An Overview of the Design Concept and Hydraulic Modeling of the Glen Canyon Dam Multi-Level Intake Structure

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Introduction

The U.S. Bureau of Reclamation is currently investigating alternatives to improve habitat for endangered fish below Glen Canyon Dam. In their biological opinion on the operation of Glen Canyon Dam, the U.S. Fish and Wildlife Service recommended that Reclamation investigate ways to control the temperature of water released from the Dam. The primary goal is to establish a new population of humpback chub within the Grand Canyon. The humpback chub is currently a listed species under the Federal Endangered Species Act of 1973 and is one of the native fish species that cannot successfully reproduce because of the cold water temperatures in the Colorado River below Glen Canyon Dam. Cold temperatures are not conducive to the humpback chubs' spawning or survival in the mainstem of the Colorado River. Scientists believe that increased Colorado River water temperatures would improve habitat for the native fish. However, because of complex ecological interactions between native and nonnative fish and the aquatic environment, Reclamation is proposing to scientifically test this hypothesis. The plan being investigated calls for the power intakes to be modified to allow warm surface water to be withdrawn from Lake Powell. Warm water withdrawals would likely occur during the months of June, July and August. While not quite as flexible as a traditional multi-level selective withdrawal system, like the one recently completed at Shasta Dam (Vermeyen 1998), the proposed modifications would cost much less ($15 million vs. $80 million at Shasta Dam) and allow temperature control studies to be conducted.

Multi-Level Intake Structure (MLIS) Design Description

In 1997, Reclamation’s Technical Service Center (TSC) conducted a feasibility study (Reclamation 1997) to develop design concepts to provide warmer releases through the penstocks at Glen Canyon Dam. Three design concepts providing selective withdrawal

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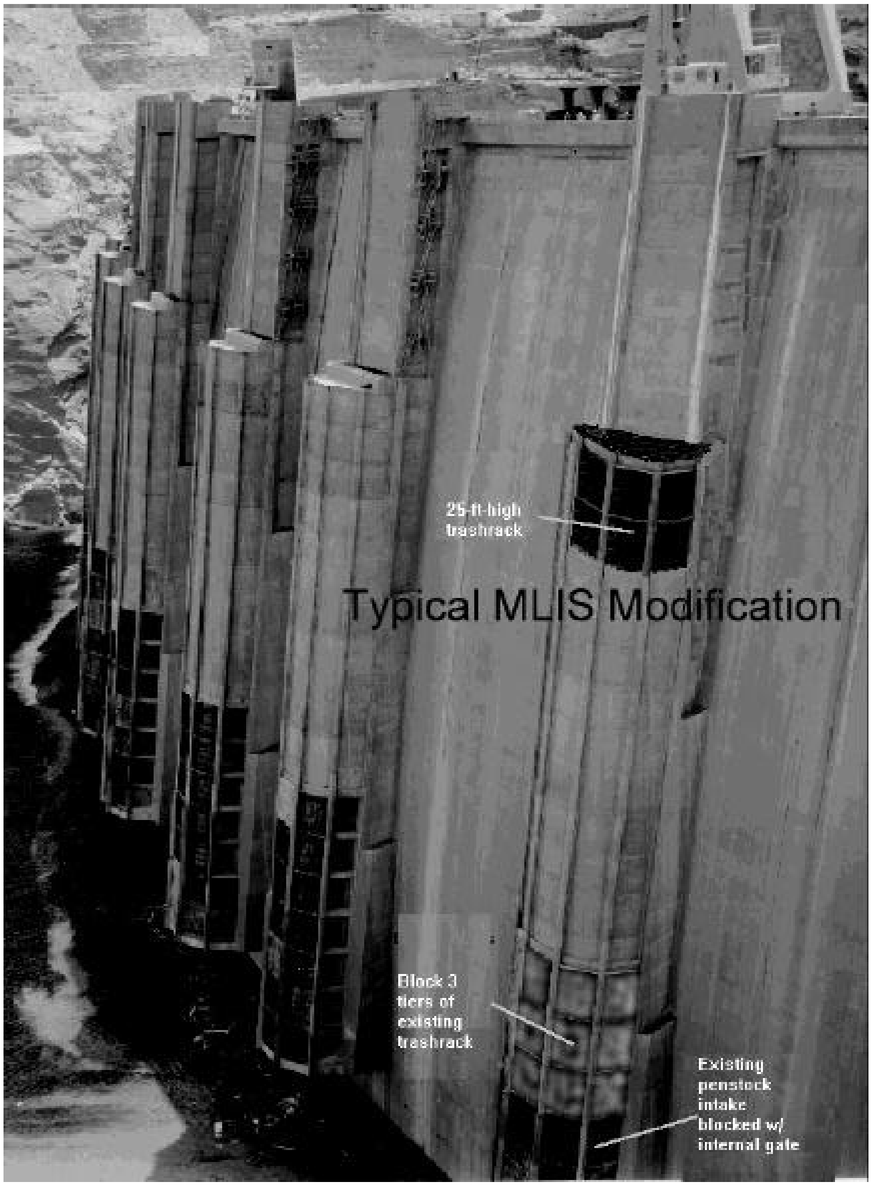

Figure 1. Photograph of existing penstock intake structures and major features (conceptual) of a typical MLIS modification.

through the existing penstock intakes were identified. Operational flexibility, construction impacts, operational constraints, and costs were all considered in the process. The preferred alternative was an uncontrolled overdraw design (flow would enter the top of the intake tower 160 ft above the existing intake) which was the most economical alternative and is well suited to study the benefits and impacts of selective withdrawal. However, its operational flexibility with respect to reservoir elevation is limited. Because this is an uncontrolled overdraw design and the reservoir elevation can fluctuate depending on hydrologic conditions, it is expected that temperature control operations will not occur every year. Frequency of operation will depend on biological objectives and whether the reservoir will have enough storage to have sustained surface withdrawals while meeting the submergence and release volume requirements. If testing shows the system to be beneficial and more operational flexibility is required, many of the features of the uncontrolled overdraw system can be incorporated into the design of a controlled overdraw system.

In January 1998, Reclamation began to design a multi-level intake structure (MLIS) for Glen Canyon Dam. The TSC will provide the drawings, specifications, and construction support to build an uncontrolled overdraw MLIS. As part of the design process a hydraulic model was tested to determine head losses, submergence requirements, water hammer pressures, and any potential vortex formation which could affect the performance of the structure and mechanical equipment. Temperature studies using computer models are being conducted to determine quantity and temperature of warm water withdrawals. The potential ecological impacts of warm water withdrawal on Lake Powell, the Colorado River through the Grand Canyon, and Lake Mead are also being studied as part of an environmental assessment which is being prepared as part of this project (Reclamation 1999). This paper concentrates on the results of the hydraulic modeling and some ecological and economic impacts associated with the proposed temperature modifications to the Colorado River.

Uncontrolled Overdraw Intake - Description of Proposed Design

The concrete lid and the top 20 ft (6 m) of the trashrack enclosure structure would be excavated from all eight intakes (figure 1). This provides a semicircular opening having an area of approximately 360 ft^2 (33 m^2) including the open area of the fixed-wheel gate slot. A semi-circular internal gate having a 12 ft (3.6 m) radius will be used to block the existing flow path at the base of each trashrack structure, see figure 2. The gate will be about 42 ft (12.8 m) high. The internal gate will block flows into the bottom 40 ft (12.2 m) of the trashrack structure. The remaining three tiers of trashracks will be blocked with steel panels. Pressure relief panels are provided within the gate to protect the structure from large differential pressures. Should the differential pressure across the structure become too large, the shear pins will fail and the panels will open to equalize the pressure.

A new trashrack structure will rest on the concrete crest and be anchored to the dam face. The trashrack radius will be the same as the concrete structure. Its height will be approximately 25 ft (7.6 m), providing an approach velocity of approximately 4 ft per second (1.2 m/s).

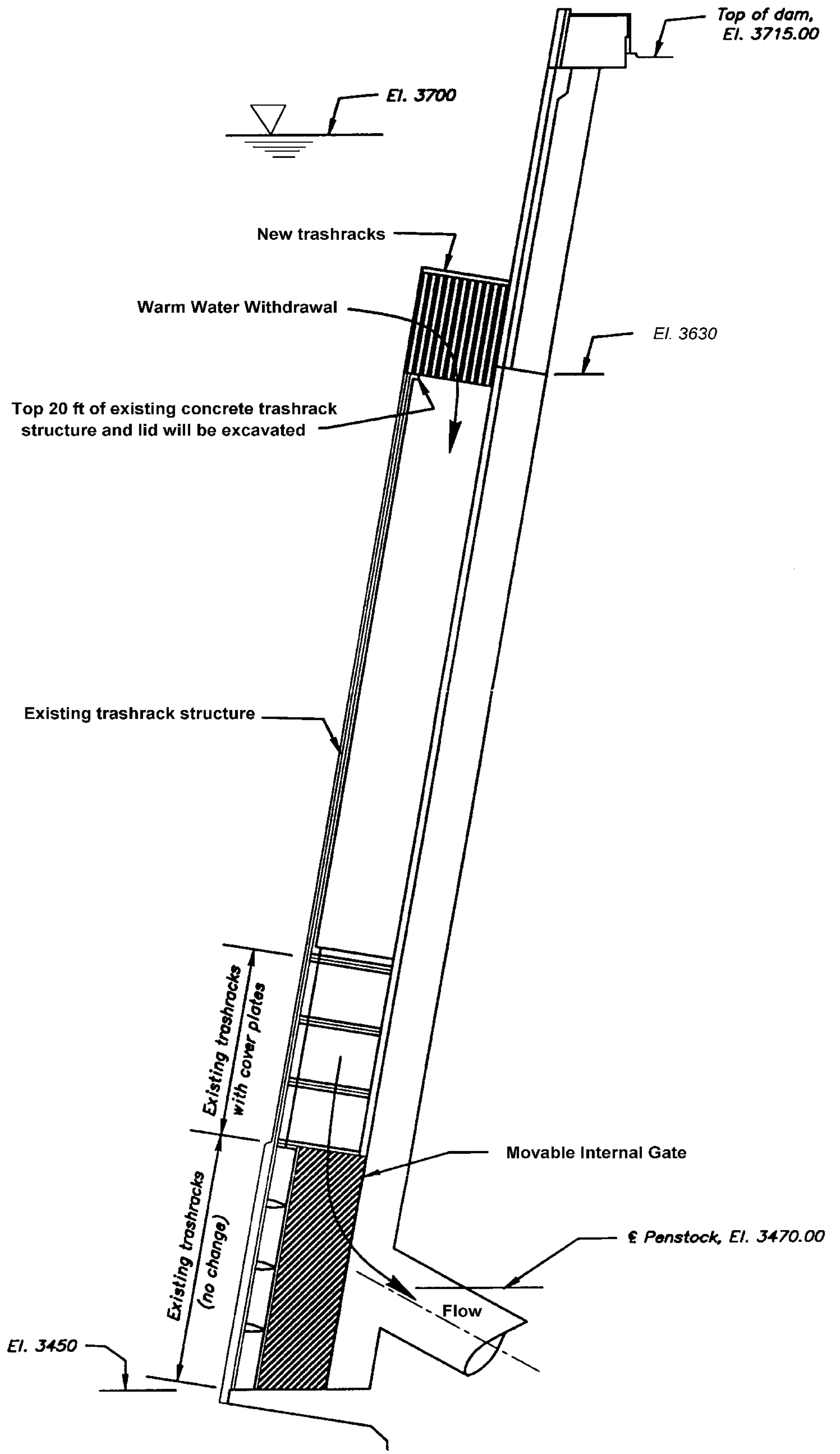

Figure 2. Schematic of proposed uncontrolled overdraw MLIS for Glen Canyon Dam configured for warm water withdrawal. (Not to scale)

Physical Hydraulic Model

As part of the design process, a 1:20 scale model was constructed in Reclamation's Water Resources Research Laboratory in Denver, Colorado (figure 3). This hydraulic model study was conducted to collect hydraulic design data for the proposed Glen Canyon Dam MLIS and to develop modifications, if necessary, to ensure satisfactory hydraulic performance. The hydraulic information obtained from the model study were head losses, submergence criteria, vortex potential, and water hammer pressures. It is important to note that this model was designed to determine the increase in head loss resulting from modifying the intake, not the overall head loss from reservoir to turbine.

Figure 3. Photograph of the 1:20 scale model of an unmodified, single penstock intake structure at Glen Canyon Dam. The vertical extent of the model is 13 ft (4 m).

Model Testing - Head losses associated with the following intake configurations were measured in this model study:

- **Existing Intake -** This test was conducted to establish baseline hydraulic performance.

- **MLIS Cold Water Withdrawal -** Internal gate in raised position blocking the upper trashrack. Solid panels blocked a portion of the lower trash racks. The fixed portion of the internal gate was installed on the floor of the trashrack structure.

- **MLIS Warm Water Withdrawal -** Surface withdrawal through a 25-ft-high (7.6 m) trashrack with the internal gate blocking the low-level intake.

Evaluating Vortex Formation - The study of vortex formation was conducted at the same time as the head loss data collection. Flow visualization techniques were used to determine vortex strength using the classification system developed by Alden Research Laboratory (Hecker 1981). Submergence requirements will be established to minimize the potential for vortex formation.

Water Hammer Pressure Tests- A series of tests were conducted to measure the dynamic pressures in the intake structure associated with an emergency wicket gate closure. These tests were compared with results from a numerical model which computes water hammer characteristics for penstocks. A quick-closing butterfly valve was installed about 10 pipe diameters (160 ft (49 m) prototype) downstream from the penstock intake. The valve was used to model a 10 second (prototype) wicket gate closure. A dynamic pressure transducer was mounted in the floor of the trashrack structure. The transducer was flush mounted on the centerline of the intake structure, about 4.2 ft (1.3 m prototype) from the face of the dam, or just upstream of the fixed-wheel gate slot.

Modeling Results

A summary of the hydraulic modeling conclusions are as follows:

- The maximum expected *additional* head loss associated with the MLIS modification operating in cold water withdrawal mode is about 0.4 ft (0.12 m) at the design flow of 4000 ft^3/sec (113 m^3/sec). This additional head loss is attributed to blocking the upper trashrack panels and adding the fixed gate section to the bottom of the trashrack structure, see figure 4.

- In surface withdrawal (warm water) mode, the head loss through the MLIS structure is significant and will result in some lost power revenues. At the design discharge, the total head loss is about 7.8 ft (2.4 m), or 3.7 ft (1.1 m) of *additional* head loss when compared to the existing intake, see figure 4.

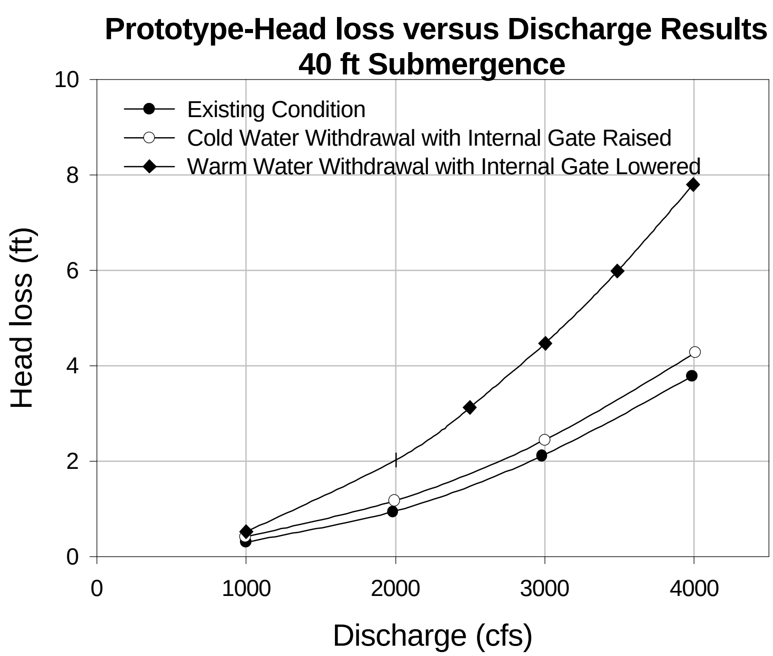

Figure 4. Comparison of head losses for existing intake configuration and the two modes of MLIS operation.

- Types 3 and 4 vortices were common during surface withdrawals and they developed near the stop log guides. Vortices pose a potential hazard to wire ropes that will be used to hoist the internal gate (figure 5). Adding a solid lid to the trashrack reduced vortex strengths to types 2 and 3, and forced the vortices to form along the perimeter of the trashrack (figure 6).

- Based on model observations, 40 ft (12.2 m) of submergence is the recommended minimum submergence for discharges at or below the design discharge. Based on this submergence requirement, warm water withdrawal operations will be acceptable for water surface elevations greater than 3670.

- Water hammer tests showed a positive pressure spike inside the trashrack structure to be 5 ft of water (1.5 m). In general, model water hammer pressures agreed relatively well with those computed by the computer model. This pressure will be used as the design value for the shear pins in the pressure relief panels.

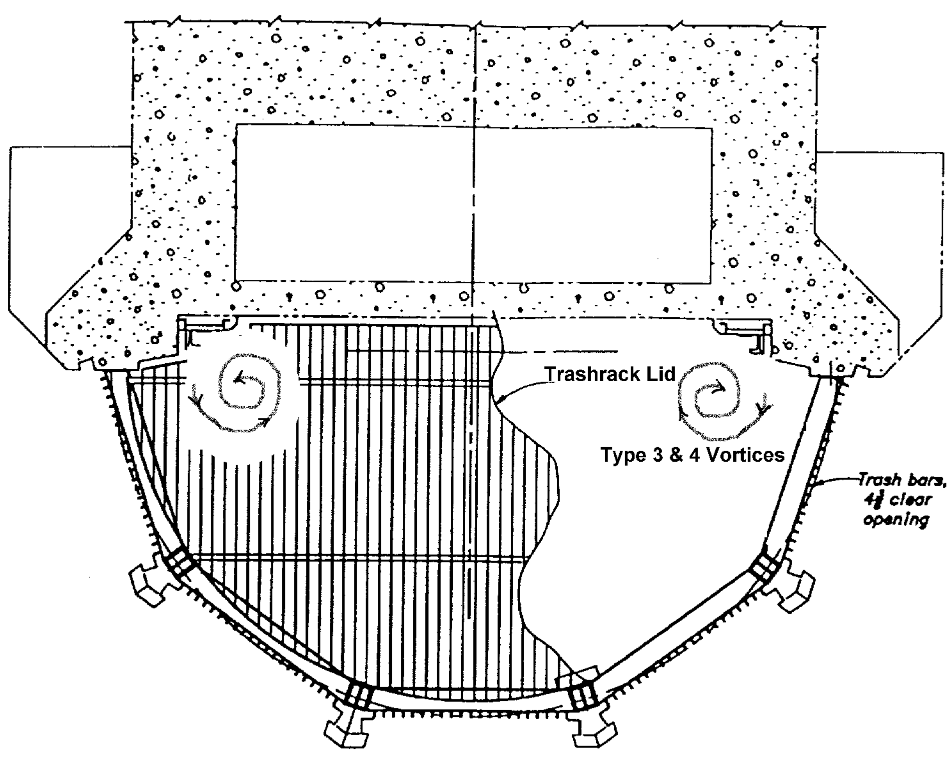

Figure 5. Location of type 3 and 4 vortices which formed with the trashrack with a porous lid.

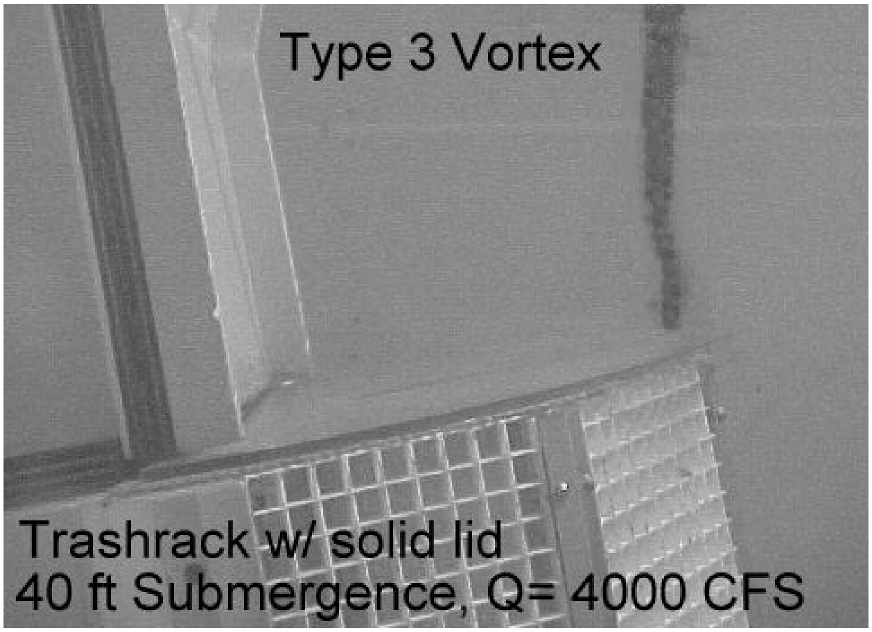

Figure 6. Photograph of vortex dye core after a solid lid was installed on the trashrack. Unlike the porous lid, these vortices were intermittent and the location of vortex formation was unpredictable.

Ecological Analysis of Temperature Control Operations

There are many ecological concerns being evaluated by Reclamation associated with no action and the proposed temperature control alternatives. A draft environmental assessment has been released to the public (Reclamation 1999). A list of the effects on water quality and natural resources are as follows:

- River Effects - Since the completion of the dam, reservoir release temperatures have been consistently in the 46-50°F (8-10°C) range. With MLIS operations, the reservoir release temperatures could be increased by as much as 18°F (10°C) to improve habitat for the native fishes. However, a maximum release temperature of 15°C is proposed to protect the rainbow trout fishery immediately below the dam. Computer modeling studies indicate that additional nutrients, detritus, and algae will be released to the river during MLIS operations, potentially increasing the productivity in the Lees Ferry Reach (first 16 miles of river below Glen Canyon Dam).

- Nonnative fish such as rainbow trout are likely to benefit from warmer tailwater temperatures in the Lees Ferry reach. Further downstream, as the water warms up, warmer water temperatures would limit the extent of trout habitat so they will not compete with native and endangered fish.

- Reservoir Effects - Computer modeling shows very little change in lake temperatures, nutrients, or dissolved oxygen levels due to the relatively small amount of water released when compared to the vast amount of storage in Lakes Powell and Mead. Surface withdrawals would bring nutrients and algae further down the length of the reservoir. Warmer inflows to Lake Mead would likely increase the availability of nutrients to algae on the surface of the lake.

- Native and Endangered Fishes - Thermal shock to endangered fish as they descend from warm tributaries into the cold mainstem is a major concern. Researchers have estimated a 98 percent mortality (Valdez and Carothers 1998). Warmer releases are expected to reduce this problem.

- Recreation, mainly commercial rafting, would benefit from warmer river temperatures in the Grand Canyon.

Economic Impacts on Glen Canyon Dam Hydropower Operations

On October 9, 1996, Secretary of the Interior, Bruce Babbitt, issued a record of decision related to the Grand Canyon Protection Act of 1992 which impacted the hydropower operations at Glen Canyon Dam. Secretary Babbitt proclaimed that the dam would be operated according to the Modified Low Fluctuating Flow (MLFF) criteria. The MLFF criteria restricts maximum flows, minimum flows, ramp rates, and daily fluctuations in flow. These flow restrictions limit the hydropower plant capacity and the ability to operate as a peaking power plant. As a result, the Glen Canyon power plant has reduced ability to meet peak power demands. An economic study of how the MLFF criteria impacts plant capacity (Harpman 1997) estimated that capacity is reduced 20.6 percent from pre-1996 operations. In addition, shifting a portion of the generation from on-peak to off-peak periods reduced the economic value of the hydroelectricity by $6,100,000 over a representative water year.

Increased head loss associated with the proposed MLIS at Glen Canyon Dam has a relatively minor economic impact on hydropower operations. Assuming MLIS operations occur during the months of June through August and all releases are surface withdrawals, the economic value of the additional head loss was estimated to be $228,000 for a representative water year. Other impacts include reduced operational flexibility during starting and ending temperature control operations in order to limit thermal shock to the tailwaters.

Conclusions

Reclamation has undertaken feasibility and hydraulic model studies on providing selective withdrawal capability at Glen Canyon Dam and has prepared a plan and draft environmental assessment on the proposed temperature control modifications. Reclamation has begun the final design process on a uncontrolled overdraw MLIS. This design utilizes the existing intake structures to reduce costs, yet meet the performance objectives for temperature controls.

Funding for construction of the MLIS has been requested and construction could begin as early as fiscal year 2000. Construction would be completed in about 12 months and the cost to modify all eight intakes is estimated to be about $15 million.

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