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The Glen Canyon Dam
Adaptive Management
Program Presents:

Colorado River Ecosystem Science Symposium 2005

October 25-27, 2005
Fiesta Inn Resort
Tempe, AZ

Abstracts

Organized by:
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and
Research Center

Colorado River Ecosystem Science Symposium 2005

Abstracts

October 25-27, 2005
Fiesta Inn Resort
2100 South Priest Drive
Tempe, AZ

Presented by the Glen Canyon Dam Adaptive Management Program and organized by the Grand Canyon Monitoring and Research Center, U.S. Geological Survey, U.S. Department of the Interior, Flagstaff, AZ, Theodore S. Melis, Acting Chief.

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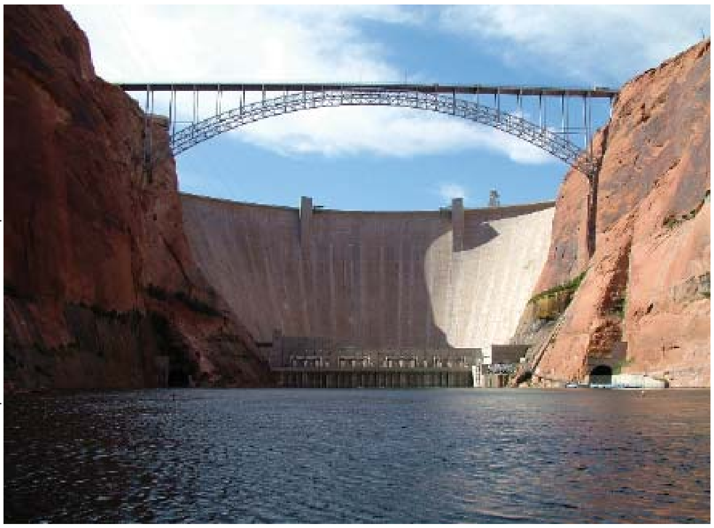
Glen Canyon Dam Adaptive Management Program and Grand Canyon Monitoring and Research Center



The international prominence of Grand Canyon National Park and public concern about the impacts of Glen Canyon Dam on downstream resources resulted in the passage of the Grand Canyon Protection Act of 1992 (GCPA). The GCPA directs the Secretary of the Interior to 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, including, but not limited to natural and cultural resources and visitor use" (GCPA, sec. 1802(a)).

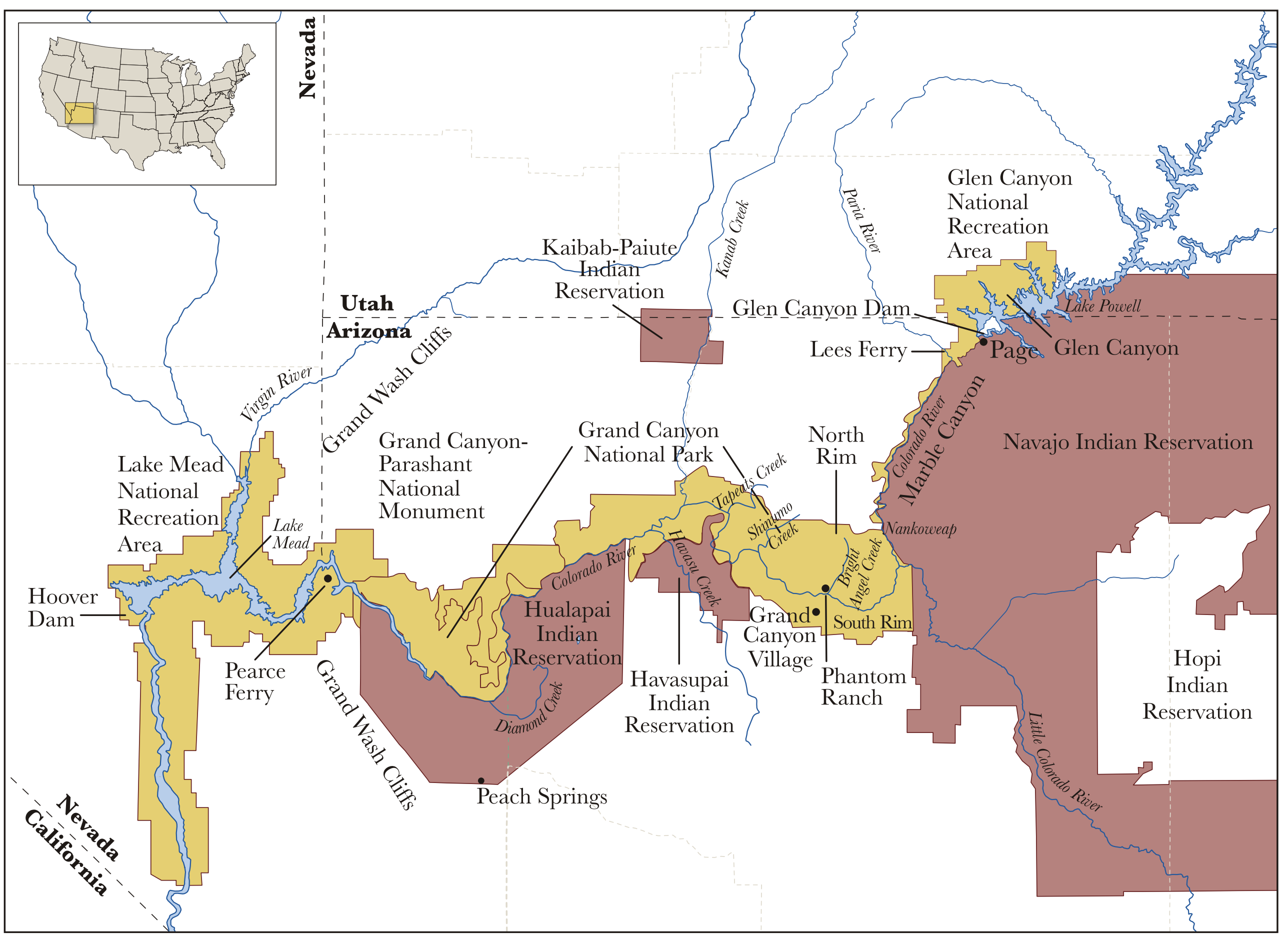
The Glen Canyon Dam Adaptive Management Program (GCDAMP) is largely an outgrowth of this legislation. Adaptive management was selected to create a process whereby the effects of dam operations on downstream resources would be assessed and the results would form the basis for future modifications of dam operations. The GCDAMP is administered by the U.S. Department of the Interior and facilitated by the Adaptive Management Work Group, a Federal Advisory Committee. The GCDAMP is comprised of the Technical Work Group, a set of Independent Review Panels, and the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center, which has responsibility for scientific monitoring and research efforts for the program.

Appropriately, the Grand Canyon Monitoring and Research Center is housed within the U.S. Geological Survey. The USGS is the primary science provider for the U.S. Department of the Interior and serves the Nation as an independent fact-finding agency that collects, monitors, analyzes, and provides scientific understanding about natural resource conditions, issues, and problems. The scientific nature of the USGS, its national perspective, and its non-regulatory role enable USGS scientists to provide information and understanding that are policy relevant and policy neutral.

As such, the mission of the Grand Canyon Monitoring and Research Center is to provide credible, objective scientific information to the GCDAMP on the effects of operating Glen Canyon Dam under the Record of Decision and other management actions on the downstream resources of the Colorado River ecosystem, utilizing an ecosystem science approach.

Geographic Scope

The GCDAMP focuses on a study area that encompasses tthe Colorado River corridor from Glen Canyon Dam to the western boundary of Grand Canyon National Park. The study area includes the approximately 15 river miles (RM) of the river from the dam to Lees Ferry within Glen Canyon National Recreation Area and the entire 277-RM river corridor below Lees Ferry and within Grand Canyon National Park. In total, the study area includes some 293 RM of the Colorado River (see map below). The study area includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. The scope of adaptive management program activities may include limited investigations into some tributaries (e.g., the Little Colorado and Paria Rivers). 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 adaptive management program may do research outside the geographic scope defined above to obtain needed information.



Vision, Mission, and Goals of the Glen Canyon Dam Adaptive Management Program

Courtesy of Roy Averill-Murray, Arizona Game and Fish Department

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.

Goals

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 naturally 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 program 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.

Adaptive Management Work Group Members

Interior Secretary's Designee

Tribes

Hopi Tribe
Hualapai Tribe
Navajo Nation
Pueblo of Zuni
San Juan Southern Paiute Tribe
Southern Paiute Consortium

State and Federal Cooperating Agencies

Arizona Game and Fish Department
Bureau of Indian Affairs
Bureau of Reclamation
National Park Service
U.S. Department of Energy, Western Area Power Administration
U.S. Fish and Wildlife Service

Colorado River Basin States

Arizona: Arizona Department of Water Resources
California: Colorado River Board of California
Colorado: Colorado Water Conservation Board
Nevada: Colorado River Commission of Nevada
New Mexico: New Mexico Office of the State Engineer
Utah: Water Resources Agency
Wyoming: State Engineer's Office

Nongovernmental Groups

Environmental:
Grand Canyon Trust
Grand Canyon Wildlands Council

Recreation:
Federation of Fly Fishers/Northern Arizona Flycasters
Grand Canyon River Guides

Contractors for Federal Power from Glen Canyon Dam:
Colorado River Energy Distributors Association
Utah Associated Municipal Power Systems

Purpose of this Symposium

Courtesy of Jeff Sorenson, Arizona Game and Fish Department

The 2005 symposium represents an exciting opportunity to learn and to share recent findings from ongoing monitoring and research activities. The symposium also coincides both with the tenth anniversary of the environmental impact statement (EIS) that set the stage for the GCDAMP and the release of the first comprehensive summary on the impacts of the operation of Glen Canyon Dam on downstream natural, cultural, and recreational resources within Glen Canyon National Recreation Area and Grand Canyon National Park.

The report, *The State of Colorado River Ecosystem in Grand Canyon*, serves as a focal point for the first day of the symposium. It is an significant milestone in the use of adaptive ecosystem management (AEM) to support the Grand Canyon Protection Act of 1992. Importantly, its analysis and results can be a catalyst for education and interaction among the scientific community, resource managers, and the public.

The second day offers a preliminary update of the results of 2003–05 experimentation, including the November 2004 Experimental High Flow, fluctuating nonnative fish suppression releases, and efforts to mechanically remove nonnative fishes in the Colorado River within Grand Canyon. During the afternoon of the second day, monitoring and research activities in the realms of aquatic biology, economics, planning and experimentation are highlighted. The third day explores other important components of the monitoring and research program, including spatial and remotely sensed data, water quality, physical science, and primary productivity. The symposium concludes with recent findings related to the endangered humpback chub (*Gila cypha*) population in Grand Canyon.

The overarching goal of the symposium is to engender discussion on how best to use the scientific results contained in the report and other findings to advance the future monitoring and research efforts. Thank you for attending and participating in this exciting event.

Symposium Program Overview

Tuesday, October 25, 2005

8:30–8:40	Opening Remarks
8:40–9:20	Keynote Speech
9:20–10:00	Keynote Speech
10:00–10:20	Break
	The State of the Colorado River Ecosystem in Grand Canyon Report Presentations
10:20–Noon	Report Presentations
Noon–1:00	Lunch (On your own)
1:00–2:40	Report Presentations
2:40–3:00	Break
3:00–4:00	Report Presentations
4:00–5:30	Panel Discussion
5:30-7:00	Dinner (On your own)
7:00-9:30	Poster Session and Technology Demonstrations

Wednesday, October 26, 2005

8:00–8:40	Keynote Speech
	Preliminary Results of Experimentation
8:40–10:20	Hydrology and Sediment Presentations
10:20–10:30	Break
10:30–11:30	Fishes Presentations
11:30–12:30	Lunch (On your own)
12:30–2:10	Aquatic Biology Presentations
2:10–2:30	Break
2:30–2:50	Aquatic Biology Presentations (continued)
3:10–3:30	Economic Issues Presentation
3:30–4:30	Panel Discussion
4:30–5:30	Update on Experimental Planning/Knowledge Assessment Review
5:30	Dinner (On your own)

Thursday, October 27, 2005

	Nonexperimental Research
8:00–8:20	Fishes Presentation
8:20–9:55	Spatial and Remotely Sensed Data Presentations
9:55–10:15	Break
10:15–11:15	Water Quality Presentations
11:15–12:30	Physical Science Presentations
12:30–1:30	Lunch (On your own)
1:30–2:15	Primary Productivity Presentations
2:15–2:25	Break
2:25–4:15	Fishes Presentations
4:15–5:00	Closing Remarks
5:00	End of Symposium

Tuesday, October 25, 2005

8:30 *Opening Remarks* - Dennis Fenn, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center

8:40 ***Keynote Speech: The Pros and Cons of Long-Term Ecological Research Based on Lessons from Five Decades*** - Whit Gibbons, University of Georgia, Savannah River Ecology Laboratory

9:20 ***Keynote Speech: The Wisdom of the River: Why Argue with Several Million Years of Success?*** - Gary K. Meffe, University of Florida, Department of Wildlife Ecology and Conservation and Society for Conservation Biology

10:00 Break

The State of the Colorado River Ecosystem (SCORE) in Grand Canyon Report Presentations

10:20 ***Influence of Glen Canyon Dam Operations on Downstream Sand Resources of the Colorado River in Grand Canyon*** - Scott A. Wright, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

10:40 ***Fishes of Grand Canyon*** - Steven P. Gloss, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Sonoran Desert Research Station

11:00 ***Climatic Fluctuations, Drought, and Flow in the Colorado River*** - Robert H. Webb, U.S. Geological Survey, Water Resources Discipline, National Research Program

11:20 ***Water Quality in Lake Powell and the Colorado River*** - William S. Vernieu, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

11:40 ***Aquatic Ecology: the Role of Organic Matter and Invertebrates*** - Theodore A. Kennedy, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

Noon Lunch (On your own)

1:00 ***Recreational Use Values and Nonuse Values of Glen and Grand Canyons*** - John Loomis, Colorado State University, Department of Agricultural and Resource Economics

1:20 ***Riparian Vegetation and Associated Wildlife*** - Barbara E. Ralston, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

1:40 ***Birds of the Colorado River in Grand Canyon: a Synthesis of Status, Trends, and Dam Operation Effects*** - Mark K. Sogge, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Colorado Plateau Research Station

2:00	***Debris Flows in Grand Canyon and the Rapids of the Colorado River*** - Robert H. Webb, U.S. Geological Survey, Water Resources Discipline, National Research Program
2:20	***Status and Trends of Hydropower Production at Glen Canyon Dam*** - David A. Harpman, Bureau of Reclamation, Technical Service Center
2:40	Break
3:00	***Cultural Resources in the Colorado River Corridor*** - Helen C. Fairley, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center
3:20	***Recreational Values and Campsites in the Colorado River Ecosystem*** - Matt Kaplinski, Northern Arizona University, Department of Geology
3:40	***Lessons from 10 Years of Adaptive Management in Grand Canyon*** - Jeffrey E. Lovich, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center
4:00	***Panel Discussion: SCORE Findings and Implications for the Glen Canyon Adaptive Management Program's Strategic Plan***
5:30-7:00	Dinner (On your own)
7:00-9:30	***Poster Session and Technology Demonstrations***

Wednesday, October 26, 2005

8:00	***Keynote Speech: Surprise and Opportunity in Grand Canyon Adaptive Management*** - Carl Walters, University of British Columbia, Fisheries Centre

Preliminary Results of Experimentation

Hydrology and Sediment

8:40	***One Hundred Years of Sand in Grand Canyon*** - John C. Schmidt; Utah State University; Department of Aquatic, Watershed, and Earth Resources
9:00	***A Tale of Two Floods: Comparing Sandbar Responses to the 1996 and 2004 High-Volume Experimental Flows on the Colorado River in Grand Canyon*** - Joseph E. Hazel, Jr., Northern Arizona University, Department of Geology
9:20	***Sediment Transport and Budget during the November 2004 Controlled-Flood Experiment, with Comparisons to the 1996 Controlled-Flood Experiment*** - David J. Topping, U.S. Geological Survey, Water Resources Discipline, National Research Program

9:40	***Flow, Deposition, and Stability of Recirculation Eddy Bars in Response to Beach/ Habitat-Building Flows*** - Mark Schmeeckle, Arizona State University, Dept. of Geography
10:00	***Investigating Effects of the November 2004 High-Flow Release from Glen Canyon Dam on Aeolian Sand-Transport Rates in the Colorado River Corridor, Grand Canyon, AZ*** - Amy E. Draut, U.S. Geological Survey, Geologic Discipline, Coastal and Marine Geology Team, Pacific Science Center
10:20	Break

Fishes

10:30	***Mechanical Removal of Nonnative Fishes in the Colorado River within Grand Canyon*** - Lewis G. Coggins, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center
10:50	***Effects of 2003–04 Fluctuating Flows from Glen Canyon Dam on the Early Life History Stages of Rainbow Trout in the Colorado River (Part 1: Effects on the Survival of Eggs and Alevins)*** - Josh Korman; Ecometric Research, Inc.
11:10	***Effects of 2003–04 Fluctuating Flows from Glen Canyon Dam on the Early Life History Stages of Rainbow Trout in the Colorado River (Part 2: Effects on Young-of-Year Habitat Use, Growth, and Survival)*** - Josh Korman; Ecometric Research, Inc.
11:30	Lunch (On your own)

Aquatic Biology

12:30	***What Determines the Length of Stream Food Chains?*** - John L. Sabo, Arizona State University, School of Life Sciences
12:50	***Patterns within Patterns: Does Trophic Structure Influence Biotic Patterns within the Colorado River*** - Michael D. Yard, EcoNatura
1:10	***Physical Factors that Influence Spatio/Temporal Differences in Benthic Invertebrate Availability near the Little Colorado River, Grand Canyon, AZ*** - Yael A. Bernstein, Northern Arizona University, Center for Environmental Sciences and Education
1:30	***Inter- and Intra-Annual Differences in the Availability of Drifting Invertebrates near the Little Colorado River, Grand Canyon, AZ*** - Courtney Giauque, Northern Arizona University, Center for Environmental Sciences and Education
1:50	***Inter- and Intra-Annual Differences in Rainbow and Brown Trout Diet near the Little Colorado River, Grand Canyon, AZ*** - Emily Thompson, Northern Arizona University, Center for Environmental Sciences and Education
2:10	Break
2:30	***Interactions between Environment and Biota That Influence Predation of Small Bodied Fish near the Little Colorado River, Grand Canyon, AZ*** - Michael D. Yard, EcoNatura

2:50 ***Response of Drifting Invertebrates and Organic Matter to Disturbance from High Experimental Flows Prescribed for the Colorado River, Grand Canyon, AZ*** - Michael D. Yard, EcoNatura

Economic Issues

3:10 ***(1) Three Years of Experimentation at Glen Canyon Dam: the Electrical Power Economic Costs (2) The Electrical Power Economic Impacts of Liberalizing Glen Canyon Dam Operational Constraints*** - S. Clayton Palmer, U.S. Department of Energy, Western Area Power Administration

Experimentation and Planning

3:30 ***Panel Discussion: Assessing the Value of Experimentation in Support of Glen Canyon Dam Adaptive Management Program Information Needs***

4:30 ***Update on Experimental Planning/Knowledge Assessment Review*** - USGS Grand Canyon Monitoring and Research Center and Ecometric Research, Inc.

5:30 Dinner (On your own)

Thursday, October 27, 2005

Nonexperimental Research

8:00 ***Update on Status and Trends of Humpback Chub in Grand Canyon***, William Pine, University of Florida, Department of Fisheries and Aquatic Sciences

Spatial and Remotely Sensed Data

8:20 ***Effects of Spatial Accuracy Uncertainty on Change Detection and Scientific Analysis*** - Keith A. Kohl, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

8:35 ***Lies, Statistics, and Spatial Data Accuracy*** - Michael L. Dennis, Shephard-Wesnitzer, Inc.

8:50 ***Determining Water Surface Datums to Measure Hydrographic Elevations*** - F. Mark Gonzales, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

9:05 ***Using an Integrated, Remote-Sensing Methodology to Evaluate the Effects of Dam Operations on Fine-Grained Sediment Storage and Sandbar Restoration in the Eastern Grand Canyon*** - Michael J. Breedlove; Utah State University; Department of Aquatic, Watershed, and Earth Resources

9:20 ***3D Laser Scanning (LiDAR Surveying) and Oblique Photogrammetry Assessment during the 2004 High Flow Test*** - Kristin Brown, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring

9:35	***Cable-to-the-Sky: Two-Way Telemetry Adaptive Control and Communications*** - Glenn E. Bennett, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center
9:55	Break
	Water Quality
10:15	***Monitoring Streamflow on the Paria River at Lees Ferry*** - Nancy Hornewer, U.S. Geological Survey, Water Resources Discipline, Arizona Water Science Center
10:30	***Further Effects of Drought and Drought Rebound on the Tailwaters of Glen Canyon Dam in 2003–05*** - Susan Hueftle, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center
10:45	***An Improved Stars Model: Predicted Grand Canyon Water-Surface Elevations and Virtual Shorelines for Flows up to 200,000 cfs*** - Christopher S. Magirl, U.S. Geological Survey, Water Resources Discipline, National Research Program
11:00	***Evaluating Sandbar Stability with Groundwater Instrumentation and Modeling*** - Abraham E. Springer, Northern Arizona University, Department of Geology
	Physical Science
11:15	***Changes in Debris Fans and Rapids: 21 Years of Monitoring Debris Flows in Grand Canyon*** - Peter G. Griffiths, U.S. Geological Survey, Water Resources Discipline, National Research Program
11:35	***Large-Scale Modeling of Flow, Sand Transport, and Sand Storage between Glen Canyon Dam and Phantom Ranch*** - Stephen Wiele, U.S. Geological Survey, Water Resources Discipline, Arizona Water Science Center
11:55	***High-Resolution Monitoring of Suspended-Sediment Concentration and Grain Size in the Colorado River in Grand Canyon Using Laser-Diffraction Instruments and a Three-Frequency Acoustic System*** - David J. Topping, U.S. Geological Survey, Water Resources Discipline, National Research Program
12:15	***An Ex Post Facto Evaluation of Sand Mass Balance in Grand Canyon: Measurements Versus Rating Curves as a Means of Assessing the Value of Adaptive Management*** - Scott A. Wright, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center
12:30	Lunch (On your own)
	Primary Productivity
1:30	***Trends in Terrestrial Riparian Resources, 2001–04*** - Michael Kearsley, Northern Arizona University, Department of Biological Sciences

1:45 ***Estimates of Systemwide Above-Ground Biomass and Terrestrial Vegetation Inputs for the Colorado River Ecosystem*** - Theodore A. Kennedy, U.S. Geological Survey, Biological Resources Discipline, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

2:00 ***Linking Whole-System Carbon Cycling to Quantitative Food Webs in the Colorado River*** - Robert Hall, University of Wyoming, Department of Zoology and Physiology

2:15 Break

Fishes

2:25 ***A Test of the Utility of Otolith Chemistry for Studying Humpback Chub Movements*** - Brian P. Kennedy, University of Michigan, Department of Geological Sciences

2:40 ***Evaluation of the Statistical Properties of Grand Canyon Humpback Chub Population Parameter Estimates from ASMR and Alternative Mark-Recapture Models*** - David L. Otis, Iowa State University, Department of Natural Resource Ecology and Management

3:00 ***Conservation Genetics of Gila Cypha in the Colorado River Ecosystem: Shallow History*** - Marlis R. Douglas, Colorado State University, Department of Fishery and Wildlife Biology

3:20 ***Conservation Genetics of Gila Cypha in the Colorado River Ecosystem: Deep History*** - Michael E. Douglas, Colorado State University, Department of Fishery and Wildlife Biology

3:40 ***Electrofishing in the Grand Canyon, 2000–05 Status and Trends*** - R. Scott Rogers, Arizona Game and Fish Department, Research Branch

4:00 ***Little Colorado River, Lower 1200 Meter Fish Monitoring Trends, 1987–2005*** - David Ward, Arizona Game and Fish Department, Research Branch

4:15 ***Closing Remarks***

5:00 ***End of Symposium***

Oral Presentations Overviews and Abstracts

KEYNOTE ADDRESS: The Pros and Cons of Long-Term Ecological Research Based on Lessons from Five Decades

Whit Gibbons

University of Georgia, Savannah River Ecology Laboratory, Aiken, SC

Abstract. Research opportunities at the University of Georgia's Savannah River Ecology Laboratory (SREL) on the Savannah River Site (SRS) in South Carolina from 1951-2005 provided an almost unprecedented situation for developing long-term ecological studies. Research on amphibians and reptiles, based on data from more than a half century ago, have led to findings and interpretations regarding distribution and abundance patterns that would not have been possible with shorter-term projects. The findings have implications to ecology and behavior of herpetofauna as well as to those related to conservation issues. Included among the long-term datasets permitting certain ecological questions to be addressed are:

1) A 26-year mark-recapture study of amphibians (n > 500,000 individuals, 27 species) in a freshwater wetland, revealing that community structure varies continuously and that annual variation in hydroperiod is a driving environmental force,

2) A 37-year study of a freshwater wetland culminating in the capture in a single year of more than 350,000 individuals and 1.5 metric tons of reptiles and amphibians belonging to 59 species, providing the data necessary to address questions related to the environmental importance of natural wetlands to regional biodiversity and to the proper management of wetland systems,

3) A 44-year study of 101 species of reptiles and amphibians that reveals the importance of research continuity and funding in determining patterns of regional biodiversity critical for making judicious land management decisions.

A key message is that ecological interpretations based on short-term studies and short-sighted economic goals can lead to erroneous and costly conclusions that result in imprudent management decisions that could have been avoided if consistent study and longer-term information had been available.

KEYNOTE ADDRESS:
The Wisdom of the River: Why Argue with Several Million Years of Success?

Gary K. Meffe

University of Florida, Department of Wildlife Ecology and Conservation and Society for Conservation Biology, Gainesville, Florida

Abstract. The underlying theme of this presentation is simple: Nature has been managing things in the Colorado River for several million years, and humans have been at it for about 100; we still have a few things to learn. Perhaps the biggest lesson we have not fully learned is that command and control approaches to management of nature—manipulating fundamental aspects of ecosystem structure or dynamics—typically fail in the long run due to a principle called the 'pathology of natural resource management,' stated as follows: *when the range of natural variation in a system is reduced, the system loses resilience when faced with novel stresses*. This pathology arises as a three-step process: human control of a natural system; increasingly efficient control of the system by the responsible agencies with concomitant distancing from behavior of the original system; and economic capitalization within the system that demands continued and even increasingly successful control. Examples of the pathology include failures in fire management, flood control and floodplain development, and chemical pest control in agriculture. Many ecosystems have become less resilient due to command-and-control management and some have changed to alternate configurations as a result. Adaptive management—conducting management as an experiment with a genuine willingness to learn, admit mistakes, and change directions—is the alternative to command and control. With respect to management of native biota in the Grand Canyon, I present data regarding flooding as a natural management tool. Species native to rivers of the American Southwest generally evolved in wildly fluctuating systems characterized by extremes of violent flood and drought, to which the biota is well adapted. Stabilization of such systems by dams (i.e., command and control) leads to the pathology described: native species are less resilient in these stabilized systems to invasion by exotic species that evolved in much more stable and predictable environments. I present data showing that large and violent floods in free-flowing rivers selectively remove exotic species and favor natives. It is only in such free-flowing systems that native species typically still thrive. Successful adaptive management of biotic resources in the Grand Canyon requires that we understand these principles, the environments in which organisms evolved, and the dangers of modifying historic conditions. The closer we can manage the Colorado River to its natural state, the easier it will be to maintain native species and an intact ecosystem.

The State of the Colorado River Ecosystem in Grand Canyon Presentations

Background. *The State of the Colorado River Ecosystem in Grand Canyon* report is an important milestone in the effort by the Secretary of the Interior to implement the Grand Canyon Protection Act of 1992 (GCPA; title XVIII, secs. 1801–1809, of Public Law 102-575), the most recent authorizing legislation for Federal efforts to protect resources downstream from Glen Canyon Dam. The report's findings are intended to provide decision makers and the American public with relevant scientific information about the status and recent trends of the natural, cultural, and recreational resources of those portions of Grand Canyon National Park and Glen Canyon National Recreation Area affected by Glen Canyon Dam operations. The information presented in the report is a product of the Glen Canyon Dam Adaptive Management Program (GCDAMP), a federally authorized initiative to ensure that the primary mandate of the GCPA is met through advances in information and resource management. The U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) has responsibility for the scientific monitoring and research efforts for the program, including the preparation of reports such as this one.

Influence of Glen Canyon Dam Operations on Downstream Sand Resources of the Colorado River in Grand Canyon (Chapter 1)

Scott A. Wright[1], Theodore S. Melis[1], David J. Topping[2], and David M. Rubin[3]

[1]U.S. Geological Survey, Biological Resources Discipline, Flagstaff, AZ
[2]U.S. Geological Survey, Water Resources Discipline, Flagstaff, AZ
[3]U.S. Geological Survey, Geology Discipline, Santa Cruz, CA

Overview. The U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center and its cooperators have conducted extensive monitoring and research on fine-sediment transport and sandbar evolution in Grand Canyon. This session presents a summary of the results of studies since the 1970s, as well as conclusions derived from recent syntheses of streamflow, sediment transport, and geomorphic data from 1921 to 2004, including recent sediment budgets. The effects of the modified low fluctuating flow operating alternative at Glen Canyon Dam (1996–2004) on fine-sediment transport and sandbars are examined in the context of these historical data. Finally, options identified by sediment scientists for testing alternative operations aimed at more effective conservation of fine-sediment resources are discussed.

Fishes of the Grand Canyon (Chapter 2)

Steven P. Gloss[1] and Lewis G. Coggins[2]

[1]U.S. Geological Survey, Biological Resources Discipline, Tucson, AZ
[2]U.S. Geological Survey, Biological Resources Discipline, Flagstaff, AZ

Overview. This presentation examines the status, trends, and recent condition of Grand Canyon fishes, focusing particular attention on the endangered humpback chub (*Gila cypha*) because of its prominence within the Glen Canyon Dam Adaptive Management Program. The session begins with a discussion of the conditions that led to the development of the Grand Canyon's unique native fish populations and then moves on to the reasons for their decline. The effects of the modified low fluctuating flow alternative on fish populations are also examined. The presentation concludes with a discussion of possible management options to slow or reverse the decline of humpback chub numbers.

Climatic Fluctuations, Drought, and Flow in the Colorado River (Chapter 3)

Robert H. Webb[1], Richard Hereford[2], and Gregory J. McCabe[3]

[1]U.S. Geological Survey, Water Resources Discipline, Tucson, AZ
[2]U.S. Geological Survey, Geology Discipline (emeritus), Flagstaff, AZ
[3]U.S. Geological Survey, Water Resources Discipline, Denver, CO

Overview. A persistent drought beginning in 2000 raised concern that decreases in runoff entering Lake Powell could follow and releases from Glen Canyon Dam could be severely reduced or constrained. Inflows to Lake Powell were below average from 2000 through 2004 and on January 27, 2005, the reservoir contained 8.5. million acre-feet, which is only 35% of the reservoir's capacity and a little more than 1 yr of annual flow releases. The factors that caused and sustained the early 21st century drought have not been positively identified. However, the drought can be examined in a broader historical and climatic context, which suggests that the drought beginning in 2000 probably had its origins in several hemispheric scale atmospheric and oceanic processes that affect moisture delivery to the Colorado River Basin. In this context, the general causes of drought in the Southwest are described. The long-term perspective on drought duration in the basin is explored based on tree-ring reconstruction and global climate indices are examined for their ability to explain Colorado River flows. Scenarios of future climate and runoff in the Colorado River Basin are presented.

Water Quality in Lake Powell and the Colorado River (Chapter 4)

William S. Vernieu[1], Susan J. Hueftle[1], and Steven P. Gloss[2]

[1]U.S. Geological Survey, Biological Resources Discipline, Flagstaff, AZ
[2]U.S. Geological Survey, Biological Resources Discipline, Tucson, AZ

Overview. Water temperature, nutrient concentrations, turbidity, and other water-quality parameters are of interest to managers and scientists because these parameters influence a range of ecosystem components, from support of aquatic microorganisms and invertebrates to the behavior of native and nonnative fishes. Any investigation of the dynamics of the Colorado River ecosystem in Grand Canyon must not only document and understand the water quality in the Grand Canyon itself but also the water quality in Lake Powell. For this reason, an overview of water-quality trends and conditions in both Lake Powell and the Grand Canyon ecosystem are provided. Because Lake Powell and Glen Canyon Dam operations have a strong influence on downstream water quality, the water quality of the reservoir is discussed in some detail. Recent drought-induced changes and the effects of the modified low fluctuating flow alternative are also addressed.

Aquatic Ecology: the Role of Organic Matter and Invertebrates (Chapter 5)

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Overview. Considerable effort has been directed toward understanding the aquatic ecology of the Colorado River through Grand Canyon since the closure of Glen Canyon Dam, which resulted in changes in the physical environment of the ecosystem. The results of the research and monitoring activities that have investigated the kinds of organic matter and invertebrate communities in the Colorado River below Glen Canyon Dam are described. Collectively, organic matter and the aquatic invertebrates that consume it largely constitute the food base for fish in the Colorado River ecosystem. Patterns, trends, and important controls on the amount and sources of organic matter and invertebrates that are primary food resources for humpback chub (*Gila cypha*) and rainbow trout (*Oncorhynchus mykiss*) are the focus of the discussion in an effort to understand the role that food plays in determining the distribution, population density, and growth of these fish in this ecosystem. Furthermore, most of the research and monitoring that have been conducted on organic matter and invertebrates in this ecosystem have centered on food items that are important for these two species. The discussion also addresses how organic matter and invertebrates are affected by the timing and magnitude of water releases from Glen Canyon Dam, including the modified low fluctuating flow alternative, which was implemented in 1996 and continues as the operating regime for Glen Canyon Dam today. Finally, a brief discussion of possible research directions and management actions is presented.

Recreational Use Values and Nonuse Values of Glen and Grand Canyons (Chapter 9)

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Overview. This symposium session focuses on how recreation use and economic values are influenced by alternative river flow regimes and Glen Canyon Dam operations. The information presented draws from research conducted over the last two decades to summarize the available information on recreation use, benefits, and public values, including nonuse values, of Grand and Glen Canyons. This partial information is the best available at the present time to inform adaptive management of Grand and Glen Canyons about the consequences of operational changes on recreation use and public values.

Riparian Vegetation and Associated Wildlife (Chapter 6)

Barbara E. Ralston

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Overview. Changes in the riparian and fluvial marsh communities along the Colorado River in Grand Canyon from the closure of the Glen Canyon Dam and the beginning of the regulation of the river in 1963 to the present are described. To provide a better understanding of how dam operations have affected riparian vegetation, changes in Grand Canyon riparian vegetation during three periods of time (1963–80; 1981–90; 1991–present) that correspond to major operational changes at Glen Canyon Dam are discussed. The effects on riparian vegetation of both the modified low fluctuating flow (MLFF) alternative, which was implemented beginning in 1996, and the recent drought are explored. The presentation concludes with a summary of the findings with respect to riparian vegetation as habitat and its relationship to other resources and with a discussion of monitoring priorities within the context of the Glen Canyon Dam Adaptive Management Program.

Birds of the Colorado River in Grand Canyon: a Synthesis of Status, Trends, and Dam Operation Effects (Chapter 7)

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Overview. The considerable information available from recent studies on the ecology of Grand Canyon bird species and communities is summarized. Because changes in riparian habitat undoubtedly influence the abundance and distribution of Grand Canyon birds, the presentation starts by briefly examining dam-induced habitat alterations that may affect birds. The direct and indirect effects of Glen Canyon Dam operations, including the modified low fluctuating flow alternative that was implemented starting in 1996, are considered for how they influence specific bird species and communities. Particular attention is given to species of special concern, including the southwestern willow flycatcher (*Empidonax traillii extimus*), California condor (*Gymnogyps californianus*), bald eagle (*Haliaeetus leucocephalus*), and American peregrine falcon (*Falco peregrinus anatum*). The session concludes with a summary and a discussion of research priorities within the context of the Glen Canyon Dam Adaptive Management Program.

Debris Flows in Grand Canyon and the Rapids of the Colorado River (Chapter 8)

Robert H. Webb[1], Peter G. Griffiths[1], Christopher S. Magirl[1], and Thomas C. Hanks[2]

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Overview. Monitoring the input of coarse sediment into the Colorado River ecosystem and its long-term redistribution by the river is critical to understanding how dam operations affect coarse sediment deposition and, indirectly, other ecosystem components. Scientists are able to model debris-flow magnitude and frequency from extensive data sets developed through long-term monitoring. Also, this session estimates the amount of sediment contributed by debris flows and models its deposition at tributary junctures to evaluate the effects of debris flows over several temporal and spatial scales, including the recent period of operations of Glen Canyon Dam. Data are combined with modeling to evaluate long-term changes in rapids and to explain large-scale features. The session also summarizes data from debris-fan monitoring activities by the U.S. Geological Survey's Grand Canyon Monitoring and Research Center and research by Water Resources and Geology Discipline scientists. Finally, the discussion considers the role of experimental high flows and the modified low fluctuating flow alternative on coarse-sediment reworking.

Status and Trends of Hydropower Production at Glen Canyon Dam (Chapter 10)

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Overview. This session describes the Glen Canyon Dam and powerplant and their operation. The basics of electricity, the role of hydropower in the interconnected electricity system and the conceptual basis for estimating the economic value of hydropower are introduced. Short discussions of the Federal role in hydropower development, the Basin Fund, and associated financial issues are presented. The environmental constraints imposed at Glen Canyon Dam and their relative effects on hydropower production are described. Several studies estimating the costs of environmental measures are then summarized. The remainder of the session focuses on the current status and recent trends in hydropower production. The discussion concludes with an assessment of likely future resource conditions.

Cultural Resources in the Colorado River Corridor (Chapter 11)

Helen C. Fairley

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Overview. This session describes research, monitoring, and mitigation activities during the past 15 years that have evaluated and addressed ongoing impacts to cultural resources in the Colorado River corridor because of dam operations and other agents of deterioration, such as visitation and rainfall-induced erosion. The presentation begins with a summary of research and inventory activities prior to the early 1990s, which is followed by a summary of the monitoring and research activities initiated in response to the Operation of Glen Canyon Dam Final Environmental Impact Statement and the Secretary of the Interior's Record of Decision. The session ends with some potential strategies for the future.

Recreational Values and Campsites in the Colorado River Ecosystem (Chapter 12)

Matt Kaplinski[1], Jeff Behan[2], Joseph E. Hazel, Jr.[1], Roderic A. Parnell[1], and Helen C. Fairley[3]

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Overview. This session presents an assessment of the current state of knowledge concerning the impacts of Glen Canyon Dam operations on the changing condition of campsite areas and sandbars and the implications of physical changes of the Grand Canyon ecosystem for visitor capacity and quality of experience. After defining the study area and some key concepts, the presentation briefly reviews the relationships between the condition and extent of Colorado River sandbars and the quality of the visitor recreation experience. An overview of historical status and trends of the number and size of campsites along the Colorado River is followed by a summary of recent findings. Discussion focuses on the effects of the modified low fluctuating flow alternative and high-volume experimental flows on campsite area. The session concludes with an evaluation of these results relative to the stated recreation goals and management objectives of the Glen Canyon Dam Adaptive Management Program.

Lessons from 10 Years of Adaptive Management in Grand Canyon (Chapter 13)

Jeffrey E. Lovich and Theodore S. Melis

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Overview. The end of a decade of research and monitoring provides an important opportunity to evaluate the effects of Glen Canyon Dam operations on resources of concern and to determine if the desired outcomes are being achieved and whether they are compatible with one another or not. In this concluding session, we present a summary of adaptive management of the Colorado River ecosystem below Glen Canyon Dam by reviewing predictions contained in the Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS). We compare EIS predictions for how key resources would respond under the preferred alternative of modified low fluctuating flows to the actual response of resources. During preparation of the EIS, the best scientific data available were used to generate those prognostications; however, a decade later we have significant new information for evaluating the operation of Glen Canyon Dam in relation to the objectives of the 1995 EIS and the 1992 Grand Canyon Protection Act.

KEYNOTE ADDRESS:
Surprise And Opportunity In Grand Canyon Adaptive Management

Carl Walters

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Abstract. In the design of adaptive management programs, it has generally been assumed that a critical need is to have well-planned, scientifically defensible experimental designs for comparing alternative management schemes or treatments, with the treatment options selected as the best possible ones based on modeling studies. The Glen Canyon Dam Adaptive Management Program has been repeatedly criticized for not adopting such a design, and we have, in fact, made little use of the complicated Grand Canyon Model as a formal tool for policy screening and design. Treatments like the 2000 Low Summer Steady Flow (LSSF) "experiment" seem to have come out of nowhere, without clear scientific justification or design or commitment to the usual scientific standards of replication and comparison. Yet look how much we have been surprised by, i.e. have learned from, such "random" treatment choices, especially the 2000 LSSF flows, about things ranging from horizontal thermocline formation and native fish habitat use to vulnerability of native fish to floods to conditions needed for strong tamarisk recruitment. Perhaps we have been thinking too rigidly as scientists about just what constitutes good experimental design and treatment choice for adaptive management, and should be thinking more in terms of imaginative treatment options that could uncover various surprising opportunities for improved ecosystem management.

One Hundred Years of Sand in Grand Canyon

John C. Schmidt

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Abstract. The riverine ecosystem of the Colorado River between Glen Canyon Dam and Bright Angel Creek had less fine sediment on its bed, in eddies, and as channel-margin deposits in 2001 than it did prior to completion of the dam. Changes in dam operations in the 1990s did not arrest this trend.

The decrease in fine sediment storage is documented by comparison of historical oblique photographs, analysis of historical aerial photographs, and field surveys since 1990. The magnitude of the decrease is uncertain. The loss of sand is probably about 25% of the area typically exposed at base flow in pre-dam photographs, but estimates range between 0 and -55%, depending on study reach and method of analysis. There is no indication that the magnitude of decrease is less in the downstream part of the study area. The cumulative loss of eddy sand is about 1 m in thickness but also varies greatly.

Eddies are now the primary storage site of fine sediment. Eddies have always been a very large storage site for fine sediment, but the bed once played a more important role than it does today. The bed has been significantly lowered in Glen Canyon, but the bed has only degraded in pools and ponded backwaters in Marble and Upper Grand Canyons. There is no evidence that fine sediment aggrades on the main channel bed or in the deep parts of eddies for longer than a few weeks to a few months, and these parts of the river respond quickly to changes in flow and sediment transport. These areas evacuate fine sediment during flows typical of the 1990s. Post-dam flood deposits have a longer response time and adjust over a period of years to decades to changes in dam operations. These deposits are only constructed by dam releases that exceed power plant capacity. They are subject to large erosion rates during the first months following flood recession, but erosion rates thereafter decrease. The area of these deposits caused by the 1996 controlled flood lasted about 5 years, although some individual deposits remain large today.

A Tale of Two Floods: Comparing Sandbar Responses to the 1996 and 2004 High-Volume Experimental Flows on the Colorado River in Grand Canyon

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Abstract. The magnitude and timing of controlled floods required to redistribute sand into eddies and rebuild eroded sandbars is a critical objective of research and monitoring in the Colorado River ecosystem, downstream from Glen Canyon Dam. In this study we compare the effects of the 1996 Beach/Habitat Building Flow (BHBF) and the 2004 High Experimental Flow (HEF). The 1996 BHBF consisted of a 7-day release of 45,000 ft^3/s, whereas the 2004 HEF had a 60-hour duration of 41,000 ft^3/s. We conducted topographic surveys of sand bars before and after each of these experimental flows in order to quantify sediment redistribution in Marble Canyon and eastern Grand Canyon.

The results for the 1996 BHBF show that net deposition was accompanied by area loss due to bar narrowing. Bar narrowing was caused by erosion of bar area in the fluctuating zone (5,000-25,000 ft^3/s). The source for much of the sand redistributed to high elevation (>25,000 ft^3/s) was in large part supplied from the fluctuating zone and lower elevation parts of bars. In contrast, following the 2004 HEF the average bar area and volume increase in the upstream half of Marble Canyon was a factor of 3 greater than that observed in 1996. In lower Marble Canyon and eastern Grand Canyon, the pattern of change was similar to that observed in 1996: deposition consistently occurred at high elevation but many sites also had low-elevation area loss. Half (3/6) of the sites in the upstream half of Marble Canyon were larger in both area and volume than they were following the 1996 BHBF, whereas only one site (1/6) surveyed in the downstream half of Marble Canyon was larger in both area and volume. In eastern Grand Canyon, one site (1/5) was larger in both area and volume than that observed following the 1996 BHBF.

These results show that there was a distinct difference in bar response in upper Marble Canyon between the 1996 BHBF and 2004 HEF. In contrast, the response style at sites located further downstream in lower Marble Canyon and eastern Grand Canyon was similar in 1996 and 2004. This suggests that there was more bar building in upper Marble Canyon in 2004. We attribute this longitudinal difference in bar response to differences in suspended sand concentrations during the two experimental releases (see Topping et al., this volume). The 1996 BHBF was conducted during a period of limited sediment supply because tributary inputs of new sand were relatively low in the year preceding the 1996 BHBF and dam releases were moderate to high. In contrast, the 2004 HEF followed accumulation and retention of new tributary sand inputs in the channel and low dam releases. Therefore, it appears that the newly retained sediment prior to the 2004 HEF was sufficient to result in substantial increases in sandbar area and volume in only the upstream half of Marble Canyon.

Sediment Transport and Budget during the November 2004 Controlled-Flood Experiment, with Comparisons to the 1996 Controlled-Flood Experiment

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Abstract. Prior to the 7-day 45,000 ft^3/s 1996 controlled-flood experiment, the sediment-transport paradigm for the regulated Colorado River in Grand Canyon was that, under normal powerplant releases from Glen Canyon Dam, tributary-supplied sand would accumulate in the channel of the river over multi-year timescales and that this accumulated sand could be transferred from the channel bed to eddies during controlled floods, increasing both the area and volume of eddy sandbars. As summarized in Rubin et al. (EOS, 2002), work conducted during and subsequent to the 1996 controlled flood indicated that this paradigm was based on assumptions that were either false or only partially true. First, sand did not accumulate in the channel of the river over multi-year time scales. Second, during the 1996 flood, the sand that was deposited at higher elevations in eddy sandbars was eroded mostly from the lower parts of these sandbars (not from the channel bed) resulting in bars that were smaller in area and volume (although they did contain more sand at higher elevations). Tributary inputs of new sand were relatively low in the year preceding the 1996 flood and dam releases were moderate to high. Thus, the 1996 flood experiment was conducted during a period when the Colorado River in Grand Canyon was relatively depleted with respect to sand. The design of the 2004 controlled-flood experiment was to: (1) keep dam releases relatively low (<10,000 ft^3/s) during September-November 2004 to allow the accumulation and retention of new tributary sand inputs in the channel, and (2) if >800,000 metric tons of new sand are retained in Marble Canyon, follow this period of lower dam releases by a 60-hour release of 41,000 ft^3/s to redistribute this new sand from the channel bed into the eddies.

Results indicate that more sand, silt, and clay were present in Marble Canyon during the 2004 experiment than during the 1996 experiment. At the lower end of Marble Canyon, concentrations of suspended silt and clay were three times higher and concentrations of suspended sand were 30% higher than those observed during the 1996 flood. Furthermore, during the 2004 flood, concentrations of suspended sand were slightly higher in the upstream half than in the downstream half of Marble Canyon. In contrast, during the 1996 flood, concentrations of suspended sand likely increased in the downstream direction through Marble Canyon. The spatial pattern in suspended-sand concentration during the 2004 flood results from the fact that the lower dam releases preceding the flood were effective at retaining new tributary-supplied sand in the upstream half of Marble Canyon. The response of the eddy sandbars during the 2004 flood correlates with this observed spatial pattern in suspended-sand concentration. About 2/3 of the sandbars surveyed in the upstream half of Marble Canyon were larger in both area and volume than they were immediately following the 1996 controlled-flood experiment, whereas only 1/3 of the sandbars surveyed in the downstream half of Marble Canyon were larger in both area and volume than they were immediately following the 1996 controlled-flood experiment (Hazel and otehrs, this volume).

In contrast to the results in Marble Canyon, less sand was present in Grand Canyon during the 2004 experiment than during the 1996 experiment. At the Grand Canyon gaging station (43-km downstream from Marble Canyon), concentrations of suspended sand were 30% lower than those observed during the 1996 flood. As in Marble Canyon, the response of the eddy sandbars in this downstream reach also reflects this difference in sand concentration between the two experiments, with fewer sandbars being larger in area and volume after the 2004 experiment than immediately following the 1996 experiment (Hazel and others, this volume). Therefore, it appears that the 800,000 metric tons of new sand in retention prior to the 2004 controlled flood was sufficient to result in substantial increases in sandbar area and volume in only the upstream half of Marble Canyon.

Flow, Deposition, and Stability of Recirculation Eddy Bars in Response to Beach/Habitat-Building Flows

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Abstract. The formation and stability of reattachment and separation eddy beaches in Grand Canyon depend on a number of interacting processes. Import and export of sediment from a recirculation-eddy zone ultimately is the result of turbulent transport by river flow. However, the processes of seepage erosion and beach slope failure may transport significant amounts of sediment from higher to lower elevations of beaches. Thus, scour and deposition by the river act in conjunction with beach slope failure and groundwater sapping to determine the dynamic stability of Grand Canyon beaches. A number of field and modeling studies of beach slope erosion and deposition were conducted prior to the 1996 Record of Decision (ROD) on the Operation of Glen Canyon Dam, which prescribes that daily flows should not exceed 25,000cfs and up-ramp and down-ramp rates are restricted to 4,000 and 1,500cfs/hr, respectively. These field studies measured the combined effects of beach stability processes at several beaches over limited periods of time and flow conditions, but quantitative modeling investigations of beach stability were restricted to uncombined slope failure and turbulent sediment transport efforts. Clearly, a monitoring and research effort is necessary to determine the efficacy of the current ROD flow restrictions in enhancing beach stability. This symposium presentation will report on the progress being made at Arizona State University in collaboration with scientists at the Grand Canyon Monitoring and Research Center and Northern Arizona University to develop a quantitative understanding of the combined processes that determine recirculation eddy beach stability in Grand Canyon.

One complicating factor in developing this comprehensive quantitative understanding of beach stability is that beach/habitat-building flows may build beaches that are at least partially cohesive. With the closure of Glen Canyon Dam, nearly all sediment for building recirculation eddy bars in Marble Canyon is supplied by the Paria River. This sediment is largely composed of silt, clay, and very fine sand. Monitoring efforts at 30 Mile recirculation eddy during and after the November 2004 test flood have shown that there was significant cohesive sediment deposition during the rising limb of the flood. Laboratory flume experiments have been conducted to determine the erodibility of these sediments under a range of boundary shear stresses, with the result that cohesive samples do not erode (or erode very little) at boundary shear stresses below 0.2-0.3N/m^2. Roughly, this corresponds to an average velocity in the range of 0.15-0.2m/s. At these velocities beaches can be expected to erode slowly and add turbidity to the main stem. Higher velocities would result in rapid erosion of the cohesive sediments. Flume studies are also being conducted to determine deposition rates of cohesive sediments. Flume studies are also being conducted to determine deposition rates of cohesive sediments. A 3-dimensional model of flow and fine-grained sediment transport in recirculation eddies is being constructed. The flow model will employ the Large Eddy Simulation (LES) technique, wherein large-scale turbulence, including boils produced by flow separation, is directly calculated by numerical integration of the Navier-Stokes equations. Early modeling results show that discreet, low-frequency inrushes of sediment along the eddy fence are responsible for much of the sediment import to the recirculation zone. Finally, a beach stability slot measuring 24ft in length, 8ft in height, and 2ft in width is being constructed in a laboratory. The slot will be filled with sediment at typical beach slopes. Groundwater flow within the slot can be controlled to simulate the inflow and outflow of water in response to daily discharge fluctuations. The slot can thus be used to study the processes of beach failure and seepage erosion under various dam operation scenarios.

Investigating Effects of the November 2004 High-Flow Release from Glen Canyon Dam on Aeolian Sand-Transport Rates in the Colorado River Corridor, Grand Canyon, AZ

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Abstract. In November, 2004, a 60-hour experimental flood release from Glen Canyon Dam held the Colorado River flow through Grand Canyon, Arizona, above 1160 m3 s-1 (41,000 ft3 s-1). This high-flow experiment was designed to rebuild fluvial sand deposits, restoring a component of the ecosystem that had been declining since closure of the dam in 1963. Transport and deposition of aeolian sand has important implications for archaeological resources in the river corridor, many of which are located in and covered by aeolian deposits. This study presents aeolian sediment-transport data collected in the river corridor during the year before and in the months after the flood experiment. The greatest potential for aeolian re-distribution of flood-deposited sand occurred during the April-May windy season, during which the highest measured winds locally exceeded 25 m s-1, with sand-transport rates >9 kg cm-1 day-1. At each of the six study locations, substantial new deposition of fluvial sand occurred as a result of the 2004 flood, which temporarily increased the amount of sand available for aeolian entrainment. However, high daily fluctuations (142-566 m3/s; 5,000-20,000 ft3/s) of the river flow from January to March 2005 removed much of the new sand before the start of the 2005 windy season. These data may be used to guide decisions regarding future experimental floods and subsequent flow schedules, if maximizing sand redistribution by wind is a management objective.

Mechanical Removal of Nonnative Fishes in the Colorado River within Grand Canyon

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Abstract. In response to declining trends in native fish stocks, the Glen Canyon Dam Adaptive Management Program recommended to the Secretary of Interior that a set of experimental treatments be conducted to better understand mechanisms and factors contributing to native fish recruitment dynamics. As part of this experiment, nonnative fishes were removed from humpback chub habitat near the confluence of the Little Colorado River. This effort focuses primarily on three objectives: (1) evaluating the relationship between nonnative fish abundance and humpback chub population dynamics; (2) efficacy of nonnative fish mechanical removal in a distinct segment of the Colorado River; and (3) diet and predatory habits of nonnative fishes in the Colorado River. During 12 trips conducted in winter and summer of 2003 and 2004, a total of 22,261 fishes were captured within the removal reaches (River Mile 56.2 – 72.7). Of these, 18,701 were nonnative fishes (84% of the total catch) and removed from the system. Nonnative captures were dominated by rainbow trout (94%), with brown trout (3%) and common carp (2%) making up most of the remainder. Depletion abundance estimates indicate removal efficiencies of approximately 12% per pass for rainbow trout. Persistent reductions in rainbow trout abundance over the study period suggest that this method is effective in controlling cold water nonnative fishes. Though relative abundance of native fishes, particularly flannelmouth sucker has increased throughout the study period, it is not yet possible to attribute these increases to nonnative fish removal. Warmer than normal water temperatures released from Glen Canyon Dam during 2003 through present represent a confounding factor that has likely influenced native fish survival and distribution.

Effects of 2003-04 Fluctuating Flows from Glen Canyon Dam on the Early Life History Stages of Rainbow Trout in the Colorado River
Part 1: Effects on the Survival of Eggs and Alevins

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An experimental alteration of the hydrograph from Glen Canyon Dam, targeted at reducing the survival rate of young rainbow trout through increased daily fluctuations in flow, was implemented from January through March in 2003-2005. This talk describes the impact of the experimental flow regime on the early life stages of rainbow trout below Glen Canyon Dam in 2003 and 2004. We measured the timing of redd excavation and the distribution of redds across elevations (i.e., redd hypsometry) in Glen Canyon to estimate the potential egg and alevin mortality caused by the experimental flow regime. There was minimal spawning prior to mid-January in both 2003 and 2004 and peak counts of approximately 1,000 redds were obtained by late-March/early-April. We estimated that 4,000 and 2,100 redds were excavated in 2003 and 2004, respectively. The average percentage of redds above 12, 8, and 5 kcfs at high elevation spawning sites was 27%, 54%, and 82%, respectively. The system-wide redd survey documented a total of 27 spawning locations in the Glen Canyon with the majority of redds located at elevations below 8 kcfs. Intergravel water temperatures at Four Mile and Powerline Bars increased with elevation and exceeded the lethal egg incubation limit of 16 C by mid-March at higher elevations. Estimates of the percentage of redds that did not produce viable young for Glen Canyon were 23% and 33% in 2003 and 2004, respectively. Mortality in 2004 was higher because of the implementation of a daytime Sunday steady flow of 8 kcfs between January and March. Under normal Record of Decision operations from January to March with a similar total volume released from Glen Canyon Dam to the volumes in 2003 and 2004, the model predicted a redd loss of 19% in January and 33% from February to March when the majority of spawning occurs. Thus, there was likely very little additional incubation mortality associated with the higher experimental fluctuations in January to March of 2003 and 2004. We estimated that between 1988 and 1991, when daytime minimum flows during the spawning and incubation period averaged 1-3 kcfs, total redd loss likely exceeded 75%. We predicted that redd loss rates could be increased to over 50% if a daytime Sunday steady flow of 5 kcfs was implemented.

Effects of 2003-04 Fluctuating Flows from Glen Canyon Dam on the Early Life History Stages of Rainbow Trout in the Colorado River
Part 2: Effects on Young-of-Year Habitat Use, Growth, and Survival

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Abstract. Seasonal changes in length frequencies of young of year (YoY) in Glen Canyon showed effects of hatch timing, growth, survival variation, and movement from low to steep angle shorelines. Substantial decreases in density following the early-September reduction in the minimum daily flow from 10 to 5 kcfs were observed in both 2003 and 2004, and a very big drop in density in steep angle habitats following the November 2004, 42.5 kcfs beach habitat building flow was also seen. Catch rates obtained at the minimum daily flow were 3- to 5-fold higher compared to those during the daily maximum suggesting that the majority of YoY do not follow the waters edge on a 24 hr. cycle but instead reside near the minimum daily flow elevation. The effects of this behavior on growth rate were seen through the presence of a weekly striping pattern in at least 51% of the 255 otoliths examined in 2003. The atypical weekly increment was 25% wider compared to the other increments and indicated enhanced growth during Sunday steady flow periods. Age determinations based on analysis of otolith microstructure were made from 237 and 318 fish in 2003 and 2004, respectively. Variation in length-at-age was very low with logistic growth models predicting 86-87% of the variation in forklength as a function of the number of days from hatch. YoY in steeper habitats were significantly larger at age than those in low angle habitats for fish that were at least 3 months old. Hatch date distributions for the total YoY catch in 2003 (n=966) and 2004 (n=4,647) were computed by length back-calculation. The correspondence between the back-calculated hatch date distributions and those inferred from redd counts was very strong, indicating that there was limited variation in mortality rates over the incubation period. The observation that YoY generally remain at the daily minimum flow elevation, and the post-September density reductions documented in Glen Canyon, coupled with the substantial literature on stranding impacts, suggest a 'stranding' flow operation from GCD could be used to limit YoY recruitment.

Estimates of the YoY weekly survival rate averaged over the summer and fall from a stock synthesis model applied to the data in both low and steep angle habitats were approximately 0.85. The constant and variable survival rate models provided good fits to the length frequency data and the improved fit of the latter models was useful in untangling recruitment and survival effects. Survival rates for the period between the August and September samples for low and steep angle habitats of 0.84-0.85 were significantly lower than in the previous (0.91 and 0.95) and following intervals (0.87 and 0.90). This change may have been caused by the reduction in the daily minimum flow from 10 to 5 kcfs in early-September. However, it is also possible that the decrease in survival we estimated was a natural occurrence, possibly driven by normal ontogenetic habitat shifts and/or density-dependent mortality. The stock synthesis modeling approach, applied to monthly electrofishing and otolith-derived ageing data, provides a significant advance in the ability to link dam operations to population-level effects.

What Determines the Length of Stream Food Chains?

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Abstract. Food chain length is an important aspect of community structure and ecosystem function. Most theory suggests that *either* energy or variation in the physical environment limits the length of food chains in natural ecosystems. Empirical studies in lakes and more recently on islands suggest that ecosystem size also plays a critical role by providing more space for large bodied top predators. My goal is to understand the relative importance of these three factors—ecosystem size, energy (i.e., resource supply) and environmental variation (i.e., disturbance)—in determining the length of food chains in stream ecosystems. In this talk I will first demonstrate the application of spectral methods for quantifying statistical properties of variation in daily discharge. This method makes use of extensive records from the USGS NWIS database to understand how key hydrologic parameters vary among streams as diverse as desert washes and large regulated rivers. I then will highlight some preliminary results from a collaborative project focused on testing the relative importance of hydrologic disturbance, energy supply, and ecosystem size on the length of stream food chains. Our preliminary results suggest that food chain length increases with habitat area (measured as stream cross sectional area) *and* energy production (as gross primary production). Thus, in contrast to findings in lake ecosystems, our data provide some support for Schoener's productive space hypothesis in streams. Finally, I discuss how this preliminary result may vary across streams as a function of the seasonal variation in discharge (i.e., environmental stress) as well as inter-annual variation around this seasonal trend (i.e., environmental stochasticity).

Patterns within Patterns: Does Trophic Structure Influence Biotic Patterns within the Colorado River

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Abstract. In the Colorado River, Glen and Grand Canyons, numerous biotic patterns for mass, abundance and distribution of algae, macro-invertebrates, fishes and waterfowl are strongly correlated to underwater light availability. Past research has suggested and continues to reinforce the thought that the current trophic structure and pathways are solely coupled to algal production. Carothers and Brown (1990) stated, as well as others, that *Cladophora glomerata* is "the very foundation of aquatic productivity within the entire riverine ecosystem." This river supports substantial quantities of standing algal biomass in the upper extent, yet owing to inputs of suspended sediment a declining gradient in primary production occurs with downstream distance. Unlike the Lees Ferry area where the functional feeding groups are grazers, like *Gammarus lacustris,* which depend on algae, the downstream region appears dominated by black-flies (*Simulium arcticum*). Black-flies are filter feeders or collectors that acquire their food resources directly from particulate organic matter in suspension. The origin of this organic matter is often allochthonous rather than autochthonous. Studies indicate that black-fly larvae are available in the benthos and drift, and are utilized by native (humpback chub, flannelmouth sucker, blue head suckers) and nonnative (rainbow and brown trout) fishes. Although suspended sediment regulates availability of light, it does not necessarily mean that the trophic structure is dependent on light energy; but rather these same biotic patterns might also be explained by different responses made by filter-feeding organisms and visual sight feeders to suspended sediment. Light availability in the downstream regions may play only a small role or be independent of the actual trophic structure (i.e., excluding the Lees Ferry area); therefore we contend that it is time to reexamine the conventional paradigm. For this reason, Grand Canyon Monitoring and Research Center's recent initiative to conduct research on the aquatic foodbase is very appropriate and well timed.

Physical Factors that Influence Spatio/Temporal Differences in Benthic Invertebrate Availability near the Little Colorado River, Grand Canyon, AZ

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Abstract. Black-fly (*Simulium arcticum*) larvae are a major food resource utilized by native and nonnative fishes in the Colorado River, Grand Canyon. However, this invertebrate prey-base has been ineffectively sampled using conventional gear types (Hess and Surber samplers) and the reasons for this are primarily due to limitations imposed by logistics, sampling time, and sampling depth. The use of multi-plate samplers has overcome some of these limitations and has been shown to be an affective method for measuring benthic relative abundance upstream and downstream of the confluence of the Little Colorado River. In 2004, samplers were deployed in varying habitat types (cobble bar, talus slope, and vertical-cliff) that consisted of hard substrata, which were monitored over multiple months within a winter and summer period. The relative abundance (#/MP) of black-flies was significantly higher in cobble bar habitat over other habitat types; yet densities varied seasonally and spatially. Highest densities occurred during winter however site specific differences occurred and were negatively correlated to sediment discharges from tributaries. We hypothesized that differences in the frequency of suspended sediment loads were the primary mechanism regulating the spatio/temporal distribution of black-fly densities. Results from reciprocal translocation experiments (upstream and downstream) indicated that differences in black-fly densities were related to spatio/temporal differences among sites rather than within site differences. Other treatments used to test for the effects of sampler movement showed no difference in densities when compared to control densities (no-movement) at specific sites. Results indicated that differences in densities are related to the frequency and source of suspended-loads originating from tributaries. Results from colonization experiments also supported this same pattern where black-fly densities increase or decrease in response to exposure to suspended sediment. It, however, remains uncertain whether or not black-flies are sensitive to a specific concentration or particle size.

Inter- and Intra-Annual Differences in the Availability of Drifting Invertebrates near the Little Colorado River, Grand Canyon, AZ

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Abstract. In 2003, temporal and spatial variation in invertebrate prey availability was determined by drift analysis and was conducted as part of the Mechanical Trout Removal Experiment in the Colorado River, Grand Canyon. Drift was sampled for multiple evenings (19:00 – 01:00) and sites, upstream and downstream of the Little Colorado River (LCR) confluence, and concurrent with electrofish sampling effort. Mean annual drift of total invertebrate biomass (AFDM) (1.2 mg/L ± 0.11 SE) at the LCR was considerably lower than the upstream drift values published for the Lees Ferry area (6.8 mg/L). Drifting invertebrates on average were aquatically derived (92.5%) and only during summer did the contribution of invertebrates from terrestrial environments increase (23.5%). Although there was a spatial trend of decreased drift below the LCR; however, there was no significant spatial difference detected when drift biomass was averaged across all sampling periods. This observation was unexpected because it indicated that in general the availability of aquatic invertebrate prey were similar among sites upstream and downstream of the LCR confluence. Although the availability of invertebrate biomass in the drift varied across sampling periods, the average proportion of aquatic invertebrates in the drift were: annelids (6%), gastropods (8.8%), copepods (13.5%), cladocerans (16.9%), simulids (21.2%), chironomids (22%), gammarids (2.3%), and miscellaneous aquatic invertebrates (9.3%). Observed differences in the proportion of invertebrates found in trout diet versus their availability indicated differential use. Factors that appeared to be responsible for the electivity differences were due to reduced and variable reactive distances (0.35-0.0 m RD) and prey size differences within the drift (i.e., 50% of all invertebrates are less than 0.7 mm).

Inter- and Intra-Annual Differences in Rainbow and Brown Trout Diet near the Little Colorado River, Grand Canyon, AZ

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Abstract. Considerable research has been directed toward understanding causal mechanisms limiting the aquatic food-base in the Colorado River. Although, a bottom-up perspective has provided greater understanding of resource availability; conversely, very little diet information exists (although often presumed) for higher trophic levels. The purpose of this study was to describe the diet of rainbow (RBT) and brown trout (BNT), and determine if biotic (changes in density) and environmental factors influenced consumption and interactions between species for certain prey items (invertebrates and fish), based on size, abundance, and availability. Diet (proportional consumption by weight, %W) of RBT consisted almost exclusively of aquatic invertebrates, and of those, black-fly larvae were the most abundantly consumed (60-80%W). Average total biomass in RBT foregut differed significantly among size classes and spatial strata (i.e., upstream vs. downstream of the Little Colorado River (LCR) confluence) although diet proportions remained similar across spatial strata. In comparison, diet proportions for BNT differed between downstream and upstream sites. Diet proportions upstream favored amphipods (40%W), whereas in the downstream areas the diet shifted toward black-fly larvae (30-40%W). Overall, average total biomass in BNT foregut was more variable and also differed significantly among size classes and spatial strata. However, both trout species demonstrated opportunistic feeding, some of the other types of prey items included bats, birds, lizards, and scorpions. Fish predation was observed for both species which varied across different years, seasons and spatial strata. Instantaneous predation rates were highest in the downstream area owing to differences in prey density and seasonal availability. Although diet composition was significantly different among the two trout species, the diet overlap was not large enough to avoid some degree of dietary competition.

Interactions between Environment and Biota that Influence Predation of Small Bodied Fish near the Little Colorado River, Grand Canyon, AZ

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Abstract. Fish predation analysis is central to understanding whether or not piscivory has been a leading causal mechanism in the recent recruitment decline of humpback chub in Colorado River, Grand Canyon. Although, piscivory on native fishes has been documented for rainbow (RBT) and brown trout (BNT), observations have lacked sufficient sample sizes to address whether or not predation rates varied monthly, seasonally and yearly for different densities of predator and prey, foodbase availability, and encounter rates. Stomach samples (> 18,000) collected in 2003-2004 were assessed for presence or absence of fish remains. To accurately estimate mean incidence of predation per trip required large sample sizes to reduce coefficient of variation since BNT were less abundant, and RBT were less piscivorous. BNT over RBT had the highest functional piscivorous response; yet, overall effect from piscivory was numerically higher for RBT due to its higher abundance. Therefore, cumulative effect on native fishes should be reduced due to the mechanical removal effort. Suspended sediment loads were hypothesized to effect predation because trout were visual sight feeders. Results from dietary analysis indicated that overall diet proportions for RBT remained similar among upstream and downstream sites; however, average total biomass in foregut was less downstream. Spatial differences in total foregut biomass contrasted with drift availability, indicating that within a sampling period no significant differences in the availability of drift existed among upstream and downstream sites. These differences suggested that the consumption of prey biomass had more to do with predator encounter rates than prey availability since invertebrate prey were similarly available. Based on modeled results, it was estimated that reduced reactive distances would be difficult for trout to meet all of their required daily per capita consumption using only visual sight feeding as the primary method for foraging. Therefore, differences in reactive distances may be responsible for the patterns observed for distribution, abundance, and levels of piscivory exhibited by trout.

Response of Drifting Invertebrates and Organic Matter to Disturbance from High Experimental Flows Prescribed for the Colorado River, Grand Canyon, AZ

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Abstract. In regulated rivers of the Southwest we often ignore or don't recognize that allochthonous organic matter is contributed from alternate sources. Typically these types of rivers are highly productive owing to optically clear conditions that have resulted from impoundment and loss of upstream connectivity. Yet, the quantity of particulate organic matter transported in these rivers is often reduced due to supply disruption. In November 2004, an experimental flow was released from Glen Canyon Dam for a 120-hr period to rework and suspend sediment supplied to the Colorado River during monsoonal inputs. As part of this sediment/flow experiment we measured drift concentrations of invertebrate and total organic biomass. Reference conditions were established at a stable 8,000 cfs flow 3 days prior to the experimental release (41,000 cfs). Drift was measured throughout this period, until flows returned again to low stable discharges 8,000 cfs. In comparison to reference conditions (12.6 mg/L) drift concentrations remained significantly higher following the post experimental flow (58 mg/L). Total organic drift averaged 235 mg/L (± 63 SE) for the entire period, and was comparable to concentrations (240 mg/L) measured during similar flow events in spring 1996. 60% of all organics were less than 0.6 mm in size. Zooplankton concentrations remained high and constant (2.0 mg/L ±0.38 SE) (no volumetric dilution) throughout flow period, indicating their Lake Powell origin. Most zooplankton showed signs of damage due to high organic concentrations. Maximum total organic concentrations reached levels of 1,556 mg/L. Based on expansion estimates we feel that the primary source of allochthonous organic matter supplied to this system originated from tributary discharges and was not from the inundation of the upper riparian zones. Using rather liberal estimates for annual riparian production, vegetated area, decomposition rates, and litter retention, we were unable to account for the quantities of organic matter transported during the high experimental flow. This indicated that tributary inputs were the primary source that contributed the largest quantity of particulate organic matter to the aquatic ecosystem.

(1) Three Years of Experimentation at Glen Canyon Dam: the Electrical Power Economic Costs

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Abstract. Beginning in WY 2003, Glen Canyon Dam operations were modified to see if water releases could be modified to improve the condition of the Grand Canyon population of humpback chub and to improve the conservation of sediment entering the Grand Canyon from its various tributaries. These flows include Non-native Fish Suppression Flows, low fall flows and Beach Habitat Building Flows. The economic effects on electrical power production of these Glen Canyon Dam release changes compared to the Moderate Low Fluctuating Flows. The economics effects are then examined and described and calculated. A model, the GT Max, which is a simulation model of electrical power production which simultaneously dispatches the Colorado River Storage Project (CRSP) dams in response to electrical demand and market prices forms the basis of this analysis.

(2) The Electrical Power Economic Impacts of Liberalizing Glen Canyon Dam Operational Constraints

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Abstract. Based on the Low Summer Steady Flows of 2000 and subsequent changes in releases from Glen Canyon Dam for experimental purposes, the GT Max model has been developed and calibrated in order to estimate the economic impact of proposed changes in operational parameters at Glen Canyon Dam and the other major CRSP dams. In this report, the model is described and used to examine the direction and magnitude of the economic impact on electrical power production of a variety of possible schemes that would further constrain or liberalize operational constraints at Glen Canyon Dam.

Update on Status and Trends of Humpback Chub in Grand Canyon

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Abstract. Changes in the abundance of the Little Colorado River population of federally listed humpback chub (*Gila cypha*) in Grand Canyon have been monitored since the late 1980s using catch rate indices and intensive mark-recapture programs. Analyses of data from all sources using various methods are consistent and indicate that the adult population has declined by 30% - 60% since monitoring began. Intensive tagging efforts led to a very high proportion (>80%) of the adult population being marked by the mid-1990s. Analysis of these data using both closed and open abundance estimation models agree with catch rate trend data about the extent of decline. Survival rates for age-2+ fish are strongly age-dependent, but apparently not time-dependent. Back calculation of recruitment using apparent 1990s population age structure implies periods of much higher recruitment during the late 1970s to early 1980s than is currently estimated. Our analyses indicate that the recovery criterion of stable abundance is currently not met for this population.

Effects of Spatial Accuracy Uncertainty on Change Detection and Scientific Analysis

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Abstract. The mission of the Grand Canyon Monitoring and Research Center (GCMRC) is to provide credible, objective, scientific information to managers on the operational effects of Glen Canyon Dam on downstream resources of the Colorado River ecosystem (CRE). This ecosystem-wide science approach requires integration of data across physical, biological, and cultural disciplines. GCMRC's Oracle spatial database is the tool that allows managers and scientists alike to view, assess, and investigate spatial information collected for multiple purposes and from numerous sources including both ground-based static and airborne kinematic Global Positioning System (GPS) methods, digital photogrammetry, Light Detection and Ranging surface modeling (LiDAR), robotic and manual electronic optical total stations, and multi-beam hydrography.

The foundation for all spatial measurements is the geodetic control network. An accurate network allows for consistent reference for all data acquisition. The network also provides the source for quality control and accuracy determination of spatial data representing the entire CRE. These spatial data, as well as horizontal and vertical uncertainties, are housed within the logical consistency of the Oracle database which sets the framework for data integration across natural resource arenas. Accurate quality control is necessary for GIS layer development of physical, biological and cultural resources as well as further, perhaps unintended, integrated analysis. Only after systematic evaluation can the data and resultant products be reliably served to scientists, cooperators, and managers through web applications such as GCMRC's internet map server.

Without well developed metadata defining processes such as accuracy and precision assessment, blunder detection, systematic bias determination, horizontal and vertical datum reference, collection equipment, and processing methods and assumptions, the data would loose its integrity, which may result in management decisions based on misleading information. All phases of database development must, therefore, be documented through a consistent lineage of metadata pertaining to data acquisition, verification, analytical processing, and, ultimately, information transfer. As stewards of Grand Canyon resource data, our responsibility is to provide the best science possible to resource managers, a concept that is built upon realistic spatial data accuracy determination and thorough documentation.

Lies, Statistics, and Spatial Data Accuracy: Reliable and Realistic Accuracy Determination for Spatial Data

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Abstract. The positional accuracy of spatial data should be known when the data are used to support scientific studies and to provide information for management of the Colorado River Ecosystem (CRE). There are a variety of ways to estimate accuracy, but regardless of the method, the final accuracy estimates must be realistic and consistent across the full range of positioning technologies and spatial data types used. This presents a challenge for the CRE, since several different advanced technologies are utilized to capture spatial data, including high-accuracy Global Positioning System (GPS) methods, digital photogrammetry, Light Detection and Ranging (LiDAR) surface modeling, robotic and manual electronic total stations, and multi-beam hydrography. As with all measurements, the data collected using these sophisticated technologies contain error, which are propagated through the computation process and affect the accuracy of the final spatial product. An additional challenge is that many of these technologies (especially GPS) tend to yield unrealistically optimistic accuracy estimates (based on internal precision measures). This is of particular importance for GPS since it is used both for control surveys and to position airborne sensors (e.g., LiDAR and camera systems). Such "optimistic" results, together with inappropriate computation methodologies, unmodeled systematic biases, and the absence of an explicitly stated statistical confidence level can make the data appear more accurate than actual. This can in turn affect the quality of scientific research (possibly even leading to erroneous results) and may compromise effective management by giving misleading information.

This presentation provides a brief overview of the various factors affecting spatial data accuracy determination. These include systematic errors, statistical confidence levels, and the distinction between accuracy and precision. Example data will be used to show how each of these factors effect accuracy determination, and how simple it is to generate misleading or "optimistic" results. This will serve to illustrate the importance of adhering to published and accepted standards, in particular those promulgated by the Federal Geographic Data Committee (FGDC), such as the National Standard for Spatial Data Accuracy (NSSDA) and the Standards for Geodetic Networks. Accuracy in this context is with respect to the National Spatial Reference System (NSRS), which forms the fundamental positioning framework of the National Spatial Data Infrastructure (NSDI). These standards make it possible to reliably estimate and compare accuracy consistently across a variety of datasets, and they facilitate both robust science and good decision making.

Determining Water Surface Datums to Measure Hydrographic Elevations

F. Mark Gonzales

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Abstract. Since the Bureau of Reclamation implemented the beach/sand bar test flows in 1990, there has been a need for modern, repeatable survey capabilities. These survey capabilities were required to accurately measure effects of Colorado River Ecosystem (CRE) resources resulting from Glen Canyon Dam operations. The survey data are used to generate topographic maps and digital models for analysis as well as change detection of the resources. These surveys include measurements of terrestrial and hydrographic resources.

Terrestrial and hydrographic surveys in the CRE lacked horizontal and vertical control points necessary to accurately position the survey data for independent repeatability and change detection. The survey coordinate systems used in the CRE were mostly localized or of obsolete or unknown map projections. The Glen Canyon Environmental Studies' and Grand Canyon Monitoring and Research Center's survey departments moved forward to consolidate and translate the existing survey coordinate systems, as well as establish new and updated control points for current and future research.

In many cases, the CRE canyon walls prohibit reliable satellite visibility and geometry required to get accurate positional values. The vertical control, being to most difficult to establish, is measured using long, repeated static Global Positioning System (GPS) observations. These coordinate values can then be transferred to survey control points in the CRE by adjustment or direct conventional measurement.

Hydrographic surveys traditionally utilize the water surface or tide elevation as a reference datum to measure depths. This is commonly done with an echosounder and the depth is measure by referencing the water surface. The problem with this in the CRE is that the water surface continuously slopes and changes as a result of Glen Canyon Dam operations. It became necessary to develop the capability of directly measuring the depths from the established ground-based control points.

A number of methods have been developed to accurately measure hydrographic elevations. Some of these methods include: conventional total station measurements, range azimuth tracking stations, robotic tracking systems, differentially corrected GPS (omniSTAR), and combinations of the aforementioned.

Using an Integrated, Remote-Sensing Methodology to Evaluate the Effects of Dam Operations on Fine-Grained Sediment Storage and Sand Bar Restoration in the Eastern Grand Canyon

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Abstract. Eddy sand bars and other sandy deposits in and along the Colorado River in Grand Canyon National Park (GCNP) were an integral part of the pre-dam riverscape, and are still important for habitat, protection of archeological sites, and recreation. These deposits began eroding following the 1963 closure of Glen Canyon Dam that reduced the supply of sand at the upstream boundary of GCNP by about 94% and are still eroding today. In the 1990s, resource managers and scientists began a long series of experiments and monitoring aimed at answering one primary science question: Given existing sand inputs to the ecosystem, can any set of dam operations actually restore and maintain sand bars within the Canyon?

In order to test this question, a reach-based approach was developed to examine temporal and longitudinal trends in sediment storage and composition in six, 3- to 6-kilometer reaches of the channel in eastern GCNP. The reach-based approach integrates various remote-sensing technologies to supplement historical survey techniques. These include: LiDAR and multi-beam sonar for measuring the elevations of sub-aerial and sub-aqueous surfaces; an underwater microscope (the flying eyeball) and its sub-aerial sister, the beachball, for measuring the composition of sediment surfaces; and traditional surveys to provide fine-level control. From 2000 to 2005, seven distinct measurements were made for all reaches. These bracketed two high-flow experiments (controlled floods) and intermediate periods characterized by normal Dam operations. Composite surfaces derived from these techniques, together with their composition, will allow scientists to quantify system responses to specific dam operations in attempting to address the primary science question.

(A poster accompanies this oral presentation)

3D Laser Scanning (LiDAR Surveying) and Oblique Photogrammetry Assessment during the 2004 High Flow Test

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Abstract. The Grand Canyon Monitoring and Research Center (GCMRC) survey department is actively engaged in testing and analyzing new and evolving mapping technologies, techniques, and software for application and use in support of GCMRC research programs. All technologies tested by the GCMRC survey department are proven methods that are evaluated for 1) use in the demanding canyon environment, 2) applicability to meet specified and/or specialized resource research and monitoring goals, and 3) assessment of cost-effectiveness compared to conventional approaches. Both, 3D laser scanning (LiDAR surveying - Light Detection And Ranging) and oblique photogrammetry technology can be applied to monitor physical resources, biological resources, and sensitive archaeology sites. The benefits of this evaluation include acquiring higher resolution data compared to conventional survey methods, acquiring and generating topographic data for inaccessible sites, and minimizing on-site visitation. In addition, these technologies promise to be more economical with less time and manpower spent collecting data.

LiDAR surveying is a portable system mounted on a tripod that utilizes laser technology to determine the distance to a surface from the return time of an encoded laser pulse. LiDAR surveying scans topography quickly and efficiently at a rate of up to 12,000 points per second, up to a range of 800 meters with an accuracy of 2-3 cm. The data is geo-referenced by including known control in the scan. Oblique photogrammetry is based on the principals derived from traditional aerial photogrammetry, and utilizes affordable digital cameras and computer software that quantifies the distortions of these cameras and extracts three dimensional data from the photographs. Oblique photogrammetry is geo-referenced by including known control in the site photographs and then post processed using specialized software (PhotoModeler, Erdas, Sirovision). Both LiDAR surveying and oblique photogrammetry technologies allow for precise measurements to be made to quantify resources or monitor change.

LiDAR surveying and oblique photogrammetry were evaluated collaboratively with the USGS, Coastal and Marine Program (LiDAR Surveying) and the BLM, Branch of Photogrammetric Applications (Oblique Photogrammetry) during the November 2004 High Flow Test. LiDAR scans and photographs were collected at 30 mile, Vasey's Paradise, and 66 mile (Palisades) the week prior to the onset of the high flows. The raw data was processed into topographic data; at 30 mile and 66 mile the data was evaluated for accuracy against conventionally surveyed data, and at Vasey's Paradise, the data was evaluated for its applicability habitat research. It was determined that both technologies work well in the canyon environment, but only in the absence of precipitation. They are most effective at sites with exposed ground, topographic relief, and minimal vegetation rather than flat, highly vegetated sites. These techniques show much promise in being utilized as standard mapping tools for collecting high resolution geomorphological, biological, and archeological data in the Grand Canyon.

Cable-to-the-Sky: Two-Way Telemetry Adaptive Control and Communications

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The concept of two-way telemetry for instrumentation located in remote river settings has long been a dream. During summer 2004, this dream was realized by USGS scientists at remote sites along the Colorado River within Grand Canyon National Park where surrogate, laser-acoustic sediment-transport technologies are currently used. High-resolution suspended-sediment transport data in the river are important to environmental monitoring of sediment flux below Glen Canyon Dam relative to management objectives for sand bar restoration within Grand Canyon.

Use of commercially available, broad-band satellite service at these sites, along with a variety of "off-the-shelf" computers and accessories, now allows sediment scientists unrestricted, real-time access to flow and sediment data at locations that otherwise can only be accessed with great effort. Unlike standard 'one-way' GOES satellite telemetry, the 'two-way' broad-band satellite service allows not only remote access to data but also allows scientists to monitor and control the instruments at these sites by relaying commands to the devices via the internet. In essence, the scientists access and control the various sensors as if their office computers were connected to the instruments by a very long "Cable-to-the-Sky."

Several vendors provide remote access to a single instrument however this system is adaptable to support a variety of different vendor's instruments with a single solution. Instruments that use conventional PC connections (serial, USB, etc.) can be supported providing the site PC has the proper type and number of connecting points. Currently the system has been configured to use satellite broadband internet service. The system can be configured to use other services such as landline, cellular, cable, and satellite data phones. Additionally, radio modems can be added to support instruments some distance from main telemetry site.

Monitoring Streamflow of the Paria River at Lees Ferry

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Abstract. The Paria River, an intermittently flowing tributary of the Colorado River that joins the river 15 miles downstream from Glen Canyon Dam, is the primary source of sand for Marble Canyon. Significant flow (large magnitude and/or duration) from the Paria can potentially trigger beach/habitat building releases from the dam. Consequently, the streamflow-gaging station Paria River at Lees Ferry plays an important role in the management of the Colorado River in the Grand Canyon river corridor. Monitoring of stage at the Paria River station has been complicated, however, by channel migration. Since about 1998, the main channel (of fine- to medium-grained sand) has been shifting away from the station to the right side of the channel, creating a slow-flow zone between the station and the main channel that is prone to sediment deposition. Several feet of sand can be deposited at the base of the station's stilling well, even from a modest storm that generates a flow less than 100 cubic feet per second, cutting off the hydraulic connection with the main channel.

The original stage-sensing equipment at the gaging station includes a stilling well (approximately 30 feet high), a float and encoder, and a data logger. Telemetry provides remote access to stage data. The stilling-well float works well and accurately records the hydrograph rise and peak under most conditions, but accumulation of silt prohibits accurate recording of flow recession. When stilt accumulates and accurate recording ceases, recession data must be estimated. Additional stage-sensing equipment, including a pressure sensor (or bubbler system), a laser sensor, and a downward-looking radar sensor, has been installed and tested in an effort to minimize loss of data during flow recession. The use of any of these instruments alone has been insufficient to monitor stage without loss of data, but use of the instruments in combination has significantly reduced data loss.

Further Effects of Drought and Drought Rebound on the Tailwaters of Glen Canyon Dam in 2003–05

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Abstract. By April 2005, drought conditions lowered Lake Powell 142 feet from nearly full pool elevations of the late 1990s. Slightly above-average basin runoff in 2005 raised the lake's surface more than 53 feet by mid-July. As a result, Glen Canyon Dam's penstock intakes were closer to the lake's surface layer than they have been since 1969. The combined results of low pool levels and a larger inflow resulted in even higher summer release temperatures. By the end of August 2005, the dam was releasing some of the warmest water seen since 1970, exceeding 15°C (59 °F), while low dissolved oxygen in Lake Powell drove release dissolved oxygen to unprecedented levels. As the reservoir initially filled in the 1960s and 70s, release water quality migrated from seasonal river patterns to a reservoir pattern where discharge temperatures peaked during the late fall- winter mixing followed by coldest releases in February and March. Lowered lake elevations have produced discharge temperatures over 5°C (9-10 °F) above decadal norms. Temperature alone is not affected by epilimnetic withdrawals from Lake Powell. Discharge patterns of salinity are also reflective of epilimnetic releases, which reflect the suite of chemical ions that contribute to salinity. While releases begin to resemble the reservoir's epilimnion, the epilimnion itself is transformed by the conditions of the drought and drawdown. Hypoxia has been passed downstream as oxygen levels drop in the reservoir due to uplake suspension of sediments and organics.

The changing discharge water quality may influence numerous aspects of downstream ecology, complicating ongoing experimentation. Additionally, projections for extended drought could further lower the lake and result in greater deviations from typical releases of the past 15 to 20 years. Here we provide an explanation of the processes that produce these effects, examine past instances of warm summer releases, and look into the future.

An Improved Stars Model: Predicted Colorado River Water-Surface Elevations and Virtual Shorelines for Flows up to 200,000 cfs

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Abstract. By coupling the ISTAR digital elevation model (DEM) topography collected in 2002, the Hydrologic Engineering Center's River Analysis System (HEC-RAS), and geographic information system (GIS) tools, an accurate and up-to-date model was constructed that simulates the water-surface profile along the Colorado River throughout Grand Canyon for any discharge up to 200,000 cfs. This model updates Randle and Pemberton's 1987 STARS hydraulic model, which had been the only comprehensive hydraulic model yet developed for this setting. Using the 2002 ISTAR DEM, roughly 2,700 cross sections were cut along the river corridor from Lees Ferry to Diamond Creek, a distance of 226 river miles. The cross sections extend roughly 30 m up the canyon walls to capture exceptionally large flows. Because bathymetry was not available for large portions of the river, synthetic bathymetry was created at each cross section; a trapezoidal shape was assumed with an adjusted depth to produce a predicted water-surface profile that closely matched the known water-surface profile at 8,000 cfs, following the procedure developed by Randle and Pemberton. The overall vertical accuracy of the model ranges from ±0.5 m at low discharge to ±1.5 m at high discharge. In addition, a set of GIS programs was developed to take stage-specific outputs from the 2,700 cross sections and create 'virtual' shorelines. The model predicts the high-water marks of driftwood piles from historic floods at Boulder Narrows, Granite Park, and Palisades. The new tool set also offers a way to predict inundation and shorelines for extreme flood events at any site between Lees Ferry and Diamond Creek at a finer resolution and higher discharge than the old STARS model. Perhaps most importantly, given the dynamic morphology in Grand Canyon, the new model is built with digital elevation data of topography and water-surface elevations collected within the past three years.

Evaluating Sandbar Stability with Groundwater Instrumentation and Modeling

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Abstract. During the November 2004 experimental release from Glen Canyon Dam, 4,551 m^3 of fine sediment was deposited at river mile 30.4R. Following this beach building event, the newly deposited bar was instrumented with 16 screened wells and transducers to observe how the phreatic surface of the bar responded to the return of diurnal fluctuation of stage from Glen Canyon Dam. Values of hydraulic conductivity, obtained from slug tests, ranged from 0.15 to 3.05 m/day depending on the location of the screened interval.

A numerical groundwater model was used to investigate the dynamic relationship between stage fluctuation and the rate of dewatering for sandbar 30.4R. The model was calibrated to hydrologic data collected from late November 2004 to early March 2005, during which the bar was subjected to multiple flow regimes from the operation of Glen Canyon Dam. The calibrated model was used as a predictive tool describing the relationship between stage fluctuation, the phreatic surface in the sandbar, the rate of bar dewatering, and the observed instability of active seepage faces in sediment deposited during the experimental release.

Changes in Debris Fans and Rapids: 21 Years of Monitoring Debris Flows in Grand Canyon

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Debris flows occur in 740 tributaries of the Colorado River in Grand Canyon between Lees Ferry and the Grand Wash Cliffs (river miles 0 to 276). An episodic type of flash flood, debris flows transport poorly-sorted particles ranging in size from clay to boulders to the Colorado River and create and maintain rapids and riffles. Interpretation of more than 1,300 repeat photographs spanning 120 years, supplemented with aerial photography taken between 1935 and 1990, yielded information on the historical frequency of debris flows in 147 of the 740 tributaries (20%). On average, repeat photography shows that 5.0 debris flows per year occur in Grand Canyon from 1890 through 1983, compared with an observational record of 4.9 debris flows per year from 1984 through 2004. The oldest Holocene debris flow documented in Grand Canyon occurred 8.0 ka in Whitmore Canyon ($^{3}He_{c}$), the oldest debris flow reaching the river occurred 5.4 ka (^{14}C), and the oldest known debris-fan surface is about 7.3 ka (dissolution-pit dating). Debris-fan surfaces commonly formed between 0.5 and 7.3 ka.

Long-term changes in the river's longitudinal profile were documented by comparison of survey data (1923) with Lidar data (2000). Although previous studies have suggested that the debris fans have and will aggrade in response to flow regulation, lack of documentation of debris fans in 1963 precludes a canyon-wide assessment of the effects of Glen Canyon Dam. In the case of two frequently aggraded debris fans (75 Mile Wash and Monument Creek), we used ground surveys and photogrammetry to document changes from 1935 through 2004. Multiple debris flows from 1984 through 2003 increased the area and volume of these debris fans and further constricted the river in both rapids. Profiles derived from the elevation models show maximum aggradation near the middle of the debris fan, high above the stage of either powerplant or controlled flood releases, as profile geometry shifted from concave-up to concave-down. Controlled-flood releases in 1996 and 2004 partially reworked both debris fans, although reworking generally removed far less sediment than was added by debris-flow deposition.

We modeled sediment yield from debris flows by combining a frequency model with data on debris-flow magnitude and particle-size distribution. Debris flows deliver between 0.12 and $0.25 \cdot 10^{6}$ Mg/yr of sediment to debris fans between Lees Ferry and Lake Mead and between 0.46 and $0.96 \cdot 10^{6}$ Mg/yr in Marble Canyon alone. Measured boulder content of historical debris flows averages 13.8±18.7% by volume and debris flows deposit from 5,000 to 18,000 Mg of boulders on debris fans every decade. Using our stochastic model we added sediment to a uniform river bed at tributary junctures over a millennia. All particles finer than boulders were assumed to be removed by the pre-dam Colorado River, leaving a lag of boulders in the river to form rapids. The resulting bed rise at each tributary averaged 2.25 m, which is greater than the existing average drop of 1.58 m and reflects the inadequacy of the model's reworking component. Although our model of boulder delivery is incomplete, preliminary results suggest that this is a promising approach to explaining Holocene changes in the longitudinal profile of the Colorado River as well as predicting the locations of future debris flows.

Large-Scale Modeling of Flow, Sand Transport, and Sand Storage Between Glen Canyon Dam and Phantom Ranch

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Abstract. One of the primary goals of the management of Glen Canyon Dam is the restoration and maintenance of sand deposits along the Grand Canyon corridor (U.S. Department of the Interior, 1995). Field observations have documented changes in sand storage and have suggested hypotheses regarding the manner in which dam operations influence sand deposition and retention in the system. Numerical models can contribute to the explanation of observed changes in sand storage, extrapolate field observations to unobserved flows, and evaluate alternative dam operation strategies for preserving the sand resource. We have produced a one-dimensional model that routes water and sand along the river corridor. Our model differs from conventional one-dimensional models in several significant ways: (1) exchange of sand between the main downstream current and eddies, which cannot be directly represented by a one-dimensional model, is included by parameterizing predictions over a wide range of conditions from a multidimensional model; (2) suspended sand transport over an extremely rough and sparsely sand-covered bed, which is not accurately represented in conventional sand-transport relations or boundary conditions, is calculated in our model with algorithms developed as part of this project (see and others, this symposium); (3) the channel is represented by reach-averaged properties, thereby reducing data requirements and increasing model efficiency; and (4) the model is coupled with an unsteady flow model, thereby accounting for frequent changes in discharge produced by variations in releases from Glen Canyon Dam.

Model application can address several significant management issues: (1) the potentially rapid migration of tributary sand inputs through the system, which has important implications for the engineering and institutional basis for dam operations, (2) the effect of timing, magnitude, and duration of dam-release alternatives on building sand, and (3) the linkages between dam operations, sand deposits, and the biological, recreational, and archaeological resources along the river corridor.

U.S. Department of the Interior, Bureau of Reclamation, 1995, Final Environmental Impact Statement - Operations of Glen Canyon Dam – Colorado River Storage Project, Coconino County, Arizona, p. 337.

High-Resolution Monitoring of Suspended-Sediment Concentration and Grain Size in the Colorado River in Grand Canyon Using Laser-Diffraction Instruments and a Three-Frequency Acoustic System

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Abstract. Sand transport in the regulated Colorado River downstream from Glen Canyon Dam is limited by episodic resupply from tributaries, and is equally regulated by the discharge of water and short-term changes in the grain size of sand available for transport. During tributary floods, sand on the bed of the Colorado River fines; this causes the suspended sand to fine and the suspended-sand concentration to increase even when the discharge of water remains constant. Subsequently, the bed is winnowed of finer sand, the suspended sand coarsens, and the suspended-sand concentration decreases independently of discharge. This prohibits the computation of sand-transport rates in the Colorado River using stable relations between water discharge and sand transport (i.e., sediment rating curves) and requires a more continuous method for measuring sand transport.

To monitor sediment transport in the Colorado River in Grand Canyon, Arizona, we have designed and evaluated a laser-acoustic system for measuring the concentration and grain size of suspended sediment every 15 minutes. This system consists of (1) a subaqueously deployed laser-diffraction instrument (either a LISST-100 or a LISST-25X) connected to an automatic pump sampler, and (2) 3 single-frequency acoustic-Doppler current meters (a 600 KHz Aquadopp, a 1 MHz EZQ, and a 2 MHz EZQ). When laser transmission drops below a user-defined threshold (as a result of increased suspended-sediment concentrations), the LISST triggers the automatic pump sampler to collect samples at a user-defined rate. This allows samples to be collected when the suspended-sediment concentrations exceed the upper sand limit for the LISST and the acoustic-Doppler current meters (around 2000-3000 mg/l).

In August 2002, we began testing this system on the Colorado River, and have developed stable functions relating the pump, laser-diffraction, acoustic-attenuation, and acoustic-backscatter measurements to cross-sectionally integrated measurements of suspended-sediment concentration and grain size. We relate acoustic attenuation to the concentration of suspended silt and clay; this approach yields accurate silt and clay concentrations over the range from less than 10 mg/l to about 20,000 mg/l. Suspended-sand concentration can then be computed as functions of the acoustic backscatter and acoustic attenuation; this approach yields accurate sand concentrations over the range from less than 10 mg/l to over 3,000 mg/l. LISST-100 and 3-frequency-acoustic measurements of the median size of the suspended sand are typically within 10% of the values of the median size measured by conventional methods. Silt and clay loads and sand loads computed by either the LISST-100, LISST-25X, or the 3-frequency acoustic system are well within 5% of the values computed using conventional data. This result, in conjunction with the fact that orders of magnitude more sediment-transport data can be collected each day by the laser-diffraction and acoustic instruments, indicates that a much more complete, and therefore more accurate record of suspended-sediment transport can be collected by the laser-acoustic instruments than by conventional methods alone.

An Ex Post Facto Evaluation of Sand Mass Balance in Grand Canyon: Measurements Versus Rating Curves as a Means of Assessing the Value of Adaptive Management

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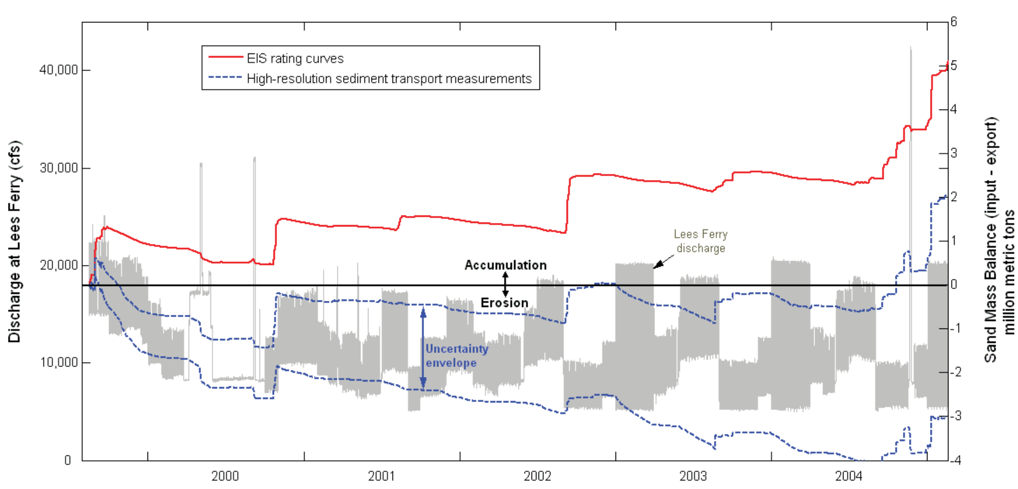
Abstract. One conclusion of the 1995 Glen Canyon Dam Environmental Impact Statement (EIS) was that sand would accumulate along the channel of the Colorado River in Grand Canyon during average to minimum release years under the preferred alternative, termed Modified Low Fluctuating Flow (MLFF) operation. The period 1999–2004 provides an excellent opportunity to assess this conclusion because 1) it was a period of MLFF during which operations were tied to mostly minimum annual releases, and 2) high-resolution sand transport measurements were begun in August 1999 thus providing the necessary data for the assessment. The included figure contains the comparison between the EIS methodology (discussed further below) and the high-resolution sand transport measurements, shown in terms of the cumulative mass balance for the reach from Lees Ferry to Phantom Ranch. It is seen that the EIS methodology predicts net accumulation of sand of about 5 million metric tons, while the high-resolution sand transport monitoring data indicate a range from 3 million metric tons of export to 2 million metric tons of accumulation, after accounting for the uncertainty in the measurements and accumulating this uncertainty through time. So, the EIS method differs from the high-resolution measurements by an amount between 3 and 8 million metric tons, in the direction of accumulation. This result is supported by several other recent findings that are summarized in chapter 1 of *The State of the Colorado River Ecosystem in Grand Canyon* report. The EIS methodology is based on the use of stable sand transport rating curves for the tributaries and the mainstem. A stable sand transport rating curve assumes that there is a unique sand concentration for a given discharge. Recent studies indicate that this assumption is invalid in the post-dam Colorado River in Grand Canyon, and that, rather, sand concentration in the mainstem is also heavily dependent on recent tributary inputs. Thus, the EIS rating curves tend to under-predict mainstem concentrations during significant tributary inputs, leading to under-prediction of the total sand export from the reach. Also, the EIS rating curve for the Little Colorado River (based on pre-1970 data) appears to over-predict sand supply during this recent 5-year period. This study demonstrates the essential need for ongoing monitoring data once traditional environmental compliance activities are completed and a preferred option is chosen.



Trends in Terrestrial Riparian Resources, 2001–04

Michael Kearsley

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Abstract. After three years of integrated sampling of vegetation, arthropods, herpetofauna, breeding birds and small mammals in riparian habitats of the Colorado River corridor of Grand Canyon National Park, several patterns emerged. First, trend analysis showed a decline in both vegetation and avifaunal abundances. Vegetation trends were in addition to effects of regulated flow and precipitation. Declines in breeding bird densities may be due to declines in vegetation abundance, but are likely also affected by factors outside of the breeding area. Second, arthropod abundances could be shown to follow parts of the hydrograph in some habitats (shoreline and low riparian) and precipitation amounts elsewhere. Herpetofaunal and small mammal abundances were highly variable and, without a fourth year of survey, could not be tied to either overall vegetation abundance or precipitation patterns.

Estimates of Systemwide Above-Ground Biomass and Terrestrial Vegetation Inputs for the Colorado River Ecosystem

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Abstract. Indirect evidence suggests that allochthonous carbon may become a significant source of energy for the Colorado River food web at downstream locations as algal biomass/production decreases. Field-based productivity estimates in combination with a comprehensive basemap for vegetation were used to quantify allochthonous litter inputs from annual herbaceous vegetation and deciduous leaf litter for discharges up to 20k cfs (the maximum discharge in recent years), and deciduous leaf litter accumulation was also quantified for the zone between 20-45k cfs to estimate potential allochthonous litter inputs that would occur during a Beach Habitat Building Flow (BHBF). Above-ground herbaceous vegetation from the current growing season (2003) was harvested in the fall 2003 from 7 sites in each of 10 geomorphic reaches for a total of 70 sample locations. Herbaceous vegetation was harvested from four 1 m^2 quadrats haphazardly placed below the 20k cfs zone at each sample location, and the location of quadrats were marked on aerial photographs in order to couple production estimates with vegetation mapping efforts. Deciduous leaf-litter was collected from quadrats that were haphazardly located beneath the canopy of the dominant deciduous vegetation types at locations both above and below the 20k cfs zone. Annual deciduous leaf litter inputs were estimated from collections below the 20k cfs stage line, while potential litter inputs in the event of a BHBF were estimated from collections above the 20k cfs stage line. Data from remote-sensing and vegetation mapping efforts provided an estimate of the canyon-wide distribution/cover for each of the dominant species contributing leaf litter to the CRE. Vegetation productivity estimates from quadrats were combined with these data and used to estimate allochthonous litter inputs for each vegetation type and each geomorphic reach. The sampling effort represents the first time that allochthonous litter inputs have been quantified along the Colorado River ecosystem. The results, to be discussed, will increase our understanding of the importance of terrestrial-aquatic linkages, and serve as an important first step towards the construction of a carbon mass balance for the Colorado River ecosystem.

Linking Whole-System Carbon Cycling to Quantitative Food Webs in the Colorado River

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Abstract. The Colorado River below Glen Canyon dam has been dramatically altered by modifications of flow, temperature, sediment, and nonnative species which has severely reduced native fish populations. These impacts have likely changed both the amount and source of carbon input available at the base of the food web and the flows within the food web (i.e., much carbon flow may be through exotic snails or fish). The proposed research will estimate the relative importance of the various food resources to fishes in this system to establish the degree to which native fishes are limited by food resources, by either low production at the base of the food web or via shunting of carbon to exotic animals. Hall and Rosi-Marshall will measure supply of basal food resources, such as primary production by riverine algae, inputs from Lake Powell, and litterfall from riparian vegetation. They will also measure rates of secondary production (or biomass produced over time) of macroinvertebrates in the river system. They will use measurements of macroinvertebrate gut contents and stable isotopes to calculate carbon flow from basal food resources to macroinvertebrates. Finally, the flow of carbon from macroinvertebrates to native fishes (humpback chub) and nonnative trout will be estimated. These data will allow them to estimate the dominant food sources for these fishes. This research will elucidate how the energy flows in the Colorado River and large desert rivers in general. Based on data from this study, the authors will propose monitoring approaches to assess future changes to foodweb function. Specifically, the measurements of food resource production and inputs, secondary production and energy flow in the food wed will provide a basis for developing hypotheses and monitoring plan about how proposed management strategies on threatened native fish species.

A Test of the Utility of Otolith Chemistry for Studying Humpback Chub Movements

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Abstract. Understanding the spatial distribution and contribution of source habitats for potadromous fishes is critical for accurately assessing their population structure and viability. The humpback chub (*Gila cypha*) is a federally endangered species whose largest extant population resides within the Grand Canyon section of the Colorado River basin. The chub is currently the subject of an intense quantitative stock assessment effort, however little is known about their spawning and rearing habitat use. In this study, we have explored the use of otolith chemistry (Sr isotopes with TIMS and elemental ratios with ICP-MS) to identify source habitats and to describe movement histories of individual chub in this geologically diverse setting. Our objectives were 1) to characterize the spatial variability of water and otolith chemistry in all major tributaries within the basin, 2) to quantify the effect of water chemistry on the otolith chemistry of resident fish, and 3) to compare the ability of elemental ratios (Sr/Ca, Ba/Ca, K/Ca, Mg/Ca, Na/Ca) with Sr isotopic signatures over a broad range of streamwater chemistry to distinguish among 14 potential source tributaries. Sr isotope ratios in otoliths of resident juvenile fish lie along a 1:1 line with river water values. In comparison, the relationship between streamwater and otoliths elemental concentrations is more variable, with Sr/Ca providing the most predictive relationship and other elements (e.g. Mg/Ca) showing no predictable otolith concentration despite large difference in streamwater concentration. Using cross-validated discriminate function analysis, Sr isotopes alone were more effective at correctly classifying individuals (66% correct) than any combination of elemental ratios (e.g. Sr/Ca and Ba/Ca together was 53%). However, correct classification of individuals to source habitats continued to improve to 95% when Sr isotopes were combined with elemental ratios.

Evaluation of the Statistical Properties of Grand Canyon Humpback Chub Population Parameter Estimates from ASMR and Alternative Mark-Recapture Models

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Abstract. Recovery goals for the Grand Canyon population of the federally endangered humpback chub (HBC; *Gila cypha*), contain criteria for down-listing and de-listing. These criteria depend on estimates of population parameters, such as absolute annual abundance, derived from mark-recapture monitoring data. Mark-recapture models represent a very rich set of different estimation techniques, each of which depends on a unique set of statistical and biological assumptions that are made about the population processes and sampling protocol that generate the data. A draft Fish and Wildlife Service guidance document (Anonymous 2002) prescribed use of a specific set of mark-recapture models for estimation of annual abundance. However, the Grand Canyon Monitoring and Research Center has developed a different set of estimation models (Age Structured Mark Recapture; ASMR), which differ substantially in their structure and assumptions (Walters and Coggins 2003). The Adaptive Management Working Group commissioned an external review in 2003 of the relative strengths and weaknesses of the alternative mark-recapture methods. A primary recommendation of the subsequent report (Kitchell et al. 2003) was to conduct computer simulation experiments to evaluate the statistical properties of candidate estimation models and mark-recapture sampling protocols, for the purpose of informing the future design and analysis of the HBC monitoring program.

I will describe the structure of the Monte Carlo simulation code used to generate populations of fish that are allowed to migrate during the spawning season between the Colorado River mainstem and the Little Colorado River (LCR), and that are subject to age and year specific mortality and recruitment schedules. Choices of population vital rates and movement patterns are based upon the mark-recapture data available from the ongoing HBC monitoring program. Additionally, I will describe several different sampling designs currently under consideration for future monitoring, and how these designs will be implemented in the simulation.

I will present initial results of the evaluation of the bias, precision, and robustness of ASMR and several alternative estimators under different 1) sampling design scenarios, 2) sets of assumptions about the underlying structure of the population vital rates, and 3) assumptions about timing and frequency of movement between the mainstem and the LCR.

Conservation Genetics of Gila Cypha: Shallow History

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Abstract. Genetic approaches have become increasingly important in assessing population structure and dynamics of imperiled taxa. A variety of molecular markers are available and each offers insights into the evolutionary history and ecology of a species at different temporal and spatial scales. Sequence analysis of mitochondrial (mt) DNA is a widely accepted methodology for defining evolutionary history of a taxon on a large spatial scale and can allow identification of evolutionary significant units. This approach provides guidance for long-term conservation goals and for management of biodiversity on a broad scale. However, to examine population structure on a finer scale and to understand contemporary ecological processes that determine population dynamics, faster evolving markers are necessary. Our analysis of mtDNA sequence variation revealed low genetic diversity both with regard to haplotype and nucleotide diversity. Distribution of haplotypes suggested limited gene flow among remnant populations of G. cypha in the Colorado River ecosystem, leading to marked differences among the two basins. To examine more detailed patterns of gene flow and population ecology in these populations, we evaluated genetic variation across 20 fast evolving nuclear microsatellite loci. Due to the high levels of polymorphism revealed by these markers, a sample size of at least 50 individuals per population is desirable. This target was achieved for three upper basin and two lower basin populations, but not for many of the smaller mainstem aggregates. Thus, our findings must be evaluated with this consideration in mind. Overall, microsatellite DNA analysis revealed surprisingly high levels of genetic variability both within and among populations and patterns of genetic diversity reflect population dynamics following a post-Pleistocene bottleneck.

Conservation Genetics of Gila Cypha: Deep History

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Abstract. Life history of G. cypha in the Colorado River Basin is mostly enigmatic, and interrelationships among subpopulations are virtually unknown. Lack of an historic baseline further complicates understanding of present-day patterns, and causal relationships between physical and biological parameters are merely a source of speculation. The most pressing questions pertain to genetic distinctiveness of local populations in the Colorado River Basin, the interrelationships among these populations, and how the sum can be adaptively managed in a perturbed environment. The objectives of this ongoing study are therefore to (a) infer interrelationships among populations of G. cypha within the basin, (b) to identify, if possible, genetically distinct units, and (c) to derive a management strategy for this endangered species. We assessed genetic interrelationships among 13 populations sampled from both lower and upper basin localities. Four rapidly evolving mitochondrial (mt) DNA regions (ATPase 8 & 6, ND2, and D-loop) were amplified and sequenced, yielding a total of 1,820 base pairs. Analyses revealed low levels of genetic diversity, both within and among populations. Although common haplotypes were shared, unique haplotypes were identified for both lower and upper basin, suggesting limited geneflow in the past between the two basins. However, apparent regional fixation of haplotypes should be interpreted cautiously as it is sample-size dependent. Implications for management and recovery are discussed.

Electrofishing in the Grand Canyon, 2000-2005, Status and Trends

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Abstract. Robust long-term monitoring of aquatic populations is important to adaptive management programs because it characterizes a "baseline" or antecedent context in which response of biota to changing management policies or experiments can be interpreted. In 2000 the Arizona Game and Fish Department, in cooperation with Glen Canyon Monitoring and Research Center, began development of an electroshocking sampling regime specifically designed to monitor rainbow trout, brown trout and common carp. After five years of sampling it has become apparent that this design is also suitable for other species such as the flannelmouth sucker.

Distribution and catch rates of rainbow trout, brown trout, and carp have remained similar between 2000 and 2004. Catch rates of rainbow trout, brown trout, and carp are highest near Marble Canyon, Bright Angel Creek, and downriver of Bright Angel Creek, respectively. Catch rates of flannelmouth sucker have increased significantly over the past 5 years. This increase is most evident on the lower part of the canyon between river miles 166 and 200.

Little Colorado River, Lower 1200 Meter Fish Monitoring Trends, 1987–2005

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Abstract. In 1987, Arizona Game and Fish Department began monitoring the status of humpback chub (*Gila cypha*) and other fish, in the lower Little Colorado River in Grand Canyon. Thirteen hoop nets are set in standardized locations and checked daily for approximately 30 days each spring. This monitoring program is one of the most consistent, long-term sampling efforts for fish in Grand Canyon. This index of catch rate is valuable for validating humpback chub mark-recapture population estimates or open population models and demonstrates the importance of long-term monitoring programs.

Recent increases in catch-per-unit-effort of flannelmouth and bluehead suckers indicate populations of these species are increasing.

Poster Session and Technology Demonstrations Overviews and Abstracts

Grand Canyon and Monitoring and Research Center Partners with Grand Canyon Youth for Youth-In-Science Program

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The Grand Canyon Monitoring and Research Center (GCMRC) measures the effects of Glen Canyon Dam operations on the resources along the Colorado River below Glen Canyon Dam. These activities support the Glen Canyon Dam Adaptive Management Program and their mandate to protect Colorado River resources based on data analysis by GCMRC. Monitoring physical, biologic, cultural and socio-economic resources are conducted using geo-referenced information from aerial photography, topographic data, and bathymetric data. The accurate positioning of this data requires control points which are the foundation for integrating spatial data into a GIS for analysis. The survey department has compiled a list of 870 control points installed by various organizations along the 240 mile stretch of Colorado River in the Grand Canyon. This list is the foundation for the Control Point Database and the control point atlas which prove to be valuable tools for assisting researchers to easily locate control points and independently geo-reference collected field data, for planning field operations with control point distribution information and inventory information, as well as for providing reference information on the historical use of a control point. The existence of each control point in the database is verified to ensure the database provides accurate, high quality information for researchers. The database is missing accurate site descriptions and photo-documentation.

This deficit was resolved by turning GCMRC's data collection effort into an educational exercise for the participants of the Grand Canyon Youth. Grand Canyon Youth is a non-profit organization providing experiential education for high school aged youth. GCMRC and Grand Canyon Youth formed a partnership where GCMRC provided the logistical support, equipment, and training to conduct the field work, and Grand Canyon Youth provided the time and personnel to complete the field work. This partnership has enabled us to engage 80 high school students on four educational science based river trips in the Grand Canyon in the past 2 years where the students made a significant contribution to populating the Control Point Database. In the four trips, the youth have collected information on 450 database control points (52% of the total number), including verification of point existence, photographs, accurate site descriptions concisely describing the location of the point, how to reach the point, the specific point location, and detailed bearings to visible and obvious land marks. The youth learned to locate themselves and find the points using 1:1000 scale airphotos, write detailed site descriptions, take bearings with a compass, measure and estimate vertical and horizontal distances, and use a digital camera. The youth also searched for archeology site control points using historic photographs, conducted maintenance at remote camera monitoring locations, documented sightings of big horn sheep, bald eagle, golden eagle, and red-tail hawk for the National Park Service, and emptied sand traps from weather stations monitoring aeolian sand movement at archeology sites. Our hope is that these educational trips will both expose youth to science thereby inspiring some to pursue higher education in the sciences as well as provide an opportunity for youth to learn in-depth about Grand Canyon, thereby creating the potential for a lasting feeling of environmental stewardship.

Beach Habitat Building and Status of the Endangered Kanab Ambersnail

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Abstract. Currently, two populations of Kanab ambersnails (KAS) are known to exist in the American Southwest. One population is located north of Kanab, Utah, on a privately owned wet meadow called Three Lakes. The other population occurs at a large, riverside spring in Grand Canyon National Park, known as Vasey's Paradise. As part of an adaptive approach to managing the Colorado River resources within Grand Canyon, artificial floods known as Beach/Habitat-Building Flows (BHBF) and smaller Habitat Maintenance Flows were recommended by interagency cooperators, scientists, and resource stakeholders. These experimental floods were designed to redistribute sediments from the river channel bottom to the riverbanks, create or restore sand beaches and backwaters, and help rejuvenate native fish habitat. However, it was estimated that the first BHBF in 1996, which peaked at 45,000 cubic feet per second, inundated and scoured away individual KAS (approximately 3,080) and KAS habitat (approximately 16% of total) from the Vasey's Paradise site (Stevens and others 1997b, USFWS 1997). On November 21, 2004, a second BHBF test flow was released from Glen Canyon Dam. The flow gradually increased from the normal rate of approximately 8,000 cubic feet per second to a maximum of 41,000 cubic feet per second. Our efforts to decrease the impact on KAS during the 2004 BHBF included temporarily moving both ambersnails and habitat above the high water mark. Habitat and snails were returned to their original locations after the flows returned to normal levels. This poster will discuss these efforts and present preliminary results.

The Southern Paiute Consortium and Glen Canyon Dam Adaptive Management Program: a Ten Year Relationship

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Abstract. In 1993, the Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah created the Southern Paiute Consortium (SPC) to ensure more effective government-to-government interactions between the tribes and the Bureau of Reclamation with regard to the operations and impacts of Glen Canyon Dam. In 1995, during the establishment of the Adaptive Management Program (AMP), the SPC established its Colorado River Monitoring and Environmental Education program. The program has operated for ten years, from 1996–2005. Its goal is to gather the data necessary for assessing whether or not Management Objectives established under the AMP are being met, especially those related to the preservation of resource integrity and cultural values of traditionally important resources within the Colorado River Ecosystem and the protection and maintenance of physical access to traditional cultural resources. This poster describes the history, development, and goals of the program and summarizes results from its first ten years.

Colorado River in Grand Canyon Depth Profile Obtained with Single-Beam Bathymetry at 8,000 cfs; Glen Canyon Dam to Phantom Ranch (-15.5 Mile To 87 Mile)

Elizabeth Fuller and Nick Voichick

U.S. Geological Survey, Biological Resources Discipline, Flagstaff, AZ

Abstract. A depth profile using single-beam bathymetry was collected in May 2005 between river miles -15.5 below Glen Canyon Dam to 87 mile at Phantom Ranch. This data provides a nearly continuous trace of the bed of the Colorado River along the thalweg. The bathymetric data was collected using an Innerspace 448 single-beam echosounder and the positioning was obtained with a Topcon HiPer OmniStar Global Positioning System (GPS). While the primary purpose of the single-beam survey was to collect a depth profile, a secondary result was a test of the OmniStar GPS system in the Grand Canyon environment. OmniStar GPS provided accurate positioning where a signal was available but the signal was lost intermittently for a total loss of coverage of 13%. In the areas where the GPS was not available the single-beam bathymetry positions have been interpolated using the Grand Canyon Monitoring and Research Center centerline and target files from the survey. This information will be available to the sediment modeling team for use in their models and will hopefully be repeated at a future date to be used in change detection.

A Comparison of Techniques for Mapping the Distribution of Sediment on the Bed of the Colorado River in Grand Canyon

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Abstract. The Grand Canyon Monitoring and Research Center is charged with establishing and implementing monitoring projects to provide scientific information to the Grand Canyon Adaptive Management Program on the effects of operating Glen Canyon Dam on the downstream resources of the Colorado River ecosystem. One primary resource of concern is fine-grained sediment. Sand bars are an important resource because they provide habitat for endangered native fish, protect archeological sites, provide substrate for vegetation, are used as campsites and are a distinctive feature of the pre-dam environment. The distribution of fine-grained sediment is needed to evaluate the potential for deposition onto high elevation sand bars during proposed experimental high flows. The purpose of this study was to evaluate possible technologies to be used in determining the distribution of sediment along the bed of the Colorado River in Grand Canyon. These technologies include: 1) visual interpretation of shaded relief images produced from multibeam bathymetry; 2) visual interpretation of acoustic backscatter images; 3) acoustic seabed classification using QTC Multiview. An evaluation of underwater video images was used to ground truth the various techniques.

The Development and Testing of a Sand Entrainment Formulation for the Colorado River in Grand Canyon

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Abstract. The primary objectives of the fine sediment modeling project has been the development of a reach-averaged one-dimensional flow and sediment transport model for the Colorado River from Glen Canyon Dam to the Grand Canyon gaging station near Phantom Ranch (see paper by Wiele et. al). Because of the scale and complexity of this model, it is not possible to individually verify each model component in the field. One of the components that cannot be tested in the field is the representation of the functional relationship between flow parameters and the rate of entrainment of sand from the riverbed. Traditional representations of the sand entrainment rate are strictly applicable only to sand-bedded streams where the sediment composing the bed consists exclusively of material that is available for transport. The bed of the Colorado River has a wide grain size distribution, and a significant fraction of the bed area is composed of large cobbles and boulders that are not transported by flows within the range of river management interest (from normal operating flows to upwards of 45,000 ft^3/s). Existing entrainment models have not been tested for these conditions.

We conducted a series of laboratory flume experiments designed to develop and test a formulation for sand entrainment from a partially covered coarse bed. These experiments were not designed as a scaled model of sediment transport in Grand Canyon, but as a critical test of sand entrainment under conditions analogous to those that exist in Grand Canyon. To simulate field conditions, we imposed a non-uniform transport field that resulted in longitudinally and temporally variable concentration profiles and sand-bed elevations. The experiments were scaled such that immobile bed particles were much larger than the sediment in transport and less than 10% of flow depth, the transported sediment was in the same size-range as occurs in field settings, and the bed shear stress scaled by the grain size of the transported sediment was also similar to those that occur in natural rivers. The experiments included five different combinations of flow rate, sediment feed rate, and bed-material grain size.

In the experiments conducted under conditions of equilibrium transport, we observed a narrow range of flow and sediment feed conditions for which it was possible for a stable sand bed to exist among the coarse immobile bed particles. This result indicates the presence of a threshold combination of flow and sediment concentration capable of maintaining a sand covered bed. Below this threshold, sand in particle interstices may be rapidly evacuated. Testing of the entrainment formulation under conditions of non-uniform transport required a morphodynamic model of the non-uniform transport field. Sand entrainment is predicted as a function of the velocity field, bed shear, grain size and the ratio of the average sand bed elevation to the bed roughness size. Predicted concentration profiles and sand deposition agree favorably with observed results.

Development of a Photo-Identifiable Fixed Point Database for Determining Accuracies of Airborne Remote Sensing Data in Grand Canyon, Arizona

Thomas Gushue and Keith Kohl

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Abstract. Since 1999, Grand Canyon Monitoring and Research Center has requested over 23 contracts, and spent nearly $3 million to collect and study remotely sensed data of the Colorado River ecosystem (CRE), including over 300 miles of the Colorado River through Marble and Grand Canyons, and many of its tributaries. It is well understood that most of the CRE represents an extremely difficult terrain for accurate spatial positioning, and therefore the Grand Canyon houses an extensive laboratory for assessing the spatial positioning abilities of new technologies. These emerging technologies have been successfully utilized in less complicated terrain, and have heightened the confidence of contractors and engineers to assure highly accurate data are achievable- even in complex topography such as Grand Canyon.

Testing and verifying the data is an extensive undertaking. Previous efforts of data accuracy assessment have utilized photo-panels centered on, or referenced to known control points. The setting of these panels is a logistically challenging and expensive task. The goal of the photo-identifiable fixed point database is to accurately position natural features that can be used for rectification and quality assurance/ quality control (QA/QC) of the remotely sensed data. These natural features often appear clearer in images than do the photo-panels are: 1) less likely to be disturbed by natural or human forces, 2) less intensive logistically than photo panel operations, 3) less intrusive to the fragile desert environment, and 4) stable enough to be used for decades, if not centuries into the future. The overarching objective of this database is to develop a sound process for establishing, maintaining, and verifying survey control and spatial data in support of long-term monitoring within the CRE.

Plankton Dynamics and Patterns in Lake Powell and the Tailwaters, 1993–2003

Susan J. Hueftle

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Abstract. The primary and secondary biological communities have been monitored in Lake Powell since 1992, complimenting a longer-term physical monitoring program that extends to creation of the reservoir. While complex interactions exist between the biological, chemical and hydrodynamic limnological systems, patterns have emerged that indicate the influences from climatic and even operational effects of the dam.

Drought and flood cycles alter reservoir-wide productivity. Clarity of the reservoir interacts with plankton dynamics and reflects the productivity of the system. Understanding the dynamics of plankton communities leads to better understanding of the higher trophic levels of the fisheries and can also influence the physical makeup of the reservoir. These dynamics may influence downstream releases.

Critical Climate Controls and Information Needs for Glen Canyon Dam Adaptive Management Program and Environmental Management in the Grand Canyon Region

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Abstract. Climatic drivers of episodic to interdecadal variations and the observed changes in the flood magnitude, timing and spatial scales affect the sediment inputs to the Colorado River. Since the 1963 closure of Glen Canyon Dam, the sole major supplier of sand to the Colorado River in the upper portion of Grand Canyon is the Paria River, which supplies about 6% of the pre-dam supply of sand at the upstream boundary of Grand Canyon National Park. Sand is delivered by the Paria River during short-duration (< 24 hours), large magnitude (up to 300 cubic meters/second) floods that occur primarily during the warm season (July-October). The planning and decision processes in the Glen Canyon Dam Adaptive Management Program (AMP) strive to balance numerous, often competing, objectives, such as, water supply, hydropower generation, low flow maintenance, maximizing conservation of the tributary supplied sediment, endangered species recovery, and cultural resources. In this work, we focus on a key concern identified by the AMP, related to the timing and volume of sediment input into Grand Canyon. Adequate sediment inputs into the Canyon combined with active management of the timed releases from Glen Canyon Dam support the restoration and maintenance of sandbars and instream ecology. Variability in regional precipitation distribution on multiple time scales is diagnosed with emphasis on understanding the relative role of East Pacific tropical storms, North Pacific sea surface temperatures, and subtropical moisture sources. On longer time scales, structured variations in the sediment supply imply a changing baseline for "mean" ecological and geomorphological conditions in the Canyon, counter to the static view taken in the current environmental impact assessments. Better understanding of the coupled climate-hydrologic variations on multiple time scales is increasingly recognized as critical input for adaptive management (both passive and active). In collaboration with the AMP, this work deliberately identifies the entry-points for predictive hydroclimatic information at appropriate lead times. From the standpoint of this active adaptive management program, lead climate information allows scientists and managers to anticipate geomorphic response from critical tributaries, that in turn trigger large-scale, experimental releases from Glen Canyon Dam.

Linkages among Terrestrial Riparian Resources and Dam Operations

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Abstract. After three years of integrated sampling of vegetation, arthropods, herpetofauna, breeding birds and small mammals in riparian habitats of the Colorado River corridor of Grand Canyon National Park, we found several patterns in the abundances of individual components and linkages among them. Vegetation density in spring and vegetation cover in fall are linked directly to both the hydrograph and precipitation patterns, In lower elevation habitats (below the 45 kcfs stage elevation), the hydrograph has stronger effects and above this point, precipitation is the driver of vegetation patterns. Second, the abundance of breeding birds is tied more loosely to vegetation in Grand Canyon than it is in other riparian habitats in Arizona. In Grand Canyon, vegetation appears to set an upper bound, or carrying capacity, for breeding bird density, rather than predicting it precisely. Third, the abundances of some arthropod taxa and feeding guilds are tied to the abundance of individual species of plants or functional groups of plants, but the overall abundance of arthropods is not related to any measures of vegetation. Finally, the abundances of small mammals and herpetofauna are only loosely tied to vegetation, if at all. Other components of habitat quality are better predictors of the abundances of these groups.

Methods for Open-System Metabolism Measurements in the Colorado River in Glen Canyon

Theodore A. Kennedy and Scott A. Wright.

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Abstract. Since the closure of Glen Canyon Dam and the beginning of flow regulation of the Colorado River in Grand Canyon in 1963, considerable efforts have been directed toward understanding the aquatic ecology of this altered ecosystem. Quantifying resource availability has been a central focus of these efforts because the Colorado River supports populations of sport fish and endangered humpback chub, both of which appear to be resource limited. Open-system metabolism measurements represent an ideal technique for quantifying resource availability and utilization because they yield an estimate of gross primary production (= instream primary production) and ecosystem respiration (= consumption of both autochthonous and allochthonous carbon), both of which are integrated in space and time. This technique is based on the premise that changes in the concentration of DO within a stream reach are a function of photosynthesis, ecosystem respiration, and gas exchange with the atmosphere. Research by Marzolf and others during the 1996 controlled flood demonstrated that this technique was feasible in the Colorado River. We attempted to further validate and refine the methods needed to use this technique on the Colorado River by quantifying air-water gas exchange rates. We found that wind speed was the dominant control of air-water gas exchange rates, as has been reported for other large systems including estuaries, lakes, and the open ocean. There is evidence that dam discharge regime and canyon orientation influence algal standing crop due to their effects on water velocity (scour) and solar insolation, respectively. We also tested the sensitivity of this technique by conducting whole system metabolism measurements across a range of discharge regimes and in reaches with different orientation (i.e. N-S vs. E-W).

Humpback Chub (Gila cypha) Monitoring in the Colorado River in Grand Canyon, 2002–05

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Native fish research in the Colorado River through Grand Canyon has seen several phases, from the early days of descriptive and reconnaissance work to life history and ecological studies of the humpback chub (*Gila cypha*). Currently, managers are striving to create a feasible and sustainable long-term monitoring program. The goal of this program is twofold: 1) To create a river-wide baseline of fish distribution and abundance data so that effects of management actions (such as mechanical removal of nonnative species, flow manipulations, or changes in river temperatures) may be detected, and: 2) to monitor existing populations of humpback chub and other native species. The year 2005 was the 4th year of a 5-year monitoring program. In the 3 previous years, a stratified-random sampling approach in combination with concentrated netting efforts at humpback chub aggregations was used; however, 2005 sampling concentrated netting efforts in the LCR Inflow, the largest aggregation of humpback chub in Grand Canyon. In this presentation, the Grand Canyon native fish monitoring program is examined as a case study. Humpback chub population trend detection and power analyses are compared between three sampling strategies: stratified-random sampling, sampling several aggregations each year, and concentrated sampling at the LCR Inflow Aggregation. Sample allocation concepts are addressed as well as how researchers might strike a balance between funding/logistical constraints and data collection needs or priorities.

Modeling Abundance and Growth of Lees Ferry Trout Using a Spreadsheet Stock Assessment Model

William Persons

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Abstract. A spreadsheet stock assment model was developed to model abundance and growth of Lees Ferry rainbow trout (*Oncorhynchus mykiss*) (Speas and Walters). The model was developed using historic time forcing data including: abundance from angler catch rates (1977– present), trout stockings (1965 – present), and Glen Canyon Dam discharge (1965 – present). The model is structured on an annual time scale, and runs within an Excel spreadsheet, and is a submodel of the Grand Canyon Ecosystem Model (Korman and Walters 1998). Managers can use the model and analysis to identify policy options that are defensible, and to screen out options that may be inadequate to meet management objectives. Use of the model will be demonstrated with several policy options. Further refinements of the model will be suggested, and use of the model to refine monitoring and management programs are suggested.

A GIS Vegetation Database for the Colorado River Ecosystem

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A GIS base map for vegetation is a critical information layer for monitoring and research within the Colorado River ecosystem. The utility of the vegetation base map extends beyond change detection for riparian vegetation to integration among resources including assessing riparian breeding bird habitat, estimating terrestrial productivity, and campsite area monitoring. The heterogeneous nature of riparian communities and the geographic extent of riparian habitat along the Colorado River present a challenge to accurately delineate riparian habitats quickly. Automated and photo-interpreted methods of digital color infrared imagery that was acquired in May 2002 were tested in the development of the base map. The latter was used extensively due to imagery limitations. We provide information regarding the approach taken, extent of area of dominate vegetation classes, levels of accuracies for vegetation classes, and problems encountered with automated and photo-interpreted approaches. We also provide recommendations regarding future approaches for mapping and uses of this base map for other resources.

High Releases from Glen Canyon Dam Cause Short-Term Eddy-Bar Aggradation if Timed to Coincide with Significant Input of Sediment from Tributaries

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Abstract. Monitoring of fine-grained alluvial deposits in Marble Canyon of the Colorado River shows that controlled high dam releases from Glen Canyon Dam temporarily aggrade but do not completely reverse the long-term trend of bar degradation that has been measured during the past 45 years.

Measurements made between 2000 and 2005 include short periods of high releases at the maximum capacity of the dam's powerplant in August 2000 and at the combined maximum capacity of the powerplant and by-pass tubes in November 2004. These high releases have temporarily aggraded eddy bars when the releases occurred at times immediately following large sediment delivery events from tributaries. Aggradation of eddy bars has also occurred during periods of fluctuating flows that generate hydroelectric power, if those flows occur during periods of major sediment inputs from tributaries. Smaller dam releases create eddy bars at relatively low elevations. Eddy-bars typically erode between floods, with initially high rates. Since August 2000, monitoring suggests that bar erosion has been greatest near Glen Canyon Dam and is less further downstream, suggesting that sand is longitudinally redistributed from upstream to downstream during periods when tributary inflow of sediment is low. The November 2004 high dam release also aggraded eddy-bars in Marble Canyon, but those bars were quickly eroded once daily peaks exceeded discharges of about 12,000 cubic feet per second for power generation.

Sedimentology of Deposits of the 2004 Flood in the Grand Canyon

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Abstract. Sedimentology of sand bars along the Colorado River was examined as part of the 2004 flood experiment in the Grand Canyon. Before the flood, chains were implanted vertically in selected sand bars (with the tops of the chains flush with the bar surfaces), and the chain locations and elevations were surveyed. After the flood, the chains were excavated. For all chains that were relocated and recovered, the following data were obtained: (1) maximum depth of scour during the flood (detectable by a collapse of the links of the chain), and (2) amount of deposition that followed maximum scour (equal to sand thickness overlying the top of chain); if the entire chain was standing vertically, no net scour had occurred, and the thickness of sand overlying the chain was equal to total deposition.

In addition to measurements of scour and fill, we examined vertical changes in grain-size through the flood deposit. At many sites, grain size coarsened upward, which previously has been recognized to occur as a result of winnowing of the sediment supply and coarsening of suspended sediment during a flood.

We also examined sedimentary structures in the bars to determine depositional processes that were active during the floods. At most sites, flood sediment and post-flood sediment was deposit while ripples were active on the bed. Three kinds of ripple deposits were preserved: ripples generated by waves, ripples generated by currents flowing mainly in one direction, and ripples generated by reversing currents within or adjacent to eddies. Sediment deposited by subaqueous dunes or on a flat bed (such as in beach swash) was also present but less common than rippled deposits.

Many deposits contained cyclic stratification produced by daily cycles in river discharge that occurred after the flood. One of the more unusual features discovered was a deposit that slumped down the bar slope. The slumped deposits included strata with daily cycles, demonstrating that the downslope failure occurred after the flood.

Work is underway to: (1) relate vertical trends in grain-size within flood deposits to temporal changes in grain size of suspended sediment during the flood, (2) the magnitude of upward coarsening to grain size, depth of initial scour, net change in elevation, and geomorphic setting, and (3) relate thickness and grain-size variations of post-flood daily cycles to suspended sediment concentration and grain size.

Removal and Quantification if Asian Tapeworm from Humpback Chub Using Praziquantel

David Ward

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Abstract. Asian tapeworm (*Bothriocephalus acheilognathi*) has been identified as one of six potential threats to the continued persistence of humpback chub (*Gila cypha*). It is potentially fatal to multiple age classes of fish, and can cause high mortality when infecting new host species. Field investigations to quantify tapeworm loads previously required fish to be killed and dissected so sample sizes were small and few adult fish were examined. The advantage of using Praziquantel to evaluate parasite loads is that it does not require killing fish, allowing monitoring of tapeworms in fish species that cannot be sacrificed. We used bonytail chub (*Gila elegans*) as a surrogate for humpback chub and performed laboratory experiments to evaluate the dosage and time needed to effectively remove 100% of Asian tapeworm using Praziquantel. Treatments less than 24 hours are not effective at removing all tapeworms even at high doses (36 mg/l). Commonly used dosages < 0.7 mg/l are ineffective at removing 100 % of tapeworms. No mortality or side effects of Praziquantel treatment were observed. Tapeworm loads in rare fish can be accurately quantified in the field without dissection, provided that adequate water quality can be maintained in a treatment container for a 24-hour period. We used this method to evaluate tapeworm loads in 30 humpback chub from the Little Colorado River in May of 2005. Tapeworm infestation was highly variable (0-183 per fish) and probably linked to river hydrology. Continued monitoring is needed to evaluate tapeworm infestation and impacts on humpback in the Little Colorado River.

Applications of the GCMRC Aerial Photography Scanning Project

Stephanie Wyse

U.S. Geological Survey, Biological Resources Discipline, Flagstaff, AZ

Abstract. The Grand Canyon Monitoring and Research Center (GCMRC) is embarking on a project to convert its collection of 17,650 aerial photos and film to digital format. This project will serve to preserve the original media as well as allow for more effective distribution and use of the data. All aerial film and photos will be scanned at ten microns using the Vexcel UltraScan 5000, a photogrammetric scanner. Once scanned these photos will be orthorectified using ERDAS software made by Leica. These files can then be georeferenced using surveyed control points, tying the locations to known points on the earth. Once this project is completed scientists can compare images collected over multiyear scales to measure resource changes over time.

Biographical Sketches for Keynote Speakers

KEYNOTE SPEAKER: Whit Gibbons

Whit Gibbons is Professor of Ecology at the University of Georgia and former Head of the Environmental Outreach and Education Program at the Savannah River Ecology Laboratory. He received degrees in biology from the University of Alabama (B.S.-1961; M.S.-1963) and Michigan State University (Ph.D. - 1967).

He is author or editor of ten books on herpetology and ecology, including *Their Blood Runs Cold: Adventures with Reptiles And Amphibians (*U.of Alabama Press), *Life History and Ecology of the Slider Turtle (*Smithsonian Institution Press), *North American Watersnakes: A Natural History* (University of Oklahoma Press). *Ecoviews: Snakes, Snails, and Environmental Tales* (Whit Gibbons and Anne Gibbons; University of Alabama Press, 1998) won a Choice Outstanding Academic Book Award.

Whit has published more than 200 articles in scientific journals, has had commentaries on National Public Radio (Living on Earth, Science Friday, and others), and has had more than 300 popular articles on ecology published in magazines and newspapers, including a weekly environmental column distributed by the New York Times Regional Newspaper Group. His encyclopedia articles have appeared in *World Book, Compton's,* and for the past 20 years have included the annual summary of Zoology for the *Encyclopaedia Britannica* Year Book. He wrote the latest edition of *Reptile and Amphibian Study*, the merit badge booklet for the Boy Scouts of America.

Recent awards include the Southeastern Outdoor Press Association's First Place Award for the Best Radio Program, the South Carolina Governor's Award for Environmental Education, the Meritorious Teaching Award presented by the Association of Southeastern Biologists (ASB), and the ASB Senior Research Award.

Whit is a frequent banquet speaker at meetings, both civic and scientific, and gives talks each year to college and pre-college school groups. Many of the talks use live animals, particularly reptiles and amphibians, in discussions of ecological research and environmental awareness.

KEYNOTE SPEAKER: Gary K. Meffe

Gary K. Meffe is an Adjunct Professor in the Department of Wildlife Ecology and Conservation at the University of Florida. He received his Ph.D. in Zoology at Arizona State University in 1983. He has published over 75 scientific papers on topics that include desert fishes and their conservation, fish community and evolutionary ecology, and conservation management approaches and problems. He is co-author of two college textbooks, *Principles of Conservation Biology*, and *Ecosystem Management. Adaptive, Community-based Conservation*, co-author of *Biodiversity on Military Lands: A Handbook*, and co-editor of *Ecology and Evolution of Livebearing Fishes*. Since 1997, he has served as editor of the international scientific journal *Conservation Biology*.

KEYNOTE SPEAKER: Carl Walters

Dr. Carl Walters is currently Professor of Zoology and Fisheries at the University of British Columbia, Vancouver, Canada. Walters received his B. S degree from Humboldt State College, and his M. S. and Ph. D. degrees from Colorado State University. He has worked at the University of British Columbia since 1969.

Dr. Walters is a specialist in fisheries stock assessment, adaptive management, and ecosystem modeling. He uses mathematical modeling and computer simulation techniques to better understand the dynamics of exploited marine ecosystems and to find more effective methods to manage them in the face of natural variability and high uncertainty. He advocates cooperative arrangements between governments and fishing industries to provide improved information for stock assessment and management via methods such as industry-based surveys. His main research work is on the theory of harvesting in natural resource management, with a primary interest in the basic problem of how to behave adaptively in the face of extreme uncertainty. He is one of the main developers of the ecosystem simulation program known as Ecosim, which is being used to test ideas about organization of trophic interactions in marine systems, and the implications of these interactions for sustainable harvesting theory.

He has written over 160 articles and three books, including *Adaptive Management of Renewable Resources (*MacMillan Publishing Company), and *Quantitative Fisheries Stock Assessment and Management (with Ray Hilborn,* Chapman-Hall Publishing Company), and *Fisheries Ecology and Management* (with Steve Martell, Princeton Univ. Press). He also serves on the Editorial Boards of a number of journals, including the *Canadian Journal of Fisheries and Aquatic Sciences, Conservation Ecology,* and *Ecosystems.*

Dr. Walters is a Fellow of the Royal Society of Canada (1998) and a Pew Fellow in Marine Conservation (2001). He was also the 2001-2001 Mote Eminent Scholar at Florida State University and the Mote Marine Laboratory.

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