

Long-Term Monitoring and Research in Lake Powell

By G. R. Marzolf and Charles W. Wood

Lake Powell, the reservoir behind Glen Canyon dam, is at the heart of the Glen Canyon National Recreation Area (NRA) and is one of the nation's largest reservoirs. Recreation and tourism on Lake Powell, in Glen Canyon NRA, and in Grand Canyon NP are increasing rapidly.

Given historic conflicts over water shortage in the southwest, Lake Powell is one of the most visible reservoirs in terms of water economics and policy. The Glen Canyon dam is crucial for controlling water supply to the Lower Basin of the Colorado River and for generating hydropower. Superimposed on all of this are multiple and overlapping state and federal responsibilities for management and monitoring for compliance with water quality standards and regulations.

Lake Powell is a complex limnological system whose hydrologic regime causes considerable year to year variation in water quality and quantity. The chemically variable flows of the Colorado River into this deep, voluminous reservoir cause a complex interaction between thermal and salinity induced density structure. The high spring flows cause high spatial variability in chemical constituents and biological productivity.

Quality of water the Colorado River downstream from Glen Canyon dam is dominated by these processes in Lake Powell. The discharge



Figure 1. Lake Powell is located in the canyon country of Utah-Arizona. Access to pristine wild lands is part of its recreational attraction.

volumes and flow velocities of the river discharging from Lake Powell are usually so overwhelming that any subsequent physical, chemical, and biological processes do not change either temperature or the concentrations of most constituents in the entire reach from Glen Can-

yon dam to Lake Mead. There may be tributary influences during infrequent and unpredictable flooding, but most of the time Lake Powell discharge dominates the water quality of the river.

Continued on page 8

VOLCANO STUDIES...CONT'D FROM P. 6

emptying of a subsurface magma chamber during a large explosive eruption. USGS investigations at CLNP are focused on the processes by which magma accumulated beneath the volcano and then catastrophically erupted 7700 years ago. Geologic mapping of the volcano and radiometric dating of pre-caldera lavas have improved our understanding of the volcanic history prior to the catastrophic eruption. Results will aid in evaluation of the hazards posed by the volcano and will lead to a better understanding of explosive volcanism elsewhere in the world.

Related studies at CLNP include deformation monitoring. Distances between bench marks on opposite sides of the caldera, and elevations along three road segments, are measured periodically in order to detect changes in horizontal distances and ground tilt that might be related to impending volcanic activity. Other studies, funded partly by the Geothermal Research Program of the USGS, are aimed at understanding the hydrothermal system of hot subsurface fluids that developed after the caldera formed. All post-caldera lavas were vented on the caldera floor, many of them beneath Crater Lake. Post-caldera lavas have been sampled and hydrothermal features on the lake floor have been observed by use of a manned submersible in cooperation with NPS and NPS-sponsored investigators.

C) Mount Rainier NP (MRNP)

Mount Rainier is arguably the most hazardous volcano in the conterminous U.S.: its steep slopes are weakened by fumarolic alteration, it is extensively covered by glaciers, and it is close to a major population area. The most recent eruptions occurred in the late 1800's and an eruption is likely within a few centuries (Crandell, 1973). The volcano poses a major hazard to Puget Sound and Columbia River drainages because of the potential for large mudflows of meltwater generated during an eruption. Even without eruptive activity, landslides and avalanches have occurred several times in the past few thousand years (Crandell and Mullineaux, 1967). Mount Rainier is the second most seismically active volcano in the Cascade Range (Norris, 1991) and is seismically monitored by the University of Washington and the USGS.

The volcano is sited within MRNP and is a potential threat to park visitors and facilities. Additionally, parts of Puget Sound communities outside MRNP are built on mudflows as young as 500 years (Scott and others, 1990). The NPS, USGS, and other state and federal agencies hope to better determine the nature of the hazards posed by Mount Rainier. NPS personnel and state, federal, and university geologists met recently to discuss ways to enhance monitoring, to improve our understanding of how the volcano works, and to translate these

studies into a comprehensive disaster-response plan (Swanson and others, 1992).

Reihle is with the USGS, in Reston VA; Herrman is with the NPS, Fort Collins CO; Bacon is with USGS, Menlo Park CA; Samora is with the NPS Mount Rainier NP WA; and Heliker with USGS, Hawaiian Volcano Observatory HI

References Cited

- Crandell, D.R., 1973, Map showing potential hazards from future eruptions of Mount Rainier, Washington: USGS Miscellaneous Geologic Investigations Map I-836, scale 1:250,000.
- Crandell, D.R., and Mullineaux, D.R., 1967, Volcanic hazards at Mount Rainier, Washington: USGS Bulletin 1238, 26 p.
- Heliker, Christina, and Wright, T.L., 1991, The Pu'u 'O'o-Kupaianaha eruption of Kilauea: EOS, Trans. American Geophys. Union, v. 72, p. 521, 526, and 530.
- Norris, R.D., 1991, The Cascades volcanoes: monitoring history and current land management: USGS Open-File Report 91-31, 89 p.
- Scott, K.M., Pringle, P.T., and Vallance, J.W., 1990, Sedimentology, behavior, and hazards of debris flows at Mount Rainier, Washington: USGS Open-File Report 90-385, 112 p.
- Swanson, D.A., Malone, S.D., and Samora, B.A., 1992, Mount Rainier: a decade volcano: EOS, Trans. American Geophys. Union, v. 73, p. 177, 185, 186.
- Wright, T.L., Chun, J.Y.F., Esposo, J., Heliker, C., Hodge, J., Lockwood, J.P., and Vogt, S.M., 1992, Map showing lava-flow hazard zones, Island of Hawaii: USGS Miscellaneous Field Studies Map MF-2193, scale 1:250,000.
- Wright, T.L., and Pierson, T.C., 1992, Living with Volcanoes: USGS Circular 1073, 57 p.

General Background

In the United States, about 2,500 reservoirs with capacities of 5,000 acre feet or more, provide about 480 million acre feet (MAF) of storage, thus, about 25 percent of the annual runoff can be stored. Storage capacity is dominated by large reservoirs. Almost 90 percent of the total storage occurs in 574 of the largest reservoirs. At full pool volume of 27 MAF, Lake Powell is one of the largest of these, capable of storing up to three years discharge of the river.

The Colorado River drains about 8 percent of the United States. The basin is an arid region where economic development and populations have been limited historically by the availability of water. The river flows through areas managed by the NPS, including free-flowing river reaches and reservoirs. These represent public commitment to resource preservation and recreation. The construction of the reservoirs represents similar commitment to water conservation and development for economic growth. These dual commitments have generated tension and conflict for more than a century. When management goals are incompatible, decisions are more difficult and better information is required. Thus, long-term monitoring and research on Lake Powell respond to real policy and management needs and respond to recent calls for "science for the parks" and "science in the parks" (NAS 1992).

Characteristics of reservoirs

Reservoirs differ from natural lakes in several respects. The drainage basin of a natural lake is typically about 10 times the area of the lake itself, but the drainage basin of most reservoirs is relatively larger (500 times the area of the reservoir is not uncommon). Impoundment changes many natural patterns in rivers. While the resulting reservoirs exhibit many of the same phenomena as occur in natural lakes, they tend to be more affected by water depletions and direct human uses, such as power generation.

The goal of coordinated work among scientists in the Park Service and the USGS is to better understand natural river/reservoir phenomena in order to help (1) document changing water quality conditions, (2) evaluate the implications of all possible management decisions, (3) evaluate the implications of no management actions, and (4) support and evaluate the performance of management actions.

Examples of natural and man induced aging phenomena in reservoirs.

Extinction of endemic species and the invasion of exotic species:

The recent decline of native fishes in the Colorado River is well documented. Four species of this unique fish fauna, now federally listed as endangered, are known to occur in Lake Powell and in associated inflow habitats during at least some part of their life cycle. Effort to prevent their eventual extinction must include investigation of water quality and other water-related habitat requirements. The fate of other



Scenic beaches have attracted heavy public use, predicted to increase to six million by year 2000.

aquatic organisms in the face of environmental change is less well known.

Habitat alteration, such as impoundment, also creates new environments, often suitable for invading species. Furthermore, inadvertent transfer of species from native environments to new ones has increased. These may seem to be innocuous events but in some instances exotic species have caused major water resource problems.

Invasions become problems when invading species that have one or more damaging life history features are released from natural control mechanisms and respond with explosive population growth. A recent example in Lake Powell is the Asian clam, *Corbicula*, that spread through the United States in the 1960s. The introduction of predaceous fishes for sport also may have unintended negative effects.

Sediment accumulation:

Sediment deposits represent "interim sinks" for nutrients and contaminants that, prior to impoundment, were transported to the sea. Materials such as organic pesticides, toxic by-products of industry, trace metals and salts from irrigation return flow, agricultural and domestic fertilizers, etc., are of increasing concern to many water users. Between 1963 and 1986, 1.1 billion tons of sediment was deposited in Lake Powell's deltas. Lake Powell's location in the arid west and the fact that it receives return flow from irrigated agriculture suggest that sediments in Lake Powell may represent an extreme case where the study of nutrients and contaminants might be particularly useful.

Eutrophication:

Eutrophication occurs naturally as lakes accumulate nutrients that stimulate biotic productivity but human influence hastens the process and has been implicated in a wide range of problems that degrade water supplies and recreational resources.

The transport of nutrients by rivers has not caused wide-spread eutrophication problems in

reservoirs, however, because planktonic biota are not characteristic of flowing water. Upon impoundment, however, plankton density increases rapidly and responds immediately to nutrient and contaminant inflows. Reservoir eutrophication is more an immediate response to the impoundment of flowing water than an accelerated process in a pre-existing lake. This issue has an additional twist in the case of Lake Powell because of increased recreational use as described below.

Current and emerging issues

Lake Powell is increasingly popular for recreational boating and angling. Public use of Lake Powell for recreation has increased annually reaching 3.2 million visitors in 1992, 1.5 million of these as visitor nights camping on the shores, with a projected increase to 5 to 6 million annually by the end of 1999.

A consequence to Lake Powell of this popularity is the problem of waste management in a pristine area. The list of potential contaminants includes human excreta from chemical toilets or from lakeside camping, waste water that is used for domestic washing in galley, shower, and sinks, as well as fuel spills and trash (paper products, cans, and lost equipment). There are few public access points that have the capability to treat sewage. The present facilities for handling sewage and trash are heavily taxed and inadequate to deal with the projected use.

Historically, increasing salinity associated with irrigation return flows after the construction of diversion works has been the primary water quality concern. Most available information was collected for salinity evaluation and modeling and other aspects of water quality work received less attention.

Water quality monitoring at shoreline sites on Lake Powell recently confirmed contamination by fecal bacteria in excess of established standards for body contact recreation. Addi-

Continued on page 9

tionally, waste-water discharges could potentially affect eutrophication, particularly in embayments and canyons with limited circulation. With growing use, these problems are expected to increase.

As Lake Powell was filling in the 1970s, research supported by the National Science Foundation laid the ground work for extensive work in Lake Powell, but the value of consistent and coherent long-term monitoring and research was not yet persuasive. Since Lake Powell filled in 1980 the river has had unusually high flow in 1984, 1985, and 1986 and unusually low flow since 1987. Currently, because of drought, Lake Powell is about half of its full volume. It is unfortunate that such a program was not in place to document trends and learn through this unusual decade.

Present conceptual understanding of Lake Powell relies heavily on these data, but full interpretation is difficult because attention since the '70s was focussed singularly on salinity problems to the exclusion of biological and chemical processes. Recently new concerns about the quality of inflow waters are related to irrigation, waste disposal and petroleum or mineral development in the upper basin. Because attention to preserving the integrity of this water resource is urgently required, the Park Service and the USGS have joined with the other agencies to address that issue.

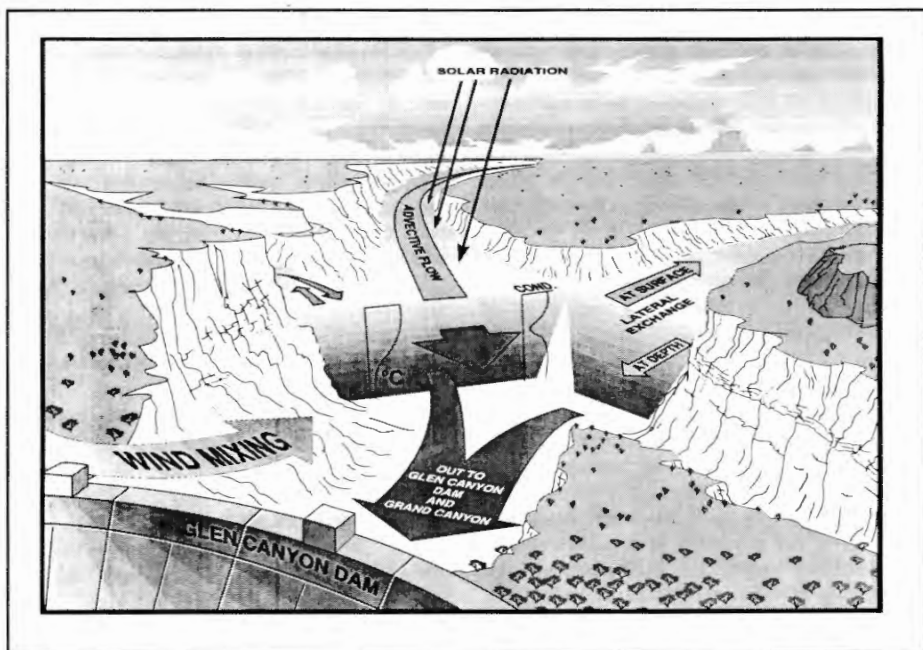
The NPS has the primary management mandate for Lake Powell and surrounding lands. Even so, other agencies have regulatory and management responsibilities and research interests. State Departments of Environmental Quality and of Game and Fish or Wildlife in Arizona and Utah, the NPS, the USGS, the Bureau of Reclamation, and the USFWS all have legal mandates for elements of operation, management, study, and understanding of Lake Powell.

The opportunity to coordinate programs, maximize the efficient use of funds already being spent to address Lake Powell's problems, and to develop new cooperative proposals for monitoring and research is extraordinary. Several interagency meetings were held at Glen Canyon NRA in 1992. They resulted in a plan for interagency monitoring and research that includes expanded water quality monitoring under existing programs by NPS and Reclamation, and a new effort to investigate contaminants in gamefishes by the USFWS. The USGS was given the charge to develop an integrated plan that serves monitoring requirements and also addresses the information gaps identified by participants in these work sessions.

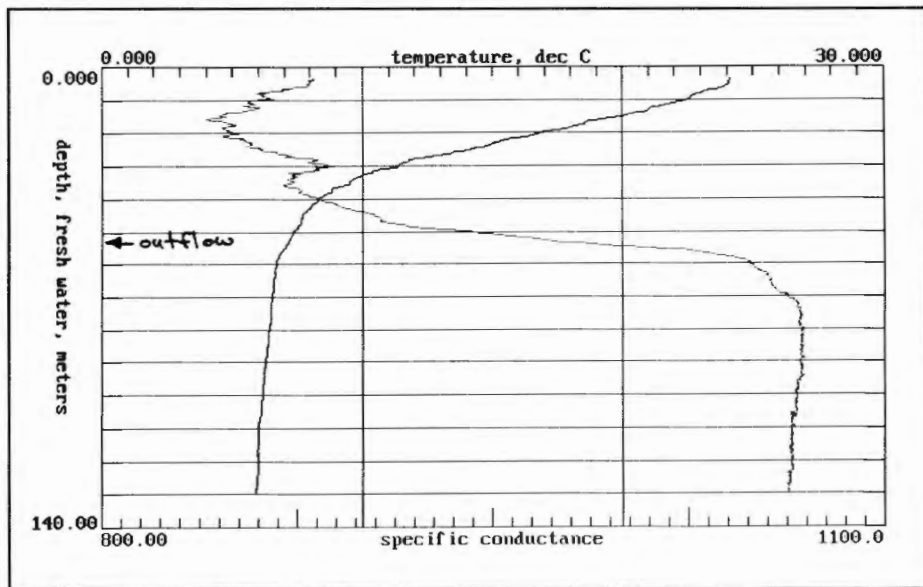
Marzolf is with the USGS Water Resources Division; Wood is with the NPS Glen Canyon NRA.

Further reading:

Adams, V.D. and V.A. Lamarra. 1983. Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Science. 697 pp.



Events and patterns in the lake are dominated by the hydrologic regime of the Colorado River; imposing a strong longitudinal effect on chemistry and biology. Superimposed on this effect is the vertical pattern resulting from insolation and density stratification associated with salinity; an important vertical structure in this deep reservoir. Third is the lateral component represented by processes in the tributary canyon embayments, hypothesized to be the most active biological areas in the lake.



A vertical profile of temperature and conductivity (an index of salinity) in Lake Powell near Glen Canyon Dam. The depth of the outflow to the Colorado River varies with lake level. These profiles were measured on July 24, 1992 when the outflow was at a depth of 52 meters.

Marzolf, G.R. 1991. The role of science in natural resource management: the case for the Colorado River. In: Colorado River Ecology and Dam Management. National Academy Press.

National Academy of Sciences. 1992. Science and the National Parks. National Academy Press. 122 pp.

Potter, L.D. and C.L. Drake. 1989. Lake Powell: virgin flow to dynamo. University of New Mexico Press. 311 pp.

Stanford, J.A. and J.V. Ward. 1991. Limnology of Lake Powell and the chemistry of the Colorado River. In: Colorado River Ecology and Dam Management. National Academy Press.