United States Department of the Interior

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Washington, DC 20240

IN REPLY REFER TO:

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TECHNICAL DECISION MEMORANDUM

Date: March 26, 2024

Issue: Establishment of Interim Operating Guidance for Glen Canyon Dam during Low Reservoir Levels at Lake Powell

Submitter: Richard LaFond
Director, Technical Service Center

RICHARD LAFOND Digitally signed by RICHARD LAFOND Date: 2024.03.27 08:17:26 -06'00'

Decision Makers: Director, Dam Safety and Infrastructure
Regional Director, Upper Colorado Basin
Manager, Upper Colorado Basin Power Office

Type of Decision: Command

A. Purpose

The purpose of this Decision Paper is to establish prudent operating guidance to address the potential for negative consequences associated with the long-term operation of the river outlet works at Glen Canyon Dam at low reservoir levels. Reclamation has limited experience operating the facility under these conditions. Investigations, studies, and physical modeling are ongoing, including temporary and permanent remedial actions; therefore, this guidance may be and continue to be updated as appropriate. Based on currently available data, Reclamation is adopting the following interim operating guidance for the facility:

1. Exercise the full extent of operational capabilities within the Upper Colorado Basin to attempt to maintain reservoir level at or above elevation 3,490 feet (ft)[1], minimum power pool (MPP), to allow redundant downstream delivery of water through the penstocks and river outlet works if needed. [2]

2. To minimize the potential for cavitation damage in the river outlet works, the maximum flow through any one of the four conduits should not exceed the interim maximum flows

[1] All elevations referenced in this document are based on NGVD29 feet above mean sea level unless otherwise noted.
[2] Any changes in Colorado River agreements or policy needed to maintain 3,490 ft are outside the technical scope of this document.

shown in Table 1 below. Values shown are based on preliminary estimates of head losses in the conduits and cavitation development in their upper vertical bends.

Table 1: Interim Maximum Flows through any one River Outlet Works Conduit in cubic feet per second (cfs)		
Reservoir Water Surface Elevation (ft)	Design Maximum Flow (cfs)	Interim Maximum Flow (cfs)
3,550 and above	3,750	3,750
3,540	3,750	3,693
3,530	3,750	3,597
3,520	3,750	3,500
3,510	3,750	3,397
3,500	3,750	3,293
3,490	3,680	3,185
3,480	3,610	3,073
3,470	3,580	2,958
3,460	3,380	2,837
3,450	3,120	2,711
3,440	2,880	2,580
3,430	2,540	2,439
3,420	2,200	2,200
3,410	1,800	1,800
3,400	1,200	1,200
3,390	0	0

Based on Reclamation's most recent elevation projections in the March 2024 24-Month Study, the most probable Lake Powell elevation is expected to be no lower than 3,558 ft through February 2026.

B. Physical Models

Reclamation's Technical Service Center (TSC) is operating two physical models in its Hydraulics Laboratory to better define river outlet works operational issues at low reservoir levels and potential mitigation strategies.

1. Glen Canyon River Outlet Works – Tailrace Model

A 1:32 scale physical model of the Glen Canyon dam tailrace and downstream river is being used to determine if sediment scour and deposition generated from operation of the river outlet works will impact the powerplant. The model includes four operational river outlet work hollow jet valves, a movable bed which simulates real world bed materials, a fixed bed at the approximate location of the bedrock and broken up tailrace slab material. Deposition and scour maps will be generated for the scenarios tested. Exploratory solutions to prevent recirculation of the sediments will be tested and documented. Additionally, powerplant discharges will be added to the model to test combined powerplant and river outlet works discharges with any solutions that are found.

2. Glen Canyon River Outlet Works Cavitation Model

A 1:12 scale model of the upper bend of one outlet works conduit is being used to determine pressures on the inside of the bend in the vicinity of each miter joint. The pressure data will aid the assessment of cavitation potential during low-reservoir operations. The model begins at the conduit intake and includes the bellmouth entrance, the horizontal pipe run leading to the first bend, the bend itself, and a portion of the conduit that descends past the bend toward the hollow jet valves at the base of the dam. Accompanying computational fluid dynamics modeling is also being performed.

C. Background

Glen Canyon Dam, which forms Lake Powell, is a concrete arch dam that was constructed from 1956-1964 as the key storage unit of the Colorado River Storage Project (CRSP) authorized under Public Law 84-485. The other initial units of the CRSP are the Wayne N. Aspinall Unit (Blue Mesa, Crystal, and Morrow Point Dams), Flaming Gorge Dam, and Navajo Dam.

Water can be released from Glen Canyon Dam through the penstocks, river outlet works, and the spillways. See attached drawing 557-D-73. Lake Powell has a maximum active pool water surface elevation of approximately 3,700 ft (also referred to as full pool) with a total live storage of approximately 23.3 million acre-feet (maf) (The maximum flood control elevation is approximately 3,750 ft). Total release capacity at elevation 3,700 ft is 33,200 cubic feet per second (cfs) through the penstocks, 15,000 cfs through the outlet works, and 276,000 cfs through the spillways. Water cannot be released from the spillways below elevation 3,648 ft, nor through the penstocks below elevation 3,490 ft. Water can theoretically be released from the outlet works down to elevation 3,370 ft, which is the intake invert and dead pool elevation. For the purpose of this document, elevation 3,394 ft, 20 ft above the river outlet works intake centerline elevation, is considered a minimum discharge elevation based on river outlet works discharge curves. (The volume of water between elevation 3,490 ft and 3,394 ft is estimated to be approximately 3.7 maf.)

The outlet works conduits are embedded in the concrete of the dam near the left abutment. The outlet works consist of two trashrack intake structures, four 96-inch diameter steel pipes with design thickness between 9/16 inches and 7/8 inches, four cast iron bell mouth intakes, four 96-inch ring-follower gates used for isolation and emergency closure located about 60 ft from the upstream face of the dam, and four 96-inch hollow-jet valves for flow regulation at the discharge end of the outlet pipes. The vertical bends of the river outlet works were constructed with mitered steel pipe segments welded together in accordance with the requirement of the 1951 edition of the American Petroleum Institute-American Society of Mechanical Engineers (API-ASME) Code for Design, Construction, Inspection and Repair of Unfired Pressure Vessels for Petroleum Liquid and Gasses [1]. The interior of the river outlet works is lined with approximately 125 mils of coal tar enamel (original lining) but is planned to be relined in 2024 with 12-18 mils of solvent borne epoxy[3]. A single bulkhead gate is stored on top of the dam for isolation of an individual outlet pipe. The centerline of the intakes is located at elevation 3,374 ft. The outlet works are the only means for releasing water below elevation 3,490 ft. Maximum recommended operational discharge through each outlet is 3,750 cfs for a combined capacity of 15,000 cfs.

Glen Canyon Powerplant is located immediately downstream at the toe of the dam. Embedded in the concrete of the dam are eight 15-foot-diameter steel penstocks that deliver water to eight powerplant turbines (denoted as powerplant units 1 through 8). The centerline of each penstock intake is at elevation 3,470 ft. The interior of the penstocks is lined with approximately 30 mils of coal tar epoxy, which was re-lined between 2001 and 2003. Glen Canyon Powerplant has a total rated capacity of 1,320 Megawatts (MW). Bulkhead gates for each of the draft tube openings that discharge into the tailrace are stored in the upper portion of their gate slots and raised and lowered by a 10-ton gantry crane.

D. Guidance Considerations

This interim operating guidance is based on the following considerations.

1. Minimum Power Pool (MPP)

The Technical Record of Design and Construction for Glen Canyon Dam and Powerplant [1] established elevation 3,490 ft as the minimum reservoir elevation for power production, which is 20 ft above the centerline of the penstock intakes. This elevation is believed to be based on designers' estimates of the level at which intake vortex formation would occur at the powerplant. Vortex formation can cause problems such as air entrainment, vibration, surging (pressure pulsations), efficiency loss, cavitation, flow reduction, damage from debris entrainment, and more. Vortex formation is highly variable and dependent on flow rate, intake submergence, and site-specific characteristics. Turbine flowrates at elevation 3,490 ft are estimated to be 1,600 to 2,300 cfs per unit without damage to turbine runners or units.

2. Dependence on Long-Term Operation of River Outlet Works

Since August 1965, when powerplant units 1 through 5 were brought online and the combined turbine discharges alone were sufficient to meet downstream water requirements, the

[3] Relining the river outlet works is planned for 2024-2025. The Technical Service Center has developed technical specifications and the Upper Colorado Basin is working on issuing a contract. After the contract is issued, it is estimated that the recoating work would require approximately 8 months to complete. The project may be suspended or postponed if the river outlet works are needed for operations.

river outlet works have only been used to augment powerplant and spillway discharges and typically not for long durations. These instances include flood releases in 1983 which lasted about three months [2], additional flood releases in 1984-1987, three experiments conducted prior to the development of the protocol for high flow experiment (HFE) releases in 1996, 2004, and 2008, and scheduled HFE releases in 2012, 2013, 2014, 2016, 2018, and 2023 with durations on the order of a few days to one week [3]. All of these releases were made at reservoir levels well above elevation 3,490 ft. The river outlet works were also used in 1965, at a reservoir elevation of 3,492 ft and this use is discussed in the next section of this memorandum.

In the various Glen Canyon Dam references cited, there is nothing to indicate the river outlet works were intended for long-term water conveyance use at low reservoir water levels. Rather, the 1964 Hydraulic Model study [4] states "The outlets will be used principally to maintain minimum downstream river flow before the powerplant is in operation and to control storage in the reservoir during the flood seasons after the right diversion tunnel is closed." The Technical Record of Design and Construction [1] states "The river outlets provide for releases for downstream commitments when the powerplant is not in operation and during the period of final closure of the diversion tunnels. The outlets will also be used to maximum capacity during maximum flood releases." and "The pipe diameter was chosen for best balance between factors representing desired discharge, energy dissipation, and maximum allowable velocity short of destructive cavitation and vibration. The maximum designed velocity of 74.60 feet per second (ft/s) is about 10 ft/s faster than that used in previous outlet pipes."

While the outlets were intended to maintain minimum river flow before the powerplant was in operation, records of construction and operations history show that it did not occur in this sequence. The Technical Record of Design and Construction [1] states "the ring-follower gates and controls were first placed in service by passing water through the outlet works in January 1965" and the operational history for initial power generation shows powerplant units 1, 2, and 3 began generating between September and December of 1964.

Although not dispositive in this interim operating guidance, it is noteworthy that the stilling well, which is the official measurement device for Lake Powell reservoir elevations, ends at the top of the penstocks (elevation 3,477.5 feet). This is an indication that reservoir elevations below minimum power pool were not anticipated.

3. Cavitation Damage in River Outlet Works

The Technical Record of Design and Construction [1] states that the maximum capacity of all four-outlet pipes is limited to 15,000 cfs (3,750 cfs for each outlet pipe) for reservoir elevations above about 3,500 ft. This limit is enforced by not allowing full-open operation of the hollow-jet valves, which ensures that average water velocity in the outlet pipes does not exceed 75 ft/s. The discharge capacity begins to diminish below elevation 3,500 ft but remains relatively high. For example, at reservoir elevation 3,490 ft (MPP), the capacity of each river outlet work is approximately 3,680 cfs, resulting in a conduit velocity of 73 ft/s, which is still considered high.

The high water velocity in the steel outlet pipes makes them susceptible to cavitation and coating damage especially at locations of the pipe where there are offsets, changes in pipe direction such as bends, and at locations of pipe connections/attachments such as manhole connections, especially during extended periods of discharge releases. Cavitation occurs in high velocity flows when flow streamlines separate from the boundary creating local pressures below the vapor limit that allow liquid water to change phase to water vapor (gas bubbles) within the flow. Vapor bubbles formed in low pressure zones can change back to liquid water when pressures become momentarily higher than the vapor limit (due to turbulent fluctuations or impingement of flow against conduit surfaces at changes of direction). The phase change back to liquid water is destructive, as bubbles implode against flow surfaces and create extremely high pressures that can, over time, erode all types of solid materials, up to and including coatings, concrete, and carbon and stainless steels.

Cavitation potential at the upstream vertical bend is suspected from cavitation index estimates as well as historical operations and inspection reports. Cavitation potential is increased at low reservoir levels due to the reduction of static pressure within the river outlet work conduits. Prior to the April 2023 HFE, engineers from Reclamation's Hydraulics Laboratory were asked to perform preliminary cavitation calculations based on guidance from Engineering Monograph 42 [5] to determine if there was a potential for cavitation during the planned high flows at the given reservoir level. Reservoir elevation 3,520 ft and total discharge of 3,500 cfs (70 ft/s average pipe velocity) per outlet were assumed for these calculations. The estimates showed that cavitation formation was possible although the extent and intensity could not be determined. These calculations also showed that the most suspected location for cavitation problems would be on the invert (the interior bottom elevation of the pipe) of the upstream vertical bend where local pressure would be lowest for the same average pipe velocity. This assessment was corroborated by observations of coating and pipe wall damage near this location and pressures measured during a field test in 1965 [6]. The observations in 1965 showed damage to the coating and pitting had initiated on the steel pipe wall along the invert (the interior bottom elevation of the pipe) and lower side walls downstream of each miter bend of the elbow. The duration of the 1965 test is unknown, but the cavitation conditions in 1965 were more severe (reservoir elevation of 3,492 ft and total discharge of 3,600 cfs per conduit) than the conditions during the April 2023 HFE. Patterns and locations of damage seen in the inspection after the 2023 HFE [7] indicate that cavitation likely occurred again during the HFE. Continued operations under these conditions are a concern and may cause further damage to the coating. Once the integrity of the coating is compromised by initial cavitation damage, further damage can occur from direct flow forces, additive to continuing cavitation, which will eventually damage the steel pipe if allowed to continue for long durations.

4. Reliability of Hollow-Jet Valve Operations

The four hollow-jet valves are located at the discharge end of the outlet pipes at elevation 3,175 ft. They operate at heads up to a reservoir elevation of 3,711 ft (536 ft resultant head). Valve openings of 0 percent to 100 percent are permitted for reservoir elevations below about

3,500 ft; for higher reservoir levels, valve openings are limited to avoid exceeding the discharge constraint of 3,750 cfs per conduit that limits pipe velocities to 75 ft/s.

In 2023, a special inspection of the outlet works was conducted which included a physical inspection, balanced hollow-jet valve testing, and unbalanced hollow-jet valve testing by making releases through the 70 percent valve open position. At the time of this examination, the reservoir elevation was 3524.5 ft, resulting in a maximum approximate discharge of 3,350 cfs per conduit. The 2023 Outlet Works Special Inspection – Glen Canyon Dam Report [8] states that all hollow-jet valves performed satisfactorily; however, multiple minor issues were noted as part of the examination. Most of the issues stem from the age of the hollow-jet valves and lack of major rehabilitation since fabrication in the early 1960s. When considering the pipes, ring follower-gates, and hollow-jet valves as a whole, the report [8] states "For periodic releases, including seasonal releases to augment releases from the powerplant, this examination found the condition of these three components to be sufficient. However, there is concern with using the outlet works to provide long-term releases, particularly at high flows." and "In order to achieve a high level of confidence for continuous long-term operation of the outlet works, a major overhaul or replacement of the hollow-jet valves should be considered."[4]

5. Tailrace Scour and Sediment Deposition

To prevent outlet blade cavitation of the turbine runners, an attempt was made to stabilize the tailrace channel following dam construction with a tailrace slab that would ensure an adequate tailwater level. However, the attempt was unsuccessful, as the Technical Record of Design and Construction [1] relates:

> "To ensure a minimum tailwater for the turbines, a tailrace slab was constructed between the tailrace walls. This slab sloped up on a 6:1 slope from the draft tubes to form a weir at elevation 3,132 ft, 180 feet downstream from the powerplant…During the night of April 20, 1965, the slab was undermined and portions of it sank from sight. At the time of failure, the reservoir was at elevation 3,490 ft, four of the eight units in the powerplant were operating, Outlet No. 1 was closed, Outlet No. 2 was 25 percent open, Outlets No. 3 and 4 were 90 percent open, and the tailwater was 4 to 6 feet lower than had been predicted and used in the model studies. Operating the river outlets at reservoir elevation 3,490 instead of at normal water surface elevation 3,700 ft as used in the model, caused the jets to impinge closer to the weir."

Although the specific conditions at the time of failure had not been run in the 1964 tailrace physical model, the study of other flow conditions had shown a strong clockwise recirculating eddy [4] in the tailrace during river outlet work operation. This eddy extended upstream and downstream past the location of the weir. The reverse flow from the April 20, 1965, slab failure

[4] A value planning study is currently planned to inform whether to refurbish or replace the hollow-jet valve hydraulic operating system.

had a high velocity estimated to be 15 ft/s [1]. The operation of the outlets at the lower head, operation of only four powerplant units instead of eight, and the lower tailwater intensified the eddy action compared to that observed in the physical model (which only looked at river outlet work operation with full powerplant discharges). The scour from the reverse flow undermined the toe of the slab and rapidly removed its foundation, causing collapse of the slab. The destructive power of this eddy was probably not fully appreciated before the failure occurred. The physical model was used to study physical changes to the river outlet work and tailrace geometries as well as operational changes that could reduce the strength of the eddy. The 1964 model report [4] recommended the operation of outlets 4 & 3 with outlets 2 & 1 closed to reduce the recirculation over another more costly alternative because of the "improbable flow conditions that would require operation of all four outlets".

In 1976 Pemberton [9] documented a May 1965 high flow release of 58,100 cfs, with releases from the powerplant, left river plug outlet, and the river outlet works when the reservoir elevation was about 3,490 ft [1]. Flows from this event likely were the start of the sediment bar that is present today in the right side of the tailrace, looking downstream.

Video footage of the 1983 high flow releases from the powerplant, river outlet works, and both spillways, along with a bathymetric survey from Randle and Blanton in 1986 [10] document the deposition of sediment in the tailrace and the scour at the impact location from the river outlet works. Bathymetric surveys from 2014 [11] and 2019 [12] also show the scour hole and deposition zone did not change significantly over the eight HFEs that have occurred between 1996 and 2018. Surveys have shown that the scour hole at the impact zone has reached an elevation of 3,075 ft which is consistent with the bedrock location from the original construction drawings. Witnesses at the facility have indicated that the sand and gravel bar "moves around and gets closer to the powerhouse" during high flow events that utilize the river outlet works but the sand and gravel bar has not significantly changed size or location since the earliest bathymetric survey in 1986. Rhone in the 1964 Hydraulic Model study [4] also indicated that "deposition of riverbed material on the riprap (replaced with concrete) might entail costly maintenance problems" and indicated that preventing the deposition of material in the tailrace was important. Similarly, it is noted that operation of the river outlet works has a strong tendency to move sediment in the tailrace area because of the clockwise recirculating eddy that forms. To date, there have been no known events where discharge has only been released through the river outlet works, and all high flow events utilizing the river outlet works have had powerplant discharges that prevented sediment from moving against the powerplant draft tubes. In the event that reservoir elevations drop to minimum power pool or below, releasing water from the river outlet works without powerplant releases will move and deposit sediment towards the powerplant. Lowering the bulkheads to isolate the draft tubes would prevent buildup of sediment in the draft tubes but raising the bulkheads after such deposition will require removing the deposited tailrace sediment against the bulkheads. The methods and time required to remove the sediment buildup is not currently known, and in this situation, the river outlet works would continue to be the sole means of releasing water until the bulkheads can be raised.

E. Conclusions

If water levels in Glen Canyon Dam drop below elevation 3,490 ft, releases can only pass through the river outlet works. Operation of the river outlet works at or below elevation 3,490 ft must consider the following risks and consequences:

- Safe operation of the river outlet works is controlled by submergence and discharge velocity. The original rating curves indicate that this is only possible down to elevation 3,394 ft (20 ft above the river outlet intake centerline elevation).
- If any portion of the river outlet works were to fail, releases would be limited or unavailable through that individual conduit until repairs are complete. Potential points of failure include:
    - Hollow-jet valve failure, which could include the physical valve, or any equipment required for operation of the valves.
    - Ring follower gate failure, which could include the physical gate, or any equipment required for operation of the gates.
    - Lining or conduit damage so severe the structural integrity of the conduit becomes a concern, and it is decided to close the ring follower gate to prevent further damage.
    - Intake trashrack blockage.
- Long term operation of the river outlet works will result in accelerating regular operation and maintenance tasks. This is perhaps accelerated even more so if the interim maximum flows shown in Table 1 are exceeded. These tasks include lining repairs and hollow-jet valve maintenance. During these times, discharge capacity will be reduced to only the available conduits.
- Operation of the river outlet works without powerplant releases will redistribute existing tailrace sediment, gravel and cobbles causing the size of an existing sediment-deposit to grow and potentially impound the powerplant draft tubes.
    - To prevent sediment from entering the draft tubes, bulkheads should be installed prior to releases through only the river outlet works.
    - Sediment that deposits against the draft tube bulkheads will need to be removed prior to lifting the bulkheads back into their storage positions.

In summary, at reservoir levels below the minimum power pool (elevation 3,490 ft), there are concerns with relying on the river outlet works as the sole means of sustained water releases from Glen Canyon Dam. If the situation were to occur, additional operational limits would be determined based on water needs at that time relative to the need to protect the conduits against cavitation damage and minimize stress placed on the hollow jet valves. Given the current uncertainty associated with long-term performance of the river outlet conduits and components, and tailrace scour and sedimentation deposit, it is recommended that Reclamation not rely on the river outlet works as the sole means for releasing water from Glen Canyon Dam as would be required at reservoir levels below the minimum power pool, elevation 3,490 ft.

F. Revisions to Interim Operating Guidance

Reclamation has several ongoing studies investigating the accuracy of the minimum power pool elevation and negative consequences associated with the long-term operation of the river outlet works at low reservoir levels at Lake Powell. Potential mitigation measures will be developed and implemented to reduce identified negative consequences of long-term operation of the river outlet works at low reservoir levels. Data obtained through real-time operations at low reservoir elevation may also inform these studies and interim operating guidance. More frequent inspections will be necessary to identify or verify impacts. Lessons learned from operating experience will be used to adjust operations and maintenance procedures. This interim operating guidance will be revised when additional data becomes available.

G. References[5]

[1] Technical Record of Design and Construction for Glen Canyon Dam and Powerplant – Colorado River Storage Project, Arizona-Utah, December 1970 **(CUI)**

[2] Burgi P.H., Moyes B.M. and Gamble T.W. (1984). Operation of the Glen Canyon Spillways – Summer 1983, Report PAP-714 **(CUI)**

[3] Bureau of Reclamation (2024). Glen Canyon Dam Long-Term Experimental and Management Plan. Draft Supplemental Environmental Impact Statement. Upper Colorado Basin Region.

[4] Rhone T.J. (1964). Hydraulic Model Studies of the Spillways and Outlet Works – Glen Canyon Dam Colorado River Storage Project, Arizona. U.S. Bureau of Reclamation. Denver, Colorado. Report HYD-469.

[5] Falvey H.T. (1990). "Cavitation in Chutes and Spillways – Engineering Monograph No. 42", United Staes Department of Interior, Denver, Colorado.

[6] Dexter, R.B. and Colgate, D. (1965). Piezometric Measurements of Hydraulic Friction and Bend Losses in River Outlet No. 3, Glen Canyon Dam – Colorado River Storage Project, Bureau of Reclamation. Denver, Colorado. Report TR-3125. **(CUI)**

[7] Reclamation (2023). Glen Canyon River Outlet Pipe Cavitation Inspection, U.S. Bureau of Reclamation. Denver, Colorado. Report TR-2023-01. **(CUI)**

[8] 2023 Outlet Works Special Inspection – Glen Canyon Dam Colorado River Storage Project, Bureau of Reclamation. Denver, Colorado, January 2023. **(CUI)**

[9] Pemberton, E.L (1976). Channel Changes in the Colorado River Below Glen Canyon Dam. U.S. Bureau of Reclamation E&R Cetner, Denver Colorado.

[10] Randle, T. and Blanton, J. (1986). "Under water Mapping River Channels and Reservoirs", Bureau of Reclamation, Denver, Colorado.

[11] Foster, M.A., (2021). Glen Canyon Tailwater Data Review: Bathymetry and Water Surface Elevations, near Page, Arizona. Technical Report No. ENV-2021-057, prepared for the Glen Canyon Power Office, Bureau of Reclamation, Denver, Colorado. April 2021.

[5] References 1, 2, 6, 7, 8, and 12 are considered Controlled Unclassified Information (CUI) and any releases will be limited accordingly.

[12] Vermeyen, T.B. (2019). Bathymetry and Scanning Sonar Survey Report for Glen Canyon Dam and Powerplant Tailrace. Hydraulic Laboratory Technical Memorandum PAP-1164. U.S. Bureau of Reclamation Denver Colorado. **(CUI)**

Decision Maker's Concurrence

The decision makers concur that this interim operating guidance is a prudent response to available data concerning the long-term operation of the river outlet works and accept the recommendations stated above.

Recommended:

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Date: 2024.03.26 15:26:04 -06'00'

Deputy Regional Director, Upper Colorado Basin, Katrina Grantz

Concurred:

Digitally signed by NICHOLAS WILLIAMS
Date: 2024.03.26 15:34:01 -06'00'

Power Office Manager, Upper Colorado Basin, Nicholas Williams

WAYNE PULLAN
Digitally signed by WAYNE PULLAN
Date: 2024.03.26 15:44:58 -06'00'

Regional Director, Upper Colorado Basin, Wayne Pullan

KAREN KNIGHT
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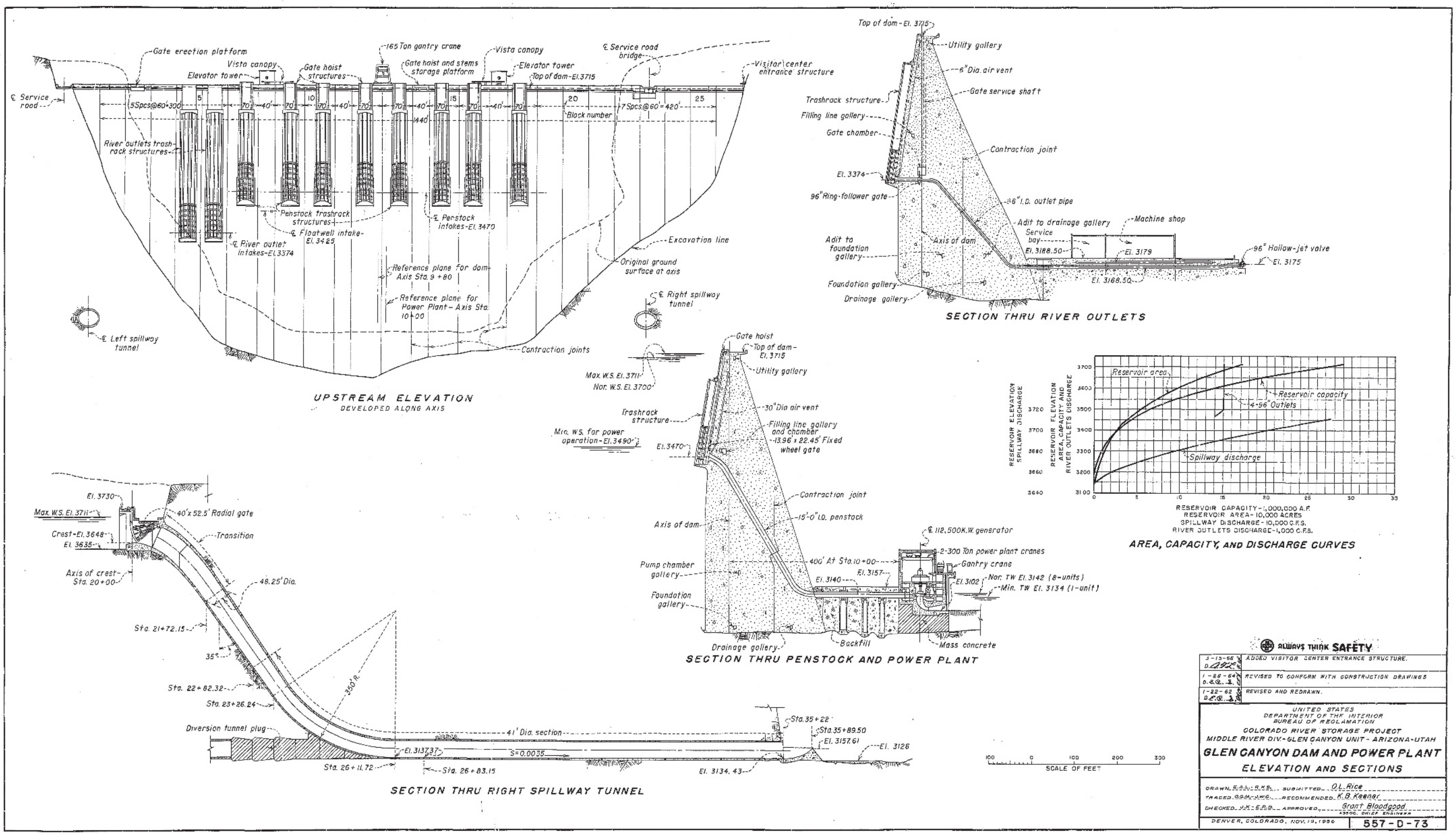
Date: 2024.03.26 16:58:26 -06'00'

Director, Dam Safety & Infrastructure, Karen Knight


UPSTREAM ELEVATION
DEVELOPED ALONG AXIS
SECTION THRU RIVER OUTLETS
SECTION THRU PENSTOCK AND POWER PLANT
SECTION THRU RIGHT SPILLWAY TUNNEL
AREA, CAPACITY, AND DISCHARGE CURVES
RESERVOIR CAPACITY - 1,000,000 A.F.
RESERVOIR AREA - 10,000 ACRES
SPILLWAY DISCHARGE - 10,000 C.F.S.
RIVER OUTLETS DISCHARGE - 1,000 C.F.S.
Reservoir area
Reservoir capacity
4-96" Outlets
Spillway discharge
SCALE OF FEET
ALWAYS THINK SAFETY
ADDED VISITOR CENTER ENTRANCE STRUCTURE.
REVISED TO CONFORM WITH CONSTRUCTION DRAWINGS
REVISED AND REDRAWN.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER STORAGE PROJECT
MIDDLE RIVER DIV.-GLEN CANYON UNIT - ARIZONA-UTAH
GLEN CANYON DAM AND POWER PLANT
ELEVATION AND SECTIONS
SUBMITTED O.L. Rice
RECOMMENDED K.B. Keener
APPROVED Grant Bloodgood
DENVER, COLORADO, NOV. 19, 1956
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