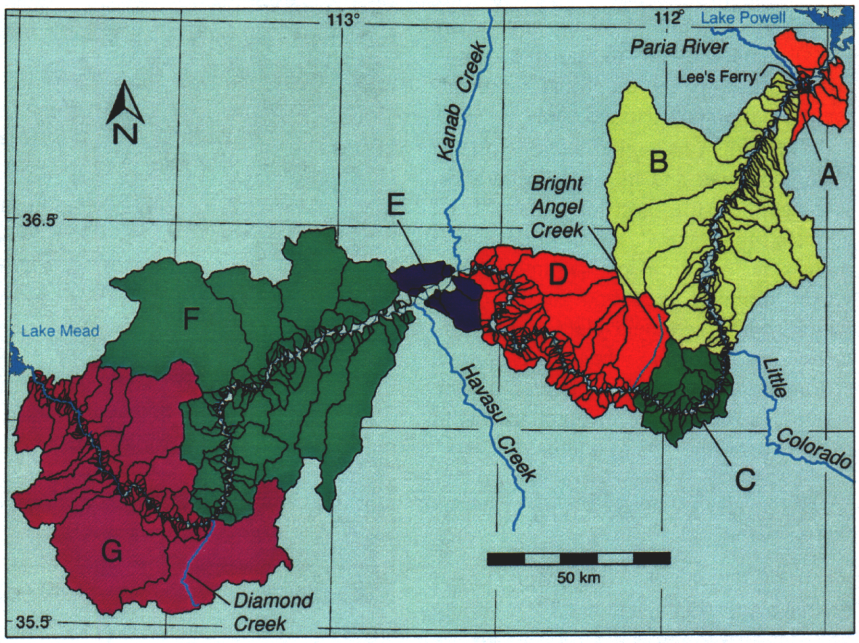


**Figure 1.** 768 ungaged tributaries of the Colorado River between Glen Canyon Dam and Lake Mead. Sediment-yield reaches are indicated by letter.

Development of a sediment budget for the Colorado River through Grand Canyon requires an estimate of the long-term sediment yields for both coarse and fine particles from all 768 tributaries but particularly from tributaries in Reaches A and B (fig. 1), where sand bar resources are most threatened. Because the size of particles transported by the river vary with discharge, data on the particle-size distribution of sediment delivered by both debris flow and streamflow are also needed. Increased knowledge of debris flow and mainstem processes in Grand Canyon will contribute to efforts to operate Glen Canyon Dam in ways that minimize downstream impacts. This Fact Sheet summarizes a report (Webb and others, 2000) that presents the total sediment yield and sand delivery rates for the ungaged tributaries.

## Streamflow Sediment Yield

Prior to this study, streamflow sediment yield from the ungaged tributaries was either unknown or assumed. Three methods were used to estimate streamflow sediment yield from the ungaged tributaries: (1) an empirical equation relating drainage area to sediment yield for all sites measured in northern Arizona, (2) an empirical relation developed by Renard (1972), and (3) a new procedure that combines regional flood-frequency analysis with sediment-rating curves. These methods are described in detail in Webb and others (2000) and proved to be reasonably consistent. Only the empirical sediment-yield equation is discussed here.

Other than at gaging stations on the Colorado River and its major tributaries, few sediment-transport data have been collected in Grand Canyon. To develop a regression equation of sediment yield versus drainage area and to determine which other sediment-yield estimation techniques might be appropriate, sediment-yield data from the region were assembled. Then a power function was fit to these data (fig. 3A) to obtain

$$Q_s = 193 \cdot A^{1.04}, R^2 = 0.86,$$

where $Q_s$ = sediment yield (Mg/yr), A = drainage area ($km^2$), and n = 37. A variety of empirical approaches developed by other workers were evaluated and produced estimates of sediment yield ranging from 43-4,110 Mg $km^{-2}yr^{-1}$. Results compared most favorably with the method given by Renard (1972), who developed a similar empirical relation for southern Arizona rangelands (fig. 3B).

Using this equation, it is estimated that Reaches A and B (the Glen and Marble Canyon reaches, river miles -15 to 61.5) deliver $0.065 \cdot 10^6$ and $0.610 \cdot 10^6$ Mg/yr of streamflow sediment, respectively ($0.68 \cdot 10^6$ Mg/yr total), to the Colorado River. This amount is 20 percent of the total sediment yield of the Paria River, the major tributary contributing sediment to this part of Grand Canyon, and is much larger than previous estimates of sediment yield from these tributaries. A relation is given in Webb and others (2000) relating the possible variation of this sediment delivery with climatic variability.

**Figure 2.** The Comanche Creek drainage basin (mile 67.2 L), from river right, in 1994. The debris fan at Comanche Creek was aggraded by a debris flow in July 1999.

## Debris-flow Sediment Yield

The model of debris-flow sediment yield in Grand Canyon in this study is composed of three elements: (1) a frequency model for all 736 tributaries in Grand Canyon that produce debris flows (from Griffiths and others, 1996), (2) a model of the expected volumes of debris flows reaching the Colorado River, and (3) an accounting for river reworking that stores sediment on debris fans because of operations of Glen Canyon Dam. This model and the assumptions used to produce it are given in Webb and others (2000).

A statistical relation for debris-flow frequency using probabilities estimated by logistic regression was developed in which the 736 tributaries had a probability greater than zero of producing a debris flow each century; 60 percent of the tributaries had a frequency of at least 1 debris flow per century; and about 5 percent of the tributaries had a frequency of more than 2 debris flows per century. Using data updated from Melis and others (1994), a regression equation relating debris-flow volumes to tributary drainage area was developed to calculate the amount of sand delivered by debris flow. By combining the frequency and volume components, a sediment-yield model for debris flow in Grand Canyon was developed. In the pre-dam era, floods in the Colorado River removed essentially all fine-grained sediment from debris fans; in the post-dam era, on average only 25 percent of the volume of debris fans are reworked each decade to introduce fine-

grained sediment into the river (Webb and others, 1999).

The results of this model indicate that debris flows deliver 0.14-0.30.106 Mg/yr of sediment to the main channel. Reach B (Marble Canyon) contributes the greatest amount of debris-flow sediment, which is consistent with both the empirical observations on where debris flows have occurred in the last century as well as the mapped distribution of probabilities in Grand Canyon (Griffiths and others, 1996). Depending upon the assumptions of the debris-flow sediment-yield model, sediment yield by debris flow ranges from 4 to 23 percent of total sediment yield.

## Particle-Size Distributions

The size of the sand fraction is of particular interest for the management and restoration of sand bars in Grand Canyon. Measurements of particle-size distributions stored in stream terraces in various tributaries, as well as suspended sediment samples from Bright Angel Creek and other small tributaries, provide sand contents ranging from 1 - 99 percent with no discernible pattern. These data were collected from a large discharge range and thus highly variable sand contents would be expected. An average sand content of 50 percent of total streamflow sediment yield was used in this study, which compares favorably with average sand content weighted by discharge for the Little Colorado and Paria Rivers (30 and 50 percent, respectively). Sand contents of 15, 50, and 75 percent are reported. Sand delivery by streamflow from the Glen and Marble Canyon reaches averages about $0.032 \cdot 10^6$ and $0.305 \cdot 10^6$ Mg/yr, respectively ($0.34 \cdot 10^6$ total), with a combined total of the two reaches ranging from $0.10\text{-}0.51 \cdot 10^6$ Mg/yr, depending on the assumed sand content. Sand contributed by tributaries in Glen Canyon is notably coarser ($D_{50}$=0.24 mm) than sand in other reaches ($D_{50}$=0.11-0.20 mm), including the Marble Canyon reach ($D_{50}$=0.20 mm) (fig. 4).

The particle-size distributions of 41 fresh, unaltered deposits of debris flows that occurred between 1965 and 1999 were determined. Pebbles are the most abundant particles at 41 percent by weight, and boulders typically account for about 14 percent. The sand content of debris flows averages about 18.2 percent and ranges from 2.4-47 percent. With debris-fan reworking limited by the operation of Glen Canyon Dam, debris flows transport from $0.006\text{ -}0.013 \cdot 10^6$ Mg/yr of sand to the regulated Colorado River, while $0.023\text{-}0.048 \cdot 10^6$ Mg/yr is stored in unreworked parts of debris fans. Depending on the volume model used and the amount of debris-fan reworking, the total sand yield of debris flows in all reaches ranges from $0.006\text{-}0.054 \cdot 10^6$ Mg/yr. Although debris

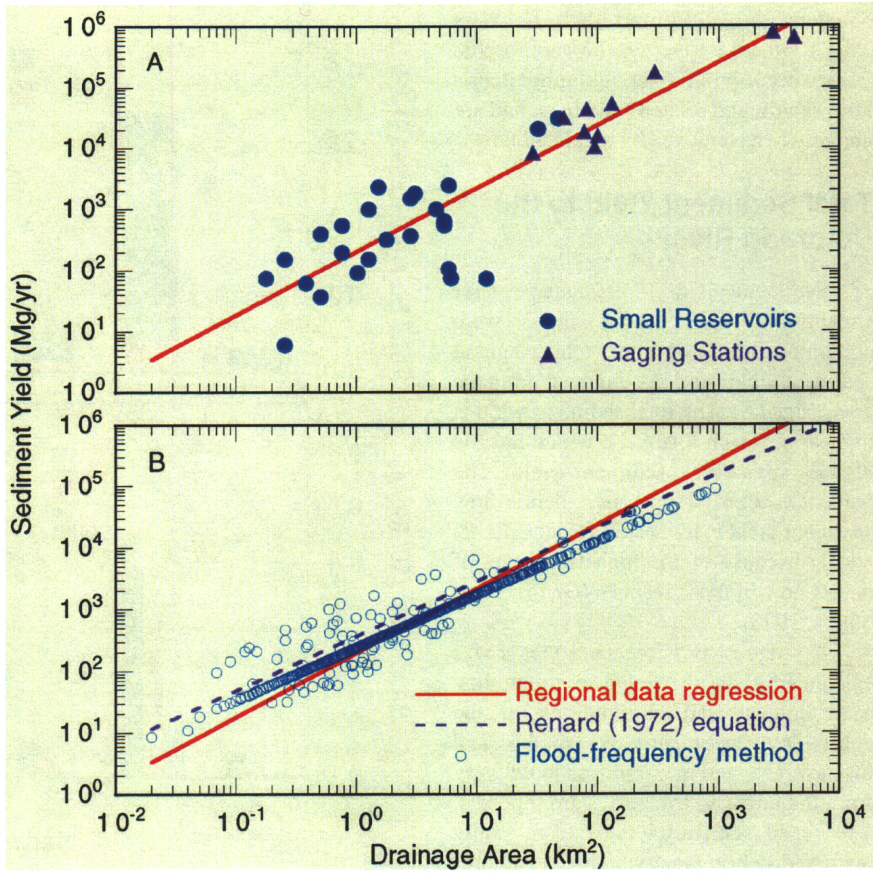


**Figure 3.** Comparison of methods for calculating streamflow sediment yield. A. Gaging station and reservoir data from the Colorado Plateau region ($r^2$ = 0.86). B. Comparison of regional data regression equation, Renard (1972) equation, and estimates for 768 ungaged tributaries by the flood-frequency rating-curve method.

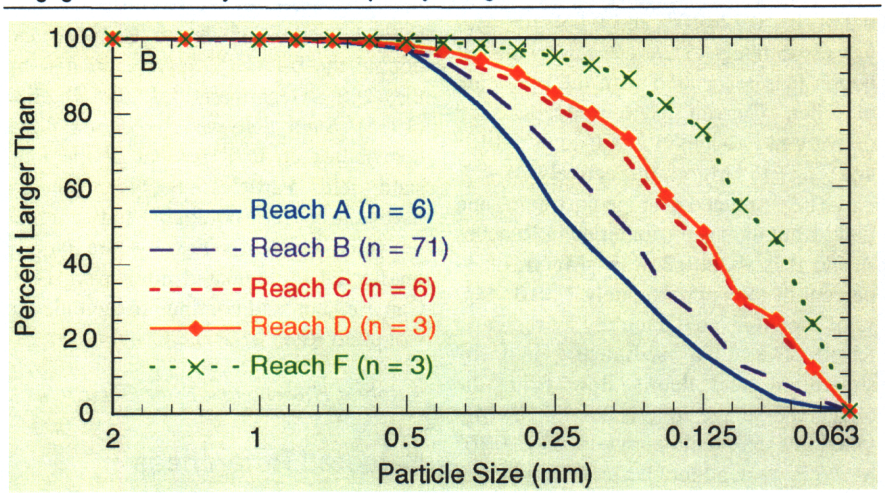


**Figure 4.** Particle-size distribution of sand delivered by streamflow from ungaged tributaries. Sand input by streamflow is increasingly finer downstream from the dam.

flows deliver only 21,000-44,000 Mg/yr of boulders ($B_{axis}$>256 mm), these boulders have a critical impact on the geomorphic framework of the river, defining debris fans, rapids, and related sand bars, and are unlikely to be removed by regulated flows.

## Total Sediment Yield to the Colorado River

Sediment-yield estimates for streamflow and debris flow were combined to estimate total annual sediment yield from the ungaged drainage areas (fig. 4A). The total sediment yield is highest in Reach F (fig. 1), which has the highest streamflow sediment yield. The percent contribution of debris-flow sediment yield is highest in Reaches B, C, and D because of the high frequency of debris flow in those reaches (Griffiths and others, 1996).

A range of possible sand yields was calculated given the range of streamflow sand content and assumptions in the debris-flow sediment-yield model and low, average, and maximum sand delivery from the ungaged tributaries are reported. The sand delivery rate from fully reworked debris fans, which reflects pre-dam conditions, averages $1.3 \cdot 10^6$ Mg/yr for all ungaged tributaries in Grand Canyon. In Reaches A, B, and C (fig. 1), the average total sand delivery is $0.030 \cdot 10^6$, $0.296 \cdot 10^6$, and $0.050 \cdot 10^6$ Mg/yr, respectively. Limited reworking of debris fans associated with the operation of Glen Canyon Dam reduces sand delivery in Reaches B and C to $0.288 \cdot 10^6$ and $0.047 \cdot 10^6$ Mg/yr, respectively.

The combined average post-dam sand yield from ungaged tributaries in Reaches A and B is about $0.318 \cdot 10^6$ Mg/yr, or 20 percent of the approximately $1.5 \cdot 10^6$ Mg/yr of sand delivered annually by the Paria River. The total sediment yield by streamflow and debris flow from the ungaged drainage areas is $2.8\text{-}3.0 \cdot 10^6$ Mg/yr. Of this total sediment yield, $0.4\text{-}2.0 \cdot 10^6$ Mg/yr is sand, although a small amount of this sand is stored in unreworked debris fans.

Even with storage in debris fans, $0.1\text{-}0.5 \cdot 10^6$ Mg/yr of sand are added to the reaches between Glen Canyon Dam and the Little Colorado River annually. This amount is up to 33 percent of the sand delivered by the Paria River, the only other source of sand-sized particles in this critical section of Grand Canyon, and double the $0.17 \cdot 10^6$ Mg/yr estimated by the U.S. Department of the Interior (1995). Sand delivered by debris flows contributes up to 8 percent of the total sand yields. Particles larger than sand — particularly the boulders and cobbles delivered by debris flow — are largely unaffected by regulated flows from Glen Canyon Dam and continue to aggrade the Colorado River in Grand Canyon.

*– Robert H. Webb and Peter G. Griffiths*

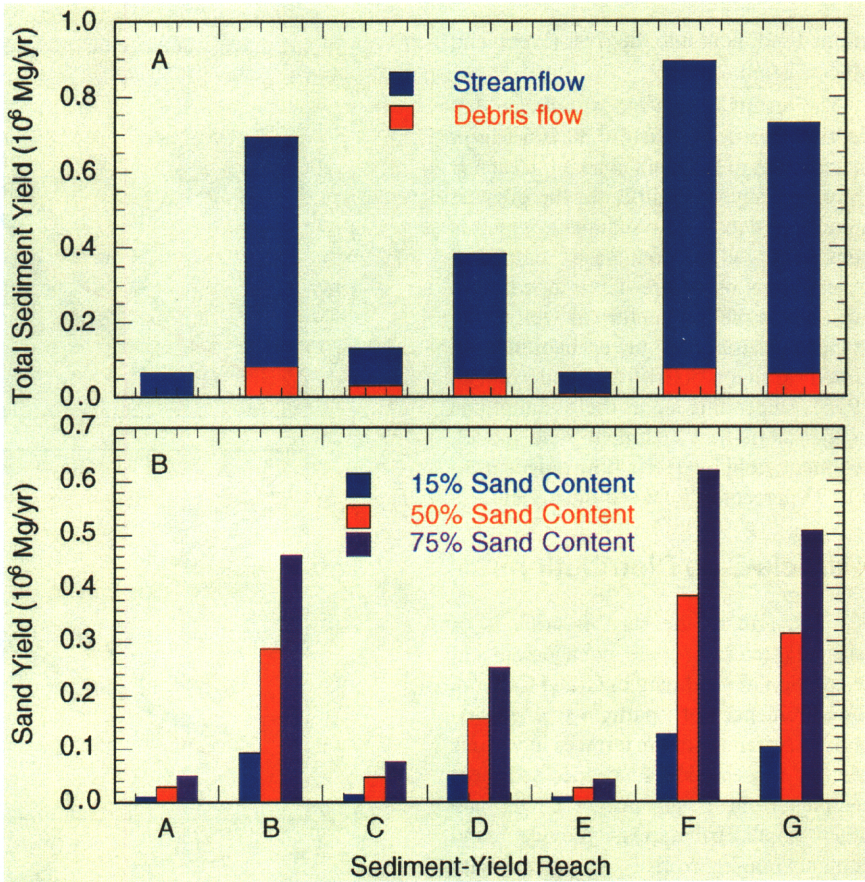


**Figure 5.** Estimates of annual sediment yield from ungaged tributaries by reach. A. Total sediment yield delivered by debris flow and streamflow. B. Total sand delivered by streamflow and debris flow to the river under a regulated flow regime. Estimates are given for 15%, 50%, and 75% sand content.

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Prepared in cooperation with the Grand Canyon Monitoring and Research Center

# Monitoring of Coarse Sediment Inputs to the Colorado River in Grand Canyon

## Introduction

Coarse sediment (particles with an intermediate diameter > 64 mm) affects the primary components of the Colorado River ecosystem. The deposition of coarse sediment at tributary junctures builds large debris fans that constrict the river and form rapids (fig. 1). Debris fans, and the debris bars that develop below rapids, provide stable substrate for aquatic organisms, notably the alga *Cladophora glomerata*. The pool above and recirculating eddy below the debris fan effectively trap fine sediment for storage on the bed or in sand bars. Debris fans and debris bars form the fan-eddy complex that attracts humpback chub (*Gila cypha*), an endangered species. Monitoring the input of coarse sediment to the Colorado River ecosystem and its long-term redistribution by the river is critical to the understanding and management of these valued resources. This fact sheet presents an overview of methods for monitoring coarse sediment input and redistribution in Grand Canyon. These methods are discussed more thoroughly in Melis (1997), Melis and others (1994, 1997), and Webb and others (1999a, 1999b, 2000).

## Debris Flows and the River

In small tributaries of the Colorado River between Powell and Mead reservoirs, coarse sediment is transported to the river almost exclusively by debris flow. While tributary streamflow deposits are well-sorted and typically have less than 3% coarse sediment by weight, debris-flow deposits are poorly sorted and contain 5 to 76% coarse sediment (Webb and others, 2000).

Debris flows can have an immediate and dramatic effect on the river corridor. Even a single small debris flow may significantly alter the topography and hydraulics of a debris fan and rapid in a matter of minutes. However, the Colorado River redistributes the coarse sediment introduced by debris flows almost immediately after deposition and during subsequent high flows. Before closure of Glen Canyon Dam, large floods on the river routinely removed all fine sediment and some coarse sediment from aggraded debris fans (a process called *reworking*), transporting coarse sediment through the pool below the rapid and depositing it as debris bars (fig. 1). In the regulated river, floods of reduced magnitude do not have sufficient stream power to rework aggraded debris fans as thoroughly (Webb and others, 1999a, 1999b). Coarse particles that are entrained by these lower discharges may be deposited in the pools below rapids, potentially altering the eddy pattern and increasing the length of the rapid. As a result, debris fans and rapids may be aggrading over the long term.

## Monitoring Debris Fans

The effective monitoring of coarse sediment requires both the short-term documentation of inputs by debris flow and the long-term evaluation of the redistribution of that sediment by the Colorado River. Both efforts involve measuring the volume and particle-size distribution of sediment delivered, as well as the effects of its redistribution on the morphology and hydraulics of the river channel. Monitoring debris flows at regular intervals will not only alert managers and researchers to sudden, potentially important changes to channel resources but also will add to an existing database designed to enable modeling of the interaction of coarse sediment and the Colorado River. The effective and efficient monitoring of

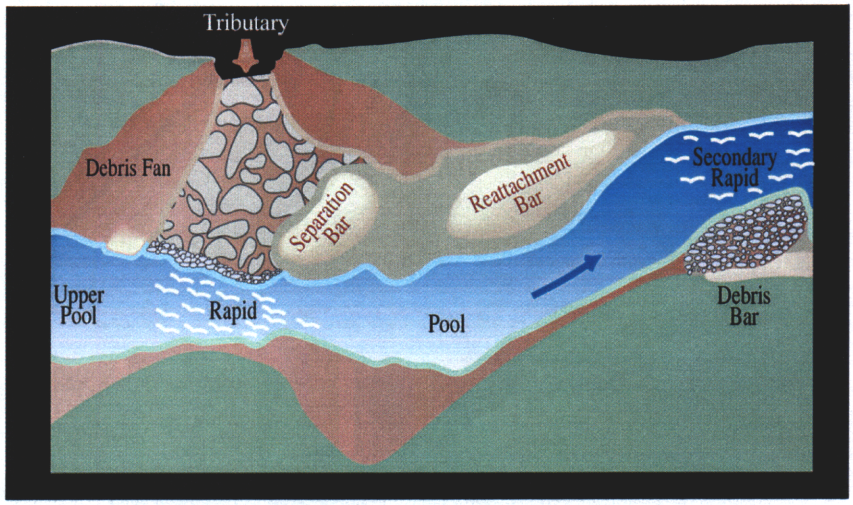


**Figure 1.** Schematic diagram of the fan-eddy complex on the Colorado River.

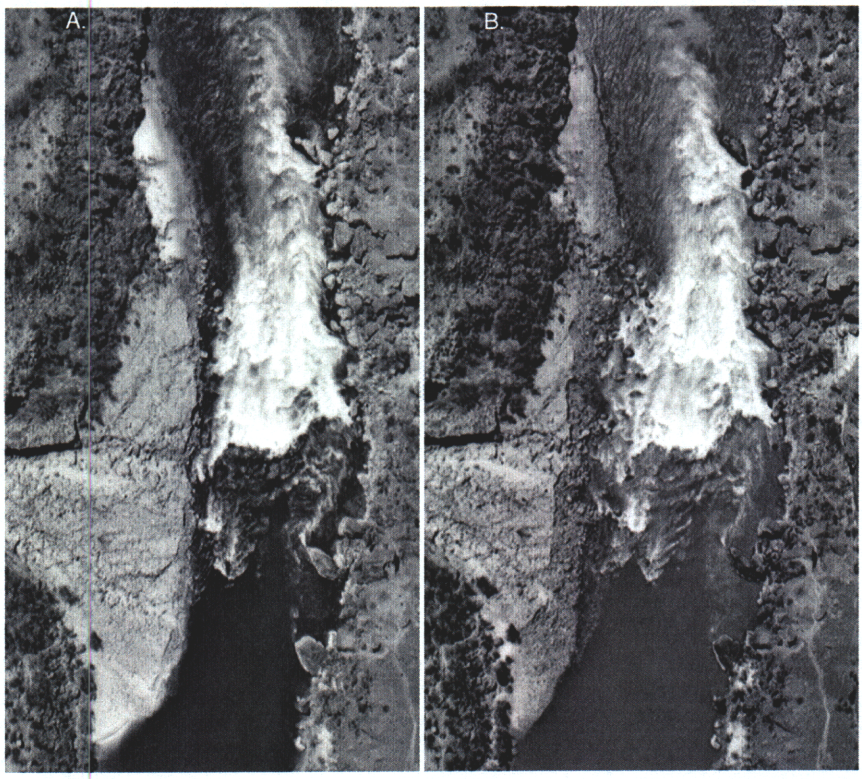


**Figure 2.** Aerial photographs of the debris fan at Lava Falls Rapid. A, (March 24, 1996) Lava Falls Rapid was constricted by a 1995 debris flow from Prospect Canyon. B, (April 9, 1996) Reworking during the rising limb of the 1996 controlled flood removed 5,900 $m^3$ of the edge of the fan, increasing the width of the rapid by an average of 5 m.

channel change is highly dependent on current efforts by the Grand Canyon Monitoring and Research Center to develop a baseline topographic map of the entire river channel.

Most debris flows in Grand Canyon occur during the summer monsoon. Given that reworking can be substantial during high flows in the river, documenting new debris flows is best done annually between fall and early spring. Despite the large number of tributaries in Grand Canyon, debris flows are relatively infrequent; no more than 8 debris flows have been documented in any given year during the past decade (Melis and others, 1994; Webb and others, 2000). For purposes of comparison and maximizing information content, all monitoring should be done at river discharges that are as equivalent and as low as possible. Flow from the dam typically is low in the fall and early spring when heating and cooling demands for electricity are low.

**Table 1.** Types and accuracies of techniques for measuring debris-fan geometry

| Technique | Expected Frequency of Measurement | Horizontal Accuracy (m) | Vertical Accuracy (m) | Spacing (m) |
|---|---|---|---|---|
| Survey | On demand (annual) | ~0.01* | ~0.01* | Variable |
| Bathymetry | On demand | 0.05 | 0.05-0.06 | Variable |
| Digital aerial photos | Annual | 1-5 | n.a.*** | 0.18 |
| LIDAR | Annual | 0.30 | 0.15 | 2 |
| Aerial photos | Annual | ~1-10** | n.a.*** | Variable |

* Depends upon instrument setup and rodman accuracy.
** Depends upon the quality of control points and the camera and flight characteristics.
*** Topography can not be extracted without stereo photography and control panels.

Several options exist for measuring debris-fan volume and area (Table 1). The most accurate measurement is obtained by combining direct survey of subaerial fan topography with multi-beam bathymetric measurements of the subaqueous debris fan. This is also the most expensive method, both in terms of field-work and data processing, and data for the topography of the debris fan before the debris flow are seldom available.

Remote-sensing techniques can overcome these limitations at the expense of lower resolution and accuracy. The most promising technique uses image analysis of digital aerial photography. If high-gain digital aerial photography is taken over clear, non-turbulent water, the images can be analyzed to reveal subaqueous topography in shallow water. Digital topography combining subaerial and subaqueous features can be developed from stereo images. The technique is new (started in 2000) and cannot be used retrospectively for pre-debris flow conditions.

A slightly less accurate but time-saving alternative is the use of LIDAR (*LI*ght *D*etection *A*nd *R*anging), an airborne laser device which is expected to be flown annually for the entire river corridor beginning in 2001. The accuracy of LIDAR data as collected in Grand Canyon is considerably less than the diameter of most of the coarse particles being monitored. LIDAR topography must be combined with either field assessments or aerial photography to accurately map debris-fan boundaries and with multi-beam bathymetric data to calculate a complete fan volume.

Aerial mapping photography, which typically is flown annually at a discharge of 8,000 $ft^3/s$, is the least accurate but cheapest and most widely available technique. Aerial photography suitable for debris-fan monitoring has been flown at least annually since the mid-1980s, providing an excellent baseline of pre-flow fan conditions. Comparison of pre- and post-event photography greatly aids in delineating the boundaries of debris flows as well as reworking by the Colorado

River (fig. 2). Standard aerial photographs must be digitized, georeferenced, and rectified before use, requiring the establishment of control points in the field. When pre-event topography is not available, fan volume can be calculated by multiplying the fan area measured from aerial photographs by an average thickness.

Particle-size distributions are best measured by combining point counts in the field with standard sieve analysis in the laboratory to capture the full range of particles found in debris flow deposits. Larger particles may be measured on site. Both unreworked deposits on fan surfaces and reworked deposits along distal fan edges are evaluated (fig. 3). Particle-size measurements should document *suturing*, or the interlocking of particles. Suturing is caused by the rearrangement and wearing together of particles, and its occurrence makes debris fans difficult to rework.

Other measurements include surveying the water-surface fall through the rapid, which can be used to calculate stream power for a given discharge (fig. 4). Surface velocity through the rapid can be measured by timing the passage of floats through the rapid. Other on-site measurements include documentation of changes in hydraulic features such as the shifting of waves and holes, and the movement, appearance, or disappearance of rocks.

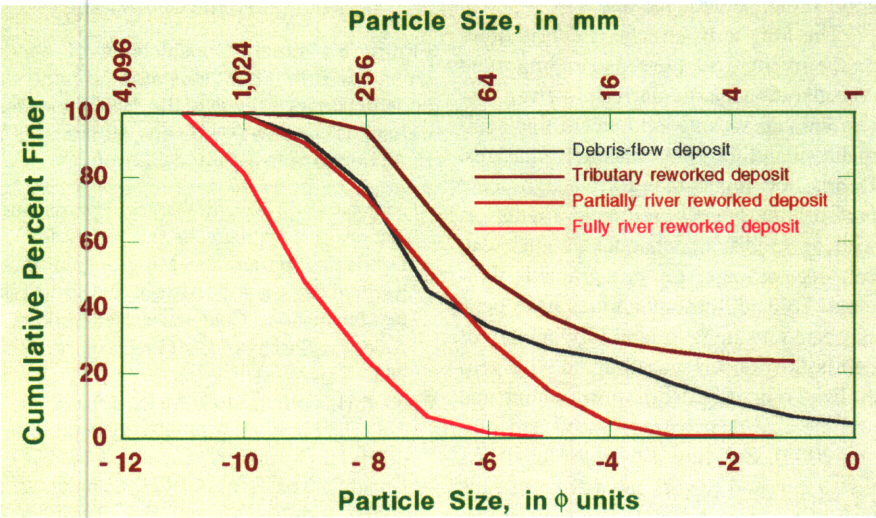


**Figure 3.** Particle-size distributions reflecting reworking on distal margins of a recently aggraded debris fan at mile 127.6 in Grand Canyon. The curve for partially river reworked deposit is the result of releases from Glen Canyon Dam. The curve of fully river reworked deposit is for reworking under pre-dam conditions.

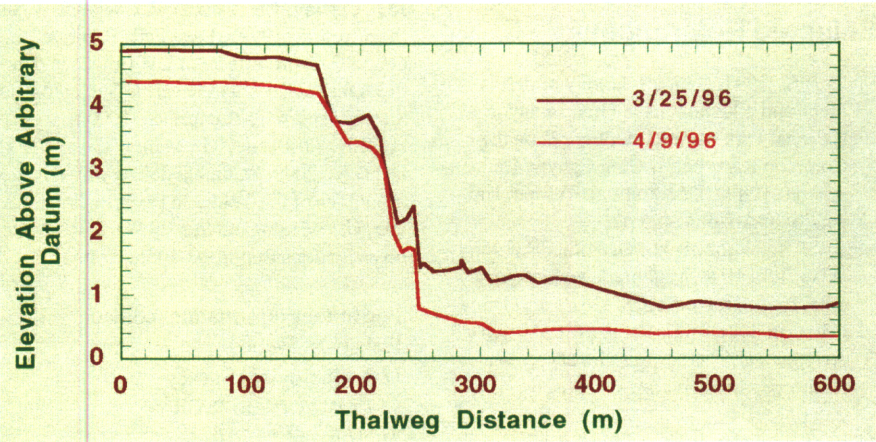


**Figure 4.** Water-surface profiles through Lava Falls Rapid showing the effects of reworking by the March 1996 flood.

Percent constriction of the river channel, a ratio of the average channel width through the rapid to the average channel width above and below the rapid (Webb and others, 1999a), is a useful measure of the impact of a debris flow on river channel morphology (fig. 5). For ease of measurement and consistency, measures of channel width are best obtained from georeferenced remote-sensing data, particularly aerial photographs. Aerial photography may also reveal qualitative changes in the hydraulics and navigability of rapids, reflecting underlying changes in the positions of boulders, and can be combined with field observations as a qualitative measure of channel change.

Because debris bars typically are unstable, much of the monitoring of these bars is best performed using remote sensing. This monitoring is most accurate when digital aerial photographs georeferenced by geographical positioning systems (GPS) are used because stable, long-term control points may be difficult to locate. Alternatively, LIDAR data of subaerial topography and multi-beam bathymetric data can be combined to give an important three-dimensional portrait of bar evolution over time. Particle-size distributions, and particularly lithologic counts, may be useful for assessing the stability and formation of debris bars.

## Long-Term Monitoring

Repeat monitoring of older fans could be performed at the same time as monitoring at recently aggraded debris fans, though additional monitoring should be done following the occurrence of atypically large reworking floods at other times of the year. Monitoring could start with an examination of new aerial photography and recalculation of debris-fan area, width of the reworked zone, and channel constriction. Because regulated floods do not overtop most fans but instead are eroded laterally, lack of change in any of these parameters indicates a stable fan where armoring is likely. Field work on these fans could be limited to annual point counts along the fan edge to evaluate the degree of armoring. Multi-year stability in particle-size distribution as well as fan area and channel constriction indicates a stable fan and monitoring could be suspended. However, any river discharge

exceeding the maximum flood that has passed that fan to date would be cause to again monitor the debris fan for change.

Conversely, change in any of these parameters, particularly after large floods, is suggestive of debris-fan reworking and additional field-work is necessary. New measures of fan volume and particle-size distribution are necessary to determine the fraction of deposit and classes of particles reworked by a given flood discharge at the site. Effects on the rapid are again measured by water-surface fall through the rapid, surface velocity, and calculations of stream power. New measures also reset the baseline for future measures of reworking. Changes in fan volume coupled with particle-size data can be used to estimate amount and sizes of coarse particles redistributed downstream to the pool or cobble bars.

## Fine Sediment

Changes in debris fans can be used to assess the overall contributions of sand from small tributaries to the upper reaches of Grand Canyon, where sand bars are diminished. Sand bars may be covered by debris flows, eliminating their usefulness as camping beaches. Monitoring of sandbar size downstream from aggraded debris fans should be a consideration of any long-term monitoring plan for coarse sediment inputs. The volume of fine sediment in the upper pool could be monitored in concert with debris fans by multibeam bathymetric measurements. As reworking floods change the debris fan, fine sediment is liberated from the upper pool and is made available for storage downstream in sand bars.

## Benefits of Debris-Fan Monitoring

Data collected from the monitoring of debris flows will have a number of important uses in the research and management of the Colorado River ecosystem in Grand Canyon. Annual monitoring provides detailed, up-to-date information on changes in Grand Canyon rapids and eddies. Monitoring also provides an empirical measure of the quantity and particle-size distribution of sediment input to the Colorado River annually by debris flow as well as changes in substrate that is important to the aquatic food base. Aquatic plants use coarse particles as anchor points, and aquatic invertebrates use the spaces between coarse sediment as habitat. Identification of stable versus unstable deposits of coarse particles will aide in long-term assessments of aquatic productivity.

Debris-flow monitoring should be part of an adaptive management program, particularly with respect to changes in both aquatic and terrestrial habitat. Addressing the processes of debris-fan reworking and armoring makes possible the determination of how much and which size classes of coarse particles actually enter the river. This empirical information should be combined with sediment-transport models to estimate the zone of influence debris flows and debris-fan reworking have on downstream aquatic habitat.

The long-term effects of debris flows on the river corridor are also an important consideration, particularly in a river system with decreasing amounts of fine-sediment mantling the channel margins. Debris-flow inputs may form a significant part of fine-grained sediment inputs, as well as modifying channel geometry to enhance storage of fine-grained sediment. To date, these quantities have been estimated using a probability model of debris-flow occurrence coupled with generalized ranges of debris-flow volume and particle-size distribution (Webb and others, 2000). Building a database of debris flow input and reworking will permit the testing of these estimates as well as the development of a more realistic model of debris-flow inputs.

*–Robert H. Webb and Peter G. Griffiths*

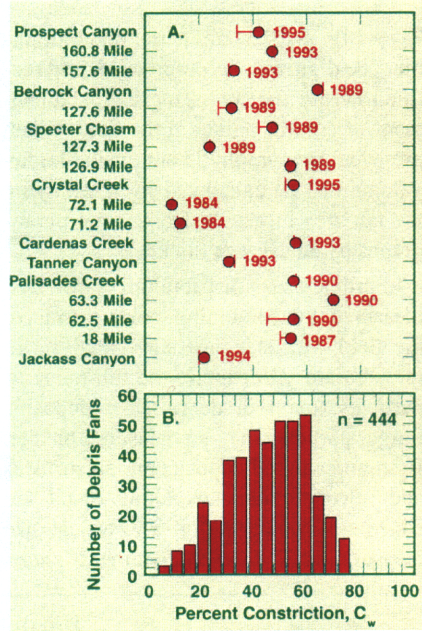


**Figure 5.** Percent constrictions of debris fans. A. Error bar indicates change in constriction as a result of the 1996 flood with date of debris flow (Webb and others, 1999). B. All debris fans in Grand Canyon.

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# Information Technology Activities

## INFORMATION TECHNOLOGY PROGRAM OVERVIEW
**Mike Liszewski, GCMRC**

The purpose of the Information Technology program is to provide scientists, stakeholders, and the public with information relative to the Colorado River Ecosystem. The information gathered, managed and delivered by the program staff varies from field-based data collection to office-based data management and delivery. Terrestrial and bathymetric surveys, aerial/remotely sensed data coordination provide information to researchers associated with monitoring programs in the physical, biological and cultural resources. The management and integration of these research and monitoring projects into spatial (GIS) and tabular data structures; library services, and World Wide Web outreach provide information to the research center staff, stakeholders, other scientists and the general public.

The value of each of these endeavors is highlighted

- **Surveying** – Provides positional reference for monitoring sites. Establishes a point of reference for long-term change. Currently is working on implementing a Canyon wide control network and generating a base map of channel hydrography.
- **Remotely Sensed Data** – Provides less intrusive, and potentially more cost-effective technologies for monitoring resources in Grand Canyon and Glen Canyon.
- **Geographic Information Systems** – Provides a spatial mechanism to integrate and monitor change in multiple resources. Provides opportunities to model proposed management strategies and spatially examine resource interactions.
- **World Wide Web** – State-of-the-art method to get information out in a timely manner.
- **Library Holdings** – Hold reports on research related to the EIS process. An archival tool to insure the preservation of data for the long-term.
- **Oracle Database** – A relational database that allows multiple data sources to be accessed for analysis. Compatible with WWW and GIS technology to allow the transfer and integration of spatial and tabular data via a website.

### Immediate Goals of the Information Technology Program

The Information Technology Program has several immediate goals that direct us toward our purpose.

**Database Development and Management** – A key requirement to success of the Information Technology Program is the development and maintenance of databases that are effectively structured to accommodate previously collected data, data that is currently being collected, and data that will be collected as the monitoring programs proceed. Designing a relational database that links tabular and spatial data has great potential for addressing, research, monitoring and management questions. The development and management is an iterative process and will continue to change overtime, reflective of the direction management and monitoring proceed.

**Outreach to Stakeholders, Scientists and the Public** – The World Wide Web is an increasingly important and effective communication tool. The Information Technology Program intends to develop web pages that link to the GIS coverages, tabular data and the library. These pages will provide a mechanism for stakeholders, scientists and the public to obtain information housed by GCMRC. Current webpages managed by GCMRC include the Technical Work Group Webpage that allows documents and agendas to be downloaded by TWG members and the GCMRC webpage. The later is in early development phase and currently has a downloadable RFP package.

**Utilize Remote Sensing Technologies for Resource Monitoring** – The Information Technology Program has participated in a remote sensing review in which recommendations were provided by researchers that use remote sensing techniques to monitor varied resources. We are exploring some of these recommendations to determine their applicability to monitoring of canyon resources. Funded research and aerial flights include multi-spectral aerial photography, 3-D photogrammetry for sandbar volumes, and thermal imaging. These have potential uses in vegetation/habitat mapping, archeological site monitoring, sandbar change.

## Terrestrial and Bathymetric Surveys

The survey department provides traditional terrestrial surveys, bathymetric surveys, and geo-referenced positioning capabilities as a supporting role to researchers in their monitoring efforts. The data gathered by the surveying department is critical for reliable long-term monitoring. Correct spatial referencing sets the stage for accurate GIS integration and long-term monitoring of scientific study sites. Our survey staff interacts with scientists on a daily basis, and has developed a variety of techniques to meet scientist's needs.

## Geographic Information Systems

A geographic information system (GIS) incorporates computer-based tools for managing, analyzing, and displaying spatial data. The combination of both tabular data associated with a resource and locality data is a powerful tool for integrative science and adaptive management. Coverages developed during the EIS period include cultural (NPS historic sites, some archeological sites), biological (vegetation monitoring sites, KAS, fish), physical (sandbar evolution studies, debris fans) resources.

The coverages are being maintained by GCMRC and it is anticipated that these coverages will be expanded as monitoring and research continues. The intent of the information technology group is to make the coverages accessible to users via arcview. Arcview is a software application developed by Arc/INFO to facilitate the use of GIS coverages among users that are unfamiliar with standard Arc/INFO software. Arcview coverages will allow the GIS files to be used by managers to examine possible management actions.

The goal of the GIS activities is to consolidate information about Grand Canyon resources and analyze trends and responses within a geographic framework.

# Section 4
# Strategic Planning

# Strategic Plan

# Strategic Plan

# Glen Canyon Dam
# Adaptive Management Program

**Final Draft**

**July 20, 2001**

**New Final Draft Strategic Plan-July20-jk**

CONTENTS

FOREWORD ..... V

1 INTRODUCTION ..... 1

GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM ..... 1

WHAT IS ADAPTIVE MANAGEMENT? ..... 1

GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM DEFINED ..... 1

ORGANIZATIONS AND POSITIONS WITHIN THE GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM ..... 2

*SECRETARY OF THE INTERIOR'S DESIGNEE* ..... 3

*ADAPTIVE MANAGEMENT WORK GROUP* ..... 3

*TECHNICAL WORK GROUP* ..... 4

*GRAND CANYON MONITORING AND RESEARCH CENTER* ..... 5

*INDEPENDENT REVIEW PANELS* ..... 6

HISTORY OF THE GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM ..... 6

*GLEN CANYON ENVIRONMENTAL STUDIES* ..... 6

*GRAND CANYON PROTECTION ACT* ..... 7

*GLEN CANYON DAM ENVIRONMENTAL IMPACT STATEMENT* ..... 8

*RECORD OF DECISION ON THE OPERATION OF GLEN CANYON DAM* ..... 8

*STATUTES, POLICIES, AND RESOLUTIONS* ..... 8

*GUIDANCE DOCUMENT FOR THE ADAPTIVE MANAGEMENT PROGRAM* ..... 9

SUMMARY OF THE GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM ..... 9

2 VISION AND MISSION ..... 10

PRINCIPLES ..... 10

GOALS ..... 11

MANAGEMENT OBJECTIVES ..... 12

INFORMATION NEEDS ..... 37

MANAGEMENT ACTIONS ..... 37

3 PROGRAMMATIC AND GEOGRAPHIC SCOPE ..... 37

INSTITUTIONAL SCOPE — WHAT THE PROGRAM INFLUENCES OR IS INFLUENCED BY ..... 38

ANNUAL OPERATING PLAN PROCESS ..... 38

TRIBAL INTERESTS WITHIN THE COLORADO RIVER ECOSYSTEM ..... 39

NATIONAL PARK SERVICE MANAGEMENT POLICIES AND ACTIVITIES ..... 39

OPERATION OF THE COLORADO RIVER STORAGE PROJECT POWER SYSTEM ..... 41

*LONG-TERM FIRM ELECTRICAL POWER* ..... 41

*OPERATION FOR A FEDERAL LOAD CONTROL ARE* ..... 41

*RESERVE SHARING GROUPS* ..... 42

*EMERGENCY SERVICE* ..... 42

PROTOCOLS AND PROCEDURES — HOW THE ADAPTIVE MANAGEMENT PROGRAM WORKS. 42

CHARTER ..... 42

OPERATING PROCEDURES OF THE ADAPTIVE MANAGEMENT WORK GROUP AND TECHNICAL WORK GROUP ..... 42

SCIENCE WITHIN THE GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM ..... 43

MANAGEMENT WITHIN THE GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM ..... 43

HOW SCIENCE AND MANAGEMENT ARE INTEGRATED INTO THE ADAPTIVE MANAGEMENT PROGRAM ..... 44

HOW MANAGEMENT OF ONE RESOURCE AFFECTS OTHER RESOURCES ..... 44

TRIBAL CONSULTATION AND COORDINATION WITHIN THE ADAPTIVE MANAGEMENT PROGRAM ..... 45

TRUST RESPONSIBILITIES AND THE ADAPTIVE MANAGEMENT PROGRAM ..... 45

HOW COMPLIANCE IS INTEGRATED INTO THE ADAPTIVE MANAGEMENT PROGRAM ..... 46

ENDANGERED SPECIES ACT ..... 46

NATIONAL ENVIRONMENTAL POLICY ACT ..... 47

NATIONAL HISTORIC PRESERVATION ACT ..... 48

ANNUAL ADAPTIVE MANAGEMENT PROGRAM CYCLE ..... 49
BUDGET DEVELOPMENT PROCESS ..... 49
ANNUAL REPORT TO CONGRESS ..... 49
STATE OF THE COLORADO RIVER ECOSYSTEM REPORT ..... 49
ANNUAL SCIENCE PLAN ..... 50
REQUEST FOR PROPOSAL PROCESS ..... 50

## FIGURES

Figure 1 – Positions and Organizations of the Glen Canyon Dam Adaptive Management Program

Figure 2 – Glen Canyon Dam Adaptive Management Program Section 7 Consultation Process (Informal Consultation)

Figure 3 – Glen Canyon Dam Adaptive Management Program Section 7 Consultation Process (Formal Consultation)

Figure 4 – Glen Canyon Dam Adaptive Management Program Section 7 Consultation Process (Implementation of Biological Opinion)

## APPENDICES

Appendix A Grand Canyon Protection Act

Appendix B Glen Canyon Dam Adaptive Management Program AMWG FACA Committee Guidance

Appendix C Glen Canyon Dam Adaptive Management Work Group – Charter

Appendix D Glen Canyon Dam Adaptive Management Work Group – Operating Procedures

Appendix E Glen Canyon Dam Technical Work Group – Operating Procedures

Appendix F Endangered Species Act Compliance

Appendix G Record of Decision on the Operation of Glen Canyon Dam

## FOREWORD

This strategic plan is a guidance document for the Glen Canyon Dam Adaptive Management Program and was developed by program members. Elements of this plan include the Glen Canyon Dam Adaptive Management Work Group's vision and mission statements, as well as principles, goals, and management objectives. One of the primary objectives of the program is compliance with the Grand Canyon Protection Act of 1992. This Act mandates that the Secretary of the Interior will operate Glen Canyon Dam and exercise other authorities in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. The Act also mandates that Glen Canyon Dam be operated consistent with the Colorado River Compact and the other laws, regulations, treaties, and policies making up the Law of the River. Recognizing the complexity of this task, a Record of Decision for the Operation of Glen Canyon Dam Final Environmental Impact Statement directed the Bureau of Reclamation and other interested agencies, tribes, organizations and individuals to use an adaptive management approach for implementing the preferred alternative. This approach is described in this strategic plan.

It is anticipated that this strategic plan is a long-term plan; however, it is recommended that the Adaptive Management Work Group review this plan at the beginning of every other federal fiscal year. The review process should be completed within six months of the beginning of the fiscal year in which the review takes place. If any of the stakeholders or the interested public identify changes that are needed to the strategic plan, including changes to any of the goals, management objectives, or information needs, these recommendations will be made to the Adaptive Management Work Group for approval and incorporation in a revised plan.

# 1 INTRODUCTION

This strategic plan describes the adaptive management approach that the Glen Canyon Dam Adaptive Management Program uses in making recommendations to the Secretary of the Interior regarding management of the Colorado River ecosystem (see Glossary). This strategic plan presents the vision, mission, principles, and goals of the Glen Canyon Dam Adaptive Management Program. As the main planning document of the Adaptive Management Program, this plan has been prepared based on consultation and coordination among those organizations, institutions, and individuals with interests in the operation of Glen Canyon Dam and its downstream effects.

The plan presents the background and history of the Glen Canyon Dam Adaptive Management Program, the scope of the program, the program members or stakeholders, the statutory and organizational framework, and the details of how the Adaptive Management Program operates. The plan details the specific management objectives needed to realize the vision and goals of the program. Supporting documents are provided in a series of appendices.

## GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM

### What is Adaptive Management?

Adaptive management has gained widespread acceptance in resource management since Holling (1978) developed the concept. Lee (1993:9) defines adaptive management with a simple imperative: "policies are experiments; *learn from them.*" Other characteristics (as described by Nyberg 1998; Walters 1986; Taylor et al. 1997) include:

- A focus on ecosystems;
- Experimentation and manipulation of managed ecosystems;
- A time scale based on the biological generation or longer;
- Acknowledgement of uncertainty about what policy or practice is best for a particular management issue;
- Careful implementation of a plan of action designed to reveal the critical knowledge;
- Monitoring of key response indicators;
- Analysis of outcomes in consideration of original objectives; and
- Incorporation of results into future decisions.

### Glen Canyon Dam Adaptive Management Program Defined

Due to the significant levels of uncertainty surrounding the resources of the Colorado River ecosystem and the effects of dam operations on those resources, the Glen Canyon Dam Environmental Impact Statement stipulated an adaptive management approach. This approach allows for scientific experimentation that adds to the knowledge base of effects of the operation of Glen Canyon Dam, primarily on downstream resources, and

results in the development of recommendations to the Secretary of the Interior regarding additional operational changes.

The adaptive management approach being taken to manage Glen Canyon Dam operations and the resources affected by dam operations is as follows:

- The Adaptive Management Program focus is on the Colorado River ecosystem;
- Models are developed of potential effects of policies, activities, or practices that are being considered for implementation;
- Questions are formulated as testable hypotheses regarding the expected responses or linkages of the Colorado River ecosystem to dam operations and other management actions;
- Questions are formulated as testable hypotheses;
- Experiments are conducted to test hypotheses and answer questions;
- Management activities reveal, through monitoring and evaluation of results, the accuracy or completeness of the earlier predictions; and
- New knowledge and information are produced through experimentation and are incorporated into management discussions and recommendations to the Secretary of the Interior.

## Organizations and Positions Within the Glen Canyon Dam Adaptive Management Program

With the signing of the Record of Decision for the Glen Canyon Dam Environmental Impact Statement (Reclamation 1996), the Glen Canyon Dam Adaptive Management Program was established, along with the following positions or organizations:

- Secretary of the Interior's Designee
- Adaptive Management Work Group
- Technical Work Group
- Independent review panels
- Grand Canyon Monitoring and Research Center

The roles, functions, and relationships of these positions and organizations are graphically depicted in Fig. 1 and are described in detail below based on the descriptions in the Glen Canyon Dam Environmental Impact Statement (Reclamation 1995) and Record of Decision (Reclamation 1996).

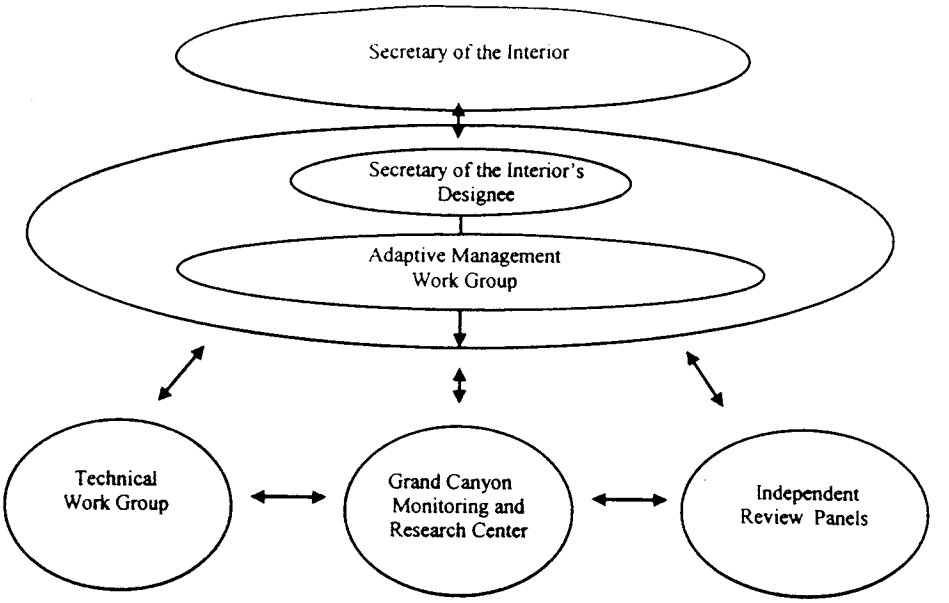


***Figure 1. Organizational components of the Glen Canyon Dam Adaptive Management Program.***

*Secretary of the Interior's Designee*

The Secretary of the Interior's Designee serves as the principal contact for the Glen Canyon Dam Adaptive Management Program and as the focal point for issues and decisions associated with the program. Responsibilities of the position include:

- Chairs the Adaptive Management Work Group;
- Ensures that the Department of the Interior complies with its obligations under the Grand Canyon Protection Act and Record of Decision for the Glen Canyon Dam Environmental Impact Statement;
- Ensures that the Department of the Interior fulfills its trust responsibilities to American Indian tribes with interests or assets affected by the program; and
- Reviews, modifies, accepts, or remands recommendations from the Adaptive Management Work Group in making decisions about any changes in dam operation and other management actions and forwards the approved recommendations to the Secretary of the Interior.

*Adaptive Management Work Group*

The Adaptive Management Work Group is a Federal Advisory Committee that includes representatives from the stakeholder tribes, organizations, and institutions listed below. The Secretary of the Interior appoints the Adaptive Management Work Group members. Responsibilities of the Adaptive Management Work Group as delineated in the Glen Canyon Dam Environmental Impact Statement (Reclamation 1995:36) are:

- Provides the framework for Glen Canyon Dam Adaptive Management Program policy, goals, direction, and priorities;
- Develops recommendations for modifying operating criteria and other resource management actions, policies, or procedures;
- Facilitates coordination and input from interested parties;
- Reviews and forwards the annual report to the Secretary of the Interior and his/her designee on current and projected year operations;
- Reviews and forwards annual budget proposals; and
- Ensures coordination of operating criteria changes in the Annual Operating Plan for Colorado River Reservoirs and other ongoing activities.

Representatives from the following tribes, organizations, or interest groups are presently included in the Adaptive Management Work Group:

- Arizona Department of Water Resources
- Arizona Game and Fish Department
- Bureau of Reclamation
- Bureau of Indian Affairs
- Colorado River Board of California
- Colorado River Commission of Nevada
- Colorado River Energy Distributors Association
- Colorado Water Conservation Board
- Grand Canyon River Guides
- Grand Canyon Trust
- Hopi Tribe
- Hualapai Tribe
- National Park Service
- Navajo Nation
- New Mexico State Engineer's Office
- Pueblo of Zuni
- Southern Paiute Consortium
- Southwest Rivers
- Trout Unlimited
- U. S. Fish and Wildlife Service
- Utah Associated Municipal Power Systems
- Utah Division of Water Resources
- Western Area Power Administration
- Wyoming Interstate Streams Engineer

*Technical Work Group*

The Technical Work Group is comprised of technical representatives of Adaptive Management Work Group members and operates at the direction of the Adaptive Management Work Group. The Technical Work Group's main function is to provide technical assistance to the Adaptive Management Work Group. Technical Work Group functions may include (Reclamation 1995:37):

- Developing, with the Grand Canyon Monitoring and Research Center, criteria and standards for monitoring and research programs and providing periodic reviews and updates of these;
- Developing, with the Grand Canyon Monitoring and Research Center, resource management questions and information needs for the design of monitoring and research programs;
- Reviewing and commenting on the scientific studies conducted or proposed by the program;
- Listening to views provided by Technical Work Group members, external scientists, the public, and other interested parties (see Glossary);
- Providing information as necessary for preparing annual resource reports and other reports as required by the Adaptive Management Work Group; and
- Reviewing strategic plans, annual work plans, long-term and annual budgets, and other assignments from the Adaptive Management Work Group.

*Grand Canyon Monitoring and Research Center*

The Grand Canyon Monitoring and Research Center was created to fulfill the mandate in the Grand Canyon Protection Act for the "establishment and implementation of a long-term monitoring and research program to ensure that Glen Canyon Dam is operated in a manner that protects the values for which the Grand Canyon National Park and the Glen Canyon National Recreation Area were created." The Grand Canyon Monitoring and Research Center serves as the science center for the Glen Canyon Dam Adaptive Management Program. The Grand Canyon Monitoring and Research Center leads the monitoring and research of the Colorado River ecosystem and facilitates communication and information exchange between scientists and members of the Technical Work Group and Adaptive Management Work Group. Other functions of the Grand Canyon Monitoring and Research Center are:

- Advocate quality, objective science, and the use of that science in the adaptive management decision process;
- Provide scientific information about resources in the Colorado River ecosystem;
- Support the Secretary of the Interior's Designee and the Adaptive Management Work Group in a technical advisory role;
- Develop research designs and proposals for implementing (by the Grand Canyon Monitoring and Research Center or its contractors) monitoring and research activities in support of information needs;
- Coordinate review of the monitoring and research program with independent review panels;
- Coordinate, prepare, and distribute technical reports and documentation for review and as final products;
- Prepare and forward technical management recommendations and annual reports, as specified in Section 1804 of the Grand Canyon Protect Act, to the Technical Work Group;
- Manage data collected as part of the Adaptive Management Program and serve as a repository for other information about the Colorado River ecosystem;
- Administer research proposals through a competitive contract process, as appropriate;
- Develop, with the Technical Work Group, criteria and standards for monitoring and research programs; and
- Develop, with the Technical Work Group, resource management questions and information needs for the design of monitoring and research programs.

*Independent Review Panels*

Independent Review Panels, as called for in the Glen Canyon Dam Environmental Impact Statement (Reclamation 1995:38), are comprised of qualified individuals not otherwise participating in the long-term monitoring and research studies. The panels include peer reviewers, science advisors, and protocol evaluation panels whose primary responsibility is to assess the quality of research, monitoring, or science being conducted by the Adaptive Management Program and to make recommendations to improve it. Responsibilities of the panels include:

- Reviewing Glen Canyon Dam Adaptive Management Program monitoring and research programs and protocols;
- Providing reports based on their review to the Grand Canyon Monitoring and Research Center, Technical Work Group, and Adaptive Management Work Group;
- Making recommendations and providing advice to the Adaptive Management Work Group, Technical Work Group, and Grand Canyon Monitoring and Research Center regarding monitoring, research, science, priorities, integration, and management;
- Assessing proposed research plans and programs, technical reports and publications, and other program accomplishments; and
- Conducting five-year reviews of Grand Canyon Monitoring and Research Center monitoring and research protocols.

## History of the Glen Canyon Dam Adaptive Management Program

This strategic plan and the Glen Canyon Dam Adaptive Management Program cannot be understood without referencing key events since completion of Glen Canyon Dam in 1963. The plan and program arose from the Bureau of Reclamation's proposal to install additional generators on the bypass tubes and to rewind and uprate the existing generators at Glen Canyon Dam. This proposal resulted in the establishment of the Glen Canyon Environmental Studies from 1982 through 1996.

*Glen Canyon Environmental Studies*

While the National Park Service, river runners, and scientists had noticed that some beaches were disappearing and that plant and animal life along the Colorado River were changing since Glen Canyon Dam was completed in 1963, the Glen Canyon Environmental Studies program of the Bureau of Reclamation was the first systematic effort to investigate the effects of dam operations on downstream resources. The program began in 1982 and lasted through 1996. The Glen Canyon Environmental Studies did identify a mix of positive and negative consequences of dam operations on the downstream environment. In response to substantial public concern over the findings of the Glen Canyon Environmental Studies, in 1989, the Secretary of the Interior announced that an environmental impact statement would be completed to direct future operation of Glen Canyon Dam. With this announcement, the Glen Canyon Environmental Studies focused on providing specific data for use in the Glen Canyon

Dam Environmental Impact Statement (Reclamation 1995).

*Grand Canyon Protection Act*

The Grand Canyon Protection Act (Appendix A) was enacted on October 30, 1992. Section 1802 states:

> (a) IN GENERAL.–The Secretary shall operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in Section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use.
>
> (b) COMPLIANCE WITH EXISTING LAW.–The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona vs. California, and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.
>
> (c) RULE OF CONSTRUCTION.–Nothing in this title alters the purposes for which the Grand Canyon National Park or the Glen Canyon National Recreation Area were established or affects the authority and responsibility of the Secretary with respect to the management and administration of the Grand Canyon National Park and Glen Canyon National Recreation Area, including natural and cultural resources and visitor use, under laws applicable to those areas, including, but not limited to, the Act of August 25, 1916 (39 Stat. 535) as amended and supplemented.

The Secretary of the Interior was also directed to establish and implement long-term monitoring programs and activities to ensure that Glen Canyon Dam is operated in a manner consistent with the Grand Canyon Protection Act. These programs include necessary research and studies to determine the effect of management of the dam on the natural, recreational, and cultural downstream resources. These actions will also be undertaken in consultation with other federal agencies, the Governors of the Basin States, Indian Tribes, and the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of federal power produced at Glen Canyon Dam. To accomplish these requirements, the Glen Canyon Dam Adaptive Management Program was established.

*Glen Canyon Dam Environmental Impact Statement*

The Glen Canyon Dam Environmental Impact Statement (Reclamation 1995) was completed in March 1995. Its purpose was to "determine specific options that could be implemented to minimize—consistent with law—adverse impacts on the downstream

environmental and cultural resources and Native American interests in Glen and Grand Canyons." The Glen Canyon Dam Environmental Impact Statement analyzed nine alternatives to allow the Secretary of the Interior to balance competing interests and to meet statutory responsibilities for protecting downstream resources and producing hydropower, and to protect affected Native American interests. The preferred alternative was the Modified Low Fluctuating Flow Alternative.

*Record of Decision on the Operation of Glen Canyon Dam*

On October 9, 1996, the Secretary of the Interior signed the Record of Decision that presented the rationale for choosing the Modified Low Fluctuating Flow Alternative. As noted in the Record of Decision:

> The goal of selecting a preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability. [Reclamation 1996:10]

The Record of Decision (Appendix G) included seven environmental commitments:

- Adaptive Management
- Monitoring and Protection of Cultural Resources
- Flood Frequency Reduction Measures
- Beach/Habitat-Building Flows
- New Population of Humpback Chub
- Further Study of Selective Withdrawal
- Emergency Exception Criteria

The commitments are explained in detail in the Record of Decision (Reclamation 1996) (Appendix G) and on pages 33-43 of the Glen Canyon Dam Environmental Impact Statement (Reclamation 1995); however, it should be noted that subsequent work of the Technical Work Group and Adaptive Management Work Group have altered some of them (e.g., Technical Work Group 1998).

*Statutes, Policies, and Resolutions*

The Colorado River is managed and operated under numerous compacts, federal and state laws, court decisions and decrees (including Native American water claim settlements), contracts, treaties, and regulatory guidelines collectively known as the Law of the River. This collection of documents apportions the water among the seven Basin States and Mexico and regulates and manages the river flows of the Colorado River. Some of the statutes included within the Law of the River that have a major impact on dam operations are the Colorado River Compact of 1922, the Upper Colorado River Basin Compact of 1948, the Colorado River Storage Project Act of 1956, the Colorado River Basin Project Act of 1968, and the Grand Canyon Protection Act of 1992. In addition to Colorado

River specific legislation, the Endangered Species Act of 1973 and court decrees including Arizona v. California affect the extent to which water developments and diversions can be utilized in the Colorado River Basin. The Law of the River and this additional legislation control and influence the Adaptive Management Program.

Additional laws, executive orders, policies, tribal resolutions, etc., that control or influence the Adaptive Management Program include the National Park Service Organic Act, enabling legislation for Grand Canyon National Park and Glen Canyon National Recreation Area, and Executive Orders that established reservation boundaries for the Navajo Nation and the Hualapai Tribe. In addition, Section 204 of Title II of Public Law 106-377 controls the level of funding of Adaptive Management Program activities from Colorado River Storage Project power revenues. The Federal Advisory Committee Act controls operation of the Adaptive Management Work Group and the Technical Work Group.

Environmental laws and regulations are of great importance to the Adaptive Management Program. These include, but are not limited to, the Endangered Species Act, National Historic Preservation Act of 1966, and National Environmental Policy Act of 1969. Adaptive Management Program compliance with these statutes, regulations, policies, directives, etc., is described in a later section.

*Guidance Document for the Adaptive Management Program*

Since the Adaptive Management Program became fully operational in 1997, questions and uncertainties have arisen over the relationships of program elements, compliance priorities, and other legal matters. Answers were sought from a Department of the Interior Solicitor. The questions posed and answers received from the Department of the Interior's Solicitor (Loveless 2000) are called the "Guidance Document for the Adaptive Management Program." This document is provided as Appendix B.

**Summary of the Glen Canyon Dam Adaptive Management Program**

The Adaptive Management Program was developed and designed to provide an organization and process for a collaborative, science-based integration of dam operations, resource protection and management, and monitoring and research information. The Adaptive Management Program should meet the environmental commitments of the Glen Canyon Dam Environmental Impact Statement and Record of Decision, and comply with the Grand Canyon Protection Act. The Adaptive Management Program must also remain in compliance with the Law of the River and relevant environmental statutes, regulations, and policies. With all these demands, the Adaptive Management Work Group devised a vision and mission statement to guide its activities and decision making.

# 2 VISION AND MISSION

The Grand Canyon is a homeland for some, sacred to many, and a national treasure for all. In honor of past generations, and on behalf of those of the present and future, we envision an ecosystem where the resources and natural processes are in harmony under a stewardship worthy of the Grand Canyon.

We advise the Secretary of the Interior on how best to protect, mitigate adverse impacts to, and improve the integrity of the Colorado River ecosystem affected by Glen Canyon Dam, including natural biological diversity (emphasizing native biodiversity), traditional cultural properties' spiritual values, and cultural, physical, and recreational resources through the operation of Glen Canyon Dam and other means.

We do so in keeping with the federal trust responsibilities to Indian tribes, in compliance with applicable federal, state, and tribal laws, including the water delivery obligations of the Law of the River, and with due consideration to the economic value of power resources.

This will be accomplished through our long-term partnership utilizing the best available scientific and other information through an adaptive ecosystem management process.

## PRINCIPLES

The nine principles of the Glen Canyon Dam Adaptive Management Program are:

1. The goals represent a set of desired outcomes that together will accomplish our vision and achieve the purpose of the Grand Canyon Protection Act. Some of the objectives and actions that fall under these goals may not be the responsibility of the Adaptive Management Program, and may be funded by other sources, but are included here for completeness.
2. The construction of Glen Canyon Dam and the introduction of non-native species have irreversibly changed the Colorado River ecosystem.
3. Much remains unknown about the Colorado River ecosystem below Glen Canyon Dam and how to achieve the Adaptive Management Program goals.
4. The Colorado River ecosystem is a managed ecosystem. An ecosystem management approach, in lieu of an issues, species, or resources approach, will guide our efforts. Management efforts will prevent any further human-induced extirpation or extinction of native species.
5. An adaptive management approach will be used to achieve Adaptive Management Program goals, through experimentation and monitoring, to meet the intent of the Grand Canyon Protection Act, Glen Canyon Dam Environmental Impact Statement, and the Record of Decision.
6. Dam operations and management actions will be tried that attempt to return ecosystem patterns and processes to their range of natural variability. When this is not appropriate, experiments will be conducted to test other approaches.

7. Because management actions to achieve a goal may benefit one resource or value and adversely affect another, those action alternatives that benefit all resources and values will be pursued first. When this is not possible, actions that have a neutral impact, or as a last resort, actions that minimize negative impacts on other resources, will be pursued consistent with the Glen Canyon Dam Environmental Impact Statement and the Record of Decision.
8. If the target of a management objective proves to be inappropriate, unrealistic, or unattainable, the Adaptive Management Program will reevaluate that target and the methods used to attain it.
9. Recognizing the diverse perspectives and spiritual values of the stakeholders, the unique aesthetic value of the Grand Canyon will be respected and enhanced.

## GOALS

The 12 goals of the Adaptive Management Program are:

1. Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.
2. Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat.
3. Restore populations of extirpated species, as feasible and advisable.
4. Maintain a wild reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.
5. Maintain or attain viable populations of Kanab ambersnail.
6. Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat.
7. Establish water temperature, quality, and flow dynamics to achieve the Adaptive Management Program ecosystem goals.
8. Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve the Adaptive Management Program ecosystem goals.
9. Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of the Adaptive Management Program ecosystem goals.
10. Maintain power production capacity and energy generation, and increase where feasible and advisable, within the framework of the Adaptive Management ecosystem goals.
11. Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations.
12. Maintain a high quality monitoring, research, and adaptive management program.

## MANAGEMENT OBJECTIVES

***Goal 1. Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| The target for all the Management Objectives in Goal 1 is adequate food availability to support trout and native fish above the Paria River, and native fish below the Paria River. Linkages: See the numbers of fish desired under Goals 2, 3, and 4. | | | | | | | |
| 1.1 | Maintain or attain | Primary producers: algae on hard substrates, rooted macrophytes on soft substrates, and diatoms | Biomass | Mainstem from Glen Canyon Dam to the Paria River in both pools and on cobble bars identified by specific sampling sites | $x \pm y$ g/m$^2$ (cobble)$^0$<br>$a \pm b$ g/m$^2$ (pool)<br><br>(To be provided from Shannon et al.) | $x \pm y$ g/m$^2$ (cobble)<br>$a \pm b$ g/m$^2$ (pool)<br><br>(Need to resolve differences between data from Shannon et al. and AGFD.) | Also see McKinney et al. 1999[22]<br><br>The small group suggested the target should be the average of 1996 and 1997 data which they believe represents the best biomass estimates for the period in which data are available, and because they appeared to be good years to support the desired species. |
| | | | Composition | | River Mile / % Algae / % Macro-phytes<br>Pools<br>IN / IN<br>IN / IN<br>IN / IN<br>Cobbles<br>IN / IN<br>IN / IN<br>IN / IN | Information Need | Given the change in composition, the idea of Cladophora as a keystone species has been called into question. Scientists have said composition is an Information Need and should not be broken down below algae and macrophytes at this point in time. |
| 1.2 | Maintain or attain | Benthic invertebrates | Biomass | Mainstem from Glen Canyon | $x \pm y$ g/m$^2$ (Cobble)<br>$a \pm$- $b$ g/m$^2$ (Pool) | $x \pm y$ g/m$^2$ (Cobble)<br>$a \pm b$ g/m$^2$ (Pool) | Also see McKinney et al. 1999[22] |

# MANAGEMENT OBJECTIVES

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|---|---|---|---|---|---|---|---|
| The target for all the Management Objectives in Goal 1 is adequate food availability to support trout and native fish above the Paria River, and native fish below the Paria River. Linkages: See the numbers of fish desired under Goals 2, 3, and 4. | | | | | | | |
| | | | Composition | Dam to Paria River | Cobble:<br>__ % Tubificids<br>__ % *Gammarus*<br>__ % Chironomids<br>__ % Gastropods<br>__ % Other<br>Pool:<br>__ % Tubificids<br>__ % *Gammarus*<br>__ % Chironomids<br>__ % Gastropods<br>__ % Other<br>(Data to be filled in by Joe Shannon and AGFD.) | Information Need | Metric is relative % of species. |
| 1.3 | Maintain or attain | Primary producers: algae on hard substrates, rooted macrophytes on soft substrates, and diatoms | Biomass | Mainstem below the Paria River on cobble bars identified by specific sampling sites | River Mile / $g/m^2$<br>Cobble<br>2<br>61<br>68<br>127<br>205 | $50\ g/m^2$ (27) | |
| | | | Composition | | River Mile / % Algae / % Macro-phytes<br>Pools<br>2<br>61<br>68<br>127<br>205<br>Cobble<br>2<br>61<br>68<br>127<br>205 | Information Need | Metric is relative % of algal species. MAMB is for miscellaneous algae, macrophytes, and bryophytes |

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***Goal 1. Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 1.4 | Maintain or attain | Benthic invertebrates | Biomass | Mainstem below the Paria River | 0.960 g/m$^2$ (Cobble)[27]<br>0.054 g/m$^2$ (Pool)[27] | To be provided based on 1996-97 data. | |
| | | | Composition | | Cobble:<br>__ % Tubificids<br>__ % *Gammarus*<br>__ % Chironomids<br>__ % Gastropods<br>__ % Other<br><br>Pool:<br>__ % Tubificids<br>__ % *Gammarus*<br>__ % Chironomids<br>__ % Gastropods<br>__ % Other | Obtain from literature | Metric is relative % of species. |
| 1.5 | Maintain or attain | Foodbase drift:<br>Diptera<br>*Gammarus*<br>Other Bugs<br>CPOM<br>FPOM<br>DOC | Abundance | Mainstem below GCD | River Mile / AFDW<br>2<br>61<br>68<br>127<br>205 | To be provided based on 1996-97 data.) | |

***Goal 2. Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 2.1 | Maintain or attain | Humpback chub (150 mm and larger) (Length is based on the size at which a HBC is able to be pit-tagged.) | Abundance | LCR aggregation (The definition of the LCR aggregation will be resolved following completion of the stock assessment workshop and the PEP review.) | 4330-4811 individuals[3] with a mean of 4508 individuals | Information Need | The target is viable populations and removal of jeopardy.<br><br>Target to be based on 91-96 population estimate, PVA, & $N_e$. |
| | | | | Eight mainstem aggregations | Information Need<br><br>?? Confidence interval with a mean of 225 individuals?? | Information Need | |
| 2.2 | Maintain or attain | Humpback chub (51 mm to 150 mm) | Year class strength | LCR aggregation | Information Need. Consider using a CPUE index for different year classes, at some place in the LCR at some time during the year. | Information Need. Intended to be an index that will indicate spawning success. | The target is viable populations and removal of jeopardy.<br><br>Metric is "catch per unit effort" (CPUE). See Gorman and Bramblett.[9] See synthesis by Coggins. |
| | | | | Eight mainstem aggregations | Information Need | Information Need | |
| 2.3 | Maintain or attain | Humpback chub (> 200 mm) (This is the length at which 50% of the fish are thought to be sexually mature.) | Recruitment | LCR aggregation | Information Need | Information Need | The target is viable populations and removal of jeopardy. |
| | | | | 8 mainstem aggregations | Information Need | Information Need | |
| 2.4 | Establish | Humpback chub | Spawning aggregation | CRE below GCD | One spawning aggregation in the LCR | A second spawning aggregation | The target is removal of jeopardy. |

***Goal 2. Maintain or attain viable populations of existing native fish, remove jeopardy from humpback chub and razorback sucker, and prevent adverse modification to their critical habitat.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 2.5 | Attain | Humpback chub | Condition | LCR aggregation | Information Need | Information Need. There should be a minimum threshold. | The target is viable populations and removal of jeopardy. PEP should be asked to evaluate the method that would be used to calculate condition and the value to be established as the threshold. |
| | | | | 8 mainstem aggregations | Information Need | Information Need | |
| | | | Disease and other parasites | LCR aggregation | Information Need | Information Need | |
| | | | | 8 mainstem aggregations | Information Need | Information Need | |
| 2.6 | Reduce | Native fish | Mortality due to non-native fish predation as a % of overall mortality | LCR | Information Need | Information Need | The target is reduction of non-native fish predation so it does not impinge on native fish viability. Linkages: The native fish MOs in Goal 2 and Goal 3. |
| | | | | Mainstem | Information Need | Information Need | |
| 2.7 | Attain | Razorback sucker | Abundance | CRE below GCD | 0 individuals[9] | Information Need | The target is derived from the capability of the habitat to support the species, and includes the removal of jeopardy. |
| 2.8 | Maintain | Flannelmouth sucker | Abundance | CRE below GCD | AGFD to provide [9] | Information Need | Appropriate metric to be determined. The target is viable populations. |
| | | | Distribution | | AGFD to provide [9] | Information Need | |
| | | Bluehead sucker | Abundance | | AGFD to provide [9] | Information Need | |
| | | | Distribution | | AGFD to provide [9] | Information Need | |
| | | Speckled dace | Abundance | | AGFD to provide [9] | Information Need | |
| | | | Distribution | | AGFD to provide [9] | Information Need | |

*Goal 3. Restore populations of extirpated species, as feasible and advisable.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 3.1 | Restore | Colorado pikeminnow | Abundance | CRE downstream of GCD | 0 individuals[9] | Information Need | |
| | | Bonytail | | | 0 individuals[9] | Information Need | |
| | | Roundtail Chub | | | 0 individuals[9] | Information Need | |
| | | River otter | | | 0 individuals[10] | Information Need | |

***Goal 4. Maintain a wild reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| Linkages: See Issue Paper B (trout). | | | | | | | |
| 4.1 | Maintain or attain | Rainbow trout (RBT) | Abundance | Mainstem from Glen Canyon Dam to Paria River | 260,000 +/- 30,000 Age II+ individuals[23] | 100,000 Age II+ individuals | The target is adequate abundance of wild-reproducing Rainbow trout to maintain a quality recreational fishery, while not adversely affecting native fish population viability. |
| | | | | | Electrofishing CPUE | Information Need | |
| | | | Proportional Stock Density (see below) | | 15% | Information Need | Might replace measure of "length at age" in the future. Value of metric needs to be assessed. |
| | | | Length at age | | 15" by Age III[23] | 15 – 18" by Age III | |
| | | | Condition | | $W_r = 0.82$[23] | $W_r = 0.90$ | |
| | | | Whirling disease and other parasitic infections | | Absence | Absence | |
| | | | Spawning habitat | | Information Need | Information Need | Metric is quality and abundance of habitat. |
| | | | Natural recruitment | | 100% | 100% | This MO restates and measures the goal. |
| 4.2 | Limit | Lees Ferry RBT | Distribution | CRE below the Paria River | Information Need | Information Need. Need research and data that demonstrate predator / prey and competitive effect. | The target is minimal competitive or predator / prey effect on downstream native fish. |

Proportional Stock Density is the ratio that results by dividing the number of fish great than 16" by the number of all fish greater than 12". This provides a measure of the abundance of fish at a certain size, which should translate into a target for both abundance and length at age.

## *Goal 5. Maintain or attain viable populations of Kanab ambersnail.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 5.1 | Attain and maintain | Kanab ambersnail | Population | Vasey's Paradise | 7100 (April 1999)<br>6400 (May 1999)<br>20,000 (July 1999)<br>35,000 (Sept/Oct 1999)<br>(Individuals below 70,000 cfs stage)[24] | Information Need (to be measured in the spring and before any Management Action that may affect the population) | The metric is the population parameter(s) that indicate viability. The target is a viable population. "Viable" includes the entire population, not just those below 70,000 cfs.<br>Management Action: monitor the KAS populations at Keyhole, Elves, and Deer Creek |
| 5.2 | Maintain | Kanab ambersnail | Habitat | Vasey's Paradise | 82-99 $m^2$ monkeyflower and 36.6 $m^2$ watercress below 70,000 cfs stage.<br><br>Information Need (for above new stage level when it is determined) | Information Need. An x-year running average greater than or equal to y% of the total area of occupied habitat measured at Vasey's in March 1996, with a minimal level TBD. | The target is the level needed to sustain a viable population. Purpose is to limit human impact, by intentional flooding or other actions, to habitats occupied by Kanab ambersnail. |

*Goal 6. Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| The target is an achievable and appropriate mix of four types of communities: marsh, open sand beach, old high water zone (OHWZ), and new high water zone (NHWZ). All four communities are important for maintaining the diversity of wildlife, visitor use, and cultural resources. See the Riparian Issue Paper for more information. | | | | | | | |
| 6.1 | Maintain | Marsh community | Abundance | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | 1215 patches (4.6 ha)[7] | For an x-year running average of y or more marsh patches >/= 10 $m^2$, as determined by standard criteria for wetland species, soil type, and wetted area. | See Kearsley[15] and Stevens et al.[29]. |
| | | | Composition | | Information Need | No loss of native species. Species are assumed still to be present when they have been detected by monitoring within the last 10 years. | |
| | | | Area | | Information Need | For an x-year running average area equal to +/- y% of the area defined by aerial imaging in 2000. | |
| 6.2 | Maintain | New high water zone community | Patch number and distribution | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | Information Need | Information Need | The target is to allow for scouring of NHWZ vegetation to 1984 levels for patch number and distribution, and then allow its return through successional processes |
| | | | Composition | | Information Need | Species are assumed still to be present when they have been detected by monitoring within the last 10 years. | The target is to allow no loss of native plant or animal species. |
| | | | Area | | Information Need | For an x-year running average area equal to ±- y% of the area defined by aerial imaging in 2000. | NHWZ vegetation & sand beaches occur in the same strip of land. An increase to NHWZ vegetation will reduce the amount of open sand, and vice versa. These objectives are therefore closely linked to each other, as well as to the beach-building effects of BHBFs. |

*Goal 6. Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 6.3 | Maintain | Old high water zone community | Abundance | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | In 1992, there was an estimated 1,870 acres of OHWZ vegetation (Stevens 1992). | Information Need | The target is no significant loss of area. |
| | | | Composition | | Information Need | Information Need | The target is no loss of native plant or animal species. |
| | | | Distribution | | Information Need | Information Need | |
| 6.4 | Maintain | Sand Beach community | Abundance | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | Information Need | Information Need | See Kearsley [15] and Stevens et al. [29] |
| | | | Composition | | Information Need | Information Need | |
| | | | Distribution | | Information Need | Information Need | |
| 6.5 | Reduce | Invasive non-native species | Abundance (Abundance refers to number of individuals within the species. These species should be limited to invasive ones, not just non-natives.) | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | 95+ species (Plants)[28]<br>3 species (Birds)[28] | No new non-native species. Invasive non-native species cover </= x% of total riparian area. The targets are species-specific. (Information Need) | The target for abundance is the level at which these species do not impinge on biological, recreational, and cultural resources. |
| | | | Distribution | | Information Need | Information Need | The target for distribution is no spreading of invasive non-native species to areas where they do not already occur. |

*Goal 6. Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 6.6 | Maintain | Spring and wetland | Habitat occupied by rare and endemic species | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | Information Need | Information Need | The target is to maintain the capability of these habitats to support the rare and endemic species known to live there. The targets should recognize the dynamic nature of these habitats as influenced by flow events. |
| 6.7 | Maintain | Southwest willow flycatcher | Riparian habitat | CRE below GCD, and above Lake Mead's water level as it fluctuates due to Hoover Dam operations | Information Need | Information Need | The target is the capability of the habitat to support the species. The target is a dynamic mosaic of NHWZ, OHWZ, and marsh vegetation. The definition of critical habitat will change as we learn more about the species' needs. |

*Goal 7. Establish water temperature, quality, and flow dynamics to achieve GCDAMP ecosystem goals.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 7.1 | Attain | Water | Temperature range | Mainstem | 6.93-18.56 °C[17] | Information Need | The target may include several stations in the mainstem. |
| | | | Seasonal variability of temperature | | Information Need | Information Need | |
| The target for MO 7.1 is a temperature range and pattern of seasonal variability based on the range of natural variability, the physical capacity of the dam, and the range that optimizes conditions for the targeted resources. Targeted resources may include foodbase, native fish, trout, and people (human health and safety – microorganisms and hypothermia).<br><br>Temperature patterns should have as their first priority the improvement of conditions for native biological resources, including native fish, and including foodbase and trout interactions. This is based on the special status of native fish. Linkages: MO 13; Principles 4, 6, and 7; and the Vision-Mission statement. | | | | | | | |
| 7.2 | Maintain | Water | Quality | Mainstem | Information Need (for the specific water quality parameters to use). | Information Need | Parameters may include nutrients, salinity, pH, DO, nitrogen, phosphorus, microbes, and others. Data available from NASQWAN.[35] |
| The target for MO 7.2 is water quality based on the range of natural variability, the physical capacity of the dam, the legally defined state water quality standards, and the range that optimizes conditions for the targeted resources. The targeted resources may include foodbase, native fish, trout, Southwestern willow flycatcher, riparian and spring communities, the recreational experience, and cultural resources. Linkages: Goals 1-3, 8-10, and 12. | | | | | | | |
| 7.3 | Maintain | Flow dynamics | Power plant operations | Mainstem | ROD operating criteria | Dam operating criteria then in effect | See MO 50 for experimental flows. |
| | | | BHBF flows | | Maximum 45,000 cfs (March to April) | Dam operating criteria then in effect | |
| | | | Habitat maintenance flows | | ROD operating criteria | Dam operating criteria then in effect | |

***Goal 8. Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve GCDAMP ecosystem goals.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| The target for Goal 8 is enough sediment to achieve the biological, recreational, and cultural goals. Given limited sediment inputs, we need to retain enough sediment in the system to achieve ecosystem patterns in these goals). For the biological goals, the purposes are habitat and nutrient storage. For the cultural goal, the purposes are enhancing plant habitat and preserving historical properties. For recreational goals, the purposes are camping beaches and trout spawning habitat. Linkages: Recreational, biological, and cultural goals: 1-4, 7-10, and 12. | | | | | | | |
| 8.1 | Maintain or attain | Sediment | Abundance | Main channel below 5,000 cfs | Information Need | Current volumes or higher (trend), including some timeframe based on tributary inputs and high flows timing (Information Need). | Metric is volume ($m^3$) as a rolling average. |
| | | | Grain-size | | Information Need | Current level or finer (trend), including some timeframe based on reach, tributary inputs and high flows timing (Information Need). | Metric is D50 (median) grain size. Also, see Kondolf.[16] |
| | | | Distribution | | Information Need Current level to be obtained from side scan sonar and video (Anima) and/or multi-beam. | Current level or more areally extensive (trend), including some timeframe based on tributary inputs and high flows timing (Information Need). | Metric is patchiness and area ($m^2$) of sand on channel bottom. |
| 8.2 | Maintain or attain | Sediment | Abundance | Channel margins (not eddies) from 5,000 to 25,000 cfs | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Metric is area ($m^2$) and volume ($m^3$) as a rolling average. |
| | | | Grain-size | | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Also, see Kondolf. |
| | | | Distribution | | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Metric is number of sandbars by reach. |

*Goal 8. Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve GCDAMP ecosystem goals.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 8.3 | Maintain or attain | Sediment | Abundance | Eddies below 5,000 cfs | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Metric is area ($m^2$) and volume ($m^3$) as a rolling average |
| | | | Grain-size | | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing | |
| | | | Distribution | | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Metric is # of sandbars by reach |
| 8.4 | Maintain or attain | Sediment | Abundance | Eddies between 5,000 and 25,000 cfs | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Metric is area ($m^2$) and volume ($m^3$) as a rolling average The target level should consider spawning habitat for trout in Glen Canyon and sediment needed for BHBFs. |
| | | | Grain-size | | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing | The target level should consider spawning habitat for trout in Glen Canyon and sediment needed for BHBFs. |
| | | | Distribution | | Information Need | Information Need, including some timeframe based on tributary inputs and high flows timing. | Metric is # of sandbars by reach The target level should consider spawning habitat for trout in Glen Canyon and sediment needed for BHBFs. |

***Goal 8. Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve GCDAMP ecosystem goals.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 8.5* | Maintain or attain | Sediment | Abundance | Shorelines above 25,000 cfs | Information Need | Information Need | Metric is area ($m^2$) and volume ($m^3$) as a rolling average |
| | | | Grain-size | | Information Need | Information Need | |
| | | | Distribution | | Information Need | Information Need | Metric is # sandbars by reach |

*This MO is intended to include all shorelines (eddies and channel margins) between 25,000 cfs and the highest level of potential dam effects on pre-dam sand bars (about 125,000 cfs or pre-dam alluvium (pda) terrace of Hereford et al. 1998). The highest level will be determined through discussions with sedimentological, cultural, recreational, and riparian workers on how best to constrain this boundary and in how many areas it should be monitored.

NOTE: Coarse sediment is important to the ecosystem, as is fine sediment. There is an MO on rapids navigability under the recreation goal that indirectly addresses debris flows, as well as an MO on trout spawning habitat under the trout goal.

Information Need: consult with various researchers to determine how best to break out sub-reaches from the three broader fine sediment reaches as described above. The riparian group suggested developing a table that has various resource concerns on the X-axis and various processes on the Y-axis. The recreation group suggested developing a table that has river miles (-15 to 278) on the X-axis and various resources on the Y-axis (those resource areas impacted by sedimentological processes).

*Goal 9. Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of GCDAMP ecosystem goals.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 9.1 | Maintain | Visitor | Physical access | Mainstem | Information Need. Obtain from current GLCA and GRCA management plans. Use 10-year average distributed by season of user-days, number of people, and distribution. | Information Need | The target level should be within the capacity of the CRE to absorb visitor impacts. The target level should consider GLCA and GRCA Management Plans |
| | | | Physical safety (other than whitewater boating) | | Information Need. Use average of NPS incident reports from Myers et al. for period 1988-92. [25] Include data and conclusions from other reports re: accident rates during interim and experimental flows and BHBF. Brown and Hahn (1987) did the baseline study in 1985-6 for GCES I, and collected data at medium and high flows. Jalbert and Mitchell (1992) collected data in 90-91 during the "experimental flows," primarily at low flows; and Jalbert (1997) again in 1996 during the BHBF. Also Underhill and Borkan (1987). | Metric is river-related deaths or injuries. The target is to minimize river-related injuries and deaths.<br><br>Information Need: To correlate flows, equipment type, and guide experience to NPS river incident reports related to wading anglers, river travel in the flatwater reaches above the Paria River and below Separation Canyon, and trails to and along the river, to determine flow-related risk. The stage of Lake Mead should be included in the correlation for the reach below Separation Canyon. | |
| 9.2 | Maintain or improve | Recreational opportunities | Quality and quantity | Glen Canyon | Information Need GLCA data: number and variety of recreational activities. | Information Need | NPS studies underway. The target level should be within the capacity of the CRE to absorb visitor impacts. The target level should consider GLCA and GRCA Management Plans.<br><br>Management action: a non-native fishing policy for concessions contracts needs to be developed. |
| | | | | Grand Canyon | Information Need. GRCA data: number and variety of recreational activities. | Information Need | |

***Goal 9. Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of GCDAMP ecosystem goals.***

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 9.3 | Increase | Camping beaches | Size | Mainstem | Information Need From Kaplinski et al. in prep. | 800 $m^2$ (Stewart et al. 2000) | The target level should be within the capacity of the CRE to absorb visitor impacts. The target level should consider GLCA and GRCA Management Plans. Metric for Quality includes parameters for vegetation, sanitation, and shade. Metric for Distribution is number of campsites required per identified reach. |
| | | | Quality | Mainstem | Information Need | Information Need Metric needs to be a "quality index." That includes parameters for open sand area, < 8 degrees slope, mooring, wind protection, ant colonies, degree of human impact (fire rings, trail erosion, litter, sanitation), vegetation encroachment, and shade. Also, need to assess and quantify the processes causing changes in beach quality and size (e.g., river flows, wind, tributary runoff, vegetation encroachment, human, other.) | |
| | | | Distribution | Critical reaches | Information Need | Minimum 21 ± 5 beaches per critical reach above maximum ROD flows (25,000 cfs) capable of accommodating 16-36 people. Also, consider NPS river travel model. | |
| | | | | Non-critical reaches | Information Need | Information Need: Suggest an average of one beach capable of accommodating 16-36 people every 2.0 river miles (Grand Canyon River Guides, personal comm.) | |

*Goal 9. Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem, within the framework of GCDAMP ecosystem goals.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 9.4 | Improve | Rapids | Navigability | Mainstem | Information Need | Information Need<br>See incident rates/flow level during the late 1980s and Interim Flow period. | The target level to be developed from NPS on-river accident rates. See Myers et al.[25] The target should address navigability across the range of flows allowed within the ROD. The metric is the number of accidents per rapid at each flow.<br><br>See also Brown and Hahn (1987), and Jalbert and Mitchell (1992). |
| | | | Whitewater boating safety | | Information Need | Metric is river-related deaths or injuries. The target is to minimize river-related injuries and deaths.<br><br>IN: To correlate flows, equipment type, and guide experience to NPS river incident reports, to determine flow-related risk. | |
| 9.5 | Maintain or enhance | Experience | Wilderness | CRE in Grand Canyon National Park | Information Need | Information Need<br><br>See GRCA data on use levels and distribution. | See Bishop, et al. (1986) for flow-related wilderness. The target level should consider GRCA and GLCA Management Plans (in progress). |
| | | | | CRE below GCD in Glen Canyon NRA | Information Need | Information Need<br><br>See GLCA data on use levels and distribution. | |

*Goal 10. Maintain power production capacity and energy generation, and increase where feasible and advisable, within the framework of GCDAMP ecosystem goals.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 10.1 | Maintain or increase | Power | Marketable capacity and energy | GCD | Current practices | Information Need | Constrained by the ROD |
| 10.2 | Maintain | Power | Existing emergency criteria for WAPA system | GCD | Current practices | Information Need | Constrained by the ROD |
| 10.3 | Maintain | Power | Existing emergency criteria for WSCC system | GCD | Current practices | Information Need | Constrained by the ROD |
| 10.4 | Maintain | Power | Regulation | GCD | Current practices | Information Need<br>Determine if the current regulation scheme, or additional regulation schemes, will cause problems for the ecosystem. | |

*Goal 11. Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present and future generations.*

| MO # | Perform some action | On some element | On some attribute | At some place | From the current level | To the target level | Comments |
|---|---|---|---|---|---|---|---|
| 11.1 | Preserve | Register-eligible properties | National Register integrity | Area of Potential Effect | Information Need (at least 264 properties) | 100% of Register-eligible properties | The target is to preserve register-eligible properties (e.g., TCPs and prehistoric and historic sites) via protection, management, and/or treatment (e.g., data recovery) for the purpose of federal agency compliance with NHPA, as well as AMP and AMWG compliance with GCPA. |
| 11.2 | Manage | Traditionally important resources | Resource integrity | CRE | Information Need (obtained through ethnographic studies, polls, interviews, surveys, and literature) | Information Need Long-term trend indicates stable or improving for each identified resource. | The target is to manage (based on current cultural values) other traditionally important resources that are not sufficiently addressed under other MOs. Specifically, this MO addresses resources not considered Register-eligible. |
| 11.3 | Protect and maintain | Traditional cultural resources | Physical access | CRE | Information Need. | Information Need | See USBR[34] The target is to provide meaningful tribal consultation on AMP activities that might restrict or block physical access by Native American traditional practitioners. See AIRFA and EO 13007. |

*Goal 12. Maintain a high quality monitoring, research, and adaptive management program.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12.1 | Maintain or attain | Socio-economic data | Hydropower | N/A | EIS | Information Need | The target level is adequate socioeconomic data for making recommendations to the Secretary. |
| | | | Air quality | N/A | EIS | Information Need | |
| | | | Wilderness | N/A | EIS | Information Need | |
| | | | Recreation | N/A | EIS and Stewart (1999) | Information Need | |
| | | | Non-use values | N/A | Non-use study accompanying the EIS. | Information Need | |
| | | | Tribal & spiritual values | N/A | EIS | Information Need | |
| 12.2 | Integrate and synthesize | Cultural and environmental data | Interdisciplinary information | CRE | Not readily available and not completely synthesized or integrated | Readily accessible by georeferencing using GIS, databases, etc. | The target is adequate cultural and environmental data for making recommendations to the Secretary. |
| 12.3 | Attain and maintain | Monitoring and research program | Natural, cultural, and recreational resources | CRE | GCMRC Strategic Plan 1998-2002 | Updated GCMRC Strategic Plan | The target is implementation of a GCMRC Strategic Plan that has been agreed to by the AMWG after review by the SAB, the PA signatories, and the TWG, and that will subsequently be reviewed on a periodic basis. |

*Goal 12. Maintain a high quality monitoring, research, and adaptive management program.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12.4 | Attain and maintain | AMP composed of all stakeholders | That acknowledges uncertainty and uses experimentation, monitoring & research | N/A | An ongoing AMP program with a Strategic Plan in development | Updated AMP Strategic Plan | The target is implementation of an AMP Strategic Plan that describes the processes for science-based collaborative resources management. |
| | | | Participation | | <u>For calendar year 2000:</u><br>Average TWG attendance = 92 %<br>Average AMWG attendance = 95 %<br>Participation on TWG and AMWG ad hoc groups = 35 %<br>This last number was the number of TWG or AMWG members who volunteered to be on ad hoc groups divided by the total number of TWG and AMWG members. | 100% attendance by all representatives at AMWG and TWG meetings plus active participation in Ad Hoc Committees. | The target is to have all AMWG and TWG members actively involved with AMP deliberations and activities, and their input recognized and valued. |

*Goal 12. Maintain a high quality monitoring, research, and adaptive management program.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12.5 | Attain and maintain | AMP | Effective tribal consultation (i.e., inclusion of tribal values and perspectives into the AMP) | CRE | Current participation at TWG, AMWG, and PA meetings | Effective dialogue between tribes and AMWG members on all AMP actions | See USBR[32] The target is to achieve, at a minimum, effective, legally mandated government-to-government consultation. To achieve this MO it is important to provide adequate funding, but funding alone is not a sufficient indicator of successful achievement. |
| 12.6 | Attain and maintain | Management activities, research, and long-term monitoring activities | Tribal participation | AMP | Information Need | Information need | The target is a set of activities that provides meaningful tribal participation and meets each tribe's interests to ensure that tribal values are incorporated in the scientific activities of the adaptive management program, and that tribal interpretations of monitoring and research data are considered.<br><br>Linkage: Vision/Mission statement, particularly the mention of federal trust responsibilities. |

*Goal 12. Maintain a high quality monitoring, research, and adaptive management program.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12.7 | Conduct | Experimental flows | Flow dynamics | Mainstem | 1996 BHBF<br>1997 HMF<br>2000 LSSF test | Information Need<br>To be proposed by the Experimental Flows Ad Hoc Group. | See GCMRC,[6] Webb et al.[37] and Topping et al.[31] The target level is the experiments needed to gain critical understanding of ecosystem function under different dam operations, e.g., BHBFs, HMFs, biological opinion flows, and financial exception criteria flows. |
| 12.8 | Conduct | Management experiments | Other management actions | CRE | Check dams<br>Translocation of KAS<br>Fishing regulations | Information Need<br>At a minimum, one management action to address native v. non-native fish interaction and one to address vegetation encroachment on beaches in the next five years. | The target level is the experiments needed to gain critical understanding of ecosystem function under different management alternatives outside of dam operations. |
| 12.9 | Build | AMP | Public support | N/A | Information Need | Information Need<br>A public outreach plan adopted by the AMWG.<br><br>Propose to have BOR, NPS, and USGS public affairs people develop the plan. | Metric should include GCMRC and BOR web pages; GCD programs and tours; AMWG Outreach Committee; publications; various AMWG member activities. The purpose is adequate public support for AMP experiments and adaptive management, and a diverse funding base. |

*Goal 12. Maintain a high quality monitoring, research, and adaptive management program.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12.10 | Maintain or attain | Funding | Foundation and Corporate | N/A | $0 | Information Need | The target is adequate funding to meet the goal<br><br>Develop a plan identifying sources for obtaining foundation and corporate funding. |
| | | | Appropriated | | $75,000 (FY 2000) | $1,010,000 USGS<br>$475,000 Tribal participation | |
| | | | State Agency | | Information Need (obtain from AGFD) | Information Need | |
| | | | Power revenues | | $6.22M (for GCMRC)<br>$1.443M (for BOR) | $7,850,000 indexed for CPI | |
| 12.11 | Maintain or attain | Participation | Externally-funded investigators | CRE | Information Need (obtain from NPS) | Information Need<br><br>MAs:<br>1. Develop a brochure that indicates support that would be provided by GCMRC and NPS to researchers who bring their own funding to address issues related to AMP MOs and INs.<br><br>2. Get outside researchers engaged and obtain their data. | Current and target levels should include small and cost-shared projects in NPS, AGFD, etc.<br><br>The target is contributions to meeting Information Needs by externally funded investigators<br><br>NOTE: Incentives could include donated office space, partial funding, letters of support, facilitated access, and logistical support. |

### INFORMATION NEEDS

To be completed.

### MANAGEMENT ACTIONS

To be completed.

# 3 PROGRAMMATIC AND GEOGRAPHIC SCOPE

The programmatic scope of the Adaptive Management Program is to provide advice and recommendations to the Secretary of the Interior on whether the environmental commitments and constraints of the Record of Decision are being met, and to ensure that the intent of the Record of Decision and Grand Canyon Protection Act are being met. If not, the Adaptive Management Program recommends changes in dam operations and implementation of other management actions.

With respect to dam operations, the Guidance Document for the Adaptive Management Program states:

> Long-term monitoring and research, including test flows within the current range of authorized operations, are intended to enable finer and finer tuning of operations over time, as additional knowledge and experience are gained, to better achieve the target mix of resource benefits, as outlined in the Glen Canyon Dam Environmental Impact Statement, pages 54-65. [Loveless 2000]

However, the Grand Canyon Protection Act authorizes other management actions to accomplish its intent of protecting the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. Examples could include water temperature modification, stabilization of historic properties, non-native fish control, and removal of exotic vegetation.

The programmatic scope of the Adaptive Management Program is limited by the range of dam operations and other management actions available to achieve a desired resource effect. This is complicated by the fact that the dam and immediate downstream areas are located at approximately the mid-point between the origin of the Colorado River in the Rocky Mountains and its terminus in the Gulf of California. Many activities, facilities, and conditions on the river occur both upstream and downstream of the geographic area covered by the Adaptive Management Program. The Adaptive Management Program has

little or no control over these other areas.

In addition, the Adaptive Management Work Group may coordinate with other organizations and programs and offer recommendations to the Secretary of the Interior regarding actions that may be undertaken by other agencies. As stated in the Adaptive Management Work Group Charter (Appendix C), activities outside the scope of the Adaptive Management Program will be funded separately and do not deter from the focus of the Grand Canyon Protection Act.

The geographic scope of the Adaptive Management Program is longitudinally from the forebay of Glen Canyon Dam downstream to the western boundary of Grand Canyon National Park at Grand Wash Cliffs on Lake Mead. The lateral scope is an issue of ongoing research and investigation to determine where the effects of dam operations are located along the floodplain. The lateral area and its definition relate primarily to compliance with Section 106 of the National Historic Preservation Act. Additional concerns on the geographic scope of the Adaptive Management Program are the effects of tributaries on the mainstream Colorado River and the potential effects of the operation of the powerplant, bypass tubes, and spillways of Glen Canyon Dam.

The Adaptive Management Program may do research outside the geographic scope defined above to obtain needed information. Such linkages with other areas "should be made on a case-by-case basis, considering ecosystem processes, management alternatives, funding sources, and stakeholder interests." (National Research Council 1999:43; Loveless 2000)

## INSTITUTIONAL SCOPE — WHAT THE PROGRAM INFLUENCES OR IS INFLUENCED BY

### Annual Operating Plan Process

The Annual Operating Plan process enables Reclamation to plan and project future Colorado River system reservoir contents and downstream releases for the upcoming water year. The planning process allows the Secretary of the Interior to determine and meet Colorado River Basin water delivery obligations. This process is conducted with input from the Colorado River Management Work Group and other members of the public in accordance with the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, and Sections 1802(b) and 1804(c) of the Grand Canyon Protection Act.

Individual reservoir operations in the Colorado River reservoir system are based on appropriate consideration of uses of the reservoirs for all purposes, as required by the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs. Because hydrologic conditions will vary from any assumptions utilized in the Annual Operating Plan process, projected reservoir operations and dam releases are subject to monthly

revision during the year to accommodate changing hydrologic conditions. However, releases must be governed in accordance with the Law of the River.

As a part of this Annual Operating Plan process, the decision on releases to the Lower Division states must be made in accordance with a "surplus," "normal," or "shortage" determination. Releases must also meet treaty delivery obligations to Mexico.

The Grand Canyon Protection Act requires criteria, operating plans, and reports "separate from and in addition to" those mandated by the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, noting that the Grand Canyon Protection Act is implemented fully consistent with and subject to the water allocation and development provisions of previous compacts and statutes contained in the Law of the River. As noted in the Grand Canyon Protection Act report language, these criteria primarily affect the Glen Canyon Dam powerplant operations and do not affect any delivery obligations to the Lower Basin or Mexico.

**Tribal Interests Within the Colorado River Ecosystem**

The Navajo Nation, Hualapai Tribe, and Havasupai Tribe have reservation lands and resources that may be affected by Adaptive Management Program activities, projects, or proposals. As discussed under the Tribal Consultation section of this plan, government-to-government consultation with these tribes must take place. In some cases, special tribal permits or permissions must be obtained for activities of the Adaptive Management Program to remain in compliance with tribal resolutions, policies, or executive orders. Other tribes, including the Hopi Tribe, the Pueblo of Zuni, and various bands among the Southern Paiute Consortium, have interests and concerns with resources or places that may be affected by the operation of Glen Canyon Dam or with the management actions or recommendations of the Adaptive Management Program.

**National Park Service Management Policies and Activities**

As manager of Grand Canyon National Park and Glen Canyon National Recreation Area, the National Park Service is the steward of the downstream natural and cultural resources affected by Glen Canyon Dam operations. The National Park Service's authority for resource management activities derives from a variety of laws, including the National Park Service Organic Act of 1916, the General Authorities Act of 1970, and the 1978 amendments to this Act (the Redwoods Amendment). Although the Organic Act and the Redwoods Amendment use different language, they define a single standard for the management of the national park system. The basic principles governing management of all units of the National Park Service's system are first to conserve park resources and values and second to provide for the enjoyment of park resources and values by the people of the United States.

The National Park Service has three levels of guidance documents: (1) National Park Service Management Policies (National Park Service 2001) that is the basic policy

document of the National Park Service, (2) interim updates or amendments accomplished through Director's Orders, and (3) detailed and comprehensive handbooks or reference manuals issued by associate directors. These documents provide National Park Service field employees with guidance to carry out Management Policies and Director's Orders.

The primary responsibility of National Park Service managers is to preserve park resources and values without impairment. Impairment is defined as a loss or harm to the integrity of park resources or values. The National Park Service cannot conduct or allow activities in parks that would impair park resources and values unless provided for by legislation or by the proclamation establishing the park. In cases of doubt as to the impact of activities on park resources, the National Park Service will decide in favor of protecting the resources.

Whether an impact constitutes impairment depends on the specific resources or values affected; the severity, duration, and timing of the influence; the direct and indirect effects of the influence; and the values and purposes for which a particular park unit was established. However, the laws do give the National Park Service the management discretion to allow impacts to park resources and values when necessary and appropriate to fulfill the purposes of a park, so long as the impact does not constitute impairment.

The National Park Service has established a tiered planning process with General Management Plans as the highest tier. The General Management Plans for Grand Canyon National Park and Glen Canyon National Recreation Area reflect the service-wide guidance that applies to all National Park Service areas, as well as the specific authorizing legislation that established these areas. They focus on what management should be achieved and maintained over time to provide a foundation from which to protect park resources while providing for meaningful visitor experiences. For example, the Glen Canyon National Recreation Area Proposed General Management Plan (National Park Service 1979) explains that the Glen Canyon National Recreation Area is "... to provide for public outdoor recreation use and enjoyment ... and to preserve scenic, scientific, and historic features contributing to public enjoyment of the area."

The next tier of park planning is implementation plans. These deal with complex, technical, and sometimes controversial issues with a level of detail and analysis beyond that appropriate at the General Management Plan or strategic plan level. The Grand Canyon National Park General Management Plan (National Park Service 1995) builds upon several implementation plans relevant to the Adaptive Management Program, including the 1988 Backcountry Management Plan, 1989 Colorado River Management Plan, and 1994 Resource Management Plan. Other relevant implementation plans subsequent to the Grand Canyon National Park General Management Plan include the 1997 Resource Management Plan and the 1998 Draft Wilderness Management Plan.

**Operation of the Colorado River Storage Project Power System**

The Glen Canyon Dam powerplant is tied to a vast system of generators, transmission

lines, and delivery points in the western United States, Canada, and Mexico. It is legally obligated to provide electricity to wholesale electrical customers and others in the West. The Bureau of Reclamation operates Glen Canyon Dam in close coordination with the Western Area Power Administration. The Western Area Power Administration markets the electrical power produced by the Colorado River Storage Project dams and owns and operates the federal transmission system that delivers the electricity.

*Long-Term Firm Electrical Power*

Under the authorizing legislation for the Colorado River Storage Project, federal dam operators are required to produce "the greatest practicable" amount of long-term firm power at Glen Canyon Dam, integrating the operation of Glen Canyon Dam with the other Colorado River Storage Project powerplants and other federally-owned electrical powerplants.

The Western Area Power Administration's long-term contracts for electricity are with small municipalities, other political subdivisions, rural electrical cooperatives, federal defense facilities and other federal and state institutions, and Indian tribes. This power is sold strictly in the Colorado River Storage Project market area that includes Colorado, Wyoming, Utah, Arizona, New Mexico, and Nevada. Revenues from these sales are placed into the Basin Fund, a fund that repays the United States Treasury the capital costs of the Colorado River Storage Project mainstem dams and the irrigation assistance portion of the Upper Basin participating projects. Revenues from the sale of power also fund much of the cost of the Adaptive Management Program.

Long-term firm electrical power has been sold according to a marketing plan established by the Western Area Power Administration. The contracts for electricity made possible under this plan end in 2024. The Western Area Power Administration is obligated to deliver electricity in the amounts specified in these contracts. This can be supplied by the Colorado River Storage Project generators or the Western Area Power Administration may purchase some of this power from other generators. The contract amount can be adjusted every five years to take into account changing circumstances or resources.

*Operation for a Federal Load Control Area*

The Western Area Power Administration operates two load control areas that are electrically tied to Glen Canyon Dam. A load control area is a geographical area assigned to a controller to monitor electrical demand and generation and make sure that they "match" on a moment-by-moment basis. This is referred to as "regulating." Currently, Glen Canyon Dam generation can change by up to 1,000 cubic feet per second to adjust to these "swings" in demand. The contribution by Glen Canyon Dam to these two load control areas is evenly divided. The Western Area Power Administration's Operation Center in Phoenix, Arizona, sends a "regulation" signal every few seconds directly to Glen Canyon Dam.

*Reserve Sharing Groups*

Reserves are required by electrical production and distribution companies to serve as a "back-up" in case of unforeseen electrical system problems. The existence of reserves minimizes the possibility of interruption of electrical service. The Western Area Power Administration has contractual agreements with two reserve sharing groups. Reserve sharing groups are formed to share the "damage" caused by generator and transmission outages, transmission overloads and other emergencies, or unplanned events.

For the two reserve sharing groups, the Western Area Power Administration is obligated to provide up to 70 megawatts of power from one or more of the Colorado River Storage Project powerplants. Typically, Glen Canyon Dam has provided the bulk of this service.

*Emergency Service*

The Western Area Power Administration calls upon Glen Canyon Dam and other Colorado River Storage Project dams to respond to a variety of electrical system emergencies. These emergencies and the responses to them by the Western Area Power Administration and Bureau of Reclamation are a requirement of all participating members of the Western Systems Coordinating Council. These are described in the Glen Canyon Dam Environmental Impact Statement and are authorized in the Record of Decision. Further details on the emergency exception criteria are contained in the Operating Agreement Associated with Glen Canyon Dam Operating Criteria between the Bureau of Reclamation and the Western Area Power Administration dated July 7, 1997. Generally, these emergencies are related to transmission line and generation outages. During these emergencies, the operating limitations on Glen Canyon Dam contained in the Record of Decision may be exceeded.

## PROTOCOLS AND PROCEDURES — HOW THE ADAPTIVE MANAGEMENT PROGRAM WORKS

### Charter

The Charter of the Adaptive Management Program (Appendix C) was recently renewed as a formal Federal Advisory Committee Act committee for an additional two years.

### Operating Procedures of the Adaptive Management Work Group and Technical Work Group

Current operating procedures of the Adaptive Management Work Group and Technical Work Group are in Appendices D and E, respectively. These procedures have been formally recommended by these two groups and agree with the Adaptive Management Work Group Charter (Appendix C). The procedures serve to give formal structure to Glen Canyon Dam Adaptive Management Work Group and Technical Work Group

meetings.

**Science Within the Glen Canyon Dam Adaptive Management Program**

The goal of scientific inquiry within the Adaptive Management Program is to discover facts about the Colorado River ecosystem using a rigorous program of monitoring, research, and adaptive management. While significant knowledge of the ecosystem has been gained since the Glen Canyon Environmental Studies, the ecosystem is extraordinarily complex. Much is still unknown.

Long-term monitoring is critical to understanding the status and trends of important resources, as well as the effects of the Secretary of the Interior's actions in operating the dam on those resources of special concern, such as endangered species or resources of tribal interest. Long-term monitoring also informs on the success or failure of management actions and produces data for long-term research hypotheses about the functioning of the Colorado River ecosystem. A stable monitoring program allows repetitive measurements on a consistent time scale, which allows short- and long-term comparison with previous measurements. Methods range from traditional field sampling techniques to multispectral remote sensing designed to identify stability or trends in key resources or indicator species. Research and monitoring attempt to enlarge our understanding of ecosystem functions, processes, and patterns.

Understanding of ecological patterns and processes has changed substantially as a result of these monitoring and research activities. The resulting answers to questions and hypotheses thus add to the knowledge base available to the Adaptive Management Work Group as it makes recommendations to the Secretary of the Interior.

**Management Within the Glen Canyon Dam Adaptive Management Program**

The Adaptive Management Program does not derogate any agency or tribal authority or responsibility for management or stewardship of resources. Instead, the Adaptive Management Program makes formal recommendations through the Adaptive Management Work Group to the Secretary of the Interior regarding dam operations and other management actions needed to comply with the Grand Canyon Protection Act. These recommendations are made by consensus where possible, but as stated in the Adaptive Management Work Group Charter (Appendix C): "...in the event that consensus is not possible, a vote should be taken." Whether achieved through consensus or by majority vote, recommendations are transmitted to the Secretary of the Interior through the Secretary of the Interior's Designee.

The Secretary of the Interior, as the final decision maker, responds to these recommendations either directly or through actions of the agencies with delegated authority. In the latter case, implementation of these recommendations by a federal agency often depends on internal discussions between the management agency and the Secretary of the Interior.

## How Science and Management are Integrated into the Adaptive Management Program

The Grand Canyon Monitoring and Research Center provides scientific data and syntheses to the Adaptive Management Program. In general, the Grand Canyon Monitoring and Research Center provides scientific data and syntheses to the Technical Work Group, which then uses this information to create management recommendations for consideration by the Adaptive Management Work Group. The Grand Canyon Monitoring and Research Center may also bring scientific information directly to the Adaptive Management Work Group. Any of the organizational components within the Adaptive Management Program may call upon the independent review panels for advice (Fig. 1).

After approval by the Adaptive Management Work Group, the Secretary of the Interior's Designee forwards recommendations to the Secretary of the Interior. Secretarial decisions are communicated back to the members of the Adaptive Management Program.

## How Management of One Resource Affects Other Resources

The Adaptive Management Program recognizes that the Colorado River below Glen Canyon Dam is part of a large and complex ecosystem. Management actions proposed to benefit one resource might adversely impact another due to the interrelationships within the system. For example, a river flow designed to benefit a threatened or endangered native fish might result in reduced recreational opportunities or limits on the access of Native Americans to a sacred sites.

When the benefit to one resource is proposed as part of a legal compliance responsibility, it is particularly important to maintain an ecosystem perspective. One example comes from the planning of the experimental Beach/Habitat-Building Flow in 1996. This experimental flow was designed to test the hypothesis that Colorado River flows greater than powerplant capacity would mobilize sediment stored in the river channel and deposit it on the river banks. However, while designing and scheduling the experimental flow for sediment conservation, the effects of the higher flow on the aquatic food base, Kanab ambersnail, Southwestern willow flycatcher, and tamarisk had to be considered. Similarly, tribes needed to be consulted on impacts to resources of tribal concern or access to sacred sites. Impacts to recreational users and power generation also had to be factored into the experiment.

## Tribal Consultation and Coordination Within the Adaptive Management Program

Federally-recognized Indian tribes are domestic dependent nations, and the legal relationship between the federal government and tribes is one set forth in the United States Constitution, treaties, statutes, executive orders, and court decisions. Indian tribes have a guaranteed right to self-govern and to exercise inherent sovereign powers over

their members and reservations. The federal government works with Indian tribes on a government-to-government basis to address issues concerning Indian tribal self-governance, trust resources, and Indian tribal treaty and other rights. Tribal trust resources include land and natural resources either on or off Indian reservations, and other assets retained by or reserved by or for Indian tribes, held by the federal government in trust and protected by a fiduciary obligation on the part of the United States.

To ensure meaningful consultation and collaboration with Indian tribal governments, various executive orders, secretarial orders, and memoranda have been issued over the last eight years. Some of these include Executive Order 13084, Executive Order 13007, Secretarial Order 3175, Secretarial Order 3206, and *Federal Register* 94-10877.

To ensure fulfillment of the federal Indian trust responsibility, the Department of the Interior has established policies and procedures for government-to-government consultation with federally-recognized Indian tribes and tribal members for the identification, conservation, and protection of American Indian trust resources, trust assets, or tribal health and safety. Indian trust assets are values derived from land resources including surface water and groundwater, natural vegetation and wildlife, and air quality. Any potential impacts from federal actions or activities to tribal trust assets must be properly addressed between the affected tribe and the appropriate federal agency prior to any disturbance to such resources.

**Trust Responsibilities and the Adaptive Management Program**

Within the Adaptive Management Program, the federal government's trust responsibility to the interested Native American tribes (Havasupai, Hopi, Hualapai, Kaibab Band of Paiute Indians, Navajo Nation, San Juan Southern Paiute Tribe, Paiute Indian Tribe of Utah, and the Pueblo of Zuni) is realized through various levels of consultation. Section 1805(c)(3) of the Grand Canyon Protection Act requires the Secretary of the Interior to consult with Indian tribes regarding the implementation of the long-term monitoring program and activities to ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802 of the Grand Canyon Protection Act.

Tribal participation and representation at the Adaptive Management Work Group and Technical Work Group levels is considered one aspect of the Secretary of the Interior's consultative requirement under the Grand Canyon Protection Act. However, given the nature and management of Native American traditional knowledge and concerns, it may be necessary for the Grand Canyon Monitoring and Research Center, Bureau of Reclamation, National Park Service, and any other federal agency involved in long-term monitoring, research, or other associated activities, to engage in more specific consultation with each of the identified Native American tribes. This is especially true for those tribes (Havasupai and San Juan Southern Paiute) that are not actively engaged in the Adaptive Management Program. This more specific form of consultation may require the Grand Canyon Monitoring and Research Center, Bureau of Reclamation, and

National Park Service to engage in a face-to-face consultation with each tribe, their tribal representatives, and identified traditional leaders regarding monitoring and research activities, proposed management actions, and any other related Adaptive Management Program activities.

The result of this consultation effort is to fully and meaningfully engage the appropriate tribes in the decision-making process regarding activities that may affect resources of tribal concern.

## HOW COMPLIANCE IS INTEGRATED INTO THE ADAPTIVE MANAGEMENT PROGRAM

Compliance with the Endangered Species Act, National Environmental Policy Act, and National Historic Preservation Act, has particular impact on the Adaptive Management Program and is described below:

### Endangered Species Act

The Adaptive Management Program is highly focused on compliance with Section 7(a)(2) of the Endangered Species Act of 1973, as amended, and its implementing regulations (50 Code of Federal Regulations [CFR] 402). This section addresses consultation between the action agency (usually the Bureau of Reclamation) and the U.S. Fish and Wildlife Service on the effects of a proposed action on federally-listed species. This section requires that any action a federal agency authorizes, funds, or carries out must not jeopardize the continued existence of any listed species or adversely modify designated critical habitat (see Appendix F). The process utilized by the federal agencies in the Adaptive Management Program for Endangered Species Act consultation is illustrated in Figs. 2, 3, and 4.

Biological opinions contain the U.S. Fish and Wildlife Service's recommendations to the action agency. Consultation is concluded when the action agency responds to the U.S. Fish and Wildlife Service by accepting the biological opinion as written, or describing if and how they will implement the biological opinion. Once this commitment has been made, the action agency is responsible for implementation.

The Endangered Species Act primarily affects the Adaptive Management Program through: (1) the requirement to consult with the U.S. Fish and Wildlife Service on any discretionary action which may affect listed species or adversely modify designated critical habitat prior to taking the action; and (2) through commitments an action agency makes to conserve species in response to Reasonable and Prudent Alternatives in biological opinions. The Regional Director of the Bureau of Reclamation sent a memorandum to the Regional Director of the U.S. Fish and Wildlife Service identifying the elements of the Reasonable and Prudent Alternative for the operation of Glen Canyon Dam that will be implemented (Calhoun 1995). These elements include:

- Formulation of an Adaptive Management Program.
- Experimental flows to benefit endangered fish.
- Determine the feasibility and expected results of installing and operating a selective withdrawal structure (temperature control device) on Glen Canyon Dam.
- Studies of the response of native fish to various temperature regimes and river flows.
- Coordinate preparation of a Little Colorado River management plan.
- Conduct a Razorback sucker workshop.
- Establish a second spawning aggregation of humpback chub in the mainstem or tributaries.
- Evaluate the over-winter survival of young-of-year humpback chub.
- Study Kanab ambersnail life cycle and distribution.

The Superintendent of Grand Canyon National Park sent a memorandum to the Regional Director of the U.S. Fish and Wildlife Service identifying additional elements they would implement (Arnberger 1998). These elements include:

- Conduct translocation of Kanab ambersnails subject to flows below 45,000 cubic feet per second from Glen Canyon Dam.
- Complete monitoring of the status of the translocated population.
- Evaluate, and where appropriate, utilize augmentation opportunities.

**National Environmental Policy Act**

The Adaptive Management Program was established in response to an environmental commitment made in compliance with the National Environmental Policy Act. The Act has five basic mandates that the Adaptive Management Program must continue to follow:

- Supplemental mandate: adds to the existing authority and responsibility of every federal agency to protect the environment when carrying out the agency mission.
- Affirmative mandate: agencies must make decisions that restore and enhance the environment.
- Substantive mandate: agencies must recognize that each person should have a healthful environment and must contribute to the protection of that environment for present and future generations.
- Procedural mandate: agencies must use their planning and decision-making process to give appropriate consideration to environmental value and amenities.
- Balancing mandate: agencies, to the fullest extent possible and consist with other essential policy considerations, must make decisions to achieve productive harmony between people and nature.

As long as the Adaptive Management Program meets the commitments made in the Record of Decision, no additional National Environmental Policy Act compliance is needed. However, if the Adaptive Management Program makes a recommendation to the Secretary of the Interior that deviates from the Record of Decision (Reclamation 1996), then the National Environmental Policy Act requires further compliance.

### National Historic Preservation Act

The Glen Canyon Dam Environmental Impact Statement included the Programmatic Agreement for Cultural Resources that represents alternate procedures by which the Bureau of Reclamation will achieve compliance with Section 106 of the National Historic Preservation Act for the continued operation of Glen Canyon Dam. The Programmatic Agreement is a legally binding document among the Advisory Council on Historic Preservation, Arizona State Historic Preservation Officer, National Park Service, Bureau of Reclamation, Hopi Tribe, Hualapai Tribe, Paiute Indian Tribe of Utah, Kaibab Band of Paiute Indians, Pueblo of Zuni, and Navajo Nation. With proposed amendments to the Programmatic Agreement, the Western Area Power Administration and possibly the Havasupai Tribe and San Juan Southern Paiute Tribe may become signatories.

The Programmatic Agreement is a process whereby all the signatories agree to specific actions relative to management of National Register eligible historic properties affected by Glen Canyon Dam. The Programmatic Agreement has stipulations which include: (1) identification and evaluation of all historic properties within the area of potential effects of dam operations; (2) development of a plan for monitoring the effects of Glen Canyon Dam operations on historic properties and for carrying out remedial actions to address the effects of ongoing damage to historic properties; and (3) preparation of an historic preservation plan.

In the Adaptive Management Program, Programmatic Agreement signatories and Grand Canyon Monitoring and Research Center staff and associated scientists provide input to Adaptive Management Work Group and Technical Work Group members on cultural resource issues. The Technical Work Group and Adaptive Management Work Group are considered interested parties to the Section 106 compliance process. Since the Programmatic Agreement is a component of the Adaptive Management Program, the Technical Work Group and Adaptive Management Work Group have input to the Programmatic Agreement program through their review and recommendations to the Secretary of the Interior. As the lead agency, the Bureau of Reclamation has primary responsibility for ensuring that the stipulations of the Programmatic Agreement are implemented.

## ANNUAL ADAPTIVE MANAGEMENT PROGRAM CYCLE

### Budget Development Process

Note: to be provided by the Budget Ad Hoc Group, including timeline for developing the Adaptive Management Program budgets.

### Annual Report to Congress

As authorized by the Grand Canyon Protection Act, each year the Adaptive Management

Program prepares a report to be transmitted to Congress. The report includes actions taken to meet the mandates of the Grand Canyon Protection Act, dam operations, and other management actions.

The report also serves to provide an update on the status of the resources addressed by the Grand Canyon Protection Act. The annual State of the Colorado River Ecosystem report prepared by the Grand Canyon Monitoring and Research Center provides valuable input to the Annual Report to Congress.

**State of the Colorado River Ecosystem Report**

Communication between scientists and managers is vital in the Adaptive Management Program. The State of the Colorado River Ecosystem report serves the critical purpose of assessing the condition of the ecosystem, including a comprehensive reporting of status and trends among Colorado River ecosystem resources. Through the use of qualitative and quantitative targets, it also provides a mechanism for determining if the management objectives are being met.

Results of annual monitoring and research activities should be made available to the Technical Work Group and Adaptive Management Work Group by April of each year. Results of the science program, both data and synthesis reports, are available at the Grand Canyon Monitoring and Research Center. The Grand Canyon Monitoring and Research Center provides many of the reports on the Internet. Copies are also provided to the National Archives in compliance with the Federal Records Act.

**Annual Science Plan**

Each year the Grand Canyon Monitoring and Research Center prepares a detailed science plan describing the monitoring and research activities proposed for the upcoming year. The plan is discussed with the Technical Work Group and the Technical Work Group budget ad hoc group in an effort to identify both important monitoring and research questions and relative priorities among the scientific activities. The Grand Canyon Monitoring and Research Center also consults with the Programmatic Agreement signatories to determine if there are any potential effects from the proposed monitoring or research activities delineated in the annual science plan. Final recommendation to the Secretary of the Interior rests with the Adaptive Management Work Group.

The annual science plan is critical to the evaluation of the effectiveness of actions taken to protect downstream resources. The plan must have a stable and long-term monitoring component to address long-term trends. It must also have a research component to address new questions that arise through scientific investigations. Finally, it must have the statistical rigor required to substantiate its conclusions. The annual work plan will include a report on the prior year's activities.

**Request for Proposal Process**

The Grand Canyon Monitoring and Research Center utilizes a competitive proposal solicitation process open to government employees, public sector contractors, and universities through an open Request for Proposals process. All Adaptive Management Program monitoring and research projects are selected on the basis of their support of scientific capability and merit, submission timeliness on previous work (as evaluated through an independent, objective, and unbiased peer review process), management objectives and information needs, demonstrated capabilities of proposers, and cost effectiveness. Following the selection of proposals, appropriate procurement mechanisms (i.e., grants, contracts, and cooperative agreements) are utilized for supporting selected projects.

The Grand Canyon Monitoring and Research Center is committed to the use of peer review and has peer review guidelines that describe the processes it follows in reviewing all Grand Canyon Monitoring and Research Center proposals, programs, publications, and other products or deliverables. The guidelines will convey the unambiguous standard of scientific objectivity and credibility followed by the Adaptive Management Program.

In general, following approval by the Adaptive Management Work Group of the long-term monitoring and research strategic plan, an annual monitoring and research program will be completed and approved each year in April. After approval of the annual monitoring and research plan, Request for Proposals will be issued. Proposals will be screened by the program managers for their responsiveness to the Request for Proposals, and all qualified proposals will undergo an independent and objective scientific peer review. Awards will be made based on the results of peer review, the program manager's evaluation of project relevance, and technical contracting requirements.

### INFORMATION NEEDS

To be completed.

### MANAGEMENT ACTIONS

To be completed.

# 3 PROGRAMMATIC AND GEOGRAPHIC SCOPE

The programmatic scope of the Adaptive Management Program is to provide advice and recommendations to the Secretary of the Interior on whether the environmental commitments and constraints of the Record of Decision are being met, and to ensure that the intent of the Record of Decision and Grand Canyon Protection Act are being met. If not, the Adaptive Management Program recommends changes in dam operations and implementation of other management actions.

With respect to dam operations, the Guidance Document for the Adaptive Management Program states:

> Long-term monitoring and research, including test flows within the current range of authorized operations, are intended to enable finer and finer tuning of operations over time, as additional knowledge and experience are gained, to better achieve the target mix of resource benefits, as outlined in the Glen Canyon Dam Environmental Impact Statement, pages 54-65. [Loveless 2000]

However, the Grand Canyon Protection Act authorizes other management actions to accomplish its intent of protecting the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. Examples could include water temperature modification, stabilization of historic properties, non-native fish control, and removal of exotic vegetation.

The programmatic scope of the Adaptive Management Program is limited by the range of dam operations and other management actions available to achieve a desired resource effect. This is complicated by the fact that the dam and immediate downstream areas are located at approximately the mid-point between the origin of the Colorado River in the Rocky Mountains and its terminus in the Gulf of California. Many activities, facilities, and conditions on the river occur both upstream and downstream of the geographic area covered by the Adaptive Management Program. The Adaptive Management Program has

little or no control over these other areas.

In addition, the Adaptive Management Work Group may coordinate with other organizations and programs and offer recommendations to the Secretary of the Interior regarding actions that may be undertaken by other agencies. As stated in the Adaptive Management Work Group Charter (Appendix C), activities outside the scope of the Adaptive Management Program will be funded separately and do not deter from the focus of the Grand Canyon Protection Act.

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The National Park Service has three levels of guidance documents: (1) National Park Service Management Policies (National Park Service 2001) that is the basic policy

document of the National Park Service, (2) interim updates or amendments accomplished through Director's Orders, and (3) detailed and comprehensive handbooks or reference manuals issued by associate directors. These documents provide National Park Service field employees with guidance to carry out Management Policies and Director's Orders.

The primary responsibility of National Park Service managers is to preserve park resources and values without impairment. Impairment is defined as a loss or harm to the integrity of park resources or values. The National Park Service cannot conduct or allow activities in parks that would impair park resources and values unless provided for by legislation or by the proclamation establishing the park. In cases of doubt as to the impact of activities on park resources, the National Park Service will decide in favor of protecting the resources.

Whether an impact constitutes impairment depends on the specific resources or values affected; the severity, duration, and timing of the influence; the direct and indirect effects of the influence; and the values and purposes for which a particular park unit was established. However, the laws do give the National Park Service the management discretion to allow impacts to park resources and values when necessary and appropriate to fulfill the purposes of a park, so long as the impact does not constitute impairment.

The National Park Service has established a tiered planning process with General Management Plans as the highest tier. The General Management Plans for Grand Canyon National Park and Glen Canyon National Recreation Area reflect the service-wide guidance that applies to all National Park Service areas, as well as the specific authorizing legislation that established these areas. They focus on what management should be achieved and maintained over time to provide a foundation from which to protect park resources while providing for meaningful visitor experiences. For example, the Glen Canyon National Recreation Area Proposed General Management Plan (National Park Service 1979) explains that the Glen Canyon National Recreation Area is "... to provide for public outdoor recreation use and enjoyment ... and to preserve scenic, scientific, and historic features contributing to public enjoyment of the area."

The next tier of park planning is implementation plans. These deal with complex, technical, and sometimes controversial issues with a level of detail and analysis beyond that appropriate at the General Management Plan or strategic plan level. The Grand Canyon National Park General Management Plan (National Park Service 1995) builds upon several implementation plans relevant to the Adaptive Management Program, including the 1988 Backcountry Management Plan, 1989 Colorado River Management Plan, and 1994 Resource Management Plan. Other relevant implementation plans subsequent to the Grand Canyon National Park General Management Plan include the 1997 Resource Management Plan and the 1998 Draft Wilderness Management Plan.

**Operation of the Colorado River Storage Project Power System**

The Glen Canyon Dam powerplant is tied to a vast system of generators, transmission

lines, and delivery points in the western United States, Canada, and Mexico. It is legally obligated to provide electricity to wholesale electrical customers and others in the West. The Bureau of Reclamation operates Glen Canyon Dam in close coordination with the Western Area Power Administration. The Western Area Power Administration markets the electrical power produced by the Colorado River Storage Project dams and owns and operates the federal transmission system that delivers the electricity.

*Long-Term Firm Electrical Power*

Under the authorizing legislation for the Colorado River Storage Project, federal dam operators are required to produce "the greatest practicable" amount of long-term firm power at Glen Canyon Dam, integrating the operation of Glen Canyon Dam with the other Colorado River Storage Project powerplants and other federally-owned electrical powerplants.

The Western Area Power Administration's long-term contracts for electricity are with small municipalities, other political subdivisions, rural electrical cooperatives, federal defense facilities and other federal and state institutions, and Indian tribes. This power is sold strictly in the Colorado River Storage Project market area that includes Colorado, Wyoming, Utah, Arizona, New Mexico, and Nevada. Revenues from these sales are placed into the Basin Fund, a fund that repays the United States Treasury the capital costs of the Colorado River Storage Project mainstem dams and the irrigation assistance portion of the Upper Basin participating projects. Revenues from the sale of power also fund much of the cost of the Adaptive Management Program.

Long-term firm electrical power has been sold according to a marketing plan established by the Western Area Power Administration. The contracts for electricity made possible under this plan end in 2024. The Western Area Power Administration is obligated to deliver electricity in the amounts specified in these contracts. This can be supplied by the Colorado River Storage Project generators or the Western Area Power Administration may purchase some of this power from other generators. The contract amount can be adjusted every five years to take into account changing circumstances or resources.

*Operation for a Federal Load Control Area*

The Western Area Power Administration operates two load control areas that are electrically tied to Glen Canyon Dam. A load control area is a geographical area assigned to a controller to monitor electrical demand and generation and make sure that they "match" on a moment-by-moment basis. This is referred to as "regulating." Currently, Glen Canyon Dam generation can change by up to 1,000 cubic feet per second to adjust to these "swings" in demand. The contribution by Glen Canyon Dam to these two load control areas is evenly divided. The Western Area Power Administration's Operation Center in Phoenix, Arizona, sends a "regulation" signal every few seconds directly to Glen Canyon Dam.

*Reserve Sharing Groups*

Reserves are required by electrical production and distribution companies to serve as a "back-up" in case of unforeseen electrical system problems. The existence of reserves minimizes the possibility of interruption of electrical service. The Western Area Power Administration has contractual agreements with two reserve sharing groups. Reserve sharing groups are formed to share the "damage" caused by generator and transmission outages, transmission overloads and other emergencies, or unplanned events.

For the two reserve sharing groups, the Western Area Power Administration is obligated to provide up to 70 megawatts of power from one or more of the Colorado River Storage Project powerplants. Typically, Glen Canyon Dam has provided the bulk of this service.

*Emergency Service*

The Western Area Power Administration calls upon Glen Canyon Dam and other Colorado River Storage Project dams to respond to a variety of electrical system emergencies. These emergencies and the responses to them by the Western Area Power Administration and Bureau of Reclamation are a requirement of all participating members of the Western Systems Coordinating Council. These are described in the Glen Canyon Dam Environmental Impact Statement and are authorized in the Record of Decision. Further details on the emergency exception criteria are contained in the Operating Agreement Associated with Glen Canyon Dam Operating Criteria between the Bureau of Reclamation and the Western Area Power Administration dated July 7, 1997. Generally, these emergencies are related to transmission line and generation outages. During these emergencies, the operating limitations on Glen Canyon Dam contained in the Record of Decision may be exceeded.

## PROTOCOLS AND PROCEDURES — HOW THE ADAPTIVE MANAGEMENT PROGRAM WORKS

### Charter

The Charter of the Adaptive Management Program (Appendix C) was recently renewed as a formal Federal Advisory Committee Act committee for an additional two years.

### Operating Procedures of the Adaptive Management Work Group and Technical Work Group

Current operating procedures of the Adaptive Management Work Group and Technical Work Group are in Appendices D and E, respectively. These procedures have been formally recommended by these two groups and agree with the Adaptive Management Work Group Charter (Appendix C). The procedures serve to give formal structure to Glen Canyon Dam Adaptive Management Work Group and Technical Work Group

meetings.

**Science Within the Glen Canyon Dam Adaptive Management Program**

The goal of scientific inquiry within the Adaptive Management Program is to discover facts about the Colorado River ecosystem using a rigorous program of monitoring, research, and adaptive management. While significant knowledge of the ecosystem has been gained since the Glen Canyon Environmental Studies, the ecosystem is extraordinarily complex. Much is still unknown.

Long-term monitoring is critical to understanding the status and trends of important resources, as well as the effects of the Secretary of the Interior's actions in operating the dam on those resources of special concern, such as endangered species or resources of tribal interest. Long-term monitoring also informs on the success or failure of management actions and produces data for long-term research hypotheses about the functioning of the Colorado River ecosystem. A stable monitoring program allows repetitive measurements on a consistent time scale, which allows short- and long-term comparison with previous measurements. Methods range from traditional field sampling techniques to multispectral remote sensing designed to identify stability or trends in key resources or indicator species. Research and monitoring attempt to enlarge our understanding of ecosystem functions, processes, and patterns.

Understanding of ecological patterns and processes has changed substantially as a result of these monitoring and research activities. The resulting answers to questions and hypotheses thus add to the knowledge base available to the Adaptive Management Work Group as it makes recommendations to the Secretary of the Interior.

**Management Within the Glen Canyon Dam Adaptive Management Program**

The Adaptive Management Program does not derogate any agency or tribal authority or responsibility for management or stewardship of resources. Instead, the Adaptive Management Program makes formal recommendations through the Adaptive Management Work Group to the Secretary of the Interior regarding dam operations and other management actions needed to comply with the Grand Canyon Protection Act. These recommendations are made by consensus where possible, but as stated in the Adaptive Management Work Group Charter (Appendix C): "...in the event that consensus is not possible, a vote should be taken." Whether achieved through consensus or by majority vote, recommendations are transmitted to the Secretary of the Interior through the Secretary of the Interior's Designee.

The Secretary of the Interior, as the final decision maker, responds to these recommendations either directly or through actions of the agencies with delegated authority. In the latter case, implementation of these recommendations by a federal agency often depends on internal discussions between the management agency and the Secretary of the Interior.

## How Science and Management are Integrated into the Adaptive Management Program

The Grand Canyon Monitoring and Research Center provides scientific data and syntheses to the Adaptive Management Program. In general, the Grand Canyon Monitoring and Research Center provides scientific data and syntheses to the Technical Work Group, which then uses this information to create management recommendations for consideration by the Adaptive Management Work Group. The Grand Canyon Monitoring and Research Center may also bring scientific information directly to the Adaptive Management Work Group. Any of the organizational components within the Adaptive Management Program may call upon the independent review panels for advice (Fig. 1).

After approval by the Adaptive Management Work Group, the Secretary of the Interior's Designee forwards recommendations to the Secretary of the Interior. Secretarial decisions are communicated back to the members of the Adaptive Management Program.

## How Management of One Resource Affects Other Resources

The Adaptive Management Program recognizes that the Colorado River below Glen Canyon Dam is part of a large and complex ecosystem. Management actions proposed to benefit one resource might adversely impact another due to the interrelationships within the system. For example, a river flow designed to benefit a threatened or endangered native fish might result in reduced recreational opportunities or limits on the access of Native Americans to a sacred sites.

When the benefit to one resource is proposed as part of a legal compliance responsibility, it is particularly important to maintain an ecosystem perspective. One example comes from the planning of the experimental Beach/Habitat-Building Flow in 1996. This experimental flow was designed to test the hypothesis that Colorado River flows greater than powerplant capacity would mobilize sediment stored in the river channel and deposit it on the river banks. However, while designing and scheduling the experimental flow for sediment conservation, the effects of the higher flow on the aquatic food base, Kanab ambersnail, Southwestern willow flycatcher, and tamarisk had to be considered. Similarly, tribes needed to be consulted on impacts to resources of tribal concern or access to sacred sites. Impacts to recreational users and power generation also had to be factored into the experiment.

## Tribal Consultation and Coordination Within the Adaptive Management Program

Federally-recognized Indian tribes are domestic dependent nations, and the legal relationship between the federal government and tribes is one set forth in the United States Constitution, treaties, statutes, executive orders, and court decisions. Indian tribes have a guaranteed right to self-govern and to exercise inherent sovereign powers over

their members and reservations. The federal government works with Indian tribes on a government-to-government basis to address issues concerning Indian tribal self-governance, trust resources, and Indian tribal treaty and other rights. Tribal trust resources include land and natural resources either on or off Indian reservations, and other assets retained by or reserved by or for Indian tribes, held by the federal government in trust and protected by a fiduciary obligation on the part of the United States.

To ensure meaningful consultation and collaboration with Indian tribal governments, various executive orders, secretarial orders, and memoranda have been issued over the last eight years. Some of these include Executive Order 13084, Executive Order 13007, Secretarial Order 3175, Secretarial Order 3206, and *Federal Register* 94-10877.

To ensure fulfillment of the federal Indian trust responsibility, the Department of the Interior has established policies and procedures for government-to-government consultation with federally-recognized Indian tribes and tribal members for the identification, conservation, and protection of American Indian trust resources, trust assets, or tribal health and safety. Indian trust assets are values derived from land resources including surface water and groundwater, natural vegetation and wildlife, and air quality. Any potential impacts from federal actions or activities to tribal trust assets must be properly addressed between the affected tribe and the appropriate federal agency prior to any disturbance to such resources.

**Trust Responsibilities and the Adaptive Management Program**

Within the Adaptive Management Program, the federal government's trust responsibility to the interested Native American tribes (Havasupai, Hopi, Hualapai, Kaibab Band of Paiute Indians, Navajo Nation, San Juan Southern Paiute Tribe, Paiute Indian Tribe of Utah, and the Pueblo of Zuni) is realized through various levels of consultation. Section 1805(c)(3) of the Grand Canyon Protection Act requires the Secretary of the Interior to consult with Indian tribes regarding the implementation of the long-term monitoring program and activities to ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802 of the Grand Canyon Protection Act.

Tribal participation and representation at the Adaptive Management Work Group and Technical Work Group levels is considered one aspect of the Secretary of the Interior's consultative requirement under the Grand Canyon Protection Act. However, given the nature and management of Native American traditional knowledge and concerns, it may be necessary for the Grand Canyon Monitoring and Research Center, Bureau of Reclamation, National Park Service, and any other federal agency involved in long-term monitoring, research, or other associated activities, to engage in more specific consultation with each of the identified Native American tribes. This is especially true for those tribes (Havasupai and San Juan Southern Paiute) that are not actively engaged in the Adaptive Management Program. This more specific form of consultation may require the Grand Canyon Monitoring and Research Center, Bureau of Reclamation, and

National Park Service to engage in a face-to-face consultation with each tribe, their tribal representatives, and identified traditional leaders regarding monitoring and research activities, proposed management actions, and any other related Adaptive Management Program activities.

The result of this consultation effort is to fully and meaningfully engage the appropriate tribes in the decision-making process regarding activities that may affect resources of tribal concern.

## HOW COMPLIANCE IS INTEGRATED INTO THE ADAPTIVE MANAGEMENT PROGRAM

Compliance with the Endangered Species Act, National Environmental Policy Act, and National Historic Preservation Act, has particular impact on the Adaptive Management Program and is described below:

### Endangered Species Act

The Adaptive Management Program is highly focused on compliance with Section 7(a)(2) of the Endangered Species Act of 1973, as amended, and its implementing regulations (50 Code of Federal Regulations [CFR] 402). This section addresses consultation between the action agency (usually the Bureau of Reclamation) and the U.S. Fish and Wildlife Service on the effects of a proposed action on federally-listed species. This section requires that any action a federal agency authorizes, funds, or carries out must not jeopardize the continued existence of any listed species or adversely modify designated critical habitat (see Appendix F). The process utilized by the federal agencies in the Adaptive Management Program for Endangered Species Act consultation is illustrated in Figs. 2, 3, and 4.

Biological opinions contain the U.S. Fish and Wildlife Service's recommendations to the action agency. Consultation is concluded when the action agency responds to the U.S. Fish and Wildlife Service by accepting the biological opinion as written, or describing if and how they will implement the biological opinion. Once this commitment has been made, the action agency is responsible for implementation.

The Endangered Species Act primarily affects the Adaptive Management Program through: (1) the requirement to consult with the U.S. Fish and Wildlife Service on any discretionary action which may affect listed species or adversely modify designated critical habitat prior to taking the action; and (2) through commitments an action agency makes to conserve species in response to Reasonable and Prudent Alternatives in biological opinions. The Regional Director of the Bureau of Reclamation sent a memorandum to the Regional Director of the U.S. Fish and Wildlife Service identifying the elements of the Reasonable and Prudent Alternative for the operation of Glen Canyon Dam that will be implemented (Calhoun 1995). These elements include:

- Formulation of an Adaptive Management Program.
- Experimental flows to benefit endangered fish.
- Determine the feasibility and expected results of installing and operating a selective withdrawal structure (temperature control device) on Glen Canyon Dam.
- Studies of the response of native fish to various temperature regimes and river flows.
- Coordinate preparation of a Little Colorado River management plan.
- Conduct a Razorback sucker workshop.
- Establish a second spawning aggregation of humpback chub in the mainstem or tributaries.
- Evaluate the over-winter survival of young-of-year humpback chub.
- Study Kanab ambersnail life cycle and distribution.

The Superintendent of Grand Canyon National Park sent a memorandum to the Regional Director of the U.S. Fish and Wildlife Service identifying additional elements they would implement (Arnberger 1998). These elements include:

- Conduct translocation of Kanab ambersnails subject to flows below 45,000 cubic feet per second from Glen Canyon Dam.
- Complete monitoring of the status of the translocated population.
- Evaluate, and where appropriate, utilize augmentation opportunities.

**National Environmental Policy Act**

The Adaptive Management Program was established in response to an environmental commitment made in compliance with the National Environmental Policy Act. The Act has five basic mandates that the Adaptive Management Program must continue to follow:

- Supplemental mandate: adds to the existing authority and responsibility of every federal agency to protect the environment when carrying out the agency mission.
- Affirmative mandate: agencies must make decisions that restore and enhance the environment.
- Substantive mandate: agencies must recognize that each person should have a healthful environment and must contribute to the protection of that environment for present and future generations.
- Procedural mandate: agencies must use their planning and decision-making process to give appropriate consideration to environmental value and amenities.
- Balancing mandate: agencies, to the fullest extent possible and consist with other essential policy considerations, must make decisions to achieve productive harmony between people and nature.

As long as the Adaptive Management Program meets the commitments made in the Record of Decision, no additional National Environmental Policy Act compliance is needed. However, if the Adaptive Management Program makes a recommendation to the Secretary of the Interior that deviates from the Record of Decision (Reclamation 1996), then the National Environmental Policy Act requires further compliance.

### National Historic Preservation Act

The Glen Canyon Dam Environmental Impact Statement included the Programmatic Agreement for Cultural Resources that represents alternate procedures by which the Bureau of Reclamation will achieve compliance with Section 106 of the National Historic Preservation Act for the continued operation of Glen Canyon Dam. The Programmatic Agreement is a legally binding document among the Advisory Council on Historic Preservation, Arizona State Historic Preservation Officer, National Park Service, Bureau of Reclamation, Hopi Tribe, Hualapai Tribe, Paiute Indian Tribe of Utah, Kaibab Band of Paiute Indians, Pueblo of Zuni, and Navajo Nation. With proposed amendments to the Programmatic Agreement, the Western Area Power Administration and possibly the Havasupai Tribe and San Juan Southern Paiute Tribe may become signatories.

The Programmatic Agreement is a process whereby all the signatories agree to specific actions relative to management of National Register eligible historic properties affected by Glen Canyon Dam. The Programmatic Agreement has stipulations which include: (1) identification and evaluation of all historic properties within the area of potential effects of dam operations; (2) development of a plan for monitoring the effects of Glen Canyon Dam operations on historic properties and for carrying out remedial actions to address the effects of ongoing damage to historic properties; and (3) preparation of an historic preservation plan.

In the Adaptive Management Program, Programmatic Agreement signatories and Grand Canyon Monitoring and Research Center staff and associated scientists provide input to Adaptive Management Work Group and Technical Work Group members on cultural resource issues. The Technical Work Group and Adaptive Management Work Group are considered interested parties to the Section 106 compliance process. Since the Programmatic Agreement is a component of the Adaptive Management Program, the Technical Work Group and Adaptive Management Work Group have input to the Programmatic Agreement program through their review and recommendations to the Secretary of the Interior. As the lead agency, the Bureau of Reclamation has primary responsibility for ensuring that the stipulations of the Programmatic Agreement are implemented.

## ANNUAL ADAPTIVE MANAGEMENT PROGRAM CYCLE

### Budget Development Process

Note: to be provided by the Budget Ad Hoc Group, including timeline for developing the Adaptive Management Program budgets.

### Annual Report to Congress

As authorized by the Grand Canyon Protection Act, each year the Adaptive Management

Program prepares a report to be transmitted to Congress. The report includes actions taken to meet the mandates of the Grand Canyon Protection Act, dam operations, and other management actions.

The report also serves to provide an update on the status of the resources addressed by the Grand Canyon Protection Act. The annual State of the Colorado River Ecosystem report prepared by the Grand Canyon Monitoring and Research Center provides valuable input to the Annual Report to Congress.

**State of the Colorado River Ecosystem Report**

Communication between scientists and managers is vital in the Adaptive Management Program. The State of the Colorado River Ecosystem report serves the critical purpose of assessing the condition of the ecosystem, including a comprehensive reporting of status and trends among Colorado River ecosystem resources. Through the use of qualitative and quantitative targets, it also provides a mechanism for determining if the management objectives are being met.

Results of annual monitoring and research activities should be made available to the Technical Work Group and Adaptive Management Work Group by April of each year. Results of the science program, both data and synthesis reports, are available at the Grand Canyon Monitoring and Research Center. The Grand Canyon Monitoring and Research Center provides many of the reports on the Internet. Copies are also provided to the National Archives in compliance with the Federal Records Act.

**Annual Science Plan**

Each year the Grand Canyon Monitoring and Research Center prepares a detailed science plan describing the monitoring and research activities proposed for the upcoming year. The plan is discussed with the Technical Work Group and the Technical Work Group budget ad hoc group in an effort to identify both important monitoring and research questions and relative priorities among the scientific activities. The Grand Canyon Monitoring and Research Center also consults with the Programmatic Agreement signatories to determine if there are any potential effects from the proposed monitoring or research activities delineated in the annual science plan. Final recommendation to the Secretary of the Interior rests with the Adaptive Management Work Group.

The annual science plan is critical to the evaluation of the effectiveness of actions taken to protect downstream resources. The plan must have a stable and long-term monitoring component to address long-term trends. It must also have a research component to address new questions that arise through scientific investigations. Finally, it must have the statistical rigor required to substantiate its conclusions. The annual work plan will include a report on the prior year's activities.

**Request for Proposal Process**

The Grand Canyon Monitoring and Research Center utilizes a competitive proposal solicitation process open to government employees, public sector contractors, and universities through an open Request for Proposals process. All Adaptive Management Program monitoring and research projects are selected on the basis of their support of scientific capability and merit, submission timeliness on previous work (as evaluated through an independent, objective, and unbiased peer review process), management objectives and information needs, demonstrated capabilities of proposers, and cost effectiveness. Following the selection of proposals, appropriate procurement mechanisms (i.e., grants, contracts, and cooperative agreements) are utilized for supporting selected projects.

The Grand Canyon Monitoring and Research Center is committed to the use of peer review and has peer review guidelines that describe the processes it follows in reviewing all Grand Canyon Monitoring and Research Center proposals, programs, publications, and other products or deliverables. The guidelines will convey the unambiguous standard of scientific objectivity and credibility followed by the Adaptive Management Program.

In general, following approval by the Adaptive Management Work Group of the long-term monitoring and research strategic plan, an annual monitoring and research program will be completed and approved each year in April. After approval of the annual monitoring and research plan, Request for Proposals will be issued. Proposals will be screened by the program managers for their responsiveness to the Request for Proposals, and all qualified proposals will undergo an independent and objective scientific peer review. Awards will be made based on the results of peer review, the program manager's evaluation of project relevance, and technical contracting requirements.

APPENDIX A - GCPA

## Appendix A

## GRAND CANYON PROTECTION ACT

SEC. 1801. SHORT TITLE.

This Act may be cited as the "Grand Canyon Protection Act of 1992."

SEC. 1802. PROTECTION OF GRAND CANYON NATIONAL PARK

(a) IN GENERAL.-The Secretary shall operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use.

(b) COMPLIANCE WITH EXISTING LAW.-The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona vs. California, and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.

(c) RULE OF CONSTRUCTION.-Nothing in this title alters the purposes for which the Grand Canyon National Park or the Glen Canyon National Recreation Area were established or affects the authority and responsibility of the Secretary with respect to the management and administration of the Grand Canyon National Park and Glen Canyon National Recreation Area, including natural and cultural resources and visitor use, under laws applicable to those areas, including, but not limited to, the Act of August 25, 1916 (39 Stat. 535) as amended and supplemented.

SEC. 1803. INTERIM PROTECTION OF GRAND CANYON NATIONAL PARK

(a) INTERIM OPERATIONS.-Pending compliance by the Secretary with section 1804, the Secretary shall, on an interim basis, continue to operate Glen Canyon Dam under the Secretary's announced interim operating criteria and the Interagency Agreement between the Bureau of Reclamation and the Western Area Power Administration executed October 2, 1991 and exercise other authorities under existing law, in accordance with the standards set forth in section 1802, utilizing the best and most recent scientific data available.

(b) CONSULTATION.-The Secretary shall continue to implement Interim Operations in consultation with-

(1) Appropriate agencies of the Department of the Interior, including the Bureau of Reclamation, United States Fish and Wildlife Service, and the National Park Service;

(2) The Secretary of Energy;

(3) The Governors of the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming;

(4) Indian Tribes; and

(5) The general public, including representatives of the academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam.

(c) DEVIATION FROM INTERIM OPERATIONS.-The Secretary may deviate from Interim Operations upon a finding that deviation is necessary and in the public interest to-

(1) comply with the requirements of Section 1804(a);

(2) respond to hydrologic extremes or power system operation emergencies;

(3) comply with the standards set forth in Section 1802;

(4) respond to advances in scientific data; or

(5) comply with the terms of the Interagency Agreement.

(d) TERMINATION OF INTERIM OPERATIONS.-Interim operations described in this section shall terminate upon compliance by the Secretary with section 1804.

SEC. 1804. GLEN CANYON DAM ENVIRONMENTAL IMPACT STATEMENT; LONG-TERM

OPERATION OF GLEN CANYON DAM.

(a) FINAL ENVIRONMENTAL IMPACT STATEMENT.-Not later than 2 years after the date of enactment of this Act, the Secretary shall complete a final Glen Canyon Dam environmental impact statement, in accordance with the National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.).

(b) AUDIT.-The Comptroller General shall-

(1) audit the cost and benefits to water and power users and to natural, recreational, and cultural resources resulting from management policies and dam operations identified pursuant to the environmental impact statement described in subsection (a); and

(2) report the results of the audit to the Secretary and the Congress.

(c) ADOPTION OF CRITERIA AND PLANS.-(1) Based on the findings, conclusions, and recommendations made in the environmental impact statement prepared pursuant to subsection (a) and the audit performed pursuant to subsection (b), the Secretary shall-

(A) adopt criteria and operating plans separate from and in addition to those specified in section 602(b) of the Colorado River Basin Project Act of 1968; and

(B) exercise other authorities under existing law, so as to ensure that Glen Canyon Dam is operated in a manner consistent with section 1802.

(2) Each year after the date of the adoption of criteria and operating plans pursuant to paragraph (1), the Secretary shall transmit to the Congress and to the Governors of the Colorado River Basin States a report, separate from and in addition to the report specified in

section 602(b) of the Colorado River Basin Project Act of 1968 on the preceding year and the projected year operations undertaken pursuant to this Act.

(3) In preparing the criteria and operating plans described in section 602(b) of the Colorado River Basin Project Act of 1968 and in this subsection, the Secretary shall consult with the Governors of the Colorado River Basin States and with the general public, including-

(A) representatives of academic and scientific communities;
(B) environmental organizations;
(C) the recreation industry; and
(D) contractors for the purpose of Federal power produced at Glen Canyon Dam.

(d) REPORT TO CONGRESS.-Upon implementation of long-term operations under subsection (c), the Secretary shall submit to the Congress the environmental impact statement described in subsection (a) and a report describing the long-term operations and other reasonable mitigation measures taken to protect, mitigate adverse impacts to, and improve the condition of the natural, recreational, and cultural resources of the Colorado River downstream of Glen Canyon Dam.

(e) ALLOCATION OF COSTS.-The Secretary of the Interior, in consultation with the Secretary of Energy, is directed to reallocate the costs of construction, operation, maintenance, replacement and emergency expenditures for Glen Canyon Dam among the purposes directed in section 1802 of this Act and the purposes established in the Colorado River Storage Project Act of April 11, 1956 (70 Stat. 170). Costs allocated to section 1802 purposes shall be nonreimbursable. Except that in fiscal year 1993 through 1997 such costs shall be nonreimbursable only to the extent to which the Secretary finds the effect of all provisions of this Act is to increase net offsetting receipts; Provided, That if the Secretary finds in any such year that the enactment of this Act does cause a reduction in net offsetting receipts generated by all provisions of this Act, the costs allocated to section 1802 purposes shall remain reimbursable. The Secretary shall determine the effect of all the provisions of this Act and submit a report to the appropriate House and Senate committees by January 31 of each fiscal year, and such report shall contain for that fiscal year a detailed accounting of expenditures incurred pursuant to this Act, offsetting receipts generated by this Act, and any increase or reduction in net offsetting receipts generated by this Act.

SEC. 1805. LONG-TERM MONITORING.

(a) IN GENERAL.-The Secretary shall establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of section 1802.

(b) RESEARCH.-Long-term monitoring of Glen Canyon Dam shall include any necessary research and studies to determine the effect of the Secretary's actions under section 1804(c) on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area.

(c) CONSULTATION.-The monitoring programs and activities conducted under subsection (a) shall be established and implemented in consultation with-

(1) the Secretary of Energy;

(2) the Governors of the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming;

(3) Indian tribes; and

(4) the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam.

SEC. 1806. RULES OF CONSTRUCTION.

Nothing in this title is intended to affect in any way-

(1) the allocations of water secured to the Colorado Basin States by any compact, law, or decree; or

(2) any Federal environmental law, including the Endangered Species Act (16 U.S.C. 1531 et seq.).

SEC. 1807. STUDIES NONREIMBURSABLE.

All costs of preparing the environmental impact statement described in section 1804, including supporting studies, and the long-term monitoring programs and activities described in section 1805 shall be nonreimbursable. The Secretary is authorized to use funds received from the sale of electric power and energy from the Colorado River Storage Project to prepare the environmental impact statement described in section 1804, including supporting studies, and the long-term monitoring programs and activities described in section 1805, except that such funds will be treated as having been repaid and returned to the general fund of the Treasury as costs assigned to power for repayment under section 5 of the Act of April 11, 1956 (70 Stat. 170). Except that in fiscal year 1993 through 1997 such provisions shall take effect only to the extent to which the Secretary finds the effect of all the provisions of this Act is to increase net offsetting receipts; Provided, That if the Secretary finds in any such year that the enactment of this Act does cause a reduction in net offsetting receipts generated by all provisions of this Act, all costs described in this section shall remain reimbursable. The Secretary shall determine the effect of all the provisions of this Act and submit a report to the appropriate House and Senate committees by January 31 of each fiscal year, and such report shall contain for that fiscal year a detailed accounting of expenditures incurred pursuant to this Act, offsetting receipts generated by this Act, and any increase or reduction in net offsetting receipts generated by this Act.

SEC. 1808. AUTHORIZATION OF APPROPRIATIONS.

There are authorized to be appropriated such sums as are necessary to carry out this title.

SEC. 1809. REPLACEMENT POWER.

The Secretary of Energy in consultation with the Secretary of the Interior and with representatives of the Colorado River Storage Project power customers, environmental organizations and the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming shall identify economically and technically feasible methods of replacing any power generation that is lost through adoption of long-term operational criteria for Glen Canyon Dam as required by section 1804 of this title. The Secretary shall present a report of the findings, and implementing draft legislation, if necessary, not later than two years after adoption of long-term operating criteria. The Secretary shall include an investigation of the feasibility of adjusting operations at Hoover Dam to replace all or part of such lost generation. The Secretary shall include an investigation of the modifications or additions to the transmission system that may be required to acquire and deliver replacement power.

APPENDIX B - Guidance Document

Appendix B

# GLEN CANYON DAM ADAPTIVE MANAGEMENT PROGRAM
# AMWG FACA COMMITTEE GUIDANCE

## Purpose of this Document

During the first two years of implementing the Glen Canyon Dam Adaptive Management Program, it has become apparent that several aspects of the program, specifically relating to the Record of Decision, the Glen Canyon Dam EIS and the Grand Canyon Protection Act need to be clarified in order to facilitate and focus the activities of both the Adaptive Management Work Group Committee (AMWG) and its subcommittee, the Technical Work Group (TWG). It is the purpose of this document to provide that direction. The following guidance represents the Department's understanding and intent concerning the purpose and role of the AMWG Committee and the scope of work given to the Committee in its Charter, pursuant to all relevant law and Departmental policy. This guidance has been assembled with the assistance and legal guidance of the Office of the Solicitor and has been shared with all members of the AMWG prior to finalization.

## Background

During the past century, there have been numerous developments affecting the Colorado River that have led to the present juncture. On November 24, 1922, the Colorado River Compact was signed at Santa Fe, New Mexico, allocating the water of the river between the Upper and Lower Basins, as defined therein, as well as establishing the rules, rights, and obligations governing the use of that water among the seven respective states within the Colorado River Basin. The United States also has a treaty with the United Mexican States (Mexico) guaranteeing Mexico 1.5 million acre feet annually from the Colorado River. Among the other obligations established in the Compact was that of the Upper Basin not to deplete the flow of the river at Lee Ferry "below an aggregate of 75,000,000 acre-feet for any period of 10 consecutive years."

Earlier, in 1908, Congress set aside the Grand Canyon as a national monument and in 1919 expanded the reservation and redesignated it as a national park. There are only about fifteen river miles separating the outlet works of Glen Canyon Dam and the upstream boundary (on the northerly side of the river) of Grand Canyon National Park. Later, Congress also established the area surrounding Lake Powell and extending down river to the Park boundary (except for the area within the pre-existing Navajo Reservation) as the Glen Canyon National Recreation Area, also managed by the National Park Service.

In large part in order to assure that the rights and obligations in the Colorado River Compact and the Upper Colorado River Basin Compact could be met without jeopardizing the water uses of the Upper Basin states in the future, Congress passed the Colorado River Storage Project Act on April 11, 1956, which provided the authority for the construction of the four "initial units" of CRSPA, namely Flaming Gorge, Aspinall, Navajo, and Glen Canyon dams. Glen Canyon Dam, storing more than 26 million acre feet, over 24 million of which represent

active capacity, is situated immediately above Lee Ferry, the delivery point to the Lower Basin. In 1968 Congress passed the Colorado River Basin Project Act which among other things provided for coordinated operations of Colorado River Basin reservoirs. Until recently, Glen Canyon Dam has been operated with essentially two functions in mind: compact deliveries to the Lower Basin, and hydropower generation. Compact deliveries from Glen Canyon assure that the Upper Basin can meet its delivery obligations to the Lower Basin states and effectively manage other Upper Basin reservoirs to meet Upper Basin water supply needs. Hydropower generation provides the revenues necessary to cover operation and maintenance costs as well as the revenues needed to assure repayment of CRSP projects.

During the 1980s, it became apparent that the existing pattern of dam operations was adversely affecting some of the riparian resources in the Park and the Recreation Area below the dam. The Department began studying the situation, initiated the preparation of an EIS, and then Congress passed the Grand Canyon Protection Act of 1992 to attempt to address this problem.

**Authority (Questions 1a, 1b, 1c, 2a, 3, 4c, 5a, 5c, 5e, 6a, 6b, 7a, 7c, 8, 12c, 13a, 14)**

**Grand Canyon Protection Act, Legislative History, and Law of the River**

It is quite clear that when Congress enacted the Grand Canyon Protection Act of 1992, 106 Stat. 4669 (GCPA), it intended to maintain all that had gone before – the Compacts, the Park units, and Glen Canyon Dam – and to find a way to operate the dam so as to "protect [sic], mitigate adverse impacts to and improve"[1] downstream NPS resources without interfering with the "Law of the River," including compact and treaty obligations for water delivery (GCPA, section 1802(a) and (b)). The Senate Report on the bill puts it quite simply: "The primary purpose of this title is to authorize changes in the operation of Glen Canyon Dam to prevent damage to downstream resources, principally the dam's power operations." The Secretary's responsibilities for water storage, allocation and delivery act as limits on the Secretary's discretion in implementing the GCPA. It is also clear that Congress understood that these objectives would have certain costs in the form of lost incremental hydropower generating opportunity (GCPA, section 1809) and that the existence of the dam was to be taken as a given.

The basic question Congress was addressing was how Glen Canyon Dam operations might be modified within the provisions of existing law so as to improve conditions for downstream NPS resources (with similar benefits certainly occurring on other similarly situated lands). The GCPA itself does not direct consideration of cultural resources within the boundaries of Native American reservations, only "the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established," although all federal agencies have similar obligations under other law. The entire adaptive management program (AMP), including the Grand Canyon Monitoring and Research Center and the Adaptive Management Work Group, must be understood within this context. In accordance with section 1804 of the GCPA, the EIS was conducted to attempt to find an answer to that question, and the 1996 ROD was the Department's best first answer. Recognizing that more experience and knowledge with

[1] The GCPA as printed contains a typographical error, using "project" instead of "protect." The legislative history makes clear that "protect" is what was intended; that word will be used throughout this document.

operations might enable further refinements in operations and might further improve downstream resource conditions, however, Congress added section 1805 to the GCPA. This section required the Secretary to "establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with section 1802," namely, "to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established," within the parameters of other applicable law and the physical constraints of the dam. Accordingly, the Department included in the EIS and in the ROD the provisions setting up the AMP, thereby allowing for further refinement of and changes to dam operations to better meet the GCPA objectives.

The charge given to the AMWG in its Charter is to "facilitate the AMP, recommend suitable monitoring and research programs, and make recommendations to the Secretary as required to meet the requirements of the Act." The scope of the AMWG responsibility, therefore, is to identify aspects of dam operations that can be modified to beneficially affect the downstream resources identified as the focus of study (i.e. "the target") in the EIS. This covers flow rates, ramping rates, periodicity of peak flows, monitoring sediment input rates and the relation of sediment movement to water release and ramping rates, chemical content and temperature of releases, among possible others -- any aspect of dam operations, in other words, which has a reasonably demonstrable effect on the downstream resources sought to be improved by the GCPA. The key to the scope of AMWG's responsibilities is whether a specific desired resource effect downstream of the dam can be achieved through some manipulation of dam operations. Under the ROD, the upper limit of planned release level is 45,000 cfs. Long-term monitoring and research, including test flows within the current range of authorized operations, are intended to enable finer and finer tuning of operations over time, as additional knowledge and experience are gained, to better achieve the target mix of resource benefits, as outlined in the EIS, pages 54-65.

Without losing track of this primary focus on improving conditions for downstream resources, the Charter also specifies that the "AMWG may recommend research and monitoring proposals outside the Act which complement the AMP process, but such proposals will be funded separately, and do not deter from the focus of the Act." This would include anything the AMWG committee considers relevant but tangential or attenuated in its effects on riparian resources downstream of the dam, as identified above. The relevant Senate Report language says, after the discussion of the primary purpose of the Act, that: "other reasonable remedial measures may be available to the Secretary. The phrase 'exercise other authorities under existing law' means that the Secretary should consider and may implement non-operational measures to address downstream effects of Glen Canyon Dam if such other remedial measures meet this title's goal of protecting, mitigating damage to, and improving the resources downstream of the dam." Again, as emphasized in the Senate Report, "the water storage, allocation and delivery requirements of the Law of the River place substantial limits on the Secretary's ability to change other elements of GCD operations. All measures undertaken pursuant to the authority of this Act have as their focus the improvement of conditions for downstream resources within the two Park Service units." The TWG's responsibility is similarly limited, but even more so; it is to carry out only specific assignments within the scope of the AMWG's responsibility, as directed by the AMWG.

The AMWG was set up pursuant to the Federal Advisory Committee Act (FACA) and must comply with FACA's requirements for notice and public meetings, etc., as laid out in the GSA regulations at 41 CFR Subpart 101-6.10. The AMWG and TWG may establish their own internal operating procedures as they wish, so long as they comply with the specific requirements of FACA and its implementing regulations.

One area that has been a source of recent discussion has been the question of planned high releases from Glen Canyon Dam for such purposes as "beach habitat building flows." The Department expects the AMWG to work and provide its recommendations within the following context. Since the GCPA is clear that it was not intended to modify the compacts or "the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin" (GCPA, section 1802(b)), any operational changes under the auspices of the GCPA are clearly subordinate to and must fit within the constraints of those provisions. Historically, there have been differences of legal opinion over some related issues, such as whether releases of water above powerplant capacity, if made for authorized purposes, can be considered as not constituting "spills" within the meaning of section 602(a) of the Colorado River Basin Project Act of 1968 and the Operating Criteria implemented pursuant to section 602, and more recently over whether the GCPA "amends" existing law by adding additional authorized purposes for the operation of Glen Canyon Dam. These legal issues have not been finally resolved, but given the limitations provided in the ROD, the Glen Canyon Dam operating criteria, and the 1996 agreement between the Department and the Basin States, it is believed that they have been adequately addressed. Clearly, section 7 of the CRSPA, which directs the Secretary "to produce the greatest practicable amount of power and energy that can be sold at firm power and energy rates" provided that the primary purposes of compact deliveries and state compact allocation development are not precluded or impaired, remains in effect, even though the GCPA (section 1809) authorized, and the EIS/ROD implemented, an incremental reduction in the value of the hydropower resource. Under the conditions of those documents (the ROD, the operating criteria, and the 1996 agreement), flows above powerplant capacity would be conducted utilizing reservoir releases required for dam safety purposes. The Department is currently focusing on operational modifications at release levels below 45,000 cfs. Modifications to the operating criteria involving flows above 45,000 cfs would require additional NEPA compliance.

**EIS/ROD (Questions 1b, 4c, 5a, 5c, 7b, 7c, 12a, 12b, 12c, 13a, 13b, 13c, 13d, 13e, 13f, 15)**

As mentioned above, the EIS conducted on Glen Canyon Dam operations contains the Department's selection of a mix of targeted resource benefits and its attempt to balance these benefits against costs to hydropower generation. As stated in the ROD:

> The goal of selecting a preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability.

The ROD represents the Department's "first cut" on providing an answer as to how that target might be achieved. The EIS and ROD are relevant to the AMP process in several respects. First of all, the EIS identifies the specific downstream resources sought to be benefitted (i.e. "protected, mitigated for, or enhanced") by changes in dam operations (see EIS, pp. 54-57 and Table II-7). Secondly, its discussions and analyses of various alternatives provide a starting point for the state of the science at the time the decision was made to implement the "modified low fluctuating flow" pattern of operations with a commitment for long-term modifications in response to further research. In the language of the ROD, "the Modified Low Fluctuating Flow Alternative was selected as the preferred alternative because it would provide the most benefits with respect to the original selection criteria, given existing information."

The monitoring, research and experimental programs are intended to develop additional information, working with the AMWG recommendations, "which could result in some additional operational changes." The selection criteria against which such changes are to be measured, however, remain unchanged. Elsewhere the ROD amplifies that this alternative was selected because it "meets the critical requirements of the sediment resource by restoring some of the pre-dam variability through floods and by providing a long-term balance between the supply of sand from Grand Canyon tributaries and the sand-transport capacity of the river" with corresponding benefits to habitat. The ROD, in part in conjunction with the EIS, also describes in detail the decision made, including modifications to the selected alternative, specific environmental and monitoring commitments, the scope and objectives of the AMP, the role and function of the Grand Canyon Monitoring and Research Center (GCMRC), and the role expected for the AMWG and TWG. It is important to understand that before either the targeted resource blend or the operational pattern in the Glen Canyon Dam operating criteria can be changed materially, additional NEPA work would have to be done.

Among the environmental commitments made in the ROD was the commitment to restrict Glen Canyon Dam release upramp rates to 4,000 cfs per hour and downramp rates to 1,500 cfs per hour. Consistently with interagency agreements between BOR and the Western Area Power Administration (WAPA) both prior and subsequent to the 1996 ROD, these figures should be understood to represent a firm limit on changes in release rates integrated over each hourly interval, to be enforced by the Secretary, subject to being exceeded only in times of emergency unless and until changed by subsequent decision of the Secretary.

As part of the adaptive management process, studies and information needs specified in the EIS/ROD are expected to be completed and to result in the identification of new information needs or definitions of effects, impacts and mitigation requirements.

All applicable federal laws must be complied with, including NEPA, NHPA, ESA, FACA, and the APA, in addition to the federal laws considered part of the "Law of the River." It is not expected that the Adaptive Management Program will result in additional required NEPA compliance unless additional resources (i.e. "management objectives") are identified and targeted for inclusion in the revised dam operations beyond those identified in the existing EIS.

## Organization (Questions 8, 9, 10, and 11)

Prior to the EIS and ROD various Federal Agencies (i.e., BIA, WAPA, BOR, NPS, FWS) had various statutory responsibilities for compliance with laws involving such areas as the environment, historical and cultural resources, and threatened and endangered species. These agencies have frequently entered into agreements among themselves to take specific actions to meet those statutory requirements. It was assumed when the AMP was adopted by the Secretary that it would include all studies necessary to determine the effects of GCD operations on the designated resources selected in the ROD. Some of these studies meet scientific needs and also meet statutory requirements under NEPA, ESA and NHPA. In fact the EIS identified some specific studies that would be a part of the AMP, such as the study of low steady flows.

The Secretary of the Interior established the AMP with four key elements: AMWG, TWG, GCMRC, and the IRP (Independent Review Panel). The four have distinct roles, but ultimately the Secretary of the Interior is responsible for seeing that the monitoring and necessary research is done to evaluate the impacts of adjustments made to dam operations. The EIS document prepared by the Secretary envisioned the AMP program to be a somewhat all-encompassing investigation of impacts, while still respecting the statutory obligations of each of the Departmental agencies. One of the mechanisms chosen by the Secretary to receive feedback through the AMP is the AMWG, which is to provide recommendations on the content of the various budgeting and planning documents. The AMWG can *recommend* studies and priorities for implementing individual studies during those reviews, preferably by consensus. In doing so, all members of the AMWG are assumed to be equal in importance when voting on recommendations, including federal agencies. However, final decisions as to the management of Interior facilities and resources, what studies to implement, when, and using funds from which sources remain, by statute, with the Secretary of the Interior and the appropriate Interior agencies.

## Funding (Questions 2b, 4a, 4b, 5b, 5d, 6a, 7a, 17, 18, 19, 20, and 21)

Funding for any federal effort comes from the statutory authorities provided by enacted laws. In the case of the AMP, several funding authorities can come into play -- the most visible being the Grand Canyon Protection Act (GCPA) of 1992. The GCPA makes several statements with regard to potential sources of funds and also imposes some restrictions. With regard to the use of revenues generated from the sale of electric power, section 1807 is specific and restrictive. The hydropower revenues may be used for preparation of the EIS, including supporting studies, and the long-term monitoring programs and activities described in section 1805. Both hydropower revenues and appropriated funds can be used for administrative expenses to implement the specified work. However, the use of such funds to pay expenses of non-government employees may be covered under FACA and other fiscal regulations and must be treated on a case by case basis. The GCPA also authorizes such sums to be appropriated as are necessary and encourages use of other authorities under existing law to determine the effect of the Secretary's actions under section 1804 (c) and 1805 (b) on the natural, recreational, and cultural resources of Grand Canyon National Park and Glen Canyon National Recreation Area. The activity and its authorization determine the funding. To date, hydropower revenues have been the source of funding for almost all AMP activities because they meet the definition above.

Research and monitoring proposals outside the Act which complement the AMP process are to be separately funded.

As stated in the authorities section above, the focus of the GCPA is downstream of the dam and primarily on the operations of the powerplant. The existence or construction of the dam and its associated impacts is not a focus. This is clear in both the EIS and ROD, i.e. in the EIS at page 2, top of page, right hand column "Since the dam has long been completed, alternatives to the dam itself have been excluded from the scope of the analysis."

To illustrate the range of activities and associated funding, some examples are provided below:

- Studies of control sites in Cataract Canyon or on reservation lands, for example, may be supported by revenues, if the studies are determined through scientific peer review to be necessary for determining the effects of the Secretary's actions downstream within the park units under 1804(c).

- Studies of water quality in Lake Powell are allowable if necessary to determine the effects on downstream resources. Studies of the effects on cultural resources around the rim of Lake Powell are not allowable under AMP (GCPA) funding.

- It is reasonable to assume that while the primary focus is on powerplant releases the releases from the bypass tubes and spillway outlet works also fall into the operational category and funding could be used to conduct experiments and study impacts from their operation. In fact, this has already occurred to a degree during the 1996 beach habitat building test flow when the bypass tubes were used.

All Federal agencies have a special responsibility to Native Americans by law, including statutes, treaties, and executive orders. With the Secretary of the Interior being trustee, Department of the Interior agencies have a special role. Certainly the direct impacts of the dam operations on the Native American trust resources within the park units can and should be funded from hydropower revenues, but such impacts outside the boundaries of the river corridor in the park units must be studied using other appropriated funds. Participation in the AMP or education activities should be funded from appropriate sources. For instance education activities may come under self-governance and self-determination programs and be funded from BIA funds, activities surrounding general NPS requirements may be funded from NPS funds, and participation in AMP work group activities may be specific enough to be funded by revenues or appropriations from BOR. Funding of Native American activities should be a shared responsibility.

**Other Compliance and Consultations (Questions 11, 16, and 21)**

Prior to passage of GCPA and formation of the AMP, federal agencies had many responsibilities embodied in existing law. Those responsibilities remain today. The GCPA, EIS/ROD, and AMP did not take over responsibility for nor remove the legal obligations of the agencies to fulfill existing legal mandates. The GCPA states as much in several places. The

AMP is a process by which the Secretary of the Interior has chosen to include all studies and other compliance activities necessary to determine the effects of GCD operations on designated resources and to modify operations to meet the purposes of the GCPA.

It is possible that some of the studies recommended and performed under the AMP and the AMP budget will coincide with and help to satisfy obligations of the federal agencies under other laws, such as the Endangered Species Act. The obligations imposed by other laws must be complied with by the responsible agencies, whether they are funded as part of the AMP process or separately. The AMP budget does not imply that these compliance functions will automatically be assumed or raised to a higher priority through the AMP process, although where reasonable, the AMP process may assist or even satisfy such functions in a given instance -- "two birds with one stone," so to speak.

While the AMWG and TWG should be aware that the involved federal agencies face these responsibilities, those factors should not detract from the committee's focus as described in the GCPA, EIS, ROD, and Charter. The committee's recommendations for studies and their relative priorities should remain on the effects of dam operations on downstream resources within the park units. The implementation of such studies, their timing and funding and the like remain the decision of the Secretary and the federal agencies, as noted earlier.

Embodied in the NEPA process is the requirement to comply with ESA and cultural laws in order to discuss and present the impacts on all resources and eventually arrive at a preferred alternative. For example, the AMWG is not chartered to be a formal participant in ESA consultation processes. However, the AMP does not prevent AMWG members from participating as members of the public or in their other official capacities. In this regard, AMWG should focus on helping Reclamation determine how to apply the reasonable and prudent alternatives within the area of concern of the GCPA. In regards to the consultation requirements under NHPA, the action federal agencies and affected tribes have signed a programmatic agreement (PA) document and hold periodic meetings. Parties not signatory to the PA are welcome to attend and comment. Here too, however, the ultimate decision on how to proceed rests with the Secretary of the Interior and the federal agencies delegated the responsibility for management of the resources.

**Other Program Relationships**

While programs in other areas of the Colorado River do not require direct input from the work performed for the GCPA, it is certainly envisioned that information will be shared and that participants will keep abreast of other relevant basin activities. The GCPA requires compliance with existing laws and consultations with a variety of groups. To meet that requirement it is important that all members share knowledge obtained from activities arising from i.e., the upper basin recovery program, the salinity control program, and the lower Colorado multi-species conservation program.

## APPENDICES:

## QUESTIONS

Scott Loveless has responded to and the TWG has discussed a list of questions which was prepared by Bob Winfree on December 15, 1998, and which was attached to Steve Magnussen's memo of December 29, 1998. Those discussions generated the following additional questions for Scott from TWG. The following numbered list embodies the questions that led to the above guidance document.

1. (a) What is the scope of the AMWG Charter?

   (b) How do the EIS, the ROD, and the Act impact the scope?

   (c) Can the AMWG charter expand upon the scope and authorities in the Act? (EIS & ROD)

2. (a) Is the AMP limited by section 1804? Can AMWG recommend changes in the operating criteria?

   (b) Can the program expend funds to study (research) impacts of proposed (recommended) changes that are clearly beyond the limitations of Sec. 1804(c)?

3. What constitutes the target?

4. (a) Can funds as designated in 1807 be used to fund studies outside the effects of dam operations (outside the operational confines of the dam)?

   (b) How direct must the impacts be to allow funding under 1807?

   (c) Where does the burden of proof lie for determining the effects of dam operations?

5. (a) Is the AMP limited to powerplant operations when hydrologic triggering criteria are not met? (paraphrase, Can you do an experimental flood when not required for dam safety purposes)

   (b) Does the GCPA authorize funding to be used for mitigation of powerplant operations, or is it broader; i.e., mitigate for spillways, bypass tubes, dam existence (Furnace Flats)? (i.e., Can AMP funding be used to mitigate sediment reduction, temperature averaging effects due to the existence of GCD.)

   (c) Does NHPA require mitigation for damage to properties eligible for listing on the National Register of Historic Sites as a result of the dam's existence?

(d) Does the law allow for funding mitigation activities related to construction [existence] of the dam versus operations of the dam?

(e) Were powerplant spills other than those hydrologically induced authorized by the Act?

6. (a) Does the monitoring program allow for research and monitoring of potential effects of releases up to 256,000 cfs?

(b) What is the legal boundary for lateral extent for all resources?

7. (a) When is it appropriate to propose experiments outside the preferred alternative?

(b) Can experiments be performed which are outside of the ROD?

(c) What are the limitations when performing an experiment outside the ROD?

8. What are the TWG responsibilities relative to review and editing of the monitoring and research plans prepared by GCMRC?

9. What organization is responsible for developing needed AMP planning documents and reports other than science program reporting?

10. Do recommendations of all stakeholders represented in TWG and AMWG carry equal weight in [TWG/AMWG] decisions?

11. The AMP has only been in place for a few years. Before the AMP, the various Federal Agencies involved had certain statutory responsibilities for environmental, historical and ESA compliance and they entered into agreements to take specific actions. Does the existence of an AMP budget automatically assume these compliance responsibilities for the agencies; and if so, do the agencies compliance responsibilities automatically become the dominant focus of the program? (i.e., Biological Opinion, Cultural Resources, etc.)

12. (a) Can the management objectives as outlined in the EIS be changed and, if so, how much can they be changed?

(b) Are the management objectives as outlined in the EIS different from the expected changes in management goals adopted by the Secretary when he selected the preferred alternative?

(c) Were the recommended changes in powerplant operating criteria made to achieve the desired changes in management goals?

13. (a) What is the force and effect of the ROD?

(b) What limits does it put on our actions?

(c) Are there any parts of the paper, prepared by Reclamation and WAPA and distributed at AMWG, which are illegal?

(d) Are the numbers in the ROD hard and fast?

(e) Is it possible to exceed them?

(f) What is the penalty for exceeding limits specified in the ROD?

14. Does the GCPA authorize activities on Native American reservation lands (for example, above 124,000 cfs outside Grand Canyon National Park on Hualapai land)?

15. When is it appropriate to propose experiments outside the ROD?

16. Are there any prohibitions about AMWG contributing to the formal consultation on BO for Kanab Ambersnail?

17. What are the limits of the use of GCPA funds on other areas outside those specified in the GCPA, Grand Canyon National Park and the Glen Canyon National Recreation Area? For example, what is the restriction on the use of funds on tribal lands? Further, what about the effects that are caused by the action but do not have a resultant influence downstream? For, example what if there were effects of dam operations in Lake Mead? Could GCPA funds be used to study impacts to Lake Mead caused by operational impacts of Glen Canyon Dam? I'm thinking here of whether these funds could be used to study the effects of operations on an endangered bird species in delta area of Lake Mead.

18. Can GCPA funds (nonreimbursable power revenues) be used for agency compliance responsibilities related only to the operation of Glen Canyon Dam? Specifically, can they be used to pay for continuing activities related to BOR or NPS NHPA, Endangered Species Act Biological Opinion requirements, NEPA compliance etc. The BOR has made a very strong argument in the past that these activities are strictly an agency responsibility and outside the purview of the AMP (The AMWG makes no recommendations to the secretary on these issues). If so, and because they are not related directly to section 1804 or 1805 of the GCPA how can GCPA funds be used to support them?

19. Can GCPA funds be used to support salaries, travel, per diem etc. not directly related to Section 1804 and 1805 activities? For example, it would seem that there is a fundamental question related to the legitimacy of the use of GCPA funds for agency or stakeholder salary costs related to administration of the AMP. Sections 1804 and 1805 make no mention of administration costs for an AMP, and AMP is not directly related to research, studies, or the preparation of the EIS

20. Can GCPA funds be used to assist tribes to attend and participate in the AMP process?

21. If the BOR has legal obligations as a result of the Biological Opinion, are these obligations automatically the obligation of the AMWG?

**AMWG OPERATIONS**

FACA Overview

AMWG Member List and statement of their constituency and mission, including potential conflicts

AMWG Charter

Proposal for Renewal of AMWG Charter

AMWG Operating Procedures

Appropriations Committee language re: budget

Budget (current)

Issues papers and AMWG Guidance Document

Other issues yet to be resolved

**TWG OPERATIONS**

TWG Member List

TWG Operating Procedures, Proposal to Modify OP, Ground Rules, Consensus Definition

Recommendations regarding travel payments to TWG members

Ground rules for meetings

Code of conduct

Definition of consensus

**GCMRC OPERATIONS**

Letter Establishing GCMRC

GCMRC Monitoring and Research Center Guidelines

Center Protocols

RFP's and AMWG input
Peer Review
Administrative review (focus on priority information needs, permitting, and compliance responsibilities)
Awarding contracts, competition
Information transfer (reports, workshops, etc.)

Annual Plan (current)

Strategic Plan (current)

**LAWS, AGREEMENTS**

Law of the River synopsis

Colorado River Compact, November 24, 1922

Colorado River Storage Project Act, April 11, 1956

Colorado River Basin Project Act, September 30, 1968

Long-Range Operating Criteria, 1970

Long-Range Operating Criteria, October 30, 1992

National Environmental Policy Act (Section 7 consultation)

Grand Canyon Protection Act, October 30, 1992 and Legislative History

National Historic Preservation Act (Sections 106 and 110)

Programmatic Agreement on Cultural Resources, August 30, 1994

Historic Preservation Plan

Endangered Species Act

36 CFR 2.5 (research and specimen collection in National Park Service areas)

Record of Decision, Glen Canyon Dam Final Environmental Impact Statement. 10/25/96

BOR-WAPA Operating Agreement

Biological Opinions

Final GCD EIS (included by reference)

Rebecca Tsosie article on trust responsibility

**GLEN CANYON DAM OPERATING CRITERIA**

Operating Criteria for Glen Canyon Dam In Accordance with the GCPA, 2/24/97

Operating Guidelines Associated with Glen Canyon Dam Operating Criteria 7/7/97

Operating Criteria and other Operating Parameters (C. Palmer 7/97)

Annual Operating Plans

**AMP REPORTS AND RECOMMENDATIONS**

TWG Position Paper - Glen Canyon Dam Spillway Gate Extensions

Integration of Programmatic Agreement with AMP, Federal/Tribal Trust Responsibilities

BHBF Triggering Criteria

Spill avoidance

Glen Canyon Dam release issues recommended for further study, and GCMRC reply

Report of the NEPA/ESA Issues Subgroup

Recommendations to the TWG for expediting environmental compliance and improving coordination on Biological Opinion Issues

Letter to Secretary Babbitt from non-federal members

Management Objectives (current)

Information Needs (current)

Resource Criteria (current)

Report to Congress (current)

State of Natural and Cultural Resources in the Colorado River Ecosystem (current)

Lake Powell Assessment

BHBF Flow alternatives

**TWG, TWG, AND AMWG**
**MEETING AGENDA AND MINUTES**
**1995, 1996, 1997**

**TWG, TWG, AND AMWG**
**MEETING AGENDA AND MINUTES**
**1998**

APPENDIX C - AMP CHARTER

## Appendix C

## Glen Canyon Dam Adaptive Management Work Group
## Federal Advisory Committee

## CHARTER

Official Designation: Glen Canyon Dam Adaptive Management Work Group.

Scope and Objectives: The Committee will provide advice and recommendations to the Secretary of the Interior relative to the operation of Glen Canyon Dam in accordance with the additional criteria and operating plans specified in Section 1804 of the Act and to the exercise of authorities under existing laws in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and the Glen Canyon National Recreation Area were established, including but not limited to the natural and cultural resources and visitor use.

The Secretary of the Interior is implementing the Grand Canyon Protection Act (Act) of October 30, 1992, embodied in Public Law 102-575. The Act calls for implementation of long-term monitoring, research, and experimental programs and activities. As part of long-term monitoring, the Secretary's Record of Decision (ROD) mandated development of an Adaptive Management Program (AMP). The AMP provides for monitoring the results of the operating criteria and plans adopted by the Secretary and research and experimentation to suggest appropriate changes to those operating criteria and plans.

The AMP includes an Adaptive Management Work Group (AMWG). The AMWG will facilitate the AMP, recommend suitable monitoring and research programs, and make recommendations to the Secretary as required to meet the requirements of the Act. The AMWG may recommend research and monitoring proposals outside the Act which complement the AMP process, but such proposals will be funded separately, and do not deter from the focus of the Act.

Duration: It is the intent that the AMWG shall continue indefinitely, unless otherwise terminated by the Secretary.

Agency or Official to Whom the Committee Reports: The AMWG reports to the Secretary through the Secretary's designee who shall serve as the chairperson and Designated Federal Official of the AMWG. In the absence of the Chairperson, a senior level Interior representative will act as Chairperson for the AMWG.

The Secretary's designee shall be responsible for preparation of meeting agendas and scheduling meetings of the AMWG. The Secretary's designee shall attend and chair all meetings of the AMWG. The Secretary's designee will also be responsible for sending a formal summary report after each Advisory Committee meeting directly to the Secretary of the Interior with copies of subject summary report to be provided to all AMWG members.

Bureau Responsible for Providing Necessary Support: The logistical and support services for the meetings of the AMWG shall be provided by the Bureau of Reclamation (Reclamation).

Estimated Annual Operating Costs: The operating costs are estimated at $200,000 annually for the establishment and support of the AMWG. This includes costs for required staff support, Reclamation staff and AMWG members, and expenses incurred in the recording and reproduction of meeting minutes, reports, notices, etc.

Description of Duties: The duties or roles and functions of the AMWG are in an advisory capacity only. They are to:

a. Establish AMWG operating procedures.

b. Advise the Secretary in meeting environmental and cultural commitments of the Record of Decision.

c. Recommend the framework for the AMP policy, goals, and direction.

d. Define and recommend resource management objectives for development and implementation of a long-term monitoring plan, and any necessary research and studies required to determine the effect of the operation of Glen Canyon Dam on the values for which the Grand Canyon National Park and Glen Canyon National Recreation Area were established, including but not limited to natural and cultural resources, and visitor use.

e. Review and provide input on the report required in Section 1804 (c)(2) of the Act to the Secretary, the Congress, and the Governors of the Colorado River Basin States. The report will include discussion of dam operations, the operation of the AMP, status of resources, and measures taken to protect, mitigate, and improve the resources defined in the Act.

f. Annually review long-term monitoring data to determine the status of resources and whether the AMP Strategic Plan goals and objectives are being met. If necessary, develop recommendations for modifying the GCDEIS ROD, associated operating criteria, and other resource management actions pursuant to the Grand Canyon Protection Act.

g. Facilitate input and coordination of information from stakeholders to the Secretary to assist in meeting consultation requirements under Sections 1804 (c)(3) and 1805 (c) of the Act.

h. Monitor and report on compliance of all program activities with applicable laws, permitting requirements, and the Act.

Allowances for Committee Members (compensation, travel, per diem, etc.) While engaged in the performance of official business at AMWG and AMWG sub-group meetings (regular, ad hoc, and Protocol Evaluation Panel meetings) away from home or their regular places of business, all

AMWG members or AMWG sub-group members shall, upon request, be reimbursed for travel expenses in accordance with current Federal travel regulations.

Estimated Number and Frequency of Meetings: The AMWG is expected to meet biannually. The Secretary's designee, who will serve as the Designated Federal Official, may call additional meetings as deemed appropriate. Fifteen members must be present at any meeting of the AMWG to constitute a quorum.

In accordance with FACA, a notice of each meeting of the AMWG shall be published in the Federal Register at least 15 days prior to the meeting advising the date, time, place, and purpose of the meeting. If it becomes necessary to postpone or cancel an announced meeting, a subsequent notice shall be published in the Federal Register as early as possible and shall explain the reasons for the postponement or cancellation. A news release for each meeting, postponement, or cancellation shall also be provided to selected major newspapers in Arizona, California, Colorado, Nevada, New Mexico, Wyoming, and Utah. News releases shall also be provided to agencies and organizations expressing interest in publishing meeting announcements in newsletters.

In accordance with FACA, all meetings of the AMWG shall be open to the general public. Any organization, association, or individual may file a written statement or, at the discretion of the AMWG, provide verbal input regarding topics on a meeting agenda in accordance with FACA.

The minutes of each AMWG meeting; reports; related documents; and copies of all documents received, issued, or approved by the AMWG shall be available for public inspection and duplication during regular business hours within 30 working days after the meeting at the:

Upper Colorado Regional Office
Bureau of Reclamation
125 South State Street, Room 6107
Salt Lake City, Utah 84138-1102
(801) 524-3880

Termination Date: It is the intent that the AMWG shall continue indefinitely, unless otherwise terminated by the Secretary. The committee is subject to the provisions of the Federal Advisory Committee Act (FACA), 5.U.S.C. Appendix 2, and will take no action unless the charter filing requirements of section 9 of FACA have been complied with. The Committee is subject to biennial review and will terminate 2 years from the date the charter is filed, unless, prior to that time, the charter is renewed in accordance with Section 14 of the FACA.

Committee Membership: Members of the AMWG to be appointed by the Secretary shall be comprised of:

a. Secretary's Designee, who shall serve as chairperson for the AMWG.

b. One representative each from the 12 cooperating agencies associated with the EIS:

(1) Bureau of Reclamation
(2) Bureau of Indian Affairs
(3) U.S. Fish and Wildlife Service
(4) National Park Service
(5) Western Area Power Administration
(6) Arizona Game and Fish Department
(7) Hopi Tribe
(8) Hualapai Tribe
(9) Navajo Nation
(10) San Juan Southern Paiute Tribe
(11) Southern Paiute Consortium
(12) Pueblo of Zuni

c. One representative each from the seven basin states:

(1) Arizona
(2) California
(3) Colorado
(4) Nevada
(5) New Mexico
(6) Wyoming
(7) Utah

d. Two representatives each from:

(1) Environmental groups
(2) Recreation interests
(3) Contractors who purchase Federal power from Glen Canyon Powerplant

Members will be appointed to the AMWG by the Secretary, with input and recommendations from the cooperating agencies, States, tribes, contractors for Federal power from Glen Canyon Dam, environmental representatives, and other stakeholders. To be eligible for appointment to the AMWG, a person must (a) be qualified through education, knowledge, or experience to give informed advice on water supply, diversion and delivery facilities, and their operation and management, or the environmental aspects of such operation; and (b) have the capability to

constructively work in a group setting toward a common objective of structuring a mechanism for program implementation.

Members of the AMWG will be appointed for a 4-year term. At the discretion of the Secretary, members may be reappointed to additional terms. Vacancies occurring by reason of resignation, death, or failure to regularly attend meetings will be filled by the Secretary for the balance of the vacating member's term using the same method by which the original appointment was made.

Failure of an organization to be represented at two consecutive meetings will substantiate grounds for dismissal. The Chairperson will make the final determination in dismissing a member.

To avoid conflict of interest issues arising from entities, including Federal agencies, having representatives on the AMWG and also submitting responses to request for proposals to perform work, the Federal procurement process shall be strictly adhered to. While members of the AMWG may give advice to the Secretarial Designee, all decisions in the procurement process shall be made by Federal procurement officials free of influence from AMWG members.

Subgroups: The committee may establish such workgroups or subcommittees as it deems necessary for the purposes of compiling information, discussing issues, and reporting back to the AMWG.

Authority: The Grand Canyon Protection Act (Act) of October 30, 1992, embodied in Public Law 102-575, directs the Secretary of the Interior (Secretary), among others, to operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in section 1804 of the Act and to exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and the Glen Canyon National Recreation Area were established, including but not limited to the natural and cultural resources and visitor use. The Secretary shall implement this section in a manner fully consistent with and subject to Section 1802 of the Act. Section 1805 of the Act calls for implementation of long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802.

Bruce Babbitt
Secretary of the Interior

January 10, 2001
Date signed

January 10, 2001
Date Filed

APPENDIX D - AMWG OPERATING PROCEDURES

Appendix D

# GLEN CANYON DAM
# ADAPTIVE MANAGEMENT WORK GROUP
# OPERATING PROCEDURES

## FOREWORD

The Grand Canyon Protection Act (Act) of October 30, 1992, (Public Law 102-575) directs the Secretary of the Interior (Secretary) to "establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of section 1802" of the Act. "The monitoring programs and activities shall be established and implemented in consultation with the Secretary of Energy; the Governors of the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming; Indian tribes; and the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam." In order to comply with the consultation requirement of the Act, the Glen Canyon Dam EIS recommended formation of a Federal Advisory Committee. To fulfill this requirement the Glen Canyon Adaptive Management Work Group (AMWG) has been established. The AMWG Charter imposes the following criteria: (1) the AMWG shall operate under the Federal Advisory Committee Act (Public Law 92-463); (2) the Chairperson shall be designated by the Secretary; (3) the Secretary's Designee, shall also serve as the Designated Federal Official under the Federal Advisory Committee Act; (4) the Bureau of Reclamation will provide the necessary support in taking accurate minutes of each meeting; and (5) the AMWG shall continue in operation until terminated or renewed by the Secretary of the Interior under the Federal Advisory Committee Act.

## OPERATION

1. Meetings. The AMWG is expected to meet semiannually. The Secretary's Designee may call additional meetings as deemed appropriate. A minimum of one meeting will be held annually. All meetings shall be announced by notice in the Federal Register and by news release to local newspapers.

Fifteen members must be present at any meeting of the AMWG to constitute a quorum.

Robert's Rules of Order will be generally followed, except that some flexibility will be allowed as needs dictate.

The Bureau of Reclamation is responsible for arranging meetings and for other duties associated with operation of the AMWG. They will arrange for meeting location, provide staff for the Designee, minutes, Federal Register Notices and other operational requirements of the AMWG.

Meetings of the AMWG shall be held in the following locations: Flagstaff, Las Vegas, Phoenix, and Salt Lake City. Meetings shall be rotated between the four sites as decided upon by the work group.

2. Chairperson. The Chairperson will be the Secretary's Designee, who will preside over the meetings of the AMWG. In the absence of the Chairperson, the Chairperson will appoint an alternate. The Chairperson will designate an alternate who is a member of the Department of the Interior. The Chairperson or designated alternate must be present before a meeting of the AMWG may convene. The Chairperson or his alternate is authorized to adjourn an AMWG meeting at any time.

3. Members. Membership shall follow the guidelines in the AMWG Charter. Members of the AMWG will be designated by the Secretary of the Interior. They shall serve for a term of four years. Members may be re-designated to serve for more than one term.

4. Alternate Committee Members. Each AMWG member may designate an alternate to serve for the same term as the member. Alternates must be identified to the Chairperson in writing. If the alternate is to represent the member at any AMWG meeting, the member will so notify the chairperson 1.5 days prior to such meeting. Alternates must meet the same qualifications as the member. Alternates will have authority to participate in AMWG business, including quorum and voting privileges. Representation by an alternate does not satisfy the minimum personal attendance requirement of the member as described in the Charter. A list of members and alternates shall be maintained and made available to AMWG members.

5. Agenda. At least thirty days prior to any meeting of the AMWG, a draft of the proposed agenda and related information will be sent to the group members. Members shall review the agenda and return comments and proposed agenda items to the Designee within two weeks of the agenda mailing date. The final agenda will be sent to the members 15 to 30 days prior to the meeting. The Secretary's Designee shall approve the agendas.

6. Voting. The maker of a motion must clearly and concisely state and explain his or her motion. Motions may be made verbally or submitted in writhing in advance of the meeting. Notice of motions to be made by any member of the AMWG should be announced in the Federal Register and presented on the agenda. Motions may be proposed by any member in meetings where they are related to an agenda topic. After a motion there should be presentations by staff followed by a discussion and a call for questions. The public will be given opportunity to comment during the question period as allowed by the Chairperson. Any member of the public asked to address the AMWG, shall have a minimum of 2 minutes to comment. The Chairperson can limit the total time allowed to the public for comments. Comments shall address the motion and not be repetitive to presentations, group discussions or other comments previously presented. The motion must be fully documented for the minutes and restated clearly by the Chairperson before a vote is taken.

The group should attempt to seek consensus but, in the event that consensus is not possible, a vote should be taken. Voting shall be by verbal indication or by raised hand. Approval of a motion will require a two-thirds majority of members present and voting. The views of any dissenting member or minority group shall be transmitted to the Secretary along with the majority recommendation. Voting shall occur only with the formal meetings of the group.

7. Minutes. Detailed minutes of each meeting will be kept. The minutes will contain a record of persons present and a description of pertinent matters discussed, conclusions reached, and actions taken on motions. Minutes shall be limited to approximately 5 to 15 pages. The corrections and adoption of the minutes will be by vote of the AMWG at the next subsequent meeting. The Secretary's Designee shall approve all minutes. The Bureau of Reclamation is responsible for recording and disseminating minutes to AMWG members within 60 days of the subject meeting.

8. Public Involvement. No later than fifteen days prior to each meeting of the AMWG or any subcommittee thereof, a notice will be published in the Federal Register. Meetings will be open to the public and advertised in local newspapers. Interested persons may appear in person, or file written statements to the AMWG. Public comments can be on any issue related to operation of the Glen Canyon Dam. A specific time for public comment will be identified in the agenda. Advance approval for oral participation may be prescribed, and speaking time may be limited. Minutes of the AMWG meetings and copies of reports submitted to the AMWG will be maintained for public review at the Bureau of Reclamation's Upper Colorado Regional Office in Salt Lake City, Utah and at the Library of Congress in Washington, D.C.

9. Payment of Travel. Members of the AMWG may receive compensation for travel expenses, including travel and per diem. Compensation for those expenses will be made under relevant federal guidelines. Alternates representing the official committee member may also receive compensation for travel expenses.

10. Open/Closed Meetings. If any member proposes discussion of a sensitive issue felt to require a closed session, he or she should so state in a proposal submitted to AMWG members in sufficient time to include it in the agenda published in the Federal Register Notice announcing the next meeting. A closed executive session may be held during a regular meeting, but should be used rarely. Any sensitive cultural issues will require consultation with Native Americans prior to meeting.

Telephone conference meetings must have a notice in the Federal Register 15 days prior to the call. There must be adequate opportunity for the general public to listen to the conference call.

The AMWG may conduct business outside of formal meetings through telephone polls conducted by the Chairperson or his/her designee. In emergency situations, telephone polls can be requested by the AMWG member to act on clearly defined written motions for AMWG approval. Following approval by the Chairperson, a telephone poll will be conducted within 7 working days. During a telephone poll, all members will be contacted and requested to vote. Approval of a motion will be by at least a two-thirds majority of all members voting. The Chairperson is responsible for documenting in writing how each member voted and distributing the record to all AMWG members.

11. Reports and Record Keeping. The Annual Report (AR) required by the Grand Canyon Protection Act shall be written by the AMWG. The State of the Natural and Cultural Resources in the Colorado River Ecosystem report developed by the Grand Canyon Monitoring and Research Center will be attached to the AR and shall contain information on the condition of the resources

impacted by the operation of Glen Canyon Dam. The AR shall be concise, containing critical resource issues and recommendations to the Secretary on future dam operations.

AMWG staff will supply GSA the required information to complete the summary report for Federal Advisory Committees.

12. Committee Expenses and Cost Accounting. An accounting of the expenses for operation of the AMWG shall be maintained by Reclamation. Expenses and other information will be submitted to GSA as required by FACA. Committee expenses are limited to approximately $154,000 annually.

**SUB-GROUPS**

1. Formation. -The AMWG may form sub-groups in order to facilitate the mission of the AMWG as identified in the Act and the AMWG Charter. Sub-groups will be formed for completion of specific tasks or for specified periods of time. Sub-group members will be named by the members of the AMWG. Upon formation of a sub-group, the Chairperson of the AMWG, with the advice of AMWG members, will approve nominated members to serve on the sub-group. Effort shall be made to keep sub-groups small. Sub-groups will be formed or dissolved by a vote of the AMWG.

2. Requirements. -Sub-groups may choose their chairperson from among the AMWG named sub-group members. The chairperson of any sub-group may convene group meetings at his or her discretion. Sub-groups may develop their own operating procedures. Sub-group meetings must follow requirements of FACA, except they need not be chartered and members need not be appointed by the Secretary. One standing sub-group or subcommittee of the AMWG will be the Glen Canyon Technical Work Group (TWG). The TWG membership shall consist of one representative names from each organization represented in the AMWG, with the exception that two members from the National Park Service representing the Grand Canyon National Park and the Glen Canyon Recreational Area, and one representative from the US Geological Survey. All sub-groups will elect their own officers. Names of all sub-group members will be announced to the AMWG at regular meetings and will be attached to the minutes. Sub-group members may designate alternates subject to approval of the Designee and the AMWG.

3. Charge. -Sub-groups will receive their charges from the AMWG. Sub-groups will work only on issues assigned them by the AMWG. They will not be empowered to follow other issues on their own. They are encouraged to submit issues to the AMWG they feel worthy of consideration and discussion, but the AMWG must approve work on all new issues. The AMWG may require the sub-groups to develop plans and direct them to come to a consensus or majority opinion at their discretion. Sub-groups shall determine their own operating procedures, which must be reduced to writing and included with the AMWG and sub-group records.

4. Reporting. - Sub-groups will report at least annually to the AMWG at the request of the Chairperson. Sub-groups shall report only to the AMWG. They shall provide information as necessary for preparing annual resource reports and other reports as required for the AMWG.

5. Ad Hoc Groups. Ad hoc groups shall consist of members of the sub-group only. These groups may meet to discuss assignments from the sub-group. Ad hoc meetings will not require federal register notices. Minutes are recommended but, not required. Ad hoc groups shall report only to the main body of the sub-group. On a case by case basis the AMWG will provide direction to the subgroups on the flexibility they have in forming Ad hoc groups.

Adopted by vote of the TWG on January 16, 1998 in Phoenix, Arizona.

Approved: Stephen V. Magnussen — June 18, 1998

Chairperson — Date

APPENDIX E - TWG OPERATING PROCEDURES

Appendix E

# GLEN CANYON DAM TECHNICAL WORK GROUP OPERATING PROCEDURES

## FOREWORD

The Grand Canyon Protection Act (Act) of October 30, 1992, (Public Law 102-575) directs the Secretary of the Interior (Secretary) to "establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of section 1802" of the Act. "The monitoring programs and activities shall be established and implemented in consultation with the Secretary of Energy; the Governors of the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming; Indian tribes; and the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors for the purchase of Federal power produced at Glen Canyon Dam." In order to comply with the consultation requirement of the Act, the Glen Canyon Dam EIS recommended formation of a Federal Advisory Committee and a Technical Work Group. To fulfill this requirement the Glen Canyon Adaptive Management Work Group (AMWG) was established. The AMWG held their first meeting on September 10-11, 1997 and officially formed the Glen Canyon Technical Work Group (TWG) as a subgroup. This group is comprised of technical representatives who represent the various stakeholders on the AMWG. The TWG shall perform those tasks charged to them by the AMWG. Additional responsibilities of the TWG are to develop criteria and standards for monitoring and research programs; provide periodic reviews and updates; develop resource management questions for the design of monitoring and research by the Grand Canyon Monitoring and Research Center; and provide information, as necessary, for preparing annual resource reports and other reports, as required, for the AMWG. The TWG shall comply with all regulations of the Sunshine Act and the Federal Advisory Committee Act pertaining to sub-committees. (See 41 CFR 101-6.10 Federal Advisory Committee Management). Staff resources for the TWG shall be provided by the Grand Canyon Monitoring and Research Center and Reclamation.

## OPERATION

1. Meetings. - TWG meetings will be held quarterly or more frequently as required. Where possible meetings will be scheduled 2-3 months in advance. Information will be provided to all interested parties. The Bureau of Reclamation (Reclamation) will be responsible for submitting meeting notices to be published in the Federal Register 15 days prior to meetings. Federal register notices may provide information on up to 3 meetings at a time. The Chairperson will draft a reminder meeting notice to the TWG members and the staff will distribute it at least 10 days prior to the meeting. Meeting format will be in accordance with these Operating Procedures. Sixteen members must be present at any meeting of the AMWG to constitute a quorum.

2. Officers. - The TWG will elect its own officers. The Chairperson will be elected for a 1-year term and selected by a vote of the TWG. The elected chairperson shall have the option of appointing an alternate member to represent the stakeholder for the term of the chairperson, however, the

stakeholder shall have only one vote. With the recommendation of the TWG, compensation for the chairperson may be provided from Adaptive Management Program (AMP) funds. A Vice-chair will be selected to assist the Chairperson and will be an employee of Reclamation to ensure requirements of federal regulations are met and to provide assistance. Reclamation and GCMRC will provide staff and meeting resources. Reclamation shall be responsible for, and shall assure compliance with, the applicable federal regulations including those referenced above. The Chairperson shall be elected in the December meeting of the TWG or the meeting prior to the first calendar year meeting of the AMWG. The new Chairperson will take office at the first meeting of the TWG following the first meeting of the AMWG of the year.

Chair responsibilities:

Attend all TWG and AMWG meetings when possible.

Facilitate TWG meetings by leading discussions, arranging for an outside facilitator when required, and inviting input from TWG members, technical experts, and the public.

Organize or disband Ad Hoc task groups per TWG direction.

Ensure recognition of consensus or voting on decision items as appropriate, including development of minority opinion papers when consensus cannot be reached.

Present overview of TWG activities and recommendations at AMWG meetings.

Vice-Chair responsibilities include:

Attend all TWG and AMWG meetings when possible.

Assist the chairperson in facilitating the TWG meetings, ensuring that action items, responsible parties, and future agenda items are summarized and reviewed with the group by close of meeting.

Contact speakers, ad hoc committee chairpersons, and other contributors at least three weeks before the next TWG meeting to review assignments and determine how much time should be allotted for their presentations.

Prepare draft agenda for next meeting and provide review copies by E-mail to co-chairperson, GCMRC program managers, and speakers about three weeks before the next meeting. Finalize agenda and send to co-chairperson two weeks before meeting.

Track and coordinate contributions of products for TWG/AMWG review with stakeholders, GCMRC, ad hoc groups, and others.

Ensure complete meeting preparations (meeting room, motel, audio visual equipment, recording of minutes, etc.)

Review and distribute TWG products to AMWG.

3. Grand Canyon Monitoring and Research Center (GCMRC)

Develop GCMRC planning documents for TWG review.

Provide scientific opinions, documents, presentations, and reviews of TWG documents.

Develop research designs and proposals for implementing monitoring and research identified by the AMWG, including draft budget estimates.

Provide scientific information and updates to the TWG for all resources of concern identified in the EIS. Coordinate, prepare, and distribute technical reports and documentation for review and as final products.

Prepare and forward technical management recommendations and annual reports as specified in Section 1804 of the GCPA to the TWG.

4. Members. - The TWG membership shall consist of one representative named from each organization represented in the AMWG, with the exception of two members from the National Park Service representing the Grand Canyon National Park and the Glen Canyon Recreational Area, and one representative from the U.S. Geological Survey. The TWG organizational membership was nominated by the AMWG, with the USGS representative having been nominated by the Secretary's Designee. Members were selected by the respective organization's representatives. A list of TWG members will be distributed to the AMWG at regular meetings. TWG members may designate alternates.

5. Alternate Committee Members. Alternates shall be designated by TWG members. Members can designate an alternate for any TWG or Ad Hoc group meeting they will be unable to attend, or for which the alternate is better prepared to represent the organization's interests. Alternates shall sign-in on the attendance sheet noting that they are the alternate to the official member. The officially designated alternate, in the absence of the member, is allowed to fully participate and vote in TWG meetings without prior notification and be counted in the quorum.

6. Agenda. - Members, and others, requesting an item be added to the agenda should notify the Chairperson in writing (by mail, fax, or E-mail) at least 15 days prior to the meeting. The following information should be provided with each request: a discussion topic or title, the nature of the topic (e.g., sharing of information, discussion of an issue, or a proposed action), name(s) of the presenter(s), total amount of time required for presentation, and any other relevant points for meeting planning. The agenda will be finalized when the schedule is filled or when the pre-meeting briefing documents are distributed. Requests received after the agenda is finalized may be considered under new business (time permitting), or may have to be postponed until a future meeting. An agenda will be prepared and approved by the Chairperson and forwarded to the TWG meeting recorder. The meeting recorder will distribute the final agenda (by e-mail and/or by other means) to the TWG members and others on the distribution list. Reclamation is responsible for compliance with federal

regulations. Reclamation will include in the Federal Register Notice: meeting dates, times, location, and a list of meeting agenda items.

7. Guidelines for Discussions. - The following ground rules will guide all discussions while the meeting is in session: Members will endeavor to arrive, return from breaks, and depart the meeting on schedule. Any person needing to continue private discussions after the meeting has been called to order will take their business outside the conference room. Members, alternates, and visitors wishing to address the TWG will wait to be recognized by the Chairperson or designated discussion leader before speaking. Speakers will make their points succinctly and yield the floor to the next speaker, waiting to again be recognized for rebuttals. Comments are to be applicable to the motion and not repetitive to presentations, group discussion or other comments previously presented. Discussions of new or unrelated business will be postponed until the appointed time on the agenda.

8. Voting. - The maker of a motion must clearly and concisely state and explain their motion. Motions may be made verbally or submitted in writing in advance of the meeting. Motions may be proposed by a member in meetings where they are related to an agenda topic. After a motion and a second to the motion there shall be presentations by staff, where they are necessary or desired. Presentations shall be followed by discussion and a call for questions. The public will be given opportunity to comment during the question period as provided for in these operating procedures. Any member of the public who has asked to address the TWG, shall be provided a reasonable time to comment. The Chairperson may limit the total time allowed to the public for comments. Comments shall be applicable to the motion and not be repetitive of prior presentations, group discussions, or other comments. The motion shall be fully documented for the minutes and restated clearly by the Chairperson before seeking a determination of consensus or a vote is taken.

Consensus is the desired result. All reasonable efforts will be made to bring the group to a consensus decision or recommendation, including, for example, formation of ad hoc groups. If consensus cannot be achieved, a vote will be taken on motions and recommendations to be forwarded to the AMWG. Only members of the TWG or their alternate may vote. A majority recommendation will go forward along with a minority opinion report (containing the alternate recommendation and identification of who constitutes the minority). Ad hoc groups consisting of the dissenting members may be formed as needed to prepare minority opinions. Each appointed TWG representative is expected to explain and/or clarify issues to their respective AMWG member.

Recommendations to the TWG or AMWG will be summarized in report form, will contain relevant background material on the issues, and will include a brief summary of previous discussions related to the issue (e.g., ad hoc group or TWG discussions). Requests for actions associated with a briefing document will be posed as a specific written recommendation that can be approved as written, approved with modification, or not approved. Reports and recommendations forwarded to the AMWG will be identified as having been approved through consensus of the entire TWG, except when a minority opinion is submitted to the Chairperson in writing prior to the agreed date for forwarding TWG recommendations to the AMWG (generally 60 days before the next AMWG meeting). Members subscribing to the minority opinion will be listed in the minority report, which shall follow the same format outlined above for the consensus or majority report. The TWG

Chairperson may invite a representative of the minority group to present the minority opinion to the AMWG.

9. Ad Hoc Groups and Meetings. - Ad hoc groups can be formed by the TWG as needed with membership consisting of TWG members and alternates only. Groups may invite technical advisors outside the TWG membership to assist on some issues. These groups may meet to discuss assignments from the TWG. Ad hoc meetings will not require federal register notices. Minutes are recommended, but not required. Ad hoc groups shall report of their deliberations and findings to the TWG. Presentations of findings from Ad Hoc groups may be given by individual members of the group. Ad hoc groups shall report only to the main body of the TWG. The AMWG may provide direction to the TWG on the flexibility they have in forming ad hoc groups. Ad hoc groups shall be formed by the consensus or vote of the TWG and shall terminate as soon as the assigned task is completed.

10. Minutes, Reports, and Record Keeping. - Minutes will be recorded by TWG staff support from Reclamation. Minutes will address the key topics of the TWG meetings including proposals, motions, voting/approval of motions, majority/minority opinions, public comments, presentations, findings from ad hoc groups, and other pertinent information. Minutes will not be a complete transcript of the discussions. An audio tape recording of the meeting will be kept for each meeting. The corrections and adoption of the minutes will be reached by consensus of the TWG at the following meeting.

Minutes, attachments, agendas, and materials for upcoming TWG meetings will be distributed according to the schedule below:

A. Submittal of materials for upcoming TWG Meetings.

| 15 Business Days Prior to TWG Mtg: | Responsible Person | Submit To |
|---|---|---|
| _Agenda items | Committee Members | Chairman |
| _Materials for duplication & dist. | Committee Members | Staff |

TWG members responsible for materials for an upcoming meeting shall forward them to the designated staff member in time to be included with the distribution which will occur 10 days prior to the meeting. Materials may be provided via e-mail or hard copy. Where copies of material are not provided to the designated staff member in time for normal distribution, the person or organization will be responsible for making their own copies and bringing them to the meeting. They may either: (1) e-mail, fax or other means; (2) duplicate prior to and distribute at the meeting. Staff, members, and public providing materials for distribution at the meeting should bring at least 40 copies. Meeting documents distributed at the meeting are to be provided first to the meeting recorder, TWG members, and the GCMRC Chief. Copies of all handouts will be placed in a designated location for official visitors and the public. If action is anticipated to be taken on or as a result of that material, all reasonable effort will be made to provide those materials to the members in advance of the meeting. In the event materials are not provided in advance of the meeting, action on this topic may be delayed at the Chairperson's discretion. Individuals making presentations at TWG meetings shall

notify TWG staff of any special audio visual equipment or supply needs at least two weeks before the meeting.

A mailing list containing members' mailing addresses, phone numbers, fax numbers, and E-mail addresses, as appropriate, will be maintained and distributed as needed. Updates will be prepared and the list re-distributed as appropriate. A copy of the roster of TWG members or alternates attending any meeting of the TWG shall be attached to the minutes, and shall include a list of all others in attendance.

B. Meeting material distribution to TWG members

| 10 Calendar Days Prior to TWG Meeting: | Responsible: |
|---|---|
| _Minutes and attachments from the previous meeting | Staff |
| _Agenda for the upcoming meeting | Staff |
| _Materials needed for the upcoming meeting | Staff |

E-mail, regular mail, or other means shall be used for the distribution.

Reclamation will be responsible for reports and distribution of materials to AMWG, and providing copies of information to the Library of Congress. The TWG shall assist GCMRC in preparation of the draft Annual Report to Congress pursuant to the Grand Canyon Protection Act.

Minutes, documentation from meetings, and reports shall be made available to the public at the Library of Congress in Washington, D.C. and the Upper Colorado Regional Office of the Bureau of Reclamation in Salt Lake City, Utah.

11. Arranging meetings and other duties associated with operation of the TWG. - Where possible, meetings will be scheduled 2-3 months in advance. All meetings shall also have a Federal Register Notice published 15 days or more in advance of any meeting. Meeting locations will be determined by the group in a preceding meeting. The staff will arrange meeting rooms and audio visual equipment, and block a number of hotel guest rooms. Meeting rooms will be arranged so that each of the 26 TWG members can be seated around the table. Alternates representing an absent TWG member should take their place at the table. Additional seating will be provided around the margin or rear of the room for alternates who are attending with the member, for official visitors and for the general public.

12. Public, Visitors, and Open and Closed Meetings. - All meetings are open to the public. It is not anticipated the group will require closed sessions unless a provision is made to do so. Only members of the TWG or their alternate may participate in discussions of the group. Appropriate staff of Reclamation and the GCMRC shall provide pertinent information from their organization to respond to questions or make presentations when approved by the group. The public will be allowed to comment after discussion of each agenda item requiring a decision of that group and at the end of the TWG meeting or as provided in the agenda. Each person will be given up to 10 minutes to address

the TWG members at the time specified on the agenda for public comment. Greater consideration will be given to individuals submitting discussion issues and/or requesting time in advance of the meeting to the Chairperson. The Chairperson will control adherence to the time limit so the meeting is not unduly prolonged. Each speaker will be expected to provide their name and affiliation for the meeting minutes. The Chairperson will accept written comments from the public, and will allow their distribution if copies are available for all members (40 copies required). Written comments will be attached to the meeting minutes if they are identified with the name, address, and affiliation of the provider.

Adopted by vote of the TWG on _____, Phoenix, Arizona.

Approved: Rick Johnson
Chairperson

2 Mar 00
Date

APPENDIX F - ESA

## Appendix F

## Endangered Species Act Compliance

In brief, to comply with the Endangered Species Act, an evaluation of the affects of any discretionary federal action must be conducted by the action agency in conjunction with informal consultation with the Fish and Wildlife Service. For minor activities, this can be limited to verbal communication. For a larger or more complex action, or for any major construction activity as defined, the action agency is required to prepare a biological assessment. The biological assessment describes the action and evaluates the affect to each species that may be present in the action area by comparing the current condition of the population and habitat to what it is expected to occur during and following the action. A determination is limited to either "no affect," which equates to no effect at all, positive, negative, or neutral, or to "may affect," which equates to any effect, positive, negative, or neutral. "May affect" can be further qualified with a determination of 'likely to adversely affect' or 'not likely to adversely affect.' A "may affect and is likely to adversely affect" determination triggers formal consultation with the Fish and Wildlife Service. A determination of "may affect and not likely to adversely affect" can be addressed with informal consultation with the Fish and Wildlife Service.

Any "may affect" determination triggers formal consultation which may result in either a "not likely to adversely affect" determination or issuance of a biological opinion. Once consultation is requested, the Fish and Wildlife Service has 90 days to render a biological opinion and an additional 45 days to write the biological opinion. The Fish and Wildlife Service usually prepares a draft biological opinion. The period of time that the draft is under review does not count toward the 135 days. Consultation is between the action agency, an applicant if there is one, and the Fish and Wildlife Service. If there is an affect on tribal lands or waters, the tribes must be consulted.

If the Fish and Wildlife Service determines that the proposed action will jeopardize the continued existence of the species by appreciably reducing the likelihood of both survival and recovery of the species in the wild by further reducing its number, reproduction, or distribution (the jeopardy threshold), they prepare a biological opinion which must contain a reasonable and prudent alternative. A reasonable and prudent alternative must be within the jurisdiction of the action agency, technologically and economically feasible, consistent with the original intended purpose of the project, and one that the Fish and Wildlife Service believes will remove jeopardy. The biological opinion must also contain an "incidental take" statement if any take is expected to occur, reasonable and prudent measures, and terms and conditions designed to reduce take and address adverse modification of designated critical habitat. The biological opinion can contain conservation measures, conservation recommendations, and other topics as well. Once the action agency receives the draft biological opinion, they may choose to share the document with other stakeholders (see March 1988 Consultation Handbook, Fish and Wildlife Service).

APPENDIX G - ROD

# Record of Decision

## Operation of Glen Canyon Dam

Final Environmental Impact Statement

October 1996

Approved

Eluid L. Martinez _____ Date OCT 08 1996
Commissioner, U.S. Bureau of Reclamation

Bruce Babbitt _____ Date OCT 09 1996
Secretary of the Interior

# RECORD OF DECISION

## OPERATION OF GLEN CANYON DAM
## FINAL ENVIRONMENTAL IMPACT STATEMENT

## I. INTRODUCTION

This record of decision (ROD) of the Department of the Interior, Bureau of Reclamation (Reclamation), documents the selection of operating criteria for Glen Canyon Dam, as analyzed in the final Environmental Impact Statement (EIS), dated March 21,1995 (FES 95-8). The EIS on the operation of Glen Canyon Dam was prepared with an unprecedented amount of scientific research, public involvement, and stakeholder cooperation.

Scientific evidence gathered during Phase I of the Glen Canyon Environmental Studies (GCES) indicated that significant impacts on downstream resources were occurring due to the operation of Glen Canyon Dam. These findings led to a July 1989 decision by the Secretary of the Interior for Reclamation to prepare an EIS to reevaluate dam operations. The purpose of the reevaluation was to determine specific options that could be implemented to minimize, consistent with law, adverse impacts on the downstream environment and cultural resources, as well as Native American interests in Glen and Grand Canyons. Analysis of an array of reasonable alternatives was needed to allow the Secretary to balance competing interests and to meet statutory responsibilities for protecting downstream resources and producing hydropower, and to protect affected Native American interests.

In addition, the Grand Canyon Protection Act of 1992 was enacted on October 30, 1992. Section 1802 (a) of the Act requires the Secretary to operate Glen Canyon Dam:

> "...in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use."

Alternatives considered include the No Action Alternative as well as eight operational alternatives that provide various degrees of protection for downstream resources and hydropower production.

## II. DECISION

The Secretary's decision is to implement the Modified Low Fluctuating Flow Alternative (the preferred alternative) as described in the final EIS on the Operation of Glen Canyon Dam with a minor change in the timing of beach/habitat building flows (described below). This alternative was selected because it will reduce daily flow fluctuations well below the no action levels (historic pattern of releases) and will provide high steady releases of short duration which will protect or enhance downstream resources while allowing limited flexibility for power operations.

The Modified Low Fluctuating Flow Alternative incorporates beach/habitat-building flows which are scheduled high releases of short duration designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system. In the final EIS, it was assumed that these flows would occur in the spring when the reservoir is low, with a frequency of 1 in 5 years.

The Basin States expressed concern over the beach/habitat-building flows described in the final EIS because of the timing of power plant by-passes. We have accommodated their concerns, while maintaining the objectives of the beach/habitat-building flows. Instead of conducting these flows in years in which Lake Powell storage is low on January 1, they will be accomplished by utilizing reservoir releases in excess of power plant capacity required for dam safety purposes. Such releases are consistent with the 1956 Colorado River Storage Project Act, the 1968 Colorado River Basin Project Act, and the 1992 Grand Canyon Protection Act.

Both the Colorado River Management Work Group and the Transition Work Group, which participated in the development of the Annual Operating Plan and the EIS, respectively, support this change as it conforms unambiguously with each member's understanding of the Law of the River. These groups include representatives of virtually all stakeholders in this process.

The upramp rate and maximum flow criteria were also modified between the draft and final EIS. The upramp rate was increased from 2,500 cubic feet per second per hour to 4,000 cubic feet per second per hour, and the maximum allowable release was increased from 20,000 to 25,000 cubic feet per second. We made these modifications to enhance power production flexibility, as suggested by comments received. These modifications were controversial among certain interest groups because of concerns regarding potential impacts on resources in the Colorado River and the Grand Canyom However, our analysis indicates that there would be no significant differences in impacts associated with these changes ("Assessment of Changes to the Glen Canyon Dam EIS Preferred Alternative from Draft to Final EIS", October 1995).

The 4,000 cubic feet per second per hour upramp rate limit will be implemented with the understanding that results from the monitoring program will be carefiXy considered. If impacts differing from those described in the final EIS are identified, a new ramp rate criterion will be considered by the Adaptive Management Work Group and a recommendation for action forwarded to the Secretary.

The maximum flow criterion of 25,000 cubic feet per second will be implemented with the understanding that actual maximum daily releases would only occasionally exceed 20,000 cubic feet per second during a minimum release year of 8.23 million acre-feet. 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. If impacts differing from those described in the final EIS are identified through the Adaptive Management Program, the maximum flow restriction will be reviewed by the Adaptive Management Work Group and a recommendation for action will be forwarded to the Secretary.

## III. DESCRIPTION OF ALTERNATIVES

Nine alternative methods of operating Glen Canyon Dam (including the No Action Alternative) were presented in the final EIS. The eight action alternatives were designed to provide a reasonable range of alternatives with respect to operation of the dam. One alternative would allow unrestricted fluctuations in flow (within the physical constraints of the power plant) to maximize power production, four would impose varying restrictions on fluctuations, and three others would provide steady flows on a monthly, seasonal, or annual basis. The names of the alternatives reflect the various operational regimes. In addition, the restricted fluctuating flow and steady flow alternatives each include seven elements which are common to all of them. These common elements are: 1) Adaptive Management, 2) Monitoring and Protecting Cultural Resources, 3) Flood Frequency Reduction Measures, 4) Beach/Habitat-Building Flows, 5) New Population of Humpback Chub, 6) Further Study of Selective Withdrawal, and 7) Emergency Exception Criteria. A detailed description of the alternatives and common elements can be found in Chapter 2 of the final EIS. A brief description of the alternatives is given below.

### UNRESTRICTED FLUCTUATING FLOWS

**No Action**: Maintain the historic pattern of fluctuating releases up to 31,500 cubic feet per second and provide a baseline for impact comparison.

**Maximum Power plant Capacity:** Permit use of full power plant capacity up to 33,200 cubic feet per second.

### RESTRICTED FLUCTUATING FLOWS

**High:** Slightly reduce daily fluctuations from historic levels.

**Moderate:** Moderately reduce day fluctuations from historic levels; includes habitat maintenance flows.

**Modified Low (Preferred Alternative):** Substantially reduce daily fluctuations from historic levels; includes habitat maintenance flows.

**Interim Low:** Substantially reduce daily fluctuations from historic levels; same as interim operations except for addition of common elements.

STEADY FLOWS

**Existing Monthly Volume**: Provide steady flows that use historic monthly release strategies.

**Seasonally Adjusted**: Provide steady flows on a seasonal or monthly basis; includes habitat maintenance flows.

**Year-Round**: Provide steady flows throughout the year.

Table I shows the, specific operational criteria for each of the alternatives.

## IV. SIGNIFICANT ISSUES AND ALTERNATIVES

The Glen Canyon Dam EIS scoping process was initiated in early 1990 and the public was invited to comment on the appropriate scope of the EIS. More than 17,000 comments were received during the scoping period, reflecting the national attention and intense interest in the EIS.

As a result of the analysis of the oral and written scoping comments, the following were determined to be resources or issues of public concern: beaches, endangered species, ecosystem integrity, fish, power costs, power production, sediment, water conservation, rafting/boating, air quality, the Grand Canyon wilderness, and a category designated as "other" for remaining concerns. Comments regarding interests and values were categorized as: expressions about the Grand Canyon, economics, nonquantifiable values, nature versus human use, and the complexity of Glen Canyon Dam issues.

The EIS team consolidated and refined the public issues of concern, identifying the significant resources and associated issues to be analyzed in detail. These resources include: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

Further meetings were held with representatives from the cooperating agencies and public interest groups who provided comments on the criteria for development of reasonable alternatives for the EIS. The public also had an opportunity to comment on the preliminary selection of alternatives at public meetings and through mailings. The final selection of alternatives took into consideration the public's views.

## V. COMMENTS RECEIVED ON THE FINAL EIS

Many comments and recommendations on the final EIS were received in the form of pre-printed postcards and letters that addressed essentially the same issues. The comments are summarized below along with Reclamation's responses.

COMMENT: **Maintain Draft EIS flows.** Modifying the upramp, rate and maximum flows

Table 1.—Operating limits of alternatives identified for detailed analysis

| | Unrestricted Fluctuating Flows | | Restricted Fluctuating Flows | | | | | Steady Flows | |
|---|---|---|---|---|---|---|---|---|---|
| | No Action | Maximum Powerplant Capacity | High | Moderate | Modified Low | Interim Low | Existing Monthly Volume | Seasonally Adjusted | Year-Round |
| Minimum releases (cfs)[1] | 1,000 Labor Day-Easter<br>[2]3,000 Easter-Labor Day | 1,000 Labor Day-Easter<br>[2]3,000 Easter-Labor Day | 3,000<br>5,000<br>8,000 depending on monthly volume, firm load, and market conditions | 5,000 | 8,000 between 7a.m. and 7 p.m.<br>5,000 at night | 8,000 between 7a.m. and 7 p.m.<br>5,000 at night | 8,000 | [3]8,000 Oct-Nov<br>8,500 Dec<br>11,000 Jan-Mar<br>12,500 Apr<br>18,000 May-Jun<br>12,500 Jul<br>9,000 Aug-Sep | Yearly volume prorated[4] |
| Maximum releases (cfs)[5] | 31,500 | 33,200 | 31,500 | 31,500 (may be exceeded during habitat maintenance flows) | 25,000 (exceeded during habitat maintenance flows) | 20,000 | Monthly volumes prorated | 18,000 (exceeded during habitat maintenance flows) | Yearly volume prorated[4] |
| Allowable daily flow fluctuations (cfs/24 hours) | 30,500 Labor Day-Easter<br>28,500 Easter-Labor Day | 32,200 Labor Day-Easter<br>30,200 Easter-Labor Day | 15,000 to 22,000 | ±45% of mean flow for the month not to exceed ±6,000 | [6]5,000<br>6,000 or 8,000 | [6]5,000<br>6,000 or 8,000 | [7]±1,000 | [7]±1,000 | [7]±1,000 |
| Ramp rates (cfs/hour) | Unrestricted | Unrestricted | Unrestricted up, 5,000 or 4,000 down | 4,000 up<br>2,500 down | 4,000 up<br>1,500 down | 2,500 up<br>1,500 down | 2,000 cfs/day between months | 2,000 cfs/day between months | 2,000 cfs/day between months |
| Common elements | None | None | Adaptive management (including long-term monitoring and research)<br>Monitoring and protecting cultural resources<br>Flood frequency reduction measures<br>Beach/habitat-building flows<br>New population of humpback chub<br>Further study of selective withdrawal<br>Emergency exception criteria | | | | | | |

1 In high volume release months, the allowable daily change would require higher minimum flows (cfs).
2 Releases each weekday during recreation season (Easter to Labor Day) would average not less than 8,000 cfs for the period from 8 a.m. to midnight.
3 Based on an 8.23-million-acre-foot (maf) year; in higher release years, additional water would be added equally to each month, subject to an 18,000-cfs maximum.
4 for an 8.23-maf year, steady flow would be about 11,400 cfs.
5 Maximums represent normal or routine limits and may necessarily be exceeded during high water years.
6 Daily fluctuation limit of 5,000 cfs for monthly release volumes less than 600,000 acre-feet; 6,000 cfs for monthly release volumes of 600,000 to 800,000 acre-feet; and 8,000 cfs for monthly volumes over 800,000 acre-feet.
7 Adjustments would allow for small power system load changes.

between the draft and final EIS has neither been open for public review nor subjected to serious scientific scrutiny. These changes should have been addressed in the draft EIS and made available for public comment at that time. Credible proof, based on the testing of a specific scientific hypothesis, that alterations in operating procedures at Glen Canyon Dam follow the spirit and intent of the Grand Canyon Protection Act needs to be provided. The burden of proof that there will be no impact on downstream resources rests with those proposing changes.

RESPONSE: The modification of the preferred alternative, which incorporated changes in the upramp rate and maximum flows, was made after extensive public discussion. The new preferred alternative was discussed as an agenda item during the May, June, August, and November 1994 public meetings of the Cooperating Agencies who assisted in the development of the EIS. A wide range of public interest groups received advance mailings and agendas and were represented at the public meetings. The environmental groups attending these meetings included: America Outdoors, American Rivers, Desert Flycasters, Environmental Defense Fund, Friends of the River, Grand Canyon River Guides, Grand Canyon Trust, Sierra Club, and Trout Unlimited. Meeting logs indicate that representatives from at least some of these groups attended all but the May meeting. In addition, approximately 16,000 citizens received periodic newsletters throughout the EIS process. This included a newsletter outlining the proposed changes issued several months prior to the final EIS. The environmental groups mentioned above were included on the newsletter mailing list.

Reclamation's research and analysis has been thorough with regards to changes in flows and ramping rates and potential impacts upon downstream resources. A complete range of research flows was conducted from June 1990 to July 1991. These included high and low fluctuating flows with fast and slow up and down ramp rates. Glen Canyon Environmental Studies Phase II identified cause and effect relationships between downramp rates and adverse impacts to canyon resources. However, no cause and effect relationships between upramp rates and adverse impacts to canyon resources were identified. The draft EIS, (a public document peer reviewed by GCES and the EIS Cooperating Agencies) states that upramp rates have not been linked to sandbar erosion (page 95) and that "Rapid increases in river stage would have little or no effect on sandbars." (page 190).

With respect to potential impacts occurring with the change in flows, it should be noted that sand in the Grand Canyon is transported almost exclusively by river flows. The amount of sand transported increases exponentially with increases in river flow. Maintaining sandbars over the long term depends on the amount of sand supplied by tributaries, monthly release volumes, range of flow fluctuations, and the frequency and distribution of flood flows. Conversely, occasional flows between 20,000 and 25,000 cubic feet per second may cause minor beach building, and may provide water to riparian vegetation.

As part of the EIS, the effects of each alternative on long-term sand storage in Marble Canyon (river miles 0 to 61) were analyzed. The Marble Canyon reach was chosen for analysis because it is more sensitive to impacts from darn operations than downstream reaches. For each fluctuating flow alternative, the analysis used 20 years of hourly flow modeled by Spreck Rosekrans of the Environmental Defense Fund and 85 different hydrologic scenarios (each representing 50 years of

monthly flow data). This analysis was documented in the draft EIS on page 182, and Appendix D, pages 4-5. The analyses relating to the probability of net gain in riverbed sand for each alternative is documented in the draft EIS on pages 54-55, 184, 187, and 194.

Specific peer reviewed studies relating to the above analyses are listed in Attachment 1.

COMMENT: **Do not change the upramp rate and maximum flow criteria at the same time.** While acknowledging Reclamation's good efforts to identify and establish optimum operating criteria for all users of Glen Canyon Dam, changing two flow criteria (upramp rate and maximum flow criterion of preferred alternative) does not make prudent scientific sense. It will not result in reliable data. Not enough information is at hand to predict the outcome of these proposals.

**RESPONSE**: Viewed from the purely scientific viewpoint, it would be preferable to change variables one at a time in a controlled experiment. However, many uncontrolled variables already exist, and from a resource management standpoint the interest lies in measuring the possible resource impact, if any, which might result from jointly changing both criteria. The best available information suggests that the long-term impact of changing both criteria at once will be difficult, if not impossible to detect.

Even though both parameters would change, for 8 months of an 8.23 million acre foot year (minimum release year), only the upramp rate will be used. The ability to operationally exceed 20,000 cubic feet per second only exists in months in which releases are in excess of 900,000 acre feet. In a minimum release year, flows above 20,000 cubic feet per second will most likely occur in December, January, July, and August. Evaluation of the upramp rates can be initiated immediately with the evaluation of the increase in maximum flow relegated to the months with the highest volumes. New upramp and maximum flow criteria would be recommended through the Adaptive Management Program should monitoring results indicate that either of these criteria are resulting in adverse impacts to the natural, cultural, or recreational (human safety) resources of the Grand Canyon differing from those shown in the final EIS.

COMMENT: **"Habitat/Beach Building Floods" designed to redeposit sediment and reshape the river's topography much like the Canyon's historic floods should be conducted.**
An experimental release based on this premise is critical to restore some of the river's historic dynamics; without it, any flow regime will result in continued loss of beach and backwater habitat. This "spike" should be assessed and implemented for the spring of 1996, subject to a critical evaluation of its flow size, timing, impact on fisheries, and completion of a comprehensive monitoring plan. Recent side-canyon floods underscore the need for restoring natural processes.

**RESPONSE**: Reclamation and the Cooperating Agencies continue to support this concept. The preferred alternative supports such a flow regime. A test flow was conducted this spring. The results of this flow are currently being analyzed. We expect to conduct more of these flows in the future.

**COMMENT**: Endorse the Fish & Wildlife Service's Biological Opinion and implement

experimental steady flows to benefit native fishes, subject to the results of a risk/benefit analysis now in progress.

**RESPONSE**: The preferred alternative provides for experimental steady flows through the Adaptive Management Program for the reasons put forth in the Biological Opinion.

**COMMENT**: Fund and implement immediately an Adaptive Management Program. This is the appropriate forum to address important issues. It is imperative that resource management rely on good science to monitor, and respond to possible adverse effects resulting from changes in dam operations.

**RESPONSE**: The preferred alternative provides for implementation of an Adaptive Management Program.

**COMMENT: Interior Secretary Babbitt should issue a Record of Decision by December 31, 1995,** and conduct an efficient and timely audit by the General Accounting Office as mandated by the Grand Canyon Protection Act.

**RESPONSE**: In compliance with the Grand Canyon Protection Act, Interior Secretary Babbitt could not issue the Record of Decision until considering the findings of the General Accounting Office. Those findings were issued on October 2, 1996.

**OTHER COMMENTS**: Another set of comments were received from municipalities and other power user groups. These letters made up about 3 percent of the total received and were essentially identical in content. Although the authors were not totally in agreement with the preferred alternative because of the reduction in peaking power, they believe it is a workable compromise. These letters characterized the final EIS as ". . a model for resolving complex environmental issues among divergent interests." They also urged the government to protect the integrity of the process, resist efforts to overturn the FEIS, and allow the scientists' assessment to stand, in as much as the Adaptive Management Process will give Reclamation an opportunity to evaluate the effects of operational changes over time and make modifications according to scientific findings.

**RESPONSE:** While the preferred alternative may not satisfy all interests, Reclamation believes it is a workable compromise and meets the two criteria set out in the EIS for the reoperation of the dam, namely restoring downstream resources and maintaining hydropower capability and flexibility.

A letter of comment from the Environmental Protection Agency (EPA) indicates that EPA!s comments on the draft EIS were adequately addressed in the final EIS. It also expresses their support for the preferred alternative.

Samples of the comment letters and cards, and a copy of EPA's comment letter are included as Attachment 2.

## VI. ENVIRONMENTAL COMMITMENTS AND MONITORING

The following environmental and monitoring commitments will be carried out under the preferred alternative or any of the other restricted fluctuating or steady flow alternatives described in the final EIS. A detailed description of these commitments can be found on pages 33 - 43 of that document. All practicable means to avoid or minimize environmental harm from the preferred alternative have been adopted.

1. **Adaptive Management**: This commitment includes the establishment of an Adaptive Management Workgroup, chartered in accordance with the Federal Advisory Committee Act; and development of a long-term monitoring, research, and experimental program which could result in some additional operational changes. However, any operational changes will be carried out in compliance with NEPA.

2. **Monitoring and Protection of Cultural Resources**: Cultural sites in Glen and Grand Canyons include prehistoric and historic sites and Native American traditional use and sacred sites. Some of these sites may erode in the future under any EIS alternative, including the no action alternative. Reclamation and the National Park Service, in consultation with Native American Tribes, will develop and implement a long-term monitoring program for these sites. Any necessary mitigation will be carried out according to a programmatic agreement written in compliance with the National Historic Preservation Act. This agreement is included as Attachment 5 in the final EIS.

3. **Flood Frequency Reduction Measures**: Under this commitment, the frequency of unanticipated floods in excess of 45,000 cubic feet per second will be reduced to an average of once in 100 years. This will be accomplished initially through the Annual Operating Plan process and eventually by raising the height of the spillway gates at Glen Canyon Dam 4.5 feet.

4. **Beach/Habitat-Building Flows:** Under certain conditions, steady flows in excess of a given alternative's maximum will be scheduled in the spring for periods ranging from I to 2 weeks. Scheduling, duration, and flow magnitude will be recommended by the Adaptive Management Work Group and scheduled through the Annual Operating Plan process. The objectives of these flows are to deposit sediment at high elevations, re-form backwater channels, deposit nutrients, restore some of the natural system dynamics along the river corridor, and help the National Park Service manage riparian habitats.

5. **New Population of Humpback Chub:** In consultation with the U.S. Fish and Wildlife Service (FWS), National Park Service, and Arizona Game and Fish Department (AGFD), Reclamation will make every effort (through funding, facilitating, and technical support) to ensure that a new population of humpback chub is established in the mainstem or one or more of the tributaries within Grand Canyon.

6. **Further Study of Selective Withdrawal:** Reclamation will aggressively pursue and support research on the effects of multilevel intake structures at Glen Canyon Dam and use the results of this research to decide whether or not to pursue construction. FWS, in consultation with AGFD,

will be responsible for recommending to Reclamation whether or not selective withdrawal should be implemented at Glen Canyon Dam. Reclamation will be responsible for design, NEPA compliance, permits, construction, operation, and maintenance.

7. **Emergency Exception Criteria**: Operating criteria have been established to allow the Western Area Power Administration to respond to various emergency situations in accordance with their obligations to the North American Electric Reliability Council. This commitment also provides for exceptions to a given altemative's. operating criteria during search and rescue situations, special studies and monitoring, dam and power plant maintenance, and spinning reserves.

## VII. BASIS FOR DECISION

The goal of selecting a preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability.

Based on the impact analysis described in the final EIS, three of the alternatives are considered to be environmentally preferable. They are: the Moderate Fluctuating Flow Alternative, the Modified Low Fluctuating Flow Alternative, and the Seasonally Adjusted Steady Flow Alternative. Modified Low Fluctuating Flow is selected for implementation because it satisfies the critical needs for sediment resources and some of the habitat needs of native fish, benefits the remaining resources, and allows for future . hydropower flexibility, although there would be moderate to potentially major adverse impacts on power operations and possible decreases in long-term firm power marketing. Nearly all downstream resources are dependent to some extent on the sediment resource. This alternative meets the critical requirements of the sediment resource by restoring some of the pre-dam variability through floods and by providing a long-term balance between the supply of sand from Grand Canyon tributaries and the sand-transport capacity of the river. This, in turn, benefits the maintenance of habitat. The critical requirements for native fish are met by pursuing a strategy of warming releases from Glen Canyon Dam, enhancing the sediment resource, and substantially limiting the daily flow fluctuations.

The decision process for selecting the preferred alternative for the EIS followed a repetitive sequence of comparisons of effects on downstream resources resulting from each alternative. Alternatives resulting in unacceptable adverse effects on resources (such as long-term loss of sandbars leading to the destruction of cultural resource sites and wildlife habitat) were eliminated from further comparisons. Comparisons continued until existing data were no longer available to support assumed benefits.

All resources were evaluated in terms of both positive and adverse effects from proposed alternatives. Once it was determined that all alternatives would deliver at least 8.23 million acre feet of water annually, water supply played a minor role in subsequent resource evaluations. (One of the objectives of the "Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs" is a minimum annual release of 8.23 million acre feet of water fforn Glen Canyon

Dam.) The alternatives covered a range of possible dam operations from maximum utilization of peaking power capabilities with large daily changes in downstream river levels (Maximum Powerplant Capacity Alternative) to the Year-Round Steady Flow Alternative that would have eliminated all river fluctuations and peaking power capabilities. Within this range, the Maximum Powerplant Capacity, No Action, and High Fluctuating Flow alternatives were eliminated from consideration as the preferred alternative because they would not meet the first criterion of resource recovery and long-term sustainability. Data indicated that while beneficial to hydropower production, these alternatives would either increase or maintain conditions that resulted in adverse impacts to downstream resources under no action. For example, under these alternatives, the sediment resource would not likely be maintained over the long-term.

At the other end of the range, the Year-Round Steady Flow Alternative was also eliminated from consideration as the preferred alternative. This alternative would result in the greatest storage of sand within the river channel, the lowest elevation sandbars, the largest potential expansion of riparian vegetation, and the highest white-water boating safety benefits. However, it would not provide the variability on which the natural processes of the Grand Canyon are dependent (e.g. beach building, unvegetated sandbars, and backwater habitats). A completely stable flow regime would encourage the growth of vegetation thereby reducing bare-sand openings and patches of emergent marsh vegetation. This would limit beach camping and reduce the habitat value of these sites. With respect to other resources, this alternative did not provide any benefits beyond those already provided by other alternatives. Steady flows could also increase the interactions between native and non-native fish by intensifying competition and predation by non-natives on native fish. Such interactions would reach a level of concern under steady flows. Finally, this alternative would have major adverse impacts on hydropower (power operations and marketing).

The Existing Monthly Volume Steady Flow Alternative was eliminated from selection as the preferred alternative for reasons similar to those discussed above for the Year-Round Steady Flow Alternative.

Although the Interim Low Fluctuating Flow Alternative performed well over the interim period (August 1991 to the present), long-term implementation of this alternative would not restore some of the pre-dam variability in the natural system. The selected Modified Low Fluctuating Flow Alternative is an improved version of the Interim Low Fluctuating Flow Alternative because it would provide for some pre-dam variability through habitat maintenance flows.

The three remaining alternatives-the Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives-- provide similar benefits to most downstream resources (e.g.. vegetation, terrestrial wildlife, and cultural resources) with respect to increased protection or improvement of those resources (see Table 11-7 in the EIS). The Moderate Fluctuating Flow Alternative provided only minor benefits to native fish over no action conditions because of the relative similarity in flow fluctuations; and the benefits from the Seasonally Adjusted Steady Flow Alternative were uncertain given the improvement in habitat conditions for non-native fish this alternative would provide. Seasonally adjusted steady flows also would create conditions significantly different from those under which the current aquatic ecosystem has developed in the last 30 years and would adversely affect hydropower to a greater extent than the

other two alternatives. The Modified Low Fluctuating Flow could substantially improve the aquatic food base and benefit native and non-native fish. The potential exists for a minor increase in the native fish population.

Although the Moderate Fluctuating, Modified Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives provide similar benefits to most downstream resources, the Modified Low Fluctuating Flow Alternative was selected as the preferred alternative because it would provide the most benefits with respect to the original selection criteria, given existing information. This alternative would create conditions that promote the protection and improvement of downstream resources while maintaining some flexibility in hydropower production. Although there would be a significant loss of hydropower benefits due to the selection of the preferred alternative (between V 5. 1 and $44.2 million annually) a recently completed non-use value study conducted under the Glen Canyon Environmental Studies indicates that the American people are willing to pay much more than this loss to maintain a healthy ecosystem in the Grand Canyon. The results of this nonuse value study are summarized in Attachment 3 of the ROD.

The results of a General Accounting Office (GAO) audit mandated by the Grand Canyon Protection Act are in Attachment 4 of the ROD. This audit generally concludes that Reclamation used appropriate methodologies and the best available information in determining the potential impact of various dam flow alternatives on important resources. However, GAO identified some shortcomings in the application of certain methodologies and data, particutarly with respect to the hydropower analysis. Reclamation's assumptions do not explicitly include the mitigating effect of higher electricity prices on electricity demand (price elasticity). GAO also determined that Reclamation's assumptions about natural gas prices were relatively high and that two computational errors were made during the third phase of the power analysis. According to GAO, these limitations suggest that the estimated economic impacts for power are subject to uncertainty. GAO also found limitations with some of the data used for impact analysis. Certain data was incomplete or outdated, particularly data used in assessing the economic impact of alternative flows on recreational activities. Nevertheless, the National Research Council peer reviewed both the Glen Canyon Environmental Studies and the EIS, and generally found the analysis to be adequate. The GAO audit concluded that these shortcomings and limitations are not significant and would not likely alter the findings with respect to the preferred alternative and usefulness of the document in the decision-making process. The audit also determined that most of the key parties (83 percent of respondents) support Reclamation's preferred alternative for dam operations, although some concerns remain.

ATTACHMENT 1.

Specific peer reviewed sediment studies:

Beus, S. and C. Avery 1993. The influence of variable discharge regimes on Colorado River sand bars below Glen Canyon Dam. Glen Canyon Environmental Studies, Report PHY0101, Chapters I through 7. Northern Arizona University, Flagstaff, AZ

Beus, S., M.A. Kaplinski, J. E. Hazel, L. A. Tedrow, and L. H. Kearsley. 1995. Monitoring the effects of interim flows from Glen Canyon Dam on sand bar dynamics and campsite size in the Colorado River corridor, Grand Canyon National Park, AZ. Glen Canyon Environmental Studies, Report PHY 0112. Northern Arizona University, Flagstaff, AZ

Budhu, M and R. Gobin. 1994. Monitoring of sand bar instability during the interim flows: a seepage erosion approach. Glen Canyon Environmentaf Studies, Report PHY 0400. University of Arizona, Tucson, AZ

Carpenter, M., R. Carruth, Fink, D. Boling, and B. Cluer. 1995. Hydrogeology of sand bars 43.1 and 172.3L and the implications on flow alternatives along the Colorado River in the Grand Canyon. Glen Canyon Environmental Studies, Report PHY 0805. U.S. Geological Survey, Tucson, AZ

Cluer, B. 1993. Annual Report. Sediment mobility within eddies and the relationship to rapid erosion events. Glen Canyon Environmental Studies, Report PHY 0 11. National Park Service, Ft. Collins, CO

Cluer, B. and L. Dexter. 1994. An evaluation of the effects of the interim flows from Glen Canyon Dam on the daily change of beach area in Grand Canyon, AZ. Glen Canyon Environmental Studies, Report PHY 0 109. Northern Arizona University, Flagstaff, AZ

Nelson, J., N. Andrews, and J. MacDonald. 1993. Movement and deposition of sediments from the main channel to the eddies of the Colorado River in the Grand Canyon. Glen Canyon Environmental Studies, Report PHY 0800. U.S. Geological Survey, Boulder, CO

Randle, T.J., R.I. Strand, and A. Streifel. 1993. Engineering and environmental considerations of Grand Canyon sediment management. In: Engineering Solutions to Environmental Challenges: Thirteenth Annual USCOLD Lecture, Chattanooga, TN. U.S. Committee on Large Dams, Denver, CO.

Schmidt, J. 1994. Development of a monitoring program of sediment storage changes in alluvial banks and bars, Colorado River, Grand Canyon, AZ. Glen Canyon Envirorunental Studies, Report PHY 0401. Utah State University.

Smith, J. and S. Wiele. 1994. Draft report. A one-dimensional unsteady. model of discharge waves

in the Colorado River through the Grand Canyon. Glen Canyon Environmental Studies, Report PHY 0805. U.S. Geological Survey, Boulder, CO

Werrell, W., R. Ingliss, and L. Martin. 1993. Beach face erosion in Grand Canyon National Park: A response to ground water seepage during fluctuating flow releases from Glen Canyon Dam. Glen Canyon Environmental Studies, Report PHY 0101, Chapter 4 in The influence of variable discharge regimes on Colorado River sandbars below Glen Canyon Dam, Report PHY 0101. National Park Service, Ft. Collins, CO .

FIGURES 2-4

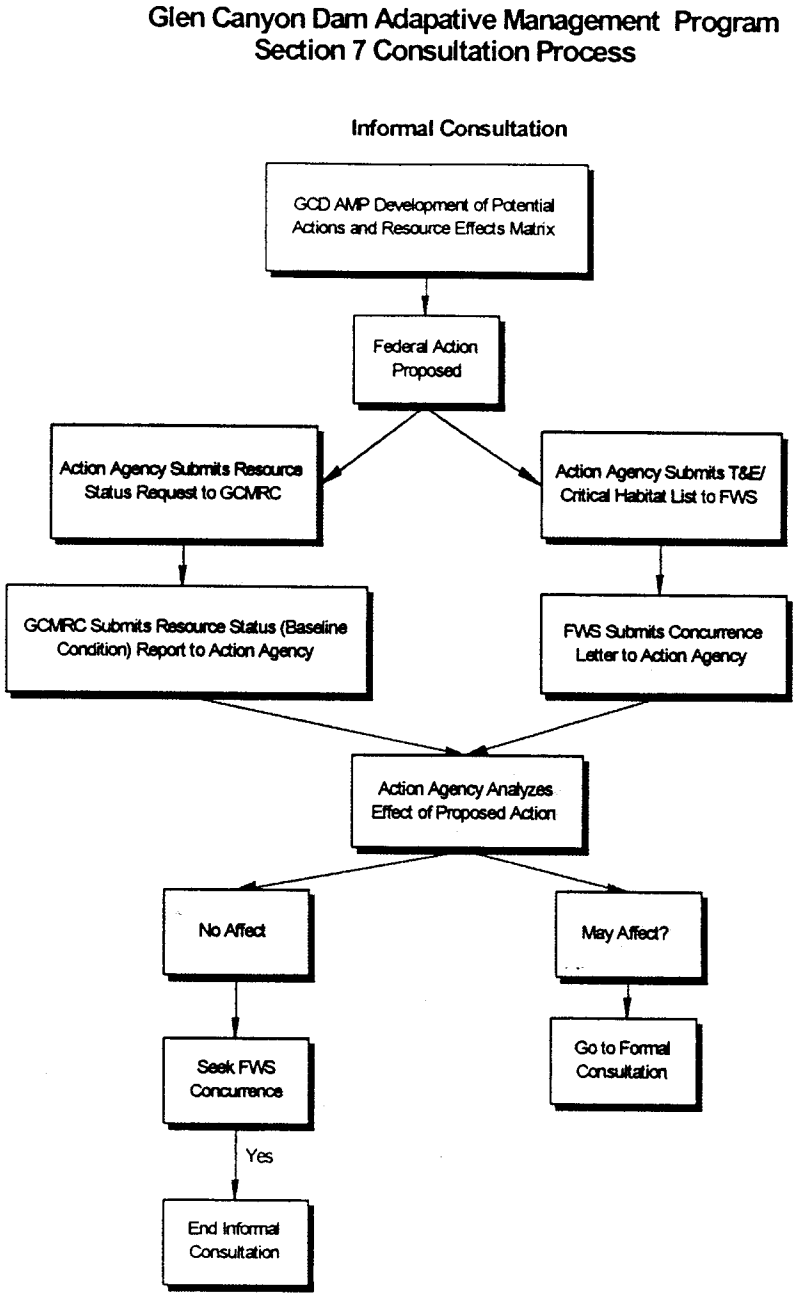


*Figure 2. Glen Canyon Dam Adaptive Management Program Section 7 Consultation Process (Informal Consultation)*

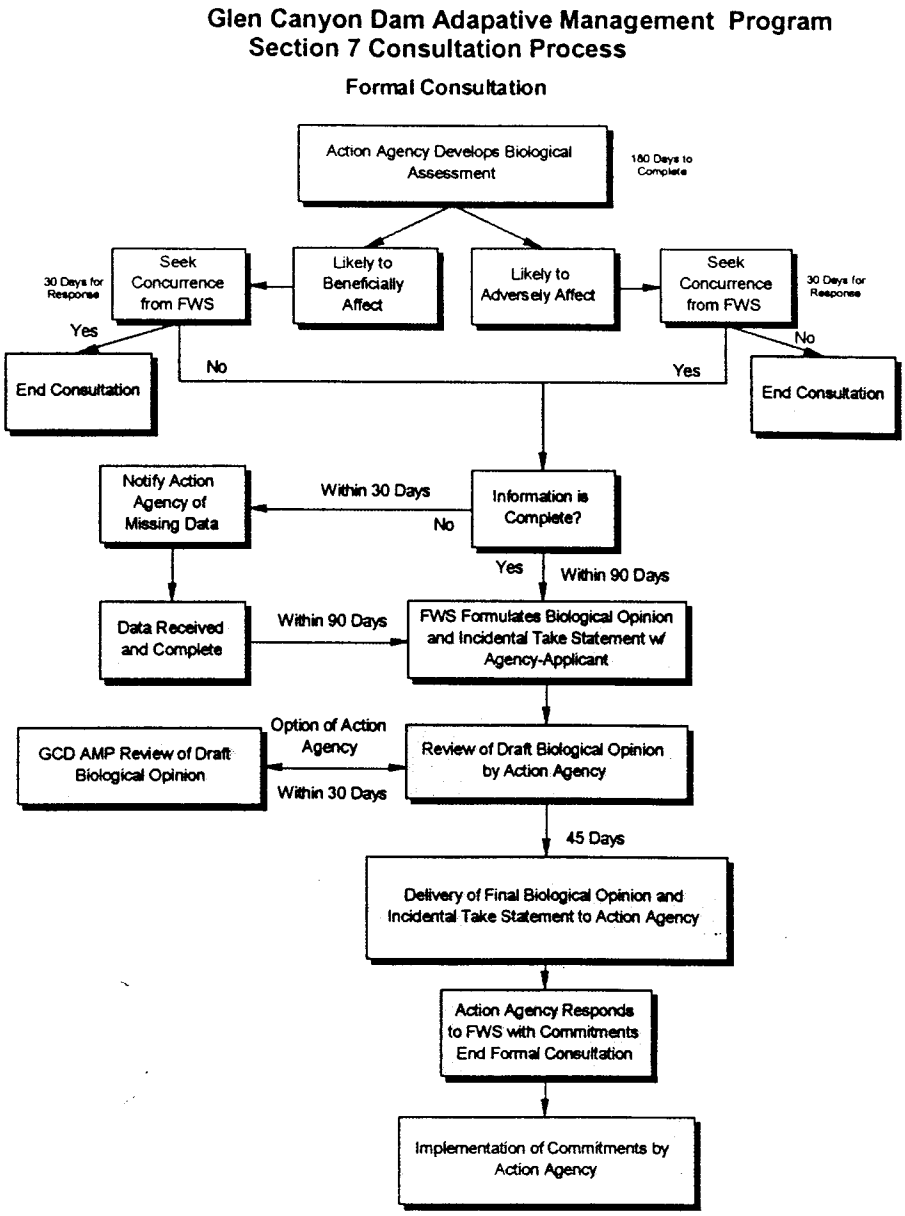


*Figure 3. Glen Canyon Dam Adaptive Management Program Section 7 Consultation Process (Formal Consultation)*

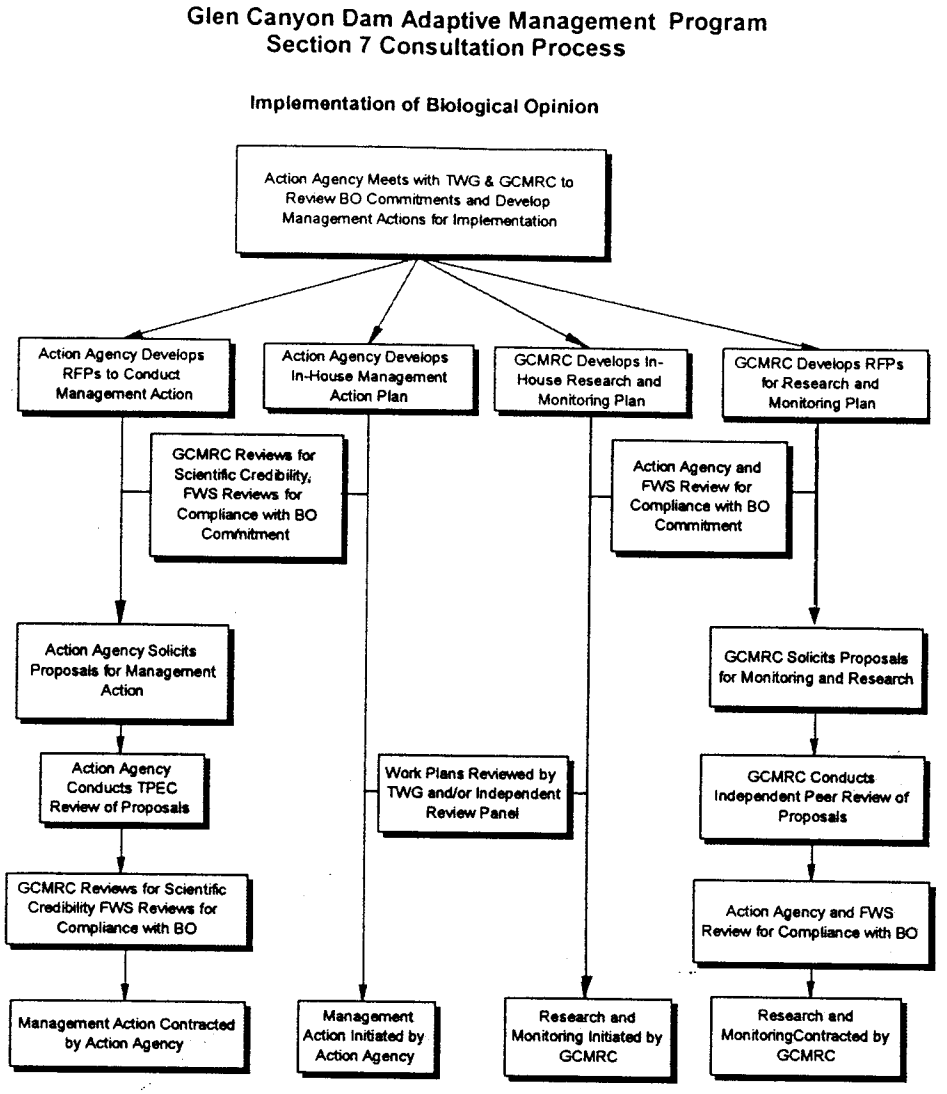


*Figure 4. Glen Canyon Dam Adaptive Management Program Section 7 Consultation Process (Implementation of Biological Opinion)*

# Information Needs

**Final DRAFT** INFORMATION NEEDS
for
Technical Work Group REVIEW

September 10, 2001

## Introduction

The Information Needs (INs) provided in this document represent data needed to meet management objectives and programmatic goals. The Information Needs are nested within Management Objectives and are categorized as: core monitoring information needs (CMIN), effects monitoring information needs (EIN), or research information needs (RIN), defined below. In an effort to reflect integration across resource programs, some Information Needs are supporting information needs for other resources (SIN). Information Needs that do not fit under any particular management objective, but are necessary to achieve the goal are placed above the Management Objectives for that goal.

## Process

The INs have been developed thorough a collaborative process led by the Grand Canyon Monitoring and Research Center (GCMRC). This process was initiated with GCMRC developing a draft set of INs for review and comment at a meeting of the Technical Work Group (TWG) and principal investigators held at the Phoenix Airport on April 3, 2001. A second meeting to discuss cultural INs was held in Flagstaff on May 8, 2001. Following these meetings, GCMRC revised the INs and discussed them at the May TWG meeting. Following this meeting the INs were put in a table and electronically mailed to the TWG for additional comment. Very few comments were provided by the TWG. At this point, the INs and the process for developing the INs was discussed in a number of conference calls and it was agreed that the INs would be reformatted into the nested outline form used in the current document. It was also agreed that the reformatted INs would be mailed to the TWG for review and comment and that a second workshop for reviewing and revising the INs would be held at GCMRC on August 8-9, 2001.

This current document results from the work conducted at the August 8-9, 2001, INs workshop and the subsequent review at the September 6 TWG meeting. On the first day of the August 8-9 INs workshop the TWG, PIs, and GCMRC staff divided into 4 concurrent breakout groups and reviewed the draft INs. Each group addressed the following questions during their review:

1) Do the INs for a given MO provide the information that is needed to address that MO? If not, please indicate how they should be revised and what should be added or deleted.
2) Are the INs written at the appropriate level of detail and correctly categorized with respect to the categories of "core monitoring," "effects monitoring," and "research"?

3) Taken together as a set do the INs and MOs represent the information needed to address a given goal?

On the second day of the August 8-9 INs workshop, a representative of each breakout group presented their proposed changes to the group as a whole. In response to these comments, the INs were either modified or the comments were captured in a table for subsequent consideration. The revised draft and the comments table were e-mailed to the TWG on August 20 for review prior to the September 6-7 TWG meeting. The National Park Service, CREDA, and WAPA provided written comments on the INs. The INs were subsequently reviewed and revised at the September 6, 2001, TWG meeting.

**Next Steps**

A revised Draft INs document is to be e-mailed by GCMRC to the TWG by Friday September 14, 2001. Recommendations for deleting INs, for specific language changes to the existing INs, or specific language for adding new INs are to be provided to GCMRC by October 5, 2001. These will be collated into a comments table, organized sequentially beginning with comments on the first IN, and will be sent back to the TWG by October 12 for review prior to an October 22 TWG meeting to revise the INs. At the October 22 TWG meeting, we will go through only those comments that you don't agree with or that you have concerns about. Following this meeting, a Final Draft INs document will be presented to the TWG at its November meeting. A recommendation to the AMWG to adopt the Final Draft INs will be sought at that meeting. A recommendation from the AMWG to adopt the Final INs will be sought at its January 2002 meeting.

**Definitions**

Management Objectives (MOs): Management Objectives define desired future resource conditions. They should be: 1) Specific; 2) Measurable; 3) Achievable; 4) Results-oriented; 5) Time-specific, and within the legal and policy framework of the Adaptive Management Program.

Information Needs (INs): Information Needs define the specific knowledge or understanding (i.e., information) one needs for accomplishing a management objective. They define what one needs to know. The information may be needed to:

a) quantify or define a management objective (i.e., help determine a target level);
b) assess whether or not a management objective is being achieved (i.e., help determine why the system is not responding as predicted);
c) develop basic understanding about cause and effect relationships;
d) meet the legal/policy requirements of consultation; and
e) test more effective ways to achieve desired resource conditions.

Information Needs are categorized as follows:

- Core Monitoring (CMIN): Consistent, long-term, repeated measurements gathered year-in and year-out using set protocols designed to establish status and trends for the CRE. Core monitoring is implemented regardless of variable factors or circumstances affecting target resources (water year, experimental flows, temperature control, stocking strategy, non-native control, etc.). Unique conditions to be studied would require specifically designed monitoring within a specific time frame, in addition to core monitoring, to evaluate specific effects. This effects monitoring is described below.

- Effects Monitoring (EIM): Data collection that takes place before and after an experiment, and that does not fit into the schedule of core monitoring or involves different measurements.

- Research (RIN): Data collected to address specific hypotheses directed at determining and understanding cause and effects relationships between dam operations, or other driving variables, and resource responses. Data may also be collected to help refine Core Monitoring.

**Glen Canyon dam Operations:** GCD operations refers to the operation of the powerplant and other release structures, such as bypass structures, spillways, and potentially a temperature control device among others. Their uses conform to applicable law. The AMWG develops recommendations for all of the dam's structures to further the purposes of the GCPA, the EIS, and the ROD. This is done within the limits of the ROD and/or through experimentation.

**Record of Decision (ROD) operations:** ROD operations are defined as the modified low fluctuating flow alternative described in the ROD including restrictions on upramp and downramp rates, the allowable range of daily fluctuations and the allowable minimum and maximum daily flows. In addition, ROD operations include beach/habitat-building flows (up to 45,000 cfs) habitat maintenance flows (up to power plant capacity) and any flows defined as experiments within the environmental commitments of the ROD.

**Goal 1. Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.**

Research INs

**RIN 1.1** What are higher trophic levels assimilating?

**RIN 1.2** How does primary productivity effect structuring of the benthic invertebrate community (e.g., production, composition, densities and accrued biomass)?

**RIN 1.3** What foodbase standards/criteria do other agencies use to assess health?

**M.O. 1.1** Maintain or attain primary producers: (algae, macrophytes, diatoms) in the Glen Canyon Reach.

Core Monitoring INs

**CMIN 1.1.1** Determine composition and biomass of primary producers in Glen Canyon Reach as a function of flow, nutrient, temperature, and light regime.

Research INs

**RIN 1.1.1** When do top-down effects override operational effects on foodbase productivity?

**RIN 1.1.2** What is the estimated productivity for the reach between GCD and the Paria River as a function of flow, nutrient, temperature, and light regime?

**M.O. 1.2** Maintain or attain benthic invertebrates in the Glen Canyon Reach

Core Monitoring INs

**CMIN 1.2.1** Determine composition and biomass of benthic invertebrates in Glen Canyon Reach as a function of flow, nutrient, temperature, and light regime.

**M.O. 1.3** Maintain or attain primary producers (algae, macrophytes, diatoms) in the mainstem and tributaries (to the extent primary producers in the tributaries are influenced by dam operations) below the Paria.

Core Monitoring INs

**CMIN 1.3.1** Determine composition and biomass of primary producers in the mainstem and tributaries below the Paria River as a function of flow, nutrient, temperature, and light regime.

Research INs

**RIN 1.3.1** What is the estimated productivity for the CRE below the Paria River?

**M.O. 1.4** Maintain or attain benthic invertebrates in the mainstem and tributaries (to the extent benthic invertebrates in the tributaries are influenced by dam operations) below the Paria.

Core Monitoring INs

**CMIN 1.4.1** Determine composition and biomass of benthic invertebrates in the mainstem and tributaries below the Paria River as a function of flow, nutrient, temperature, and light regime.

**M.O. 1.5** Maintain or attain drift (Diptera, CPOM, FPOM, DOC) in the mainstem and tributaries (to the extent drift in the tributaries is influenced by dam operations).

Core Monitoring INs

**CMIN 1.5.1** Determine composition and biomass of drift in the mainstem and tributaries as a function of flow, nutrient, temperature, and light regime.

Research INs

**RIN 1.5.1** Is invertebrate drift regulated by density-dependent or density-independent factors (e.g., flow velocities, substrate types, light intensity)?

**RIN 1.5.2** What is the carbon budget for the CRE?

**Goal 2. Maintain or attain viable populations of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to ~~its~~ associated critical habitat.**

**IN 2.1** What are the impacts of current recreational activities on native fish?

Research INs

**RIN 2.1** What is a viable population? What is the probability of extinction over what management time period for species of concern? What is the appropriate method to assess viability?

**RIN 2.2** What is necessary to remove jeopardy for humpback chub?

**M.O. 2.1** Maintain or attain humpback chub (>150 mm) abundance in the LCR and other aggregations at appropriate target levels for viable populations and to remove jeopardy.

Core Monitoring INs

**CMIN 2.1.1 What is the status and trends of HBC of all size classes in the LCR and the mainstem?**

**M.O. 2.2** Maintain or attain HBC (51-150mm) year class strength in the LCR and other aggregations at appropriate target levels for viable populations and to remove jeopardy.

Core Monitoring INs

**CMIN 2.2.1** What is the status and trends of HBC of all size classes in the LCR and the mainstem?

**CMIN 2.2.2** What is LCR discharge near mouth (below springs)?

Research INs

**RIN 2.2.1** What is the relationship between size and mortality in the LCR and the mainstem? What are the sources of mortality?

**RIN 2.2.2** What habitats enhance recruitment of native fish? What are the physical and biological characteristics of those habitats?

**M.O. 2.3** Maintain or attain HBC (>200mm) recruiting adults in the LCR and other aggregations at appropriate target levels for viable populations and to remove jeopardy.

Core Monitoring INs

**CMIN 2.3.1** What is the status and trends of HBC of all size classes in the LCR and the mainstem?

**M.O. 2.4** Establish viable HBC spawning aggregations in the CRE below GCD to remove jeopardy.

Research INs

**RIN 2.4.1** What is the genetic relationship between "aggregations" in the mainstem and LCR?

**RIN 2.4.2** What is the minimum population size of HBC that should be sustained in the LCR, to ensure a viable spawning population of HBC in the LCR?

**RIN 2.4.3** What are the appropriate habitat conditions for HBC spawning? Where are these found? Can they be created in the mainstem?

**RIN 2.4.4** What are the criteria for establishment of spawning aggregations (i.e., How does one determine it is "established")?

**RIN 2.4.5** Is implementation and operation of a TCD and/or steady flows a practical option for mainstem spawning aggregation establishment?

**RIN 2.4.6** What defines population viability, and how does this affect the objective to establish additional spawning aggregations in the CRE and removal of jeopardy?

**RIN 2.4.7** Are mainstem aggregations "sinks" of the LCR? Are aggregations real or due to sampling bias?

**RIN 2.4.8** Is humpback chub augmentation a viable management strategy to establish mainstem spawning aggregations?

**RIN 2.4.9** What techniques are available to determine natal stream of native fish in the CRE?

**M.O. 2.5** Attain HBC and other native fish condition and disease/parasite numbers in LCR and other aggregations at an appropriate target level for viable populations and to remove jeopardy.

Core Monitoring INs

**CMIN 2.5.1** What are the parasite loads on HBC found in the LCR and in the CRE?

**CMIN 2.5.2** What is status and trends of HBC condition (Kn or Wr)?

Research INs

**RIN 2.5.1** What are HBC's tolerable limits for parasite/disease loads?

**RIN 2.5.2** How will warming mainstem temperatures affect the abundance and distribution of parasites/disease?

**M.O. 2.6** Reduce native fish mortality due to non-native fish predation as a percentage of overall mortality in the LCR and mainstem to increase native fish recruitment.

Core Monitoring INs

**CMIN 2.6.1** What is the status and trends of predatory fish species in the CRE?

Research INs

**RIN 2.6.1** What is the most effective predator control method?

**RIN 2.6.2** Does predator suppression benefit native fish?

**RIN 2.6.3** To what degree, which species, and where in the system are exotic fish a detriment to the existence of native fish?

**RIN 2.6.4** Under what circumstances and to what degree do native fish prey on native fish (i.e., is cannibalism a significant problem in humpback chub)?

**M.O. 2.7** Attain Razorback sucker abundance in the CRE below GCD.

Research INs

**RIN 2.7.1** Will the introduction of razorback suckers into the CRE compromise the genetic integrity of flannelmouth suckers due to hybridization?

**RIN 2.7.2** What is the suitabaility of habitat in the CRE for razorback sucker?

**RIN 2.7.3** Determine feasibility of augmenting razorback sucker to attain a viable population including technical/legal/policy constraints.

**RIN 2.7.4** Determine advisability of augmenting razorback sucker.

**M.O. 2.8** Maintain (FMS, BHS and SPD) abundance and distribution in the CRE below GCD for viable populations.

Core Monitoring INs

**CMIN 2.8.1** What is the status and trend of FMS, BHS and SPD in the CRE?

Research INs

**RIN 2.8.1** What is a viable population? What is the probability of extinction over what management time period for species of concern? What is the appropriate method to assess viability?

**RIN 2.8.2** What habitats enhance recruitment of native fish? What are the physical and biological characteristics of those habitats?

**RIN 2.8.3** What is the age structure, including relationship between age and size, of native fish in CRE?

**RIN 2.8.4** Understand movement with respect to mainstem catch information and tributary spawning effort, particularly for flannelmouth suckers' life history and tributary fidelity.

**RIN 2.8.5** What is the relationship between size and mortality for all native fish in the CRE? What are the sources of mortality?

**RIN 2.8.6** How does temperature modification in the mainstem affect native fish vulnerability index for fish originating from tributary spawning efforts?

**Goal 3. Restore populations of extirpated species, as feasible and advisable.**

M.O. 3.1 Restore Colorado pikeminnow, bonytail, and roundtail chub, and river otter abundances in the CRE as feasible and advisable.

Research INs

**RIN 3.1.1** Determine feasibility of restoring extirpated species including technical/legal/policy constraints.

**RIN 3.1.2** Determine advisability of restoring extirpated species.

**Goal 4. Maintain a wild reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.**

M.O. 4.1 Maintain or attain RBT abundance, proportional stock density, length at age, condition, spawning habitat, natural recruitment, and prevent or control whirling disease and other parasitic infections.

Core Monitoring INs

**CMIN 4.1.1** Determine annual population estimate for age II+ rainbow trout in the LeesFerry Reach as a function of flow, nutrient, temperature, and light regime.

**CMIN 4.1.2** Determine annual PSD of rainbow trout in the LeesFerry Reach as a function of flow, nutrient, temperature, and light regime.

**CMIN 4.1.3** Determine annual rainbow trout growth rate in the LeesFerry Reach as a function of flow, nutrient, temperature, and light regime.

**CMIN 4.1.4** Determine annual standard condition (Kn) and Relative Weight of rainbow trout in the Lees Ferry Reach as a function of flow, nutrient, temperature, and light regime.

**CMIN 4.1.5** Determine if whirling disease is present in the Lees Ferry reach. Determine annual incidence and relative infestation of trout nematodes in rainbow trout in the Lees Ferry reach as a function of flow, nutrient, temperature, and light regime.

**CMIN 4.1.6** Determine quantity and quality of spawning habitat for rainbow trout in the Lees Ferry Reach on a 5-year basis as a function of flow, nutrient, temperature, and light regime.

**CMIN 4.1.7** Determine annual percentage of naturally recruited rainbow trout in the Lees Ferry reach as a function of flow, nutrient, temperature, and light regime.

Research INs

**RIN 4.1.1** What is a target Proportional Stock Density?

**RIN 4.1.2** What are trade-offs between numbers and size of rainbow trout in the Lees Ferry reach?

**M.O. 4.2** Limit Lees Ferry RBT distribution below the Paria River of the CRE to reduce competition or predation on downstream native fish.

Research INs

**RIN 4.2.1** What is the number of recaptures of RBT in the mainstem that originate from Lees Ferry? What is the rate of emigration of rainbow trout from the Lees Ferry reach?

**RIN 4.2.2** What is the most effective method to detect emigration of rainbow trout from the Lees Ferry reach?

**RIN 4.2.3** What / how do management actions affect Lees Ferry rainbow trout displacement below the Paria River?

**RIN 4.2.4** What is the target individual size, growth rate, and population size of RBT appropriate for the Lees Ferry reach? for the CRE below the Paria River? for Brown Trout in the CRE below the Paria river?

**RIN 4.2.5** To what extent is there overlap in the CRE of RBT habitat and native fish habitat?

**RIN 4.2.6** To what extent are RBT below the Paria River predators of native fish, primarily HBC?

**RIN 4.2.7** Determine effective control strategies and methods to limit RBT and BT to target population levels commensurate with protection of native and endangered fish.

**Goal 5. Maintain or attain viable populations of Kanab ambersnail.**

**IN 5.1** What is the taxonomic status of the entity at Vasey's Paradise?

**IN 5.2** Are there other populations of the Vasey's Paradise taxons?

**IN 5.3** What is the historic range of Oxyloma haydeni?

**IN 5.4** What actions are necessary to avoid jeopardy for KAS?

**MO 5.1** Attain and maintain KAS population at Vasey's Paradise from the current level to the target level.

Core Monitoring INs
**CMIN 5.1.1** What is the annual status and long-term population trend of KAS and their habitat at Vasey's Paradise?

Effects Monitoring INs
**EIN 5.1.1** What is the population size of KAS at Vasey's Paradise immediately following the scour of its habitat following a test flow?

Research INs
**RIN 5.1.1** What parameters have the greatest influence on population viability of KAS at Vasey's Paradise (e.g., parasites, predation, discharges, habitat size and quality).

**RIN 5.1.2** Develop a population dynamic model to predict KAS viability under different flows and environmental conditions (incorporating IN 5.2 –age structure life history table information associated with the snail taxon at Vasey's Paradise).

**RIN 5.1.3** If the population dynamic model predicts loss of population viability or monitoring discovers substantial habitat or KAS population declines, identify and evaluate alternative MA's to ensure viability.

**MO 5.2** Maintain KAS habitat at Vasey's Paradise from the current level to the target level.

Core Monitoring INs
**CMIN 5.2.1** Annually determine the size and composition of the habitat used by KAS at Vasey's Paradise?

**CMIN 5.2.2** What RS technologies are available to less intrusively and more cost effectively characterize and monitor KAS habitat (vegetation type and distribution)?

Effects Monitoring INs
**EIN 5.2.1** What is the size of KAS habitat loss and recovery time following test flows or natural scours?

**EIN 5.2.2** How does the size and quality of KAS habitat change following test flows, natural scours, and other operations?

Research INs

**RIN 5.2.1** How does the habitat use of KAS at Vasey's Paradise shift with the age of the snail?

**Goal 6. Protect or improve the biotic riparian and spring communities, including T&E species and their critical habitat.**

**IN 6.1** Determine the community composition of vascular plants, vertebrates, arthropods and mollusks to an appropriate taxonomic level and frequency.

**IN 6.2** What were the 1984 community levels (OHWZ / NHWZ / Marsh / beach community)?

**IN 6.3** Develop GIS coverages of natural communities in the CRE to use in identification of status and trends.

**IN 6.4** Do we need a new community classification system?

**IN 6.5** What are the seasonal patterns of abundance associated with the supporting foodbase and vertebrate consumers in the different communities?

**IN 6.6** Understand the community dynamics in response to physical processes.

**IN 6.7** How much allochtonous material from the terrestrial system goes into the aquatic system and vice versa?

**M.O. 6.1** Maintain marsh community abundance, composition and area in the CRE in such a manner that native species are not lost.

Core Monitoring INs

**CMIN 6.1.1** What is the composition and extent of marsh habitat on a 5-year schedule?

Research INs

**RIN 6.1.1** How does riparian vegetation change within marsh community following disturbance?

**RIN 6.1.2** How does marsh vegetation change on a decadal or 5-year time scale?

**M.O. 6.2** Maintain NHWZ community patch number and distribution, composition and area to be no lower than values estimated for 1984.

Core Monitoring INs

**CMIN 6.2.1** Describe the composition and extent of the NHWZ community on a 5-year schedule?

**CMIN 6.2.2** How has the NHWZ community changed since implementation of ROD flows?

Research INs

**RIN 6.2.1** How has the NHWZ community changed system-wide since 1963?

**RIN 6.2.2** How does riparian vegetation change within NHWZ community following disturbance (flooding primarily)?

**RIN 6.2.3** How does NHWZ vegetation change on a decadal or 5-year time scale?

**M.O. 6.3** Maintain OHWZ community abundance, composition and distribution in the CRE.

Core Monitoring INs

**CMIN 6.3.1** What is the composition and extent of OHWZ community on a 5-year schedule?

**CMIN 6.3.2** How has the OHWZ community changed since implementation of ROD flows?

Research INs

**RIN 6.3.1** How has the OHWZ community changed system-wide since 1963 levels? (Is 1963 the right benchmark year?)

**RIN 6.3.2** What management actions have the potential to maintain OHWZ communities at current or lower stage elevations?

**M.O. 6.4** Maintain sand beach community abundance, composition and distribution in the CRE from 1984 (Is this the right benchmark year?)

Core Monitoring INs

**CMIN 6.4.1** What is the composition and extent of sand beach community on a 5-year schedule?

**CMIN 6.4.2** How has the sand beach community changed since implementation of ROD flows?

Research INs

**RIN 6.4.1** How have the sand beach community attributes changed since 1963?

**M.O. 6.5** Reduce invasive non-native species abundance and distribution.

Core Monitoring INs

**CMIN 6.5.1** What is the distribution and abundance of exotics canyon-wide?

Research INs

**RIN 6.5.1** Are exotic species expanding or contracting at a local scale (patch or reach)?

**RIN 6.5.2** What management actions have the potential to increase or decrease non-native species distribution and abundance?

**RIN 6.5.3** Is development of an exotic vegetation map of the entire CRE including characterization of the types of habitat that supports exotic species needed?

**M.O. 6.6** Maintain spring and ~~wetland~~ seep habitat ~~occupied by rare and endemic species in the CRE~~.

Core Monitoring INs

**CMIN 6.6.1** What is the composition and extent of spring and wetland communities on a 5-year schedule including culturally important sites?

Research INs

**RIN 6.6.1** How does habitat quality and quantity change through the year and over several years?

**RIN 6.6.2** What are the attributes of these communities that are important, and are these attributes affected by dam operations?

**M.O. 6.7** Maintain riparian habitat in the CRE capable of supporting Southwest Willow Flycatcher.

Core Monitoring INs

**CMIN 6.7.1** What is the status of SWWF in the CRE?

**CMIN 6.7.2** What are the seasonal patterns of abundance associated with supporting foodbase and vertebrate consumers in the different communities?

**CMIN 6.7.3** How has riparian habitat capable f supporting SWWF changed since implementation of ROD flows?

Research INs

**RIN 6.7.1** What is the function of the CRE as a migratory corridor for Southwest Willow Flycatcher?

**RIN 6.7.2** What is the foodbase that supports birds (SWWF & other surrogate riparian species) and other vertebrates?

**RIN 6.7.3** What constitutes suitable SWWF habitat?

**Goal 7. Establish water temperature, quality and flow dynamics to achieve GCDAMP ecosystem goals.**

M.O. 7.1 Attain water temperature ranges and seasonal variability in the mainstem for biological resources (e.g., native fish, foodbase and trout).

Core Monitoring INs

**CMIN 7.1** What are the water temperature dynamics in the mainstem, tributary mouths, backwaters, and near-shore areas throughout the CRE?

Research INs

**RIN 7.1.1** What are the desired ranges of water temperatures for the CRE?

M.O. 7.2 Maintain water quality in the mainstem of the CRE.

Core Monitoring INs

**CMIN 7.2.1** How do the seasonal and yearly trends in turbidity, temperature, conductivity, DO, pH, nutrients, major ions, and appropriate metals change in the mainstem throughout the CRE?

**CMIN 7.2.2** Assess threats to human health from water-borne pathogens.

Research INs

**RIN 7.2.1** Which major ions should be measured? Where and how often?

**RIN 7.2.2** Which nutrients should be measured? Where and how often?

**RIN 7.2.3** Which metals should be measured? Where and how often?

**RIN 7.2.4** Do the hydrodynamics and stratification of Lake Powell influence the food base or fisheries downstream?

**RIN 7.2.5** How do water quality variables influence food base and fisheries in the CRE?

**NOTE: There are no management objectives for Lake Powell, should they be added?** Below are information needs for Lake Powell.

Core Monitoring INs

**CMIN LP 1** What is the quality of source water in Lake Powell for Glen Canyon dam releases? (Links to Goals 1,2,4,7,10,12)

Research INs

**RIN LP 1** What are the dynamics of stratification, circulation, and advective flow patterns in Lake Powell and their effect on potential reservoir releases?

i. What is the heat budget and temperature available for releases?
ii. How do salinity and major ion concentration change?
iii. What are the patterns of nutrient concentration associated with releases?
iv. What are the values for dissolved oxygen concentrations?
v. How do chlorophyll, phytoplankton and zooplankton respond to physical chemical reservoir dynamics?

**RIN LP 2** How accurately can modeling predict reservoir dynamics and operational scenarios?

**RIN LP 3** How do dam operations affect reservoir limnology?

**RIN LP 4** How do historic reservoir conditions relate to present and future inflow/reservoir dynamics in a modeling framework?

**RIN LP 5** How do climate and hydrology affect the water quality of the reservoir and below the dam?

**RIN LP 6** How do nutrient, major ion concentrations, and biological parameters change relative to biological processes?

**RIN LP 7** Do the hydrodynamics and stratification of Lake Powell influence the foodbase or fisheries downstream?

**RIN LP 8** To what extent do dam operations modify/effect the release water from Lake Powell?

**RIN LP 9** What effect does the release water from Lake Powell have on downstream resources?

**M.O. 7.3** Maintain flow dynamics associated with power plant operations, BHBF and habitat maintenance flows.

**IN 7.3.1** Measure releases from the dam under ROD conditions. How often should you do these flows? When should you do these flows?

**Goal 8: Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve GCDAMP ecosystem goals.**

**M.O. 8.1** Maintain or attain fine sediment abundance, grain-size, distribution in the main channel below 5,000 cfs

Core Monitoring INs

**CMIN 8.1.1** What are the biennial fine-sediment, volume and grain-size changes below 5,000 cfs stage, by reach?

**CMIN 8.1.2** What are the monthly sand and silt/clay-export volumes and grain-size characteristics, by reach, as measured at Lees Ferry, Lower Marble Canyon, Grand Canyon and Diamond Creek stations?

**CMIN 8.1.3** What are the monthly sand and silt/clay -input volumes and grain-size characteristics, by reach, as measured at the Paria and Little Colorado River stations?

**CMIN 8.1.4** What are the monthly sand and silt/clay-input volumes and grain-size characteristics, by reach, as estimated and measured from other major tributaries, such as Kanab and Havasu Creeks?

**CMIN 8.1.5** What are the monthly sand and silt/clay-input volumes and grain-size characteristics, by reach, as estimated and measured from "lesser" tributaries?

Research INs

**RIN 8.1.1** What is the longitudinal variability of fine-sediment inputs, by reach?

**RIN 8.1.2** What is the spatial/temporal fate of individual fine-sediment inputs under ROD operations, by reach?

**RIN 8.1.3** What is the temporal variability of fine-sediment inputs, by reach?

**M.O. 8.2** Maintain or attain fine sediment abundance, grain-size, distribution within channel margins (not eddies) from 5,000 to 25,000 cfs

Core Monitoring IN

**CMIN 8.2.1** What are the biennial sandbar area, volume and grain-size changes outside of eddies between 5,000 and 25,000 cfs stage, by reach?

**M.O. 8.3** Maintain or attain fine sediment abundance, grain-size, distribution, within eddies below 5,000 cfs

Core Monitoring INs

**CMIN 8.3.1** What is the biennial sandbar area, volume and grain-size changes within eddies below 5,000 cfs stage, by reach?

**M.O. 8.4** Maintain or attain fine sediment abundance, grain-size, distribution within eddies between 5,000 to 25,000 cfs

Core Monitoring IN

**CMIN 8.4.1** What are the annual sandbar area, volume and grain-size changes within eddies between 5,000 and 25,000 cfs stage, by reach?

**M.O. 8.5** Maintain or attain fine sediment abundance, grain-size, distribution, shorelines between 25,000 cfs and uppermost effects of maximum dam release

Core Monitoring INs

**CMIN 8.5.1** What are the biennial sandbar area, volume and grain-size changes above 25,000 cfs stage, by reach?

Research INs

**RIN 8.5.1** What elements of ROD operations (MLFF, HMF, BHBF, experiments, etc.) are most/least critical to conserving new fine-sediment inputs, and stabilizing sediment deposits above the 25,000 cfs stage?

**RIN 8.5.2** What is the reach-scale variability of fine-sediment storage throughout the main channel?

**RIN 8.5.3** What is the maximum fine-sediment storage potential, per reach, under ROD operations?

**RIN 8.5.4** What is the pre- and post-dam range of grain-size in fine-sediment deposits, by reach?

**RIN 8.5.5** What is the significance of aeolian processes in terrestrial sandbar reworking?

**RIN 8.5.6** How do ROD operations affect sandbar grain-sizes and fine-sediment distribution?

**RIN 8.5.7** What are the historic and ongoing longitudinal trends of fine-sediment storage, above 25,000 cfs?

Effects Monitoring INs

**EIN 8.5.1** What elements of ROD operations (upramp, downramp, maximum and minimum flow, HMF, BHBF, experiments, etc.) are most/least critical to maintaining sediment abundance on the shore between 25,000 cfs and maximum dam releases?

Supporting INs

**SIN 8.5.1** Do sandbar textures influence biological processes? If so, then how?

**SIN 8.5.2** What is the relationship between the fine-sediment budget and turbidity?

**SIN 8.5.3** What is the relationship between turbidity and biological processes?

**SIN 8.5.4** Can turbidity be managed to achieve biological objectives?

**SIN 8.5.5** Can the ongoing fine-sediment supply be managed to achieve sustainable habitats?

**SIN 8.5.6** What are the grain-size characteristics of sand bars associated with designated riparian vegetation zones?

**SIN 8.5.7** What is the minimum quantity and quality of spawning substrate necessary for maintaining an existing naturally-spawned rainbow trout fishery?

**SIN 8.5.8** What are the limiting factors that regulate substrate availability and its distribution?

**SIN 8.5.9** What is the total area of different aquatic habitat types (cobble, gravel, sand, talus, etc,) in the Colorado River Ecosystem?

**SIN 8.5.10** Are sandbar textures related to cultural site stability? If so, then how?

**SIN 8.5.11** Are sandbar textures related to recreational site stability? If so, then how?

**NEW M.O. 8.6** Maintain or attain coarse sediment (greater than 2mm) abundance, grain-size and distribution throughout the Colorado River Ecosystem needed to achieve other resource goals

Research INs

**RIN 8.6.1** Do ongoing inputs of coarse-sediment from tributaries influence storage of fine sediment within pools, runs and eddies throughout the Colorado River Ecosystem?

**RIN 8.6.2** Do ongoing inputs of coarse-sediment from tributaries alter the distribution of main channel habitats needed by benthic organisms within pools, runs and eddies throughout the Colorado River Ecosystem?

**RIN 8.6.3** Do ongoing inputs of coarse-sediment from tributaries diminish navigability of rapid throughout the Colorado River Ecosystem?

**GOAL 9: Maintain or improve the quality of recreational experiences for users of the Colorado River Ecosystem, within the framework of GCDAMP ecosystem goals.**

MO 9.1 Maintain or improve the quality and range of opportunities in Glen and Grand Canyons within the capacity of the Colorado River Ecosystem to absorb visitor impacts consistent with the NPS and tribal river corridor Management Plans.

Core Monitoring INs

**CMIN 9.1.1** What are the river-related recreational opportunities and current use levels in each of the Canyons?

**CMIN 9.1.2** What are the frequency and scheduling of river-related use patterns?

**CMIN 9.1.3** Are the visitor capacities for these activities consistent with NPS management plans?

**CMIN 9.1.4** What is the level of satisfaction for river-related opportunities in each Canyon?

**CMIN 9.1.5** What attributes contribute to satisfaction/dissatisfaction of visitor experiences?

Research INs

**RIN 9.1** What are the attributes of a quality river experience? (How do you define a "quality river experience?")

MO 9.2 Maintain or improve the quality and range of opportunities in Glen and Grand Canyons in consideration of visitor safety, and the inherent risk of river-related recreational activities.

Core Monitoring INs

**CMIN 9.2.1** What is the current accident rate for visitors participating in river-related activities in each Canyon?

**CMIN 9.2.2** What are the causes and location (i.e., on-river or off-river) of these accidents?

**CMIN 9.2.3** How do these rates compare with other similar NPS areas and comparable federally-managed rivers?

**CMIN 9.2.4** What are the accident/incident data at rapids at various flow levels?

**CMIN 9.2.5** What is the relationship between equipment type, operator experience, and accident/incident rate at various flow levels?

**M.O. 9.3** Increase the size, quality and distribution of camping beaches in critical and non-critical reaches in the mainstem within the capacity of the Colorado River Ecosystem to absorb visitor impacts consistent with NPS and tribal river corridor Management Plans.

Core Monitoring INs·

**CMIN 9.3.1** What is the distribution of camping beaches by size and stage level in Glen and Grand Canyons?

**CMIN 9.3.2** What is the quality of camping beaches at various stage levels (where quality is defined on the basis of physical and other characteristics)?

**CMIN 9.3.3** What is the desired target level of camping beaches by reach?

Research

**RIN 9.3.1** How do ROD operations affect the size, quality, and distribution of camping beaches in the Colorado River Ecosystem?

**M.O. 9.4** Maintain or enhance the wilderness experience in the ~~Grand Canyon National Park~~ CRE in consideration of existing management plans.

Core Monitoring INs

**CMIN 9.4.1** What are the elements of wilderness experience and how are these measured?

**CMIN 9.4.2** What effects do dam operations have on these elements?

**M.O. 9.5** Maintain or enhance visitor experiences as a result of GCDAMP research and monitoring activities.

Core Monitoring INs

**CMIN 9.5.1** What is the frequency and scheduling of research and monitoring activity in Glen and Grand Canyons?

**CMIN 9.5.2** What is the current level of information, education, and outreach provided for Glen and Grand Canyon river users and the general public?

**CMIN 9.5.3** What effects do administrative trips, including research and monitoring activities have on recreational users?

Research INs
**RIN 9.5.1** To what extent does the public understand and support the GCDAMP?

**Goal 10: Maintain power production capacity and energy generation, and increase where feasible and advisable, within the framework of GCDAMP ecosystem goals.**

**IN 10.1** What are the impacts to power users given the changes in dam operations under the ROD?

**IN 10.2** What are the impacts to power users from the loss of capacity and energy at Glen Canyon dam?

**M.O. 10.1** Maintain or increase power with respect to marketable capacity and energy at Glen Canyon dam

Core Monitoring INs
**CMIN 10.1.1** What is the effect of the ROD on marketable power?

Research IN's
**RIN 10.1.1.** What are the effects on the CRE of maintaining or increasing the daily fluctuation limit?

**RIN 10.1.2.** What are the effects on the CRE of maintaining or increasing the upramp and downramp limit?

**RIN 10.1.3** What are the effects on the CRE of maintaining or raising the maximum flow limit above 25,000 cfs?

**RIN 10.1.4** What are the effects on the CRE of maintaining or lowering the minimum flow limit below 5,000 cfs?

**RIN 10.1.5** What are the effects of power-marketing contract provisions on Glen Canyon dam releases?

**M.O. 10.2** Maintain or increase power within the existing emergency criteria for Western Area Power Administration systems.

Core Monitoring IN's
**CMIN 10.2.1** What are the effects of reserve group obligations?

**M.O. 10.3** Maintain or increase power within the existing emergency criteria for the western interconnected electrical system.

Core Monitoring IN's
**CMIN 10.3.1** What is the full range of effects of Glen Canyon dam responses to western interconnected electrical system emergencies?

Research IN's
**RIN 10.3.1** What are the effects of providing financial exception criteria?

**M.O. 10.4** Maintain or increase power regulation at Glen Canyon dam.

Core Monitoring IN's
**CMIN 10.4.1** What are the effects on the CRE and power of maintaining or increasing Automatic Generation Control at GCD?

Research IN's
**RIN 10.4.1** What are the effects on the CRE of maintaining or increasing Automatic Generation Control at GCD?

**Goal 11: Preserve, protect, manage and treat cultural resources for the inspiration and benefit of past, present and future generations.**

**M.O. 11.1** Preserve the National Register integrity of register-eligible properties in the area of potential effect via protection, management, and/or treatment (e.g., data recovery) for the purpose of federal agency compliance with NHPA, and AMP and AMWG compliance with GCPA.

Core Monitoring INs
**CMIN 11.1.1** What are the sources of impacts to National Register eligible sites that link loss of integrity to ROD operations?

**11.1.1A** What are the other sources of impacts to National Register eligible sites?

**CMIN 11.1.2** What are the thresholds for impacts that threaten their integrity?

**11.1.2A** Are the current monitoring programs collecting the necessary information to assess resource integrity?

**CMIN 11.1.3** How effective are the treatment methods for mitigation of adverse effects to cultural resources?

**CMIN 11.1.4** How effective is monitoring, what are the appropriate strategies to capture change at an archaeological site -- qualitative, quantitative?

Research INs

**RIN 11.1.1** What is the current number of National Register (NR) eligible properties within the APE?

**11.1.1a** For each tribe, what is the current inventory of Traditional Cultural Properties (TCPs); what is their significance (i.e., their contributing elements) and their NR eligibility status?

**RIN 11.1.2** What are the associative values of sites or contributing elements under the criteria?

**11.1.2a** What is the information potential of sites under criterion D? (Note: What is criterion D?)

**11.1.2b** What are the potential threats to sites relative to integrity and significance?

**RIN 11.1.3** How do dam operations threaten the loss of site integrity?

**11.1.3.a** What and where are the geomorphic processes that link loss of site integrity with dam operations as opposed to dam existence or natural processes?

**11.1.3b** What are the terrace formation processes and how do dam operations affect current terrace formations processes?

**11.1.3c** Where can we identify effects of dam operations?

**RIN 11.1.4** What are appropriate strategies to preserve resource integrity?

**RIN 11.1.4a** How effective are the treatment methods for mitigation of adverse effects to cultural resources?

**M.O. 11.2** Preserve resource integrity and cultural values of traditionally important resources within the Colorado River Ecosystem.

Core Monitoring INs

**CMIN 11.2.1** What are the traditionally important resources and locations for each tribe and other groups?

**CMIN 11.2.2** What is the baseline measure for resource integrity?

**CMIN 11.2.3** What are acceptable methods to preserve traditionally important resources within the CRE?

Research INs
**RIN 11.2.1** What are the cultural attributes or criteria to measure resource integrity?

**RIN 11.2.2** What are the sources of resource change?

**M.O.11.3** Protect and maintain physical access to traditional cultural resources through meaningful consultation on AMP activities that might restrict or block physical access by Native American religious and traditional practitioners.

Effects INs
**EIN 11.3.1** Do AMP actions restrict access?

**EIN 11.3.2** What are the range of activities that may potentially restrict tribal access?

**EIN 11.3.3** Are there reasonable management actions that can or should be taken to facilitate tribal access?

**Goal 12: Maintain a high quality monitoring, research, and adaptive management program.**

**IN 12.1** What contracting methods exist for more dependably assessing remote sensing contractors for their ability to do work in the Grand Canyon?

**IN 12.2** What is the most effective way to distribute information to our stakeholders and the public in a secure and accessible fashion?

**M.O. 12. 1** Maintain or attain socio-economic data about tribal and spiritual values for adequate decision-making.

Core Monitoring INs:
**CMIN 12.1.1** What is the necessary quantity and quality of cultural information for adequate decision-making?

**M.O. 12.2:** Attain or improve monitoring and research programs to achieve the appropriate scale and sampling design needed to support science-based adaptive management recommendations.

Research INs
**RIN 12.2.1** What is the most appropriate field sampling method(s) (e.g., sampling size, spatial and temporal distribution, analysis, explicit assumptions, limitations and uncertainties) to monitor the status and trends of the aquatic foodbase?

**RIN 12.2.2** What RS technologies are available to less intrusively and more cost effectively monitor the aquatic food base?

**RIN 12.2.3** Is development of a bathymetric map of the entire CRE including characterization of the types of substrate available to support the aquatic food base needed?

**RIN 12.2.4** What digital technologies exist and should be used to record field observations of food base data that facilitates integration into GCMRC databases and use by PI's and stakeholders?

**RIN 12.2.5** What technologies exist to spatially reference food base data so that it can be readily integrated with other GCMRC data?

**RIN 12.2.6** What RS technologies are available to monitor fish within the CRE?

**RIN 12.2.7** What RS technologies are available to characterize and map water and substrate parameters important to fish habitat?

**RIN 12.2.8** Is development of a bathymetric map of the entire CRE including characterization of the types of substrate available that provide fish habitat needed?

**RIN 12.2.9** What digital technologies exist and should be used to record field observations of fish data that facilitates integration into GCMRC databases and use by PI's and stakeholders?

**RIN 12.2.10** What technologies exist to spatially reference fish data so that it can be readily integrated with other GCMRC data?

**RIN 12.2.11** What RS technologies are available to less intrusively and more cost effectively characterize and monitor KAS habitat (vegetation type and distribution)?

**RIN 12.2.12** What data sets currently exist to determine historic biotic riparian and spring communities?

**RIN 12.2.13** What remote sensing data is available or can be obtained that will support the production of a system-wide vegetation map?

**RIN 12.2.14** What is the acceptable detection level for change?

**RIN 12.2.15** What remote sensing technologies are available to less intrusively and more cost effectively monitor certain water quality parameters in the CRE?

**RIN 12.2.16** Can habitat designation using a GIS application be utilized as an effective method to adjust site-specific population estimates (e.g., mark-recapture or depletion methods) to system-wide extrapolations by using catch-per-unit-effort values that are scaled relative to the proportion of different habitat types available in Glen Canyon?

**RIN 12.2.17** What are the most appropriate strategies to integrate and analyze cultural resource data?

**RIN 12.2.18** What are the appropriate technologies to inventory, map and monitor cultural resources and the processes that affect them?

**M.O. 12.3** Integrate and synthesize cultural and environmental data to increase an understanding of the past and for ongoing interactions of humans within the CRE.

Effects INs

**EIN 12.3.1** Develop research designs and workplans that integrate cultural and environmental data from western science and tribal perspectives.

**EIN 12.3.2** Develop schedules to synthesize, disseminate and evaluate cultural and environmental data.

**M.O. 12.4** Attain or maintain an integrated and synthesized "ecosystem-science"-based adaptive management program.

**M.O. 12.4a** Maintain or attain the participation of externally-funded investigators

**M.O. 12.5** Foster effective two-way communication between scientists, external reviewers, managers, decision-makers and the public.

**M.O. 12.5a** Build AMP public support through effective public outreach

**M.O. 12.5b** Attain and maintain effective communication and coordination with other resource management programs in the Colorado River basin to ensure inclusion of their values and perspectives into the AMP and vice versa.

**M.O. 12.6** Attain and maintain an effective adaptive management program, composed of informed stakeholders.

**M.O. 12.6a** Maintain or attain funding from multiple sources

**M.O. 12.7** Attain and maintain effective tribal consultation to ensure inclusion of tribal values and perspectives into the AMP.

Core Monitoring INs:
**CMIN 12.7.1** What are the current strategies to achieve tribal consultation?

**CMIN 12.7.2** Do these strategies meet legal and AMP protocols?

**M.O. 12.8** Attain and maintain tribal participation in the AMP research and long-term monitoring activities.

**M.O. 12.9** Conduct experimental flows and other management actions for flow dynamics in the mainstem to gain critical understanding of ecosystem function under different dam operations, e.g., BHBF's, HMF's, biological opinion flows, and financial exception criteria flows.

Research INs
**RIN 12.9.1** What is the impact on downstream resources of short-term increases to maximum flow, daily fluctuations and downramp limits?

# AMP Narrative

# AMP Narrative of Desired Future Resource Conditions

Attached are two drafts of the "AMP Narrative of Desired Future Resource Conditions." This narrative was originally intended to articulate the AMP's vision for the Colorado River ecosystem if the adaptive management program were successful.

The Technical Work Group later decided to discontinue this approach and not work to complete such a description.

# AMP Narrative of Desired Future Resource Conditions

## Introduction

The strategic plan for the Glen Canyon Dam Adaptive Management Program (AMP) is based on the premise that key elements of natural ecological processes can, to a sufficient degree, be simulated by management actions to achieve desired future resource conditions for the Colorado River ecosystem (CRE)[1]. In addition, the principles developed by the Adaptive Management Work Group (AMWG) explicitly recognize that Glen Canyon Dam and its provision of water and power resources are an integral part of this ecosystem. The operation of Glen Canyon Dam has altered the natural processes and habitat that support the natural, physical, and cultural resources of the CRE. Together with the introduction of non-native species and other changes, these altered natural processes have led to substantial changes in the CRE.

The ecological and biophysical attributes of the pre-dam river represent the conditions under which the natural, physical, and cultural resources in the CRE developed. It is assumed that management actions that restore elements of these conditions, consistent with the Law of the River, the operational flexibility of the dam, Grand Canyon National Park values, and other guiding legal imperatives will improve conditions of the CRE. In some cases, additional management actions (e.g. mechanical removal of existing riparian vegetation or non-native fish control) may be needed to achieve the desired future resource conditions described below.

The Glen Canyon Dam Adaptive Management Program (AMP) seeks to return flows of the Colorado River to a more natural state, consistent with the philosophy contained in the Grand Canyon Protection Act (GCPA), Final Operation of Glen Canyon Dam Environmental Impact Statement (EIS) and the subsequent Record of Decision (ROD). The desired future resource conditions described below represent the AMWG's vision for what will result from successful implementation of the AMP strategic plan.

The AMWG's desired future resource condition for the CRE centers on retaining valued components of the new, post-dam system, while embarking on a path that leads us further in the

[1] The Colorado River ecosystem is defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, a distance of approximately 293 river miles (Figure 1).

direction of viable populations and communities of native plants and animals. The AMWG sees the CRE as a mosaic of natural, cultural and recreational resources influenced and controlled by dominant physical processes including climate, tributary flows and releases from Glen Canyon Dam. At the head of the CRE and included within it is Lake Powell and Glen Canyon Dam, at the other end is Lake Mead.

When taken as a whole, implementation of the ROD introduced greater stability of flows from day to day, but greater variability from year to year. It accomplished the first by reducing daily fluctuations, and the second by the testing of lower stable flows (LSSFs) during low water years and implementing large peak flows (BHBFs and HMFs). We desire a CRE, including the dam and humans, that is dynamic in nature and is temporally punctuated by flow events such as BHBFs, HMFs, LSSFs, daily/monthly hydropower operations, and tributary flows. Adaptation to these flow events (i.e., disturbance regimes), will predominately influence the structure and composition of the plant and animal communities within the CRE, as well as recreational quality and the protection of cultural values within the corridor. Thus individual resources will vary both spatially, depending on their location in the CRE, and temporally depending on the nature (i.e., timing, magnitude, duration) of the flow event and the time since the last flow event. See Figure ? for a portrayal of these temporal effects.

Target levels recognize and reflect this dynamism rather than some optimum level. They account for potential management actions in addition to dam operations in achieving desired resource conditions. Target levels are not single values, but ranges or descriptions that encapsulate the concepts of minimum or maximum threshold levels, rates of change, and the resource's role in the overall ecosystem.

## Desired Future Aquatic Resource Conditions

We envision a system where the viability of native fish populations are not constrained or threatened by non-native predation or competition. The EIS and ROD flows have significantly increased the productivity of the aquatic environment and benefited trout, perhaps preferentially so, and management actions may need to be taken to reduce the impacts of non-native fish on native fish. We believe that the ROD leads us to test both flow and temperature variables in an attempt to reverse this threat. We desire a continuation of the nature of the current food base in the Lees Ferry reach, but recognize that the specific macrophyte and invertebrate species may change, both successionally and as efforts are made to enhance the native species below GCD.

The AMWG sees the clear-water Lees Ferry reach full of beds of benthic algae and rooted aquatic macrophytes. This plant life supports a diverse invertebrate community, and together they form the food base for a population of naturally reproducing rainbow trout in the Lees Ferry reach of Glen Canyon and native fish throughout the CRE.

Approximately 16 miles downstream of the dam, we see the first hint of the vestigial Colorado River as a small stream, the Paria River, enters from the right-hand shore. The size of the stream belies its importance, because it is a major producer of fine sediments during floods. The fine clays, silts, and sands entering the Colorado drown the sun's light as it passes through the water, stealing from the aquatic plants the very energy that allows their existence. Other ungaged tributaries, with their sporadic floods, add their contributions in the downstream journey, further suppressing light penetration and forcing the system deeper toward its past, back to its nature before the dam had its way. The Little Colorado River strikes another major blow to the world of light and plant life. This tributary enters the mainstem 75 miles below the dam after draining nearly 27,000 square miles of mountain and desert lands in northeastern Arizona. Only when the Paria, Little Colorado, and other sediment-bearing tributaries are at base flow does the river that flows from the dam retain its clear water character in the journey through Grand Canyon.

In the world of alternating darkness and light below the Paria River, the Colorado and its tributaries support a community of native fish--viable, self-sustaining populations that benefit from purposeful variations in dam releases. Except for the Lees Ferry population of rainbow trout, non-native fish are not welcome in the CRE, and positive efforts will be made to reduce their numbers.

Water quality will vary wildly though time and space dependent upon water releases and tributary flows and will greatly influence the aquatic environment. We expect that the native species adapted to the pre-dam extremes will persist and flourish within this dynamic environment.

## Desired Future Riparian Resource Conditions

With respect to riparian resources, we see a resource that varies longitudinally down river in response to substrate geomorphology, water availability, climate and the disturbance regime. The pre-dam flooding regime has limited the establishment of marshes and near-shore riparian areas. Flooding is now largely under human control through the operations of Glen Canyon Dam

and these near-shore riparian areas have come to dominate the ecosystem. A flooding regime will continue within the CRE that preserves extreme disturbance variability and supports native plant and animal communities and their habitat to the point described below. Management floods will be triggered if sufficient sand is available for deposition. Within such a regime, beaches will expand and contract through natural processes. Beach number and area within the CRE will vary between xx-yy% of the pre-dam condition. The median grain size of beach sand will tend to be zz% coarser but will support the conditions expected for riparian and animal habitat as well as recreational use.

Marshes are most affected by flooding and will come and go in specific locations quickly in response to this influence. We expect that the absolute amount to vary between virtually zero and five percent of the total riparian vegetation within the corridor. The near-shore riparian zone is more permanently established and will tend to better resist the extreme fluctuations predicted for marshes. Near-shore riparian vegetation will vary between xx-yy% of the total vegetation within the corridor depending upon the severity of the flooding regime imposed. Upslope riparian vegetation blends into the terrestrial community forming a broad ecotone that is less influenced by flooding. This community will vary xx-yy% depending on the flooding regime imposed.

We desire a change toward a more native riparian species composition, gradually eliminating non-native species, especially noxious species. We believe that aggressive management actions will be required to accomplish this. However, even with a return to native species, we desire a mix of both pre- and post-dam riparian communities such as the old high-water zone (OHWZ), new high-water zone (NHWZ), bare sand beaches and marshes. We envision a resource that changes longitudinally as one moves downstream from GCD to Lake Mead in response to changing reach geomorphology, sediment inputs, and climatic factors. We also recognize that there will be a frequency associated with the presence / absence (coming or going) of riparian features such as marshes and bare sand beaches, expecting that beach/habitat-building flows (BHBFs) will enhance the OHWZ and bare sand beaches and that in subsequent years between BHBFs the NHWZ and marshes will be favored. (See Figure ? for a diagram of how the channel cross section might change with time). As these communities change, we will continually assess our protection of endangered species, perhaps from the perspective of threshold levels of habitat that will not jeopardize the future existence of the species.

The natural communities native to the Grand Canyon will dominate the riparian ecosystem. The area above the high-water line of major floods supports native riparian communities dominated by Apache plume above river mile 40, and mesquite-acacia below river mile 40. Below the high-water line is a scour zone dominated by ephemeral species. Neither non-native species nor invasive native species will be dominant. They will not impair the abundance, composition, and distribution of natural communities nor alter the natural processes that shape these communities.

Our desire in purposefully varying dam releases is to move the physical world of the Colorado River closer to its roots, closer to the seasonal cycles experienced in pre-dam times. Yet not so close as to be too far away from the world that has allowed colonization of the streamside corridor by new forms of vegetation, both marsh and riparian. Here we balance precariously between the old and the new, for we desire to maintain pre-dam vegetation, the so-called old high water zone that was able to persist in the face of large-scale floods, yet retain the lower marsh and riparian corridor habitats.

As we pass down the river, we search for sandy beaches nestled among the expanses of marsh and riparian areas. These beaches are our refuges at the end of the day when we river runners leave the current and retreat to land before the sun sets and darkness settles over the river. To have these beaches, we must have floods; floods that will remove portions of the marsh and riparian vegetation, rise to quench the thirst of the old high water zone, and deposit clean sands to form our refugia.

Flow effects will vary as the river passes downstream, depending upon the geometry and geology of the streambed and its shores. The effects also will vary with time; large flows will serve to reset the system, to force plant communities back to earlier successional stages and to maintain a patchwork mosaic of open beaches and vegetated zones. During intervening periods, biological interactions and physical processes will change the pattern of the mosaic, and the frequency of its components, but differences in the landscape coupled with the effects of the next large flow will maintain the diversity of features that we desire in this ecosystem.

The vertebrates native to the CRE will dominate the riverine ecosystem. Native species that are/were resident to the CRE will exist as viable populations. The natural processes imposed by species that were transient to the CRE, but are now extirpated, may be mimicked by the creation of small resident populations or other management actions. Non-native species will not

be dominant and they will not impair the abundance and distribution of native species nor alter the natural processes that shape these communities.

## Desired Future Cultural Resource Conditions

The goal for cultural resources affected by the operations of Glen Canyon Dam is to identify, evaluate, register and treat the full range of properties representing significant aspects of American history, architecture, archeology, engineering, and culture. Each cultural resource or property will be evaluated within its historic context and its association with important events or persons, design or construction, information potential or traditional or cultural value will be described, classified, and assessed. A series of preservation goals will be systematically developed for each historic context and property type based upon the principles that cultural resources are irreplaceable and should be preserved in place if possible. Preservation goals and priorities will be integrated with other planning and preservation concerns and will be established based on active consultation with affected groups and with others interested in the cultural resources present within the CRE. To improve the preservation, protection and interpretation of cultural resources, all activities and decisions should be made based on principles of stewardship, accountability, consultation, and public education and outreach. Increased communication with Native American tribes will help us better respect and integrate their concerns.

## Desired Future Recreational Resource Conditions

We expect the CRE to provide a setting that facilitates an appropriate spectrum of recreational activities within the context of a full wilderness setting. Appropriate activities include hiking, fishing, boating and river running, photography, wildlife viewing etc. Specifically, visitor experience will emphasize the appreciation of wilderness values.

The nature of recreational camping beaches will change from year to year as sediment is deposited and eroded. During periods of high runoff years, large magnitude BHBFs will deposit sand high on the banks and available for visitor use, while periods of low runoff years will benefit from fall habitat maintenance flows (HMFs), released following fall tributary inputs. These disturbance releases (BHBFs and HMFs) will each be significantly higher in magnitude than dam releases ongoing at that point in time.

Recreational activity will not impair the aesthetic, ecological, cultural and spiritual values of the Grand Canyon, but will result in a deep appreciation for these values. Recreation takes the river "on its own terms" and celebrates the primitive conditions of one of the seven wonders of the world.

Recreational opportunities will be enhanced and research activities will have minimal impact on the CRE. A high value will be placed on the extensive wilderness qualities of the river corridor. The CRE is remarkable in the length and breadth of its unbroken primitive character. It provides unique opportunities for experiencing natural sounds and natural quiet of the desert and river. Opportunities for solitude, connection to nature, and personal contemplation outside the trappings of civilization will be deeply valued.

**Desired Future Water and Power Resource Conditions**

We anticipate that Glen Canyon Dam and the Power Plant will continue to be operated in a manner consistent with the "Law of the River," including the Grand Canyon Protection Act. This will allow the Upper Basin States to develop their compact allocations of water and deliver water to the Lower Basin States as required by compact. The power plant will be operated to maximize the value of the power resource. This will be done consistent with the resource balancing anticipated in the EIS, ROD, and the operating criteria established by the Secretary. We also acknowledge that these "operating criteria" may be modified in the future as the result of the long-term monitoring of their effects and further research, through the adaptive management process.

## Riparian Vegetation Attachment

Riparian vegetation assemblages in the CRE may be classified into 4 zones as one moves up-slope from the river. These include the hydro-riparian zone (HRZ; marsh), lower riparian zone (LRZ; "New High Water Zone"), middle riparian zone (MRZ), and upper riparian zone (URZ; "Old High Water Zone"). These riparian zones develop in response to flow (flood disturbance, inundation frequency and moisture availability), sediment type, (grain size, moisture retention and nutrient content), and the physical characteristics of a given geomorphic reach. Thirteen geomorphic reaches have been identified within the CRE.

Narrow geomorphic reaches encompass approximately 40% of the CRE and are characterized by steep rocky or bedrock banks. Narrow geomorphic reaches have sparse to no

riparian vegetation. Extensive riparian vegetation cannot develop in narrow reaches because little sand or suitable germination sites exist, grain size is generally larger, and stage-to-discharge relationships are steeper (more stage gain per unit increase in discharge). Wide geomorphic reaches have abundant riparian vegetation. Extensive riparian vegetation can develop in wide geomorphic reaches due to the availability of sand and suitable germination sites and lower flow gradients. In addition, within the CRE one finds debris-fan eddy complexes (DFCs) in both narrow and wide geomorphic reaches. DFCs create conditions that can support the hydro-riparian zone in low velocity, near-shore and return current channel settings, LRZ sand bar habitats, and fine-grained URZ terraces.

The distribution of riparian vegetation assemblages is strongly related to flood and inundation frequency, and grain-size. Riparian vegetation development takes place in response to changes in these state variables, and over time; however, vegetation development does not occur as a perfect stage-for-time replacement process, because of variability in life history traits of the more than 700 plant species that occur in the river corridor.

**The HRZ (8-25,000 cfs stage):** Data from the 1983-1992 time period indicates that redevelopment of marshes takes place over a 5-10 yr time period in specific fluvial habitats (rarely scoured near-shore and return channel habitats). The establishment of marsh vegetation (cattail, reed, horsetail, sedge, bullrush and rushes) requires sandy silt soils that are inundated at least 5% of the growing period. Some marsh species may persist through low-flow years with no inundation (for example, cattail stands at Lees Ferry persisted for 4 yr after the subsidence of the mid-1980's high flows). Constant water levels allow cattail to quickly (2-4 yr) dominate return current channel marshes, eliminating many other marsh species, whereas highly variable and lower inundation frequency settings favor horsetail and reed. Because these habitats are low-lying and particularly susceptible to scour during high flows, moderately increased flooding is likely to maintain diversity, whereas high flood frequency is likely to scour and eliminate riverine marshes. High productivity is strongly related to invasibility by non-native plant species, and this the case in the HRZ.

**The LRZ (ca 18,000-45,000 cfs stage):** Lower riparian zone vegetation develops in a variety of geomorphic settings and grain-sizes, including sand bars, channel margins, debris fans, and, sparsely, on rocky talus slopes. Composition is dominated by tamarisk, coyote willow, arrowweed, seep-willow, and numerous grasses and herbs. URZ vegetation is gradually

invading this zone, but this invasion is retarded by higher flood frequency because URZ dominants (mesquite and catclaw) are less flood tolerant than the phreatophytes that generally dominate the LRZ. The LRZ can redevelop swiftly after moderate floods (i.e., 1-3 yr after the 1996 flood), moderately slowly after larger floods (i.e., 5-10 yr after the 1983-1986 high flows), and cannot persist with frequent, high floods (i.e., those that characterized the pre-dam hydrograph). Like the HRZ, the relatively high productivity of this zone makes it particularly prone to invasion by non-native plant species, and tamarisk, camelthorn and numerous non-native grass and herb species dominate many LRZ settings.

**The MRZ (45,000-125,000 cfs stage):** This zone exists in a state of dynamic disequilibrium, with establishment of phreatophyes after high floods (most of which soon perish from desiccation) offset by the downslope invasion of slow-growing, flood intolerant desert plant species (i.e., cacti, creosotebush, brittlebush), which are eliminated by high flows. Compositional change in this low-productivity zone results from the gradual dominance of species like catclaw that are facultative riparian species with moderate inundation tolerance.

**The URZ (125,000-300,000 cfs stage):** This belt of pre-dam vegetation exists upslope from the 10-yr pre-dam flood return stage (125,000 cfs). The dominant woody species (mesquite, catclaw, netleaf hackberry) are long-lived (100-750 yr in age at least), and are highly resilient, having persisted through enormous pre-dam flows. Detailed studies in the mid-1980s failed to demonstrate any relationship between flooding and growth of URZ vegetation. Pre-dam flows of the 100-yr return frequency (>250,000 cfs) may have been necessary for germination of mesquite, and absence of such flows may gradually shift the composition from mesquite to catclaw; however, this process is likely to proceed at a multidecadal to century time scale because of the low productivity of this zone.

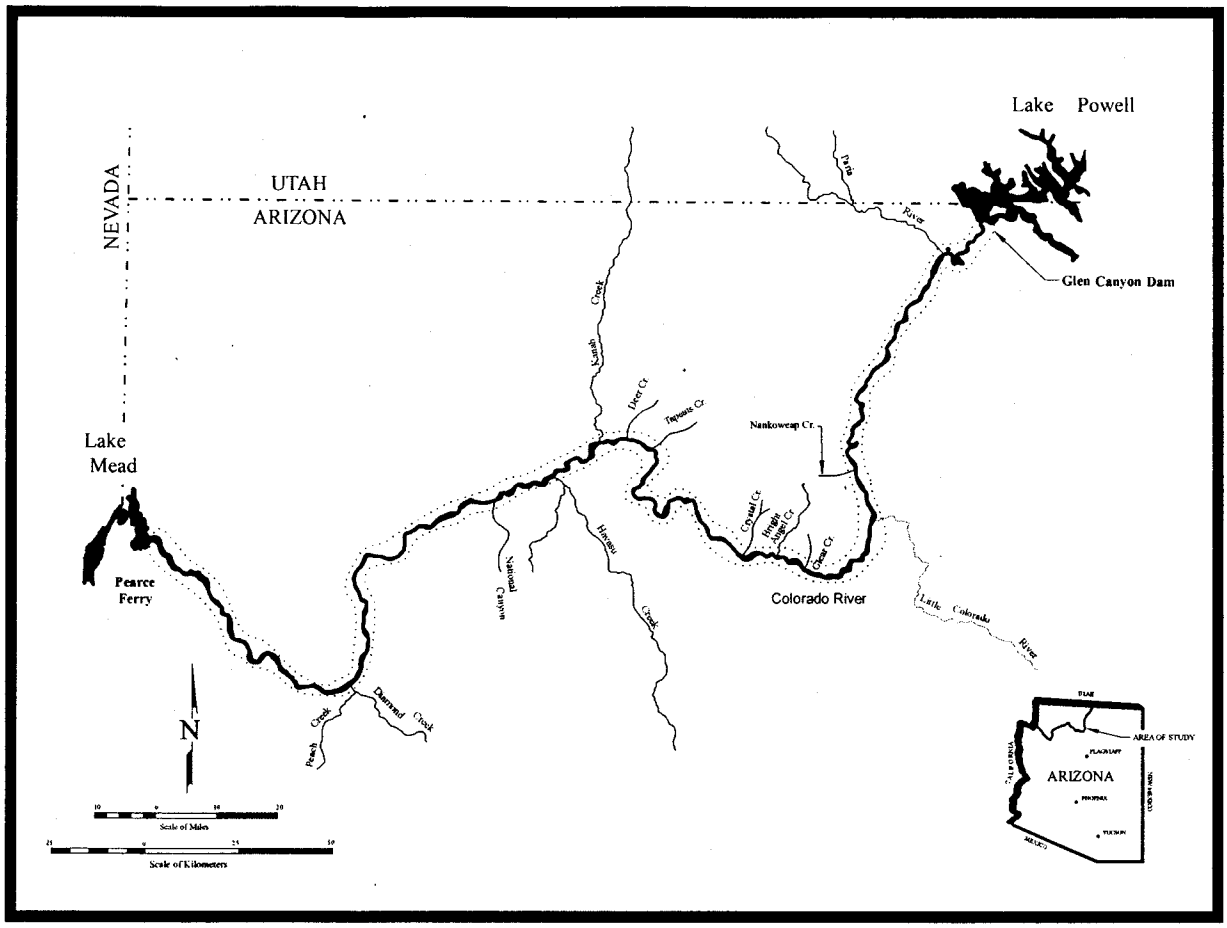


Figure 1. Map of the Geographic Extent of the Colorado River Ecosystem

# AMP Narrative of Desired Future Resource Conditions

## Introduction

The strategic plan for the Glen Canyon Dam Adaptive Management Program (AMP) is based on the premise that key elements of natural ecological processes can, to a sufficient degree, be simulated by management actions to achieve desired future resource conditions for the Colorado River ecosystem (CRE)[1]. In addition, the principles developed by the Adaptive Management Work Group (AMWG) explicitly recognize that Glen Canyon Dam and its provision of water and power resources are an integral part of this ecosystem. The operation of Glen Canyon Dam has altered the natural processes and habitat that support the natural, physical, and cultural resources of the CRE.

The biological and physical attributes of the river prior to dam construction, introductions of nonnative plants and fish, and other recent human alterations represent the conditions under which the natural, physical, and cultural resources in the CRE developed. The AMP seeks to return resource conditions of the CRE to a more natural state. It is assumed that management actions that restore elements of these conditions, consistent with the Grand Canyon Protection Act, "Law of the River," NPS Organic Act (and amending legislation), the operational flexibility of the dam, and other guiding legal imperatives, will improve conditions of the CRE.

The AMP desired future resource condition for the CRE centers on maintaining viable populations and communities of native plants and animals while retaining valued components of the post-dam system. We desire a CRE, including the dam and humans, that is dynamic in nature and is temporally punctuated by flow events such as BHBFs, HMFs, LSSFs, daily/monthly hydropower operations, and tributary flows. Adaptation to these events (i.e., disturbance regimes), will predominately influence the structure and composition of the plant and animal communities within the CRE, as well as recreational quality and the protection of cultural values within the corridor. Thus, individual resources will vary both spatially, depending on their location in the CRE, and temporally depending on the nature (i.e., timing, magnitude, duration, periodicity) of the event. **See Figure ?** for a portrayal of these temporal effects. The desired future resource conditions described below represent the AMP vision for what will result from successful implementation of the AMP strategic plan.

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[1] The Colorado River ecosystem is defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, a distance of approximately 293 river miles (Figure 1).

## Desired Future Aquatic Resource Conditions

We envision a system where ROD flows significantly increase the productivity of the aquatic environment, maintaining the nature of the aquatic plant and invertebrate food base to the benefit of naturally reproducing rainbow trout in the Lees Ferry reach and native fish throughout the CRE. Viability of native fish populations is not constrained or threatened by non-native predation or competition. Except for the Lees Ferry population of rainbow trout, positive efforts continue to control numbers of non-native fish. Below the Paria River, the Colorado and its tributaries support a community of viable, self-sustaining, native fish populations that benefit from purposeful variations in dam releases. The ROD tests both flow and temperature variables in the determination of the full extent to which the Dam can continue to be used as a tool to manage the CRE.

Water quality varies through time and space dependent upon dam releases and tributary flows, greatly influencing the aquatic environment. The most conspicuous changes result from sediment-bearing tributaries. The Paria and Little Colorado rivers produce major amounts of fine sediments during floods. Other ungaged tributaries, with their sporadic floods, continue to add their sediment contributions to the flow. These fine clays, silts, and sands entering the Colorado dramatically alter the character of the CRE below the Paria. The native species, adapted to the pre-dam extremes, continue to persist and flourish within this dynamic environment.

This system allows anglers to experience quality fishing, native fish communities to remain viable and healthy, and our grandchildren to enjoy the CRE as the experience of a lifetime.

## Desired Future Riparian Resource Conditions

We envision a resource that varies longitudinally and temporally down river in response to substrate geomorphology, water availability, climate and the disturbance regime. System disturbance is largely controlled flooding by the operations of Glen Canyon Dam. Managed floods are triggered if sufficient sand is available for redeposition. Such flooding within the CRE preserves the variability of system disturbance and supports native plant and animal communities and their habitats.

The natural communities native to the Grand Canyon dominate the riparian ecosystem. The area above the high-water line of major floods supports native riparian communities dominated by Apache plume above river mile 40, and mesquite-acacia below river mile 40. Below the high-water line, broad sand beaches sparsely vegetated with native herbaceous species dominate the scour zone.

The frequency associated with the presence/absence (coming or going) of riparian features, such as ephemeral communities is directly correlated with the frequency of flood events. As large flows reset the system and force plant communities back to earlier successional stages, a patchwork mosaic of open beaches and vegetated zones is created. There is a dynamic mix of both pre- and post-dam riparian communities, such as the old

high-water zone (OHWZ), new high-water zone (NHWZ), and bare sand beaches and marshes. Managed beach/habitat-building flows (BHBFs) enhance the OHWZ community species and bare sand beaches. In years without flood disturbance, the NHWZ community and marshes flourish. (See Figure ? for a diagram of how the channel cross section might change with time).

Non-native species, where present, are not dominant, and do not impair the abundance, composition, and distribution of natural communities nor alter the natural processes that shape these communities. However, aggressive management action may have been used to accomplish this.

The vertebrates native to the CRE dominate the ~~riverine~~ ecosystem. Native species resident to the CRE exist as viable populations. The natural processes imposed by species that were transient to the CRE, then extirpated, are mimicked by the creation of small resident populations or other management actions.

As dynamic riparian communities change, we continually assess our protection of endangered species from the perspective of threshold levels of habitat that will not jeopardize the future existence of the species.

## Desired Future Cultural Resource Conditions

The future for cultural resources affected by Glen Canyon Dam operations envisions these resources preserved, protected, and interpreted where feasible; and all future resource management activities and decisions based on principles of stewardship, accountability, consultation, and public education and outreach. All sites unaffected by dam operations are left to the natural processes of erosion and deposition.

## Desired Future Recreational Resource Conditions

We envision the CRE with an appropriate spectrum of recreational activities within the context of a full wilderness setting. Available activities include hiking, fishing, boating and river running, photography, wildlife viewing, etc. Specifically, visitor experiences emphasize the appreciation of wilderness values.

The nature of recreational camping beaches changes from year to year as sediment is deposited and eroded. When high runoff years occur, large magnitude BHBFs, two or three times power plant capacity, deposit sand high on the banks available for visitor use. When low runoff years occur, fall habitat maintenance flows (HMFs) redistribute fall tributary sediment inputs above normal, daily power plant releases.

Recreational activities do not impair the aesthetic, ecological, cultural and spiritual values of the Grand Canyon, but provide deep appreciation for these values. Visitors accept the river "on its own terms" and celebrate the primitive conditions of one of the seven wonders of the world.

Recreational opportunities are enhanced and research activities have minimal impact on the CRE. A high value is placed on the extensive wilderness qualities of the river corridor. The CRE is remarkable in the length and breadth of its unbroken primitive character. It provides unique opportunities for experiencing the natural sounds and natural quiet of the desert and river. Opportunities for solitude, connection to nature, and personal contemplation outside the trappings of civilization are deeply valued.

**Desired Future Water and Power Resource Conditions**

Glen Canyon Dam and the Power Plant continue to operate in a manner consistent with the "Law of the River," including the Grand Canyon Protection Act. The Upper Basin States develop their compact allocations of water and deliver water to the Lower Basin States as required by compact. The power plant operates to maximize the value of the power resource consistent with the resource balancing anticipated in the EIS, ROD, and the operating criteria established by the Secretary. Operating criteria continue to be modified as the result of long-term monitoring of their effects and further research, through the adaptive management process.

# Notes

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