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The Glen Canyon Dam temperature control device: restoring downstream habitat for endangered fish recovery

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Abstract

Prior to closure of Glen Canyon Dam in 1963, the temperature of water flowing down the Grand Canyon each year varied from near freezing to 30°C during the heat of summer. Since construction of the dam, cold water (7 to 10°C) has been released from the deeper levels of the reservoir. For several miles below the dam, these cold water releases have created an excellent tailwater trout fishery. But as the water flows downstream through the Grand Canyon, it only warms to about 15°C which is not warm enough to allow endangered native fish species, like the humpback chub (*Gila cypha*), to reproduce and thrive in the Colorado River. Researchers believe that increasing the water temperature from Glen Canyon Dam is an important component in restoring habitat for the humpback chub and other native fish in the Grand Canyon. However, biologists fear that increasing river temperatures may encourage nonnative warm water fishes to move up the Grand Canyon or stimulate parasites or other disease agents that are currently controlled by colder water. A TCD (temperature control device) retrofit to Glen Canyon Dam would allow operators to adjust release water temperatures to improve habitat and to minimize potential negative impacts of cold water releases. The decision to construct a TCD will involve considering the potential that warm water releases will create unacceptable levels of competition or predation by nonnative fishes, the introduction of diseases or parasites that could negatively impact the humpback chub or other species of concern. Currently, the risk versus reward of adding selective withdrawal capability to Glen Canyon Dam is being evaluated by the Glen Canyon Dam Adaptive Management Program, regulatory agencies and stakeholders.

Introduction

This paper contains a summary of design activities and environmental studies related to adding selective withdrawal capability to Reclamation's Glen Canyon Dam. Prior to the construction of Glen Canyon Dam, the Colorado River would warm seasonally from near freezing to about 30°C. Since construction of the dam, cold water (about 7 to 10°C) is withdrawn year-round from Lake Powell's hypolimnion through fixed, low-level penstock intakes. Cold water releases have created an excellent tailwater trout fishery, but are below optimal conditions for native species. While water released in the summer months warms as it flows downstream into the lower Grand Canyon, the resulting 15°C water temperature is below the optimum level for successful reproduction of the endangered humpback chub (*Gila cypha*) in the main stem of the Colorado River. Under these cold water conditions, the humpback chub only spawns successfully in the Little Colorado River, a warm water tributary to the Colorado River that enters about 75 miles below Glen Canyon Dam. In their 1994 biological opinion on the operation of Glen Canyon Dam, the U.S. Fish and Wildlife Service identified selective withdrawal as a means to control Glen Canyon release temperatures as a key component in the recovery of the humpback chub. The primary purpose of adding selective withdrawal to the power intakes is to create suitable habitat for a second spawning population in the main stem of the Colorado River below Glen Canyon Dam. To aid in the recovery of the humpback chub, the feasibility of controlling the temperature of releases from Glen Canyon Dam has been studied (starting in 1997) by engineers and scientists in Reclamation's Upper Colorado Regional Office and Technical Service Center. More recently, Reclamation has completed a design for retrofitting TCD structures around two penstock intake structures at Glen Canyon Dam. The decision to construct the TCDs is pending.

Environmental Legislation and Adaptive Management Program

In 1978 and 1995, the U.S. Fish and Wildlife Service issued Biological Opinions that stated that past, present, and future operations of Glen Canyon Dam jeopardized the continued existence of the humpback chub (U.S. Fish and Wildlife Service 1978, 1994). In the interim, the U.S. Congress passed the Grand Canyon Protection Act of 1992 (Public Law 102-575) which directed the Secretary of the Interior to manage Glen Canyon Dam in such a way 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." This act provided direction for the Glen Canyon Dam Environmental Impact Statement (GCD EIS), in that all dam operations would need to be analyzed with those stated goals in mind. After many years of study, the GCD EIS was finalized in 1995 (Reclamation 1995). The following year, a Record of Decision (ROD) for the GCD EIS was signed (Reclamation 1996). The ROD specified operating parameters for Glen Canyon Dam and mandated the use of adaptive management for resources in Grand Canyon. The act stipulated that a monitoring program be maintained to document the effects of Glen Canyon Dam operations and ordered that future modifications of those operations and management actions be considered to protect and enhance the Colorado River ecosystems.

Two technical groups were formed under the direction of the Secretary of the Interior, in compliance with the Grand Canyon Protection Act of 1992 and the 1996 Record of Decision to oversee the protection of threatened and endangered species that may be affected by Glen Canyon Dam operations (table 1). The Grand Canyon Monitoring and Research Center (GCMRC) was founded in October 1996. The GCMRC, located in Flagstaff, Arizona, is responsible for monitoring the effects of Glen Canyon Dam operations on the resources along the Colorado River from Glen Canyon Dam to Lake Mead and reporting results to a federal advisory committee, the Adaptive Management Work Group (AMWG). Both are part of the Glen Canyon Dam Adaptive Management Program (GCDAMP), which was founded in 1997. The implementation of the GCDAMP provided for flexibility in the dam's operations in order to facilitate scientific research and monitoring while continuing the project purposes for which the dam was authorized. The AMWG has the purpose of applying the adaptive management process to make recommendations to the Secretary of the Interior regarding measures to protect and enhance Colorado River ecosystems. The AMWG consists of stakeholders representing various interest groups that collaborate to identify and recommend appropriate management strategies to improve downstream resource conditions. Detailed information on these two groups can be found at the program's website: www.gcdamp.gov.

Table 1. Threatened and Endangered Species of Glen, Marble, and Grand Canyons

- Southwestern willow flycatcher (endangered)
- Mexican spotted owl (threatened)
- California condor (endangered)
- Humpback chub (endangered)
- Razorback sucker (endangered)
- Kanab ambersnail (endangered)
- Colorado pikeminnow (extirpated)
- Bonytail chub (extirpated)
- Sentry milk-vetch (endangered)
- Siler pincushion cactus (threatened)

Figure 1. A construction photograph of the penstock intake structures on the face of Glen Canyon Dam. A schematic of the proposed TCD structures has been added to illustrate their proposed size and location.

Glen Canyon Dam – General Description

Glen Canyon Dam is located on the Colorado River in north central Arizona. The dam is a concrete arch dam with a structural height of 216 m (710 ft). The top of active conservation level is at El. 3700 ft. Eight 4.6 m (15 ft) diameter steel penstocks deliver water to the turbines in the power plant. The centerline of each penstock intake is at El. 3470 ft. A reinforced concrete penstock intake structure, with structural steel trashracks, protects each intake, figure 1. The intake structure is semi-cylindrical in shape, with the top of the structure at El. 3652 ft. Trashracks cover openings in the intake structure extending between the structure floor at El. 3450 and 3530 ft. From El. 3530 to the top of the structure, the 20-cm-thick (8-inch) concrete wall of the intake structure blocks water flow into the structure. The intake structures have guides embedded in the face of the dam to allow bulkheads to be installed for inspecting and maintaining the wheel-mounted gate frames and guides.

Selective Withdrawal at Glen Canyon Dam

The feasibility determination of adding selective withdrawal at Glen Canyon Dam was included in the biological opinion and ROD as an element potentially necessary to establish a second population of humpback chub in the Grand

Canyon. Certain operational and physical mechanisms are available to support warmer river temperatures. These included changing discharge patterns and/or adding selective withdrawal capability to Glen Canyon Dam. Studies of these two mechanisms suggested that selective withdrawal would likely provide a greater potential to increase downstream river temperatures in the Colorado River with the least impact to hydropower generation. In accordance with the GCD EIS, evaluating and determining the feasibility, design, and effectiveness of selective withdrawal is the role of the Bureau of Reclamation. To fulfill this responsibility, Reclamation has developed a selective withdrawal system with the flexibility to allow resource managers to test the effects of warmer water on humpback chub recovery in the Grand Canyon.

Design and Environmental Compliance Activities

A chronological summary of Glen Canyon TCD design and environmental compliance activities over the last decade is as follows:

Value Planning Study, 1997 - This planning study was performed to review previous studies and to develop a short list of alternatives to meet selective withdrawal objectives (Reclamation 1997a).

Feasibility Study, 1997 - This feasibility study (Reclamation 1997b) was performed to assess the feasibility of the concepts put forward by the 1997 value planning study. The study team recommended an uncontrolled surface withdrawal (fixed inlet) design as the preferred alternative because it was best suited to study the impacts of selective withdrawal at a reasonable cost.

Plan and Draft Environmental Assessment, 1999 - Reclamation's Upper Colorado Regional Office released a Plan and Draft Environmental Assessment on the proposal to provide temperature control at Glen Canyon Dam (Reclamation 1999). In October 1999, as requested by the Bureau of Reclamation, the GCMRC developed a draft science plan to support the draft environmental assessment (GCMRC 1999).

Physical Model Study, 1999 - A physical model was used to study the hydraulic characteristics of the proposed multi-level intake structure for Glen Canyon Dam (Vermeyen 1999). The model was an uncontrolled overflow weir (fixed inlet) which permits warm surface water withdrawal, when needed. The design includes the installation of an upper trashrack structure on top of the existing trashrack structure, and a gate internal to the trashrack structure to block the low-level intake during selective withdrawal operations. The gate would be raised to block the upper intake when low-level withdrawals resumed. A 1:20 scale hydraulic model of a single penstock intake and trashrack structure was tested to determine the additional head losses associated with the intake modifications. Other features studied include vortex formation potential, internal and external velocity fields, submergence criteria, and water hammer pressures.

Reservoir Modeling of Selective Withdrawal Options, 2000-2004 - U.S. Bureau of Reclamation's Upper Colorado Regional Office used a laterally-averaged hydrodynamic model, CE-Qual-W2 (Cole and Wells, 2003), of Lake Powell to predict likely release temperature patterns resulting from four proposed design alternatives to modify the penstock intake structures. The model predicted different release temperature patterns for each scenario depending on hydrologic conditions, reservoir elevation, submergence criteria, time of year, physical design of the proposed alteration and hydropower demands. All four proposed design changes provided some warming over the existing conditions. Two of the proposed design alternatives provided adequate selective withdrawal performance over the full range of environmental conditions.

Survey of Selective Withdrawal Systems, 2003 - The AMWG requested information on the effectiveness of selective withdrawal systems for providing temperature control on large dams. A survey of dams with selective withdrawal systems was conducted to gather information on performance, operation and maintenance costs, and other pertinent data. A summary of the survey results was published by Reclamation (Vermeyen et al., 2003).

Feasibility Studies, 2004-2006 - Prolonged drought conditions in the western United States has caused Lake Powell's pool elevation to drop over 33 m (110 ft) in four years (2000-2004). As a result, the fixed inlet design was no longer viable, so a second round of feasibility studies was initiated to produce a design that would provide selective withdrawal capacity for a wider range of reservoir pool elevations. Two concepts were identified: a controlled overdraw option using an internal telescoping gate and an external frame selective withdrawal structure. The external frame option was selected for final design because it provided the most operational range (180 vertical ft).

Economics of TCD Operation on Hydropower Revenues, 2005 - The economic value of the lost power production attributed to selective withdrawal operation was modeled by Reclamation's Technical Service Center. Estimates were based on the 0.8 m (2.7 ft) of additional headloss associated with adding a TCD to single penstock intake structure. In summary, relative to the without temperature control case, the economic value of the electrical energy produced would be reduced by an average of about $35,500 per month/unit if units with TCDs are used year round.

Value Engineering Study, 2006 - A value engineering team was convened for a 5-day review of the external frame TCD Design. The value team developed 5 proposals intended to simplify the design and/or reduce the project costs. Three of the 5 proposals were accepted and incorporated into the final design.

Constructability Review, 2006 - The purpose of this study was to provide independent comments, recommendations, and a constructability analysis of the design for construction of TCDs at Glen Canyon Dam (Reclamation 2006a). The goal for this review was to reduce the construction cost by simplifying construction without reducing structural and operational integrity. A team of construction professionals with experience building a similar structure at Shasta Dam, California were key members of this review team.

Design, Estimating and Construction Review, 2006 - Reclamation's design process includes a Design, Estimating and Construction (DEC) review of the feasibility design and construction cost estimates. A DEC review of the TCD at Glen Canyon Dam was conducted to promote successful project accomplishment, ensure high quality work, and maintain credibility with water and power users and other customers.

Final Design, 2006-2007 - In 2006, the Upper Colorado (UC) Region evaluated construction of two external frame TCDs capable of selective withdrawal from full reservoir to 9 m (30 ft) above the level at which power generation is no longer possible, El. 3700 to 3520 ft. Assuming a 36 month construction duration and a reservoir level during construction of 3700 ft, the feasibility-level field cost estimate for constructing two of these TCDs was $71.0 million (April 2006 price level). If available construction funding permitted a 22 month construction duration, it was estimated that the field cost estimate would decrease by about $4.0 million. In 2007, Reclamation's Technical Service Center completed a final design for an external frame TCD for 2 of 8 penstock intakes at Glen Canyon Dam.

Final TCD Design Concept - General Description

The TCD structure consists of a selective withdrawal structure (SWS) supported vertically by rigid frames attached near the top of the dam, and supported laterally by guide girders connected to the dam along each side of the existing intake structure. TCDs would be installed over two of the eight penstock intakes, Units 4 and 6. Both TCDs are nearly identical and allow for future installation of additional TCDs, if needed. Installation of TCDs over Units 4 and 6 would be scheduled to coincide with ongoing turbine runner replacements in the powerplant in order to take advantage of the extended unit outage.

The TCD is designed to completely enclose one existing penstock intake structure. It extends from below the intake structure to above the maximum water surface of 3710.6 ft. Each frame would be approximately 14.6 m (45 ft) wide (cross canyon direction), 15.2 m (50 ft) deep (stream direction) and 85.3 m (280 ft) high. Three gates; control gate, intermediate gate, and lower gate, are located on the upstream face of the structure to control the level of withdrawal into the TCD. Each gate has a dedicated slot to provide unlimited movement of the gate throughout its operating range. The control gate would be used for skimming the warm reservoir surface water when the reservoir is above El. 3520 ft (assuming 10 m [30 ft] of gate submergence), and would be equipped with steel trashracks to prevent debris from entering the TCD.

Cladding panels would be provided on the bottom and along the sides of the SWS to restrict flow into the structure, and a reinforced rubber skirt board would seal the sides of the structure to the curved face of the dam. Pressure relief panels are provided on the sides of the structure to limit differential pressure across the TCD that might occur during TCD mis-operation.

A hoist/operating deck would be constructed on top of the rigid frames supporting the SWS. This deck would support hoists and controls to facilitate operation of each gate and pressure relief panel. Electrical features would limit operation to a maximum of one gate hoist per TCD operating at one time.

Because water temperatures would be significantly higher during TCD operations, lower temperature cooling water would be supplied to the unit transformers and turbine/generator bearings on a TCD unit by routing cooling water from a unit not equipped with a TCD through the existing powerplant fire protection header. To supply low temperature cooling water to the air coolers on a TCD unit, an additional cooling water pumping unit would be installed in parallel with an existing cooling water pump at two separate generating units without a TCD. Each new cooling water pump would feed low temperature cooling water to the generator air coolers of a TCD unit through the existing standby cooling water header.

Conclusions

A final design for the Glen Canyon TCDs has been completed by Reclamation and the agency has identified that it is technically feasible to construct (Reclamation 2007). However, the project has yet to receive approval from the U.S. Fish and Wildlife Service which will be required before the project can move toward construction. There are many ecological issues which must be understood before a major project such as this can be constructed and operated. Fortunately, an Adaptive Management Program, GCRMC, and AMWG are in-place to assess the risk and reward of this project and to make the appropriate recommendations to protect and recover threatened and endangered species in the Grand Canyon.

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