



— BUREAU OF —
RECLAMATION

Glen Canyon Dam Fish Escapement Appraisal Study

**Colorado River Storage Project
Upper Colorado Basin Region**



REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (MM-DD-YYYY) 04-30-2024		2. REPORT TYPE Technical		3. DATES COVERED (From - To) April 2024	
4. TITLE AND SUBTITLE Glen Canyon Dam Fish Escapement Appraisal Study				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Jason Wagner Connie Svoboda				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Technical Service Center Civil Structures Group				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Upper Colorado Basin Region				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Water levels in Lake Powell on the Colorado River in Utah and Arizona have declined to historically low levels due to extended drought in the western United States. With a reduced water surface elevation, the epilimnion approaches the penstock intake elevation at Glen Canyon Dam and the risk of fish entrainment through the dam increases, particularly for non-native fish species who threaten to compete with and/or prey on the downstream native fish community that includes threatened and endangered species. A 2022 preliminary report explored various fish exclusion devices that may limit fish escapement from Glen Canyon Dam. Following the preliminary report, a multi-agency subject matter expert team was formed to evaluate the concepts in the context of project goals such as anticipated efficacy, layouts and design features, and implementation timeframe. The team determined that two different physical exclusion concepts, a fish exclusion net and a fish exclusion curtain, should be further developed into appraisal-level alternatives. The appraisal-level designs include possible installation locations, overall device sizing, and design considerations such as material type, depth, elevation range, floatation, and anchoring strategy. Because of the unique challenges associated with installation on near-vertical canyon walls, there is considerable uncertainty in the engineering design of the anchoring system, mooring system, and canyon wall attachment requirements. Ongoing cleaning and maintenance requirements and potential impacts to dam safety must also be evaluated. Preliminary level cost estimates for a fish exclusion net and fish exclusion curtain are included.					
15. SUBJECT TERMS Glen Canyon Dam, fish passage, fish entrainment, fish escapement, fish barriers, behavioral barriers, non-native fish, temperature curtain, fish net					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	a. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)

Glen Canyon Dam Fish Escapement Appraisal Study

Colorado River Storage Project Upper Colorado Basin Region

prepared by

Jason Wagner, Bureau of Reclamation, Technical Service Center, Civil Structures Group

Connie Svoboda, Bureau of Reclamation, Reclamation, Technical Service Center, Hydraulic Investigations
and Laboratory Services Group

reviewed by

Name

Blake Biethman, Reclamation, Technical Service Center, Civil Structures Group

**U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Civil Structures Group
Denver, Colorado**

April 2024

Mission Statements

The mission of the Department of the Interior is to protect and manage the Nation's natural resources and cultural heritage; provide scientific and other information about those resources; and honor its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

The information provided in this report is believed to be appropriate and accurate for the specific purposes described herein, but users bear all responsibility for exercising sound engineering judgment in its application, especially to situations different from those studied. References to commercial products do not imply endorsement by the Bureau of Reclamation and may not be used for advertising or promotional purposes.

Cover Photo: Aerial photograph of Glen Canyon Dam.

Funding was provided by the Bureau of Reclamation's Upper Colorado Basin Region.

Contents

EXECUTIVE SUMMARY.....	1
INTRODUCTION.....	2
Background.....	2
Project Description.....	4
CONCEPT LEVEL OPTIONS.....	5
Preliminary Assessment of Options.....	5
In-Reservoir Barriers.....	5
At Dam Options.....	6
Downstream Removal.....	7
Concept Option Evaluation	7
Options Evaluated	7
Options Not Evaluated.....	11
APPRAISAL LEVEL ALTERNATIVES.....	13
Options Recommended for Appraisal Level	13
Alternative 1 – Fish Exclusion Net.....	13
Description.....	13
Design Considerations.....	15
Cost Estimate.....	18
Alternative 2 – Fish Exclusion Curtain.....	18
Description.....	18
Design Considerations.....	19
Cost Estimate.....	21
REFERENCES.....	22
APPENDIX A – SUBJECT MATTER EXPERT PANEL MEMBERS.....	24
APPENDIX B – BASIS OF COST ESTIMATE MEMO.....	25
APPENDIX C – FISH EXCLUSION NET APPRAISAL COST ESTIMATE	30
APPENDIX D – FISH EXCLUSION CURTAIN APPRAISAL COST ESTIMATE.....	35

Executive Summary

Water levels in Lake Powell on the Colorado River in Utah and Arizona have declined to historically low levels due to extended drought in the western United States. With a reduced water surface elevation, the epilimnion approaches the penstock intake elevation at Glen Canyon Dam and the risk of fish entrainment through the dam increases, particularly for non-native fish species who primarily inhabit the epilimnion. Because non-native fish species threaten to compete with and/or prey on the downstream native fish community that includes threatened and endangered species, a strategy to prevent fish escapement through Glen Canyon Dam is desired.

The 2022 report “Glen Canyon Dam Fish Escapement Options” explored various fish exclusion devices that may limit fish escapement from reservoirs (Svoboda 2022). The report examined options for physical and behavioral exclusion within the reservoir, along with alternatives to reduce downstream survival for fish that may pass through the dam. The report concluded that there is no clear alternative that can fully eliminate non-native fish escapement at Glen Canyon Dam, but a forebay barrier net or multi-stimulus barrier were most likely to minimize entrainment at the scale required for application to Lake Powell while limiting impacts to power production, operations, and recreation.

Following the preliminary report, a multi-agency subject matter expert team was formed to discuss and evaluate the concepts presented in Svoboda (2022). Concepts were evaluated in greater detail in the context of project goals such as anticipated efficacy, layouts and design features, and implementation timeframe. The multi-stimulus barrier concept was not recommended for further development because efficacy of behavioral barriers is not fully understood for this application. The team determined that two different physical exclusion concepts, a fish exclusion net and a fish exclusion curtain, should be further developed into appraisal-level alternatives. A flexible fish exclusion net allows water to pass through while physically blocking the movement of fish larger than the net open area. Fish exclusion nets are typically made from polyethylene fiber or similar material. The exclusion net is attached to floating buoys and the net extends vertically in the water column. A fish exclusion curtain is similar to a fish exclusion net, but it is a solid flexible barrier where water flows under the curtain. A curtain may have the added benefit of reducing downstream release temperatures.

Appraisal level designs for a fish exclusion net and curtain installed in the reservoir are presented. Site-specific conditions were considered when identifying possible installation locations and overall device sizing. Design considerations such as material type, depth, elevation range, floatation, and anchoring strategy are discussed. Although large-scale applications of nets and curtains have been deployed in other locations, a similar installation location with near-vertical canyon walls like Lake Powell was not identified. Because of the unique challenges associated with the installation location, there is considerable uncertainty in the engineering design of the anchoring system, mooring system, and canyon wall attachment requirements. Constructability of a net or curtain will need to be assessed, along with requirements for ongoing cleaning and maintenance. Potential impacts to dam safety must be evaluated in detail if a fish barrier net is recommended for installation upstream of Glen Canyon Dam. Preliminary level cost estimates from April 2023 are \$22,000,000 for the fish exclusion net and \$23,000,000 for the fish exclusion curtain.

Introduction

Background

Glen Canyon Dam is a concrete arch structure located on the Colorado River in the southwestern United States in northern Arizona, near the city of Page (Figure 1). The dam has a structural height of 710 ft, a hydraulic height of 583 ft, and a crest length of 1,560 ft. Glen Canyon Powerplant is located immediately downstream at the toe of the dam, consisting of eight Francis turbines and a total rated capacity of 1,320 Megawatts. Eight 15-ft-diameter steel penstocks are embedded in the dam for power production. The minimum water surface elevation for power operation is 3490 ft. The river outlet works, located near the left abutment, consist of two intake structures with trashracks, four 96-inch-diameter steel pipes, ring-follower guard gates, and hollow-jet valves for flow regulation. The centerline of each river outlet intake is 96 ft below the centerline of the penstock intakes (Figure 2 and 3).

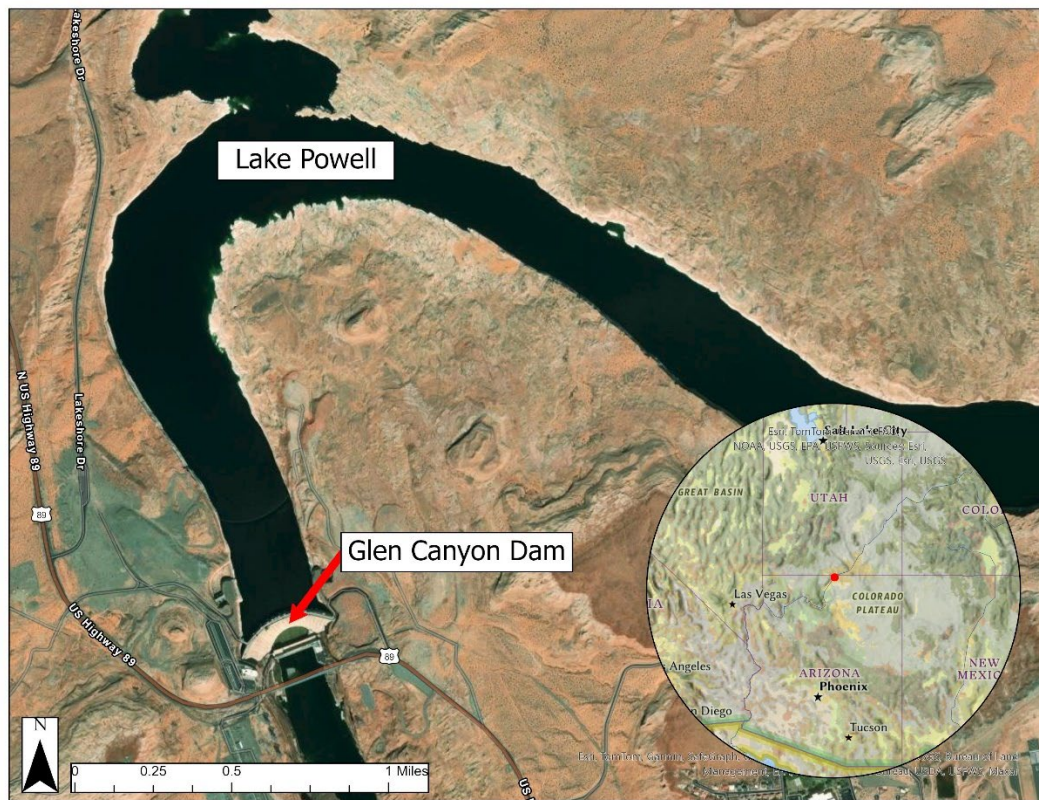


Figure 1. Glen Canyon Dam and powerplant location on the Colorado River.



Figure 2. Photograph of Glen Canyon Dam looking upstream with powerplant at the downstream toe of the dam and four outlet works discharging at river left.

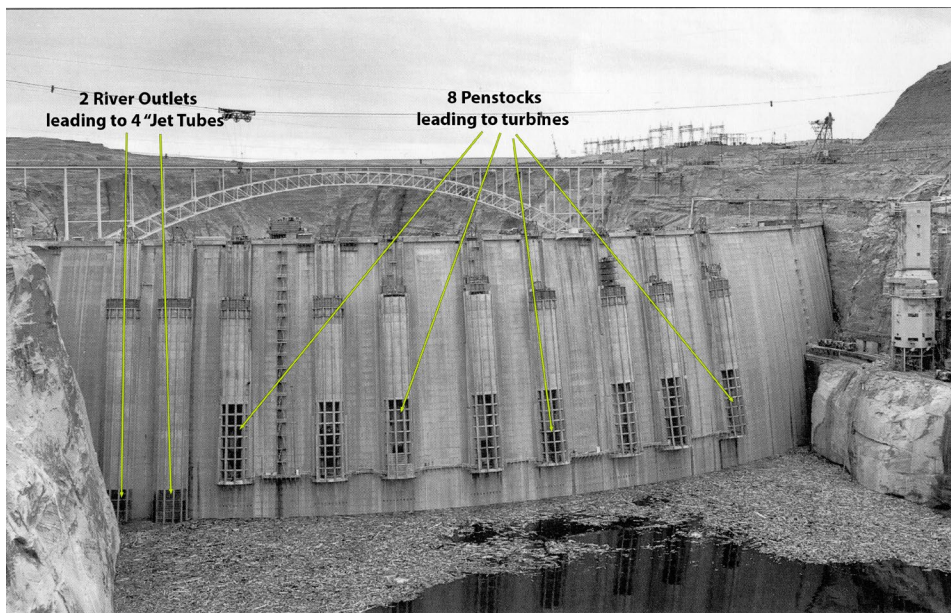


Figure 3. Photograph of Glen Canyon Dam looking downstream, showing the location of the 8 penstocks and river outlet works.

The 2016 Long-Term Experimental and Monitoring Plan Biological Opinion (U.S. Fish and Wildlife Service 2016) directed the Bureau of Reclamation (Reclamation) to pursue means of preventing the passage of invasive non-native fish through Glen Canyon Dam. Water levels in Lake Powell, the reservoir impounded by Glen Canyon Dam, have declined to historically low levels due to the extended drought in the western United States. With a reduced water surface elevation, the epilimnion approaches the penstock intake elevations at Glen Canyon Dam and the risk of fish entrainment increases, particularly for non-native species that inhabit the epilimnion (Figure 4).

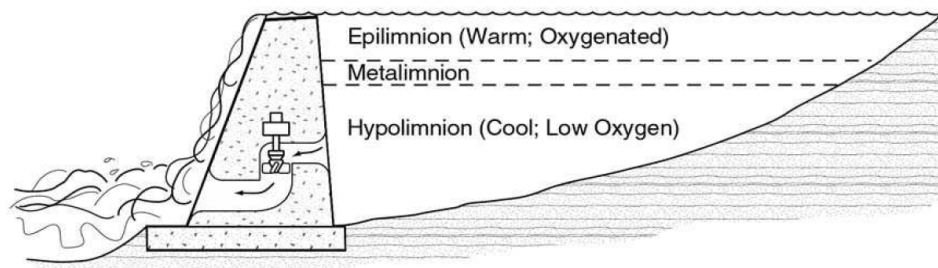


Figure 4. – Schematic of thermally stratified reservoir at a hydropower facility (Peterson et al. 2003).

Above Glen Canyon Dam, the fish assemblage consists of mostly non-native sport fish (e.g., Smallmouth Bass *Micropterus dolomieu*, Striped Bass *Morone saxatilis*, Walleye *Sander vitreus*, Green Sunfish *Lepomis cyanellus*, Black Crappie *Pomoxis nigromaculatus*, Bluegill Sunfish *Lepomis macrochirus*, Channel Catfish *Ictalurus punctatus*). Below Glen Canyon Dam in Glen, Marble, and Grand Canyons, the fish assemblage consists of mostly native fish including the threatened Humpback Chub *Gila cypha* and endangered species Razorback Sucker *Xyrauchen texanus*. There is a non-native Rainbow Trout *Oncorhynchus mykiss* fishery immediately below the dam that extends through Glen Canyon.

Hydroacoustic and netting studies in 2022 and 2023 show that non-native fishes occupy the forebay throughout the epilimnion which was 82 ft (25 m) deep in 2022 and 115 ft (35 m) in 2023. The distribution of all fish extends slightly below the epilimnion. In 2022 and 2023, the vertical extent of the epilimnion coincided with the penstock elevation (Friesen et al. 2024).

A 2007-2009 hydroacoustic survey demonstrated that non-native sport fish are present in the reservoir forebay, and those fishes could become entrained in the penstocks when water is withdrawn from the epilimnion. Fish were most abundant in the top 45.9 ft (14 m) of the water column for both light and dark periods with the first 13.1 ft (4 m) of water having the greatest density of fish (Bureau of Reclamation 2012). Forebay fish densities were highest during the spring and summer months when lake stratification occurs. Fish monitoring in 2023 revealed a much deeper epilimnion than the 2007-2009 surveys with fish occupying a deeper depth range.

Between the dam and Lees Ferry, increased numbers of smallmouth bass and other non-native fish species have been detected during routine monitoring by the Grand Canyon Monitoring and Research Center (GCMRC) and Arizona Game and Fish Department (AZGFD). Due to the low elevation of Lake Powell, current water temperatures are warm enough below the dam that there is risk of successful spawning, recruitment, and establishment of populations of these fish. These non-native fishes threaten to compete with and/or prey on the native fish community.

Project Description

The goal of this report is to document appraisal-level designs for two alternatives to prevent non-native fish in Lake Powell from passing through Glen Canyon Dam into the downstream river. Preliminary concepts presented in a 2022 options report (Svoboda 2022) are summarized along with a discussion of how concepts were selected for further development to appraisal level. Appraisal level cost estimates for the two selected alternatives are provided in this report. Future phases would include a feasibility study and the final design process.

Concept Level Options

Preliminary Assessment of Options

The 2022 report “Glen Canyon Dam Fish Escapement Options” explored various fish exclusion devices and methods that may limit fish escapement at Glen Canyon Dam (Svoboda 2022). These preliminary options were examined in a broad sense and were not finely adjusted for site-specific conditions. Current applications were considered in the context of Glen Canyon Dam using readily available site data.

The devices were grouped into three categories: 1) in-reservoir barrier options, 2) at dam options, and 3) downstream removal. Each device was evaluated for scalability to large lateral and vertical dimensions, large capacity withdrawal, effectiveness in excluding non-native fish populations (particularly mid-size fish with approximate lengths of 40-200 mm [1.5-8.0 inches]), operational impact or loss of power production, inspection and maintenance requirements including impacts by invasive species, and recreational impact.

The concept-level report concluded there is no clear alternative that can fully eliminate non-native fish escapement from Glen Canyon Dam. A forebay barrier net or multi-stimulus barrier were most likely to minimize entrainment at the scale required for application to Lake Powell while limiting impacts to power production, operations, and recreation. A summary of each option presented in Svoboda (2022) is reviewed here.

In-Reservoir Barriers

Physical Barrier Screens

Physical barrier screens prevent the movement of fish using a porous rigid structure that allows water to flow while preventing objects larger than the opening size from passing through. Screen material is typically a metal framework consisting of wedge wire, profile bar, or woven wire mesh, along with support members.

Barrier Nets

A flexible fish barrier net is installed to allow water to pass through while physically blocking the movement of fish larger than the net open area. Fish barrier nets are typically made from polyethylene fiber or similar material. Nets are deployed from a surface floatation system and may extend fully to the reservoir bottom or extend to a partial depth in the water column. Nets can be installed and removed seasonally or left in place year-round.

Air Bubble Curtains and Underwater Acoustic Barriers

Air bubble curtains are created when compressed air enters a linear air diffuser, releasing bubbles through holes in the tubing line. A continuous screen of bubbles in the water column creates an unnatural visual cue for fish to avoid along with ancillary acoustic and hydrodynamic fields that may also deter fish. Underwater acoustic barriers are sound-based behavioral deterrents. Fixed submerged sound projector arrays create sound waves at a certain frequency and amplitude to induce an avoidance response in fish.

Multi-Stimulus Barriers

Multi-stimulus barriers use several types of behavioral deterrents in combination to create an avoidance response by fish. These multi-modal systems may incorporate an air bubble curtain, sound signals, and directional strobe light in a single barrier.

Carbon Dioxide Barriers

Infusion of carbon dioxide into water has shown promise as a chemical fish deterrent. Fish respond strongly to carbon dioxide by avoiding treated areas or becoming immobilized through narcosis. Carbon dioxide is nonselective to fish size and species.

Floating Barriers/Curtains

Floating barriers such as flexible curtains and rigid plates may be used to exclude fish or induce behavioral guidance. These barriers are attached to floating buoys and extend vertically in the water column. Curtains are also used for downstream temperature control.

Electrical Barriers

When electrical current passes between two or more metal electrodes, an electrical field is formed in the water. Fish in contact with an electrical field may experience various responses from avoidance to death depending on fish size and exposure time. Commercially available electric barriers can be installed with electrodes as vertical drops suspended from a cable, attached to pilings or buoys at the water surface, or flush-mounted on the river or reservoir bottom.

Other In-Reservoir Barriers

Other in-reservoir physical barriers include weirs, culverts, rock gabions, overshot and undershot gates, guide walls, and physical structures to create velocity barriers. Other in-reservoir non-physical barriers include underwater lights, seismic water guns arrays, submerged velocity jets, flow alteration, olfactory stimulus, turbulence, infrasound, spaced louvers, hanging chains, chemicals, ozone, and pheromones.

At Dam Options

Deeper Water Withdrawal

The centerline of the river outlet works, located near the left abutment of Glen Canyon Dam, is 96 ft below the centerline of the penstocks. Releasing water from deeper in the reservoir water column may prevent downstream passage of non-native fish that reside in the reservoir epilimnion, although the hydropower plant would be bypassed during releases from the river outlet works.

Turbine Mortality

Fish passing through turbines are susceptible to direct blade strikes, pressure changes that rupture the swim bladder, and shear stress that can result in descaling, stripping of the protective mucus coating, and tissue tearing. Mortality rates can depend on broad range of variables such as species, life stage, size, pressure differential, diameter of intake pipe and turbine, number of blades, size and shape of blades, speed of blades, fish passage location within turbine, intake velocity, and entrainment duration.

Energy Dissipating Valve

Energy dissipating valves can be used on reservoir outlets for in-line pressure reduction, flow control, and energy dissipation of outflow water to minimize downstream scouring of the outlet structure and river bed. A sleeve valve model has been used to eliminate fish and fish embryo survival by passing fish through small holes at high pressure on a reservoir discharge pipe.

Other At Dam Options

Other options at the dam include application of carbon dioxide or electricity at lethal dose inside the penstocks.

Downstream Removal

Manual Collection and Removal

Non-native fish that survive passage through Glen Canyon Dam could be continuously collected and manually removed from the Colorado River downstream of the dam. Methods include river-spanning barriers that guide fish into a sorting facility or boat-based removal efforts through electrofishing or netting.

Other Downstream Removal Options

Other options for fish that have passed through the dam include nets installed in the stoplog slots directly at the penstock exit to collect fish, physical impact on blocks or grates to reduce survival, or engineered drop structures to prevent further downstream movement.

Concept Option Evaluation

Options Evaluated

Several options presented in the concept report were further investigated by a subject matter expert panel, the appraisal design team, and project sponsors. The subject matter expert panel was formed in November 2022 to assist with evaluating the concepts presented in the options report and making recommendations on which options to carry forward for appraisal-level design. The panel consisted of biologists and engineers with specialized expertise in design and performance of fish exclusion devices, fish biology, civil design and construction, power operations, and adaptive management. A list of the panel members is included in Appendix A. Additional information gathered during concept option evaluation is also presented here.

Barrier Nets

The subject matter expert panel extensively discussed fish nets in the context of Glen Canyon Dam, including aperture sizing, depth of the net, anchoring, and biofouling considerations. Fish net technology is considered well developed and the time to implementation for a fish net was deemed to be faster than many of the other concepts. Similar barrier net installations were discussed by the panel along with a discussion of lessons learned that could be applied at Glen Canyon Dam. A fish net installation location approximately 1,000 feet upstream of Glen Canyon Dam, just downstream of the existing floating boom, was discussed in the most detail.

Sizing of the net aperture should exclude the target fish size class while minimizing debris clogging. In Lake Powell, mid-size fish are of greatest concern due to the possibility of this size class surviving

passage through Francis turbines. Larger fish would likely be susceptible to turbine blade strikes and larval fish would likely be susceptible to pressure change and shear stress. Fish block nets at Highline and Elkhead Reservoirs in Colorado are constructed with 0.25-inch and 0.375-inch openings, respectively. Although smaller larval fish and eggs can pass through a 0.25-inch opening, finer mesh screens present significant debris clogging issues.

The subject matter expert panel agreed that a pure Dyneema material, a high-tech sturdy polyethylene fiber well suited for nets due to its resistance to abrasion, light degradation, and fatigue (Martinez 2002), would be best suited for this application based on experience with several existing installations. Although the upfront cost is more expensive, nets made of pure Dyneema tend to be more durable and last longer than nets made of Dyneema blend. Full-depth exclusion barrier nets installed at Upper and Lower Baker Lake Dams in Washington in 2012 to guide downstream-migrating juvenile salmon into a floating surface collector system are constructed of Dyneema. The net dimensions are approximately 500,000 ft² with square mesh sizes of 0.25 in and 0.125 in, a length of about 2,000 ft, and an average depth of 300 ft. The nets are designed to accommodate pool fluctuations of up to 70 ft. The nets are secured with shoreline embedment anchors, weighed down with chains, and anchored to the reservoir bottom by ship anchors. The nets are deployed year-round and require minimal maintenance with the debris protection provided by upstream booms. The anticipated lifespan of these Dyneema nets is approximately 10 years (Peters 2016).

The Highline Lake barrier net in Colorado is 363 feet wide and 19 feet deep. The Dyneema net is replaced about every 7-8 years. One cause of deterioration of the Highline Reservoir barrier net is algal buildup that adds weight and causes sagging at the water surface. Anecdotal evidence also indicates shoreline degradation occurs due to wave action. The Elkhead Reservoir barrier net in Colorado is 575-feet long and 30-feet deep and constructed of Dyneema material. At Elkhead Reservoir, installation downstream from an 800-ft-long floating debris barrier protects the barrier net from large woody debris. At the shoreline, the net is laid on top of padding to minimize damage from shoreline abrasion.

A barrier net can be installed as a full exclusion net from the water surface to the reservoir bottom or installed as a partial depth net to block fish in the top of the water column. A full exclusion net would provide the highest level of exclusion, but this may not be needed for much of the year in Lake Powell, since low dissolved oxygen at deeper depths in the reservoir prevent fish from residing deep in the water column. Results from hydroacoustic surveys in 2022-2023 show that species of concern are located throughout the epilimnion and the epilimnion was between 82-115 ft (25-35 m) deep.

Anchoring and mooring a large exclusion net in a canyon would present an engineering design challenge. The design strategy would be dependent on anticipated velocity and geology and would need to consider additional loading due to biofouling. To prevent fish passage near the canyon walls, the net connection to the canyon wall would require tight tolerances to avoid openings. A metal panel or screen could be attached to the uneven canyon wall with a vertical face toward the reservoir that provides a flat attachment surface for the barrier net to raise and lower. Lake levels typically fluctuate up to 50 ft during spring runoff, so a net design would need to accommodate significant changes in lake level by either detaching and reattaching or traveling along a track. Another option to improve fish exclusion at the canyon walls could be localized installation of a non-physical barrier such as a bubble curtain or electric barrier.

Biofouling of the net is an important design consideration. Infrastructure installed near the dam face or in the reservoir forebay will be susceptible to biofouling by invasive quagga mussels *Dreissena bugensis*. The highest densities of mussels are found near existing infrastructure and canyon walls, rather than in the center of the reservoir. A 2019 study found rapid progression of mussel settlement on the penstock intake trashracks since a previous survey in 2017 (Kubitschek and Vermeyen 2019). Colonial hydroid *Cordylophora caspia* were found on settlement plates in Lake Powell in 2015 (Pucherelli et al. 2016). A 2023 study at Lake Powell examining ultrasound as a mussel control strategy showed significant biofouling by mussels and Colonial hydroid on settlement plates (Pucherelli et al. 2024, in draft).

Biofouling adds weight to barrier nets and subsequent loading on the floatation system and anchors. At Highline and Elkhead Reservoirs, sagging of the nets may allow fish to pass over the top of the nets. An effective design in Lake Powell would oversize the floatation system to minimize sagging at the water surface and thereby prevent water from overtopping the net. Nets must be inspected regularly for integrity. Elkhead Reservoir net is typically cleaned about four times per year between April and October due to algal growth.

Reclamation has been testing anti-foul and foul-resistant coatings for 15 years and has not identified any coatings that would be suitable for net or curtain material. Application of commercially available silicone foul release coatings can be used on hard surfaces to limit mussel attachment. Copper ions can help to resist mussel attachment, but it may not be feasible to infuse copper in with the Dyneema fabric as a long-term solution. Pacific Northwest National Laboratory is investigating additional types of coatings that may be applied to fibers to reduce biofouling. Reclamation is currently conducting a research study to examine the effectiveness of various coatings in limiting mussel attachment on nets and curtains.

Another possible installation location for a fish net is closer to the penstock intakes. A barrier net could be constructed in a vee shape upstream of the penstocks with a rigid support column extending to the reservoir bottom at the upstream apex of the vee. The ends of the net would be affixed directly to the upstream dam face which would provide easier vertical travel when the water level changes. Installing a net closer to the penstock intakes increases dam safety concerns about the risk associated with net failure. Biofouling or debris clogging of the net would increase head loss and nonuniform high velocities entering the penstock pipes which could produce adverse flow conditions into the penstocks.

Other options discussed were the possibility of having two in-line nets, so that one remains in place when the other is removed for cleaning. Implementation of more than one deterrent technology in series was also discussed.

Air Bubble Curtains

Air bubble curtains use compressed air (typically atmospheric) in a linear air diffuser. The inner pressure releases bubbles through holes in the tubing line which forms a curtain of dispersed bubbles. Air bubble curtains can act as a visual deterrent for fish and can also create ancillary acoustic and hydrodynamic fields that may deter fish.

An air bubble curtain is an attractive option in that the time to implementation could be faster than other alternatives, the device may increase dissolved oxygen levels in the forebay, and the operation would not impact hydropower. However, exclusion rates are uncertain for species of concern and an air bubble curtain is likely to be less effective than a physical barrier at overall exclusion.

Performance of air bubble barriers is impacted by installation depth, flow velocity, turbidity, and the spacing of the bubble manifolds and air pressure (Noatch and Suski 2012).

Air bubble curtains are typically used in shallow waters. In deep water columns, air bubble curtains tend to disperse by the time the bubbles reach the water surface. Another challenge would be maintaining equal pressure across varying depths. Large-scale air bubble curtains require large volumes of air supplied by substantial onshore equipment and annual operational costs could be significant. Anchoring and mooring a large air bubble curtain in a canyon would be challenging to design. The upwelling of an air bubble curtain installed in the forebay has the potential to pull cooler hypolimnetic water closer to the reservoir water surface; however, an air bubble curtain installed near the reservoir bed may circulate nutrients with unintended consequences.

An air bubble curtain could be used in combination with a physical device such as a barrier net to provide better overall exclusion by deterring fish in locations where a net cannot provide full exclusion, e.g., along the canyon walls or between the bottom of the net and the reservoir bottom.

Floating Barriers/Curtains

Installation of a flexible impervious curtain was discussed to limit fish entrainment while providing the added benefit of passing cooler water downstream. Temperature curtains are typically suspended in the water column by floating buoys and anchored or tethered to the reservoir bottom. They are made from various types of synthetic fabrics including polyethylene. Unlike an exclusion net, which would fail to exclude fish smaller than the net open area, a curtain may provide better exclusion, assuming it extends deep enough in the water column. Hydrodynamic modeling is needed to determine if a curtain could reduce downstream temperatures below 16 degrees C at the reservoir release location to prevent spawning of smallmouth bass downstream of Glen Canyon Dam. Installation of a curtain could result in water quality issues related to increasing total dissolved solids above the salinity target in the release flow and/or reducing dissolved oxygen. A fish barrier curtain would experience higher overall loads and would require more substantial anchoring than a barrier net. Like a barrier net, a curtain would be difficult to seal along the canyon wall while allowing for vertical travel with changes in water surface elevation.

Reclamation has experience in installing thermal curtains at Whiskeytown Reservoir in California (Gee et al. 2012). The intent of this curtain is to lower the downstream release temperature rather than preventing fish movement. The first curtain was installed in 1993, and subsequently replaced in 2011 with additional repairs in 2017. The Whiskeytown curtain is approximately 2,400 ft long, 100 ft deep, and constructed of polypropylene. There is a 30 ft gap between bottom of curtain and reservoir bottom. Reclamation has also installed two temperature curtains at Lewiston Reservoir in California. An 830-ft-long, 35-ft-deep fixed temperature control curtain was installed in 1992 to reduce downstream temperatures at the Clear Creek tunnel and an 1,100-ft-long, 13-ft-deep semi-adjustable temperature curtain was installed to provide desirable water temperature to the Trinity River Hatchery (National Marine Fisheries Service 2020, Vermeyen 1997).

Energy Dissipating Valve

Installation of energy dissipating valves in the penstocks at Glen Canyon Dam would likely eliminate most fish survival, however, this option has significant drawbacks and uncertainties. While energy dissipating valves have been successfully used at Ridges Basin Dam in Colorado to reduce fish survival, there is no precedent for installation of a sleeve valve at a hydropower facility for fish mortality (Bark et al. 2014). If the valve is installed upstream of the turbines, there would be significant impacts on power generation due to increased head loss in the penstock. If the head loss

is too high, power production would no longer be feasible without the risk of damage to the turbine runners. There is also the potential for cavitation damage at the valve itself, as flow (approximately 3,000 cfs) passing through the valve openings would be at high velocity and low pressure. If located downstream of the turbines, the flow would be at low pressure with a draft tube velocity of about 5 ft/s, reducing the effectiveness of the valve for fish mortality. Pressure could also back up between the outlet and the power unit to a pressure above the design capacity of the draft tubes. This type of technology has unknown maintenance and cleaning requirements for this application. There could also be challenges with installing the valve and taking it offline in emergency situations or for regular maintenance without major disruptions to dam operations and power production.

Options Not Evaluated

The following concepts were discussed briefly by the subject matter expert panel and design team but were not evaluated in detail.

- **Physical Barrier Screen in Reservoir** – An exclusion screen in the reservoir made from wedge wire or profile bar would be difficult to design and construct due to the size of the screen and required attachment points at the canyon walls. A floatation system to support the weight of semi-fixed hanging panels would be complex to design. A rigid support structure may need to extend to the reservoir bottom to support the weight of the screen. Gaps would need to be sealed. Cleaning with automated traveling brushes, air burst, or other systems would be required to clean the screen underwater and in place. Due to the lack of sweeping velocity (the velocity vector parallel with the face of the screen), cleaned debris may not move far from the screen, and quickly be pushed back against the screen.
- **Physical Barrier Screen at Penstock Intake** – A fixed screen located at or upstream of the eight penstock intake trashracks would eliminate some design complexities related to installation in the reservoir. A screen could be constructed in a vee shape upstream of each penstock with a rigid support column extending to the reservoir bottom at the upstream apex of the vee. Alternately, the penstock intake trashracks could be modified from the current 12-inch bar spacing to a smaller opening size to exclude a target fish size class. Upstream of fixed-wheel hydraulically operated gates, guides and seats for stoplogs were installed to provide a means for inspecting and maintaining the gate frame and guides. The stoplog guides and seats could be used to install some type of screen for the same purpose. Installing screens at or near the penstock intakes may result in adverse flow conditions that impact power production. Debris clogging of a fine screen would produce increased head loss and nonuniform high velocities entering the penstock pipes. In addition to maintenance considerations related to debris clogging and removal, higher velocities could result in fish becoming impinged on the screen. Failure to keep the screens unclogged could also result in the penstock intakes becoming inoperable. Due to maintenance and operational difficulties, this concept was not advanced to appraisal level.
- **Underwater Acoustic Barriers** – Underwater acoustic barriers have uncertain effectiveness as a standalone deterrence system for the fish species present in Lake Powell. The U.S. Army Corps of Engineers has been extensively testing sound deterrence, including seismic technologies, for invasive carp species since they have specialized hearing abilities (Popper 1972), but the effectiveness of these types of systems on species of concern in a large open

water body needs to be studied prior to pursuing this type of barrier as an option for Glen Canyon Dam.

- Carbon Dioxide Barriers – The efficacy of a carbon dioxide barrier in a large reservoir setting is unknown. Carbon dioxide has been used as a deterrent in confined water bodies such as ponds and locks. It is possible that a large volume application would require significant land-based infrastructure with high ongoing operational costs and water quality impacts would need to be studied.
- Multi-Stimulus Barriers – A multi-faceted behavioral barrier deterrent (e.g., acoustic, light, air bubbles) would likely be more effective than individual behavioral deterrents, but efficacy is not fully understood for this application. Large-scale gas injection and sound modulation requires land-based infrastructure and continuous energy along with dive inspections and cleaning.
- Submerged Pump with Draft Tube – This option uses a submerged pump to move water from deep in the reservoir through a vertical draft tube toward the penstock intakes to reduce fish entrainment and reduce downstream release temperatures. The effectiveness of this type of system in deep-water reservoirs was deemed uncertain with no precedents at large-scale and water quality issues would also need to be addressed.
- Electrical Barriers – A large electrical barrier installation in the reservoir may not have high enough exclusion rates for the target size class of mid-sized fish. Other considerations include ongoing operating costs and safety concerns. There was some interest in investigating the use of lethal electricity inside the penstock pipes or downstream of the draft tube at the stop log slots. Proximity of the electric field within the penstocks to the turbines would require consideration during the design process to ensure that the power units are not negatively impacted. This type of installation has unknown efficacy, and no similar types of installations could be found. This concept could be a good candidate for future investigation due small scale, ease of access, and potential for on-site fabrication.
- Deeper Water Withdrawal – Releasing water from deeper in the reservoir has significant impacts to hydropower production because no power is generated with this option. Use of river outlet works for extended operational periods is being considered in separate studies.
- Turbine Mortality – With the existing Francis turbines, it is unlikely that turbine mortality is high enough to eliminate passage of all fish. Modifying or replacing the turbines in Glen Canyon Powerplant is not a feasible option.
- Manual Collection and Removal – Installation of a downstream collection facility is not practical in the Glen Canyon tailrace, however, electrofishing downstream of the dam could occur on an as-needed basis to manually collect fish.
- Downstream Netting at Draft Tubes – The existing stop log slots at the draft tube exit could be used to install a physical screen or net to block downstream passage of fish. In the draft tubes, flow velocities are approximately 5 ft/s, so it is unlikely that fish would experience impact mortality. The screen or mesh would have similar drawbacks and hazards as the sleeve valve installation, namely the risk of back pressuring the draft tubes and affecting turbine efficiency. A screen installed within the draft tube would also have cleaning requirements to prevent blockage and further back-pressuring.
- Flow Modifications – Options such as reducing flows during spawning periods, using flushing flows and/or releasing colder water to disrupt spawning, or increasing turbidity of release flows could reduce establishment of non-native fish downstream of the dam.

Appraisal Level Alternatives

Options Recommended for Appraisal Level

The subject matter expert panel determined that two of the conceptual design options, the fish exclusion net and the fish exclusion curtain, should advance to appraisal level design due to their likely effectiveness and potential for rapid implementation. Other concepts may merit an appraisal level design and evaluation in the future, either as standalone options or for use in conjunction with a fish exclusion net or curtain to improve the overall effectiveness of the project.

Alternative 1 – Fish Exclusion Net

Description

Alternative 1 includes a 1,050-ft-long, 100-ft-deep fish barrier net with ¼-inch openings, installed in modular 100-ft sections to allow for replacement of individual sections. The netting material should be pure Dyneema polyethylene fiber. A foul resistant coating is not included in the appraisal design. The fish barrier net would be installed in the dam forebay from canyon wall to canyon wall downstream of the existing debris boom to protect the net from impact by large debris (Figures 5 and 6). Embedment anchors would need to be installed on each canyon wall to anchor the net in place. The appraisal design includes an 18-inch-diameter co-extrusion high-visibility high density polyethylene floatation system with connections based on standard boom designs, with a submersible boat gate built in to allow for boat travel.

In similar projects, fish exclusion nets have been installed and left in place. Due to the extensive length of the net barrier and no icing concern in Lake Powell, the net can stay installed if biofouling can be managed, and invasive mussels do not occlude the openings. Nets installed in other locations are inspected and cleaned by divers several times per year to maintain effectiveness. Barrier nets can also be cleaned by removing the net, pressure washing, drying, and reinstalling the net. Depending on debris impacts and ultraviolet radiation, the lifespan of the net is estimated to be approximately 10-15 years.

Installation of a net upstream of a dam creates infrastructure safety concerns. If the net dislodges, it could block spillways or outlets or become entrained into penstocks. A Dam Safety Risk Analysis would be required to identify potential impacts to dam safety and operations if a fish barrier net were installed upstream of Glen Canyon Dam.

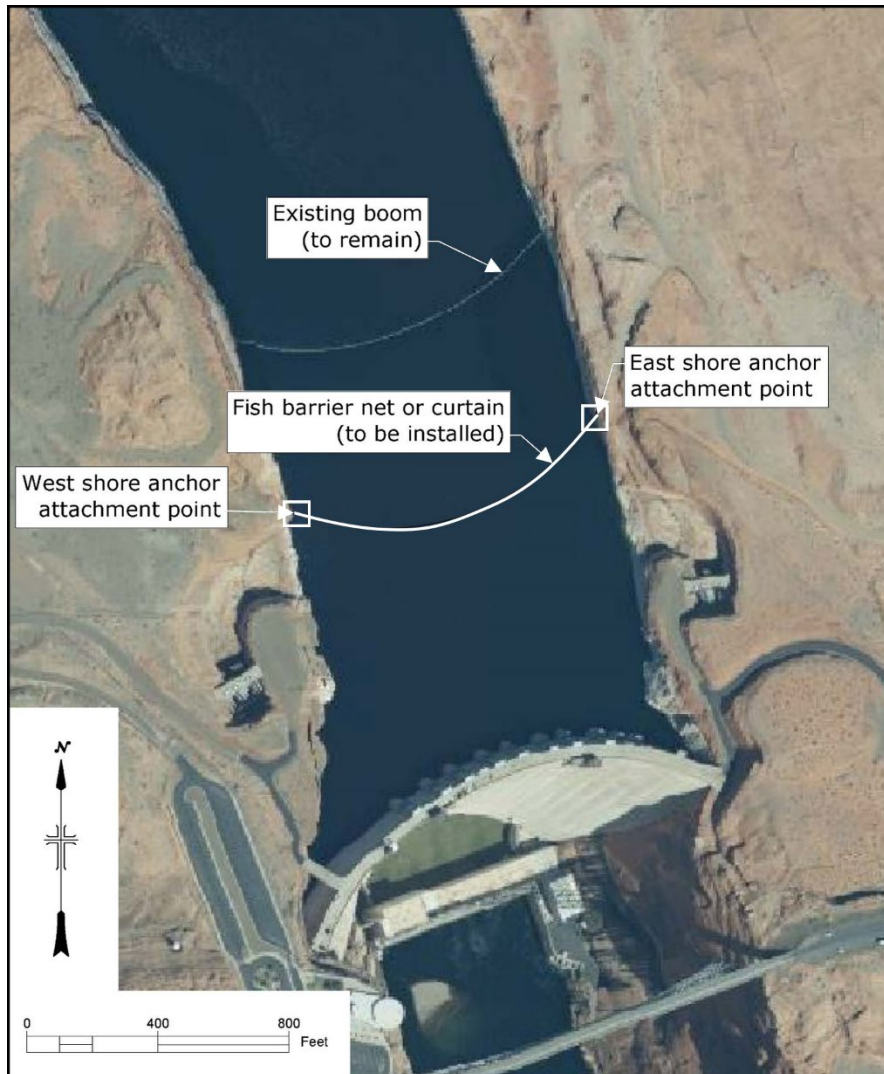


Figure 5. Approximate installation location of fish barrier net or curtain at Glen Canyon Dam in plan view.

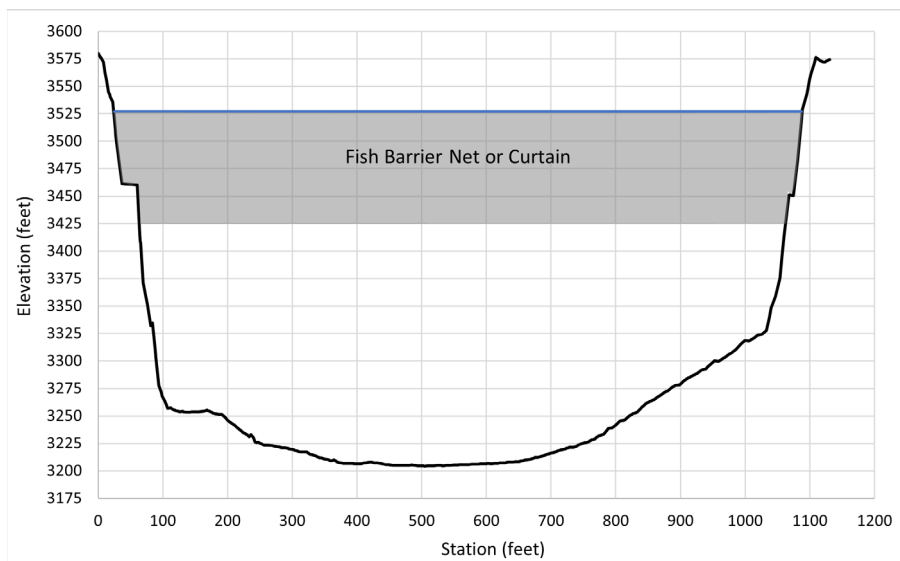


Figure 6. Example of fish barrier net or curtain placement at Glen Canyon Dam showing how the net or curtain would encompass the top 100 ft of the water column at a reservoir elevation of 3,525 ft.

Design Considerations

Mesh size

To achieve exclusion for mid-sized fish species of interest, a small mesh size is required. In general, the smaller the mesh size, the greater the fish exclusion. However, a smaller mesh size also leads to increased debris clogging, biofouling, and cost. For appraisal-level design, the subject matter expert panel recommended a square mesh with a clear opening (the space between parallel strands) of 0.25 inch.

Net depth

For installation upstream of Glen Canyon Dam, the depth of the net would need to be sized to block the maximum depth of the epilimnion layer. The location of the epilimnion varies based on water year, reservoir elevation, and time of the year. Although the net will move with changing reservoir elevation, the net depth will be fixed.

The net depth should be determined by fisheries experts using emerging data on fish abundance and location and water surface trends. The design team recommends that the net depth be revisited during final design. To prepare an appraisal design and cost estimate, a net depth of 100 ft was selected by the subject matter expert panel and project sponsor.

Elevation range

The net could either be fixed or dynamically attached to the canyon walls. A fixed attachment would be the simpler design of the two, with a net securely anchored to a fixed position on the wall. However, as the water surface drops, the net would become visible and remain suspended at the same elevation above the water. Additionally, it would only be effective under a set range of reservoir levels and would be less effective if reservoir elevations decline since some of the height of the net would be above the water. A dynamic attachment would allow the net to lower along with the water surface with the full net depth under the water surface. For the appraisal design and cost

estimate, the subject matter expert panel and project sponsor selected a total vertical elevation range of 300 ft, with 100 ft as the net depth. The estimated elevation range should also be reassessed during final design.

Anchoring and canyon wall attachments

There is considerable uncertainty in the anchoring system, mooring system, canyon wall attachment requirements, and vertical adjustment mechanism in the appraisal level design. To achieve a high level of exclusion, there must be a tight connection between the fish net and the canyon wall. The irregularity and steepness of the canyon walls do not allow for traditional reservoir net shore anchoring systems. Most nets contain sandbags under the nets along the shoreline so that as the water surface declines, the sandbags rest on the ground and maintain exclusion. A similar type of sandbag design would not work on a near-vertical face. The connection to the canyon wall would need to allow for movement, and some transfer of load from the net. It is assumed that there will need to be grouted anchors installed in the canyon wall to support such a connection. Assumptions about anchoring requirements at the appraisal level are included in the Basis of Cost Memo (Appendix B) and the Estimate Worksheet (Appendix C). These anchoring requirements should be verified with structural analysis in subsequent design phases and must consider additional loading anticipated due to biofouling of the net. To accommodate a 300 ft elevation range, on either side of the canyon, a 300-ft-high scribed, tracked, or otherwise improved connection to the canyon wall would be required. For appraisal design, this was assumed to include grouted anchor bars, expansion anchors, banding bars, and netting material (Figure 7).

Installation of the canyon wall attachments would consist of work above the water, and work below the water. For the appraisal level cost estimate, it was assumed that the work would be divided between 50 feet of work above the water and 250 feet of work below the water. Any work done below 100 feet depth increases difficulty, as it becomes full saturation diving where the divers must remain pressurized and at depth for significant amounts of time. Deep dive work also becomes costly due to these same requirements.

The specifics of the dynamic connection to the canyon wall would need to be designed by a netting specialist, and would need to satisfy the following constraints:

- Maximum opening area same as net (0.25 inch maximum gap)
- Allow for minimal operation and maintenance involvement and adjustment
- Minimize aquatic growth on attachment or can operate in the presence of mussels and aquatic vegetation

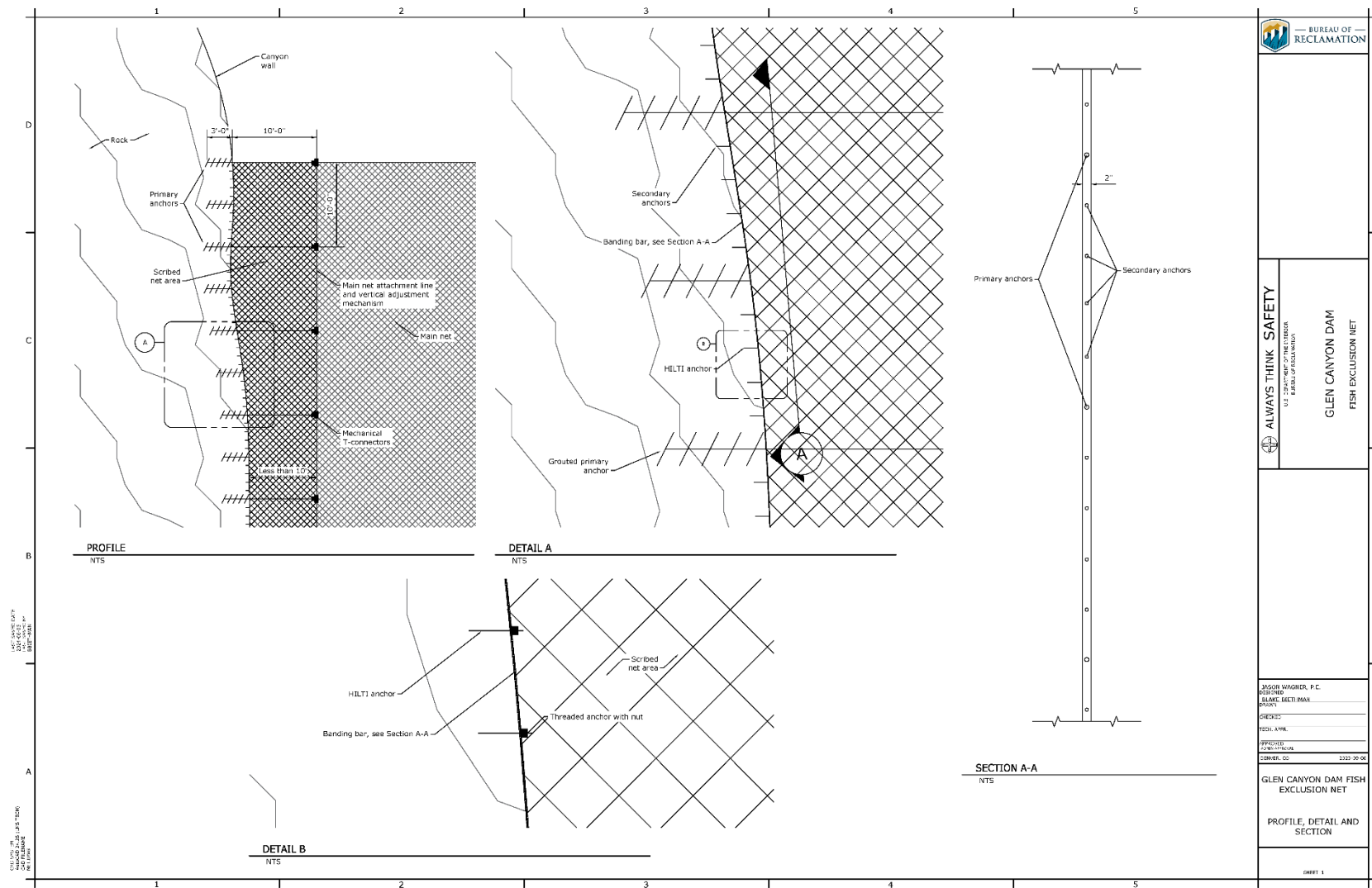


Figure 7. Appraisal level design drawing of fish exclusion net.

Cost Estimate

Table 1 presents a summary of the appraisal level cost estimate for the partial depth fish exclusion net. Appendix B includes the Basis of Cost Memo that describes the appraisal level cost estimate and Appendix C includes the Estimate Worksheet for the cost estimate. The appraisal level field cost for the fish exclusion net was \$22,000,000 in April 2023. Escalation to Notice to Proceed and non-contract costs have not been included in the cost estimate and need to be considered for budgetary purposes.

The cost estimate is based on a preliminary design with limited or no details for some components. Estimates on access and mobilization areas were made. The rock hillside attachment and anchoring system, canyon wall scribed net, vertical adjustment mechanism, and mooring system and anchors are more costly than the netting material and require additional design to reduce uncertainty in cost and constructability.

Table 1. Appraisal level cost estimate for partial depth exclusion net based on an estimate created in April 2023.

Description	Appraisal Alternative 1 – Fish Exclusion Net (April 2023)
Subtotal	\$14,125,000.00
Mobilization	Included in Pay Items
Subtotal with Mobilization	\$14,125,000.00
Contract Cost Allowances (+/-25%)	\$3,375,000.00
Contract Cost¹	\$17,500,000.00
Construction Contingencies (+/-25%)	\$4,500,000.00
Field Cost² (Apr-23)	\$22,000,000.00
Escalation to NTP	N/A
Field Cost with Escalation	N/A
Non-Contract Costs ³	To be determined by the appropriate responsible office
Feature Construction Cost⁴	To be determined by the appropriate responsible office

1) Contract Cost – The estimated cost of the contract(s) at the time of award at this Unit Price Level

2) Field Cost – Value established to accommodate construction and contract closeout

3) Non-Contract Costs – The estimated costs for Reclamation and/or service contractors to implement the work

4) Feature Construction Cost – The sum of Field Cost and Non-Contract Costs; the estimated budget value

Alternative 2 – Fish Exclusion Curtain

Description

Alternative 2 includes a 1,050-ft-long, 100-ft-deep fish exclusion curtain, installed in modular 100-ft sections to allow for replacement of individual sections. The curtain material would be vinyl sheet at a thickness of 1/8 inch. A foul resistant coating would not be included with the curtain because there are no fibers for the coating to adhere to. The curtain could be furnished with various connection options to the floats, weights, or between curtain sections such as zippers or grommets.

The curtain would be installed at the same location as Alternative 1, from canyon wall to canyon wall in the dam forebay downstream of the existing debris boom (Figures 5 and 6). Embedment anchors will need to be installed on each canyon wall to anchor the net in place like Alternative 1. The appraisal design includes an 18-inch-diameter co-extrusion high-visibility high density polyethylene floatation system with connections based on standard boom designs, with a submersible boat gate built in to allow for boat travel.

Since the fish exclusion curtain is an impervious physical barrier that blocks flow of water near the surface and forces deeper water underneath of the curtain, the barrier would act as a temperature curtain. Colder water would pass downstream of the curtain in a stratified reservoir with the potential of reducing outflow temperatures through the dam. Hydrodynamic evaluations are needed to better understand the expected reduction in downstream temperatures during various hydrologic scenarios to determine if the cooler release temperature provides added project benefits.

Like the fish exclusion net alternative, the curtain alternative assumes that the curtain will be left in place throughout the year and maintenance would be performed in place by divers. Curtain lifespan is expected to be about 10-15 years depending on debris impacts and ultraviolet radiation. Concerns about infrastructure safety exist for a curtain, and a Dam Safety Risk Analysis would be required to identify potential impacts to dam safety and if a fish barrier curtain were installed upstream of Glen Canyon Dam.

Design Considerations

Curtain depth

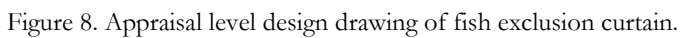
A curtain depth of 100 ft deep was selected by the subject matter expert panel and project sponsor as a basis for preparing an appraisal design and cost estimate. In addition to blocking movement of fish species of interest, the depth of the curtain could also be optimized through hydrodynamic modeling to reduce the temperature of the water released through the dam which could disrupt spawning of Smallmouth Bass and other warmwater non-native fishes.

Elevation range

For the appraisal level design and cost estimate for the curtain, the subject matter expert panel and project sponsor selected a total vertical elevation range of 300 ft, with 100 ft as the curtain depth. The estimated elevation range should be reassessed during final design.

Anchoring and canyon wall attachments

There is considerable uncertainty in the anchoring system, mooring system, canyon wall attachment requirements, and vertical adjustment mechanism in the appraisal level design for the curtain. To achieve a high level of exclusion, there must be a tight connection between the fish exclusion curtain and the canyon wall (Figure 8). Considerations for the canyon wall attachments for Alternative 1 also apply to Alternative 2.



Cost Estimate

Table 2 presents a summary of the appraisal level cost estimate for the partial depth fish exclusion curtain. Appendix B includes the Basis of Cost Memo that describes the appraisal level cost estimate and Appendix D includes the Estimate Worksheet for the cost estimate. The appraisal level field cost for the fish exclusion curtain was \$23,000,000 in April 2023. Escalation to Notice to Proceed and non-contract costs have not been included in the cost estimate and need to be considered for budgetary purposes.

The cost estimate is based on a preliminary design with limited or no details for some components. The cost of the curtain material was slightly higher than the netting material. A biofouling resistant coating was not included in the cost estimate. The floatation system was estimated as almost double that of a net due to additional loading on the curtain and the vertical adjustment mechanism cost was slightly higher. Estimates on access and mobilization areas were made. The rock hillside attachment and anchoring system, canyon wall scribed curtain, vertical adjustment mechanism, and mooring system and anchors are more costly than the curtain material and require additional design to reduce uncertainty in cost and constructability.

Table 2. Appraisal level cost estimate for a partial depth fish exclusion curtain based on an estimate created in April 2023.

Description	Appraisal Alternative 2 – Fish Exclusion Curtain (April 2023)
Subtotal	\$14,935,000.00
Mobilization	Included in Pay Items
Subtotal with Mobilization	\$14,935,000.00
Contract Cost Allowances (+/-25%)	\$3,565,000.00
Contract Cost¹	\$18,500,000.00
Construction Contingencies (+/-25%)	\$4,500,000.00
Field Cost² (Apr-23)	\$23,000,000.00
Escalation to NTP	N/A
Field Cost with Escalation	N/A
Non-Contract Costs ³	To be determined by the appropriate responsible office
Feature Construction Cost⁴	To be determined by the appropriate responsible office

1) Contract Cost – The estimated cost of the contract(s) at the time of award at this Unit Price Level

2) Field Cost – Value established to accommodate construction and contract closeout

3) Non-Contract Costs – The estimated costs for Reclamation and/or service contractors to implement the work

4) Feature Construction Cost – The sum of Field Cost and Non-Contract Costs; the estimated budget value

References

Bark, Raymond C., Eric L. Best, Kevin N. Bloom, K. Warren Frizell. 2014. Ridges Basin Dam Sleeve-Valve Passage Analysis of Nonnative Fish and Embryos at Increasing Depths and Pressures. Department of the Interior, Bureau of Reclamation, Technical Service Center. Technical Memorandum No. 86-68290-12-01.

Bureau of Reclamation. 2012. "Hydroacoustic Surveys of Pelagic Fishes in the Glen Canyon Dam Forebay: 2007-2009". Technical Service Center. Fisheries and Wildlife Resources Group. Denver, Colorado.

Friesen, Barrett, Phaedra Budy, and Casey Pennock. January 2024. "Identifying the drivers of entrainment risk of nonnative fishes through Glen Canyon Dam as a function of fluctuating reservoir elevation". Presentation at the Upper Basin Researchers meeting, Grand Junction, Colorado.

Gee, Bob, Greg Morris, and Stanford W. Slifer. June/July 2012. "Geomembrane curtain improves salmon habitat". Article in Geosynthetics magazine. Volume 30 Number 3.

Kubitschek, Joseph and Tracy Vermeyen. 2019. "Mussel-Related Impacts on Intakes at Glen Canyon Dam". Bureau of Reclamation, Technical Service Center, Hydraulic Investigations and Laboratory Services. Report ST-2019-1733-01

Lewis, Madeline C., W. Robert Cope, Thomas P. Miles, Claire Rude, Richard E. Bruesewitz, Benjamin J. Dodd, Mark K. Flammang, Kevin S. Page, Robert Weber, Michael J. Weber, and Max Wolter. 2022. Reservoir Fish Escapement in North America: A Historical Review and Future Directions. North American Journal of Fisheries Management. Special Section: Back to the Future of Reservoir Fisheries Management – What Have We Learned in 50 Years?

National Marine Fisheries Service. 2020. "Impacts of NOAA's National Marine Fisheries Service's Proposed 4(d) Determination under Limit 5 for the Trinity River Hatchery Coho Salmon Program". National Marine Fisheries Service, West Coast Region, Northern California Office.

Noatch, Matthew R. and Cory D. Suski. 2012. "Non-physical barriers to deter fish movements". Environ. Rev. Vol. 20: 1-12.

Peters, A. (2016). Technical Developments in Fish Exclusion, Guidance, and Collection Materials. In B. Crookston & B. Tullis (Eds.), Hydraulic Structures and Water System Management. 6th IAHR International Symposium on Hydraulic Structures, Portland, OR, 27-30 June (pp. 428-436). doi:10.15142/ T3130628160853 (ISBN 978-1-884575-75-4).

Peterson, M.J., G.F. Cada, M.J. Sale, and G.K. Eddlemon. 2003. Regulatory Approaches for Addressing Dissolved Oxygen Concerns at Hydropower Facilities. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies, Idaho Operations

office. DOE/ID-11071, Oak Ridge National Laboratory, Oak Ridge, TN. Published March 2003. 38 pp.

Popper, Arthur N. 1972. Pure-Tone Auditory Thresholds for the Carp, *Cyprinus carpio*. J. Acoust. Soc. Am. 52, 1714–1717.

Pucherelli S.F, J. Keele, Y.J. Passamanek, J.R. Beaver, TR. Renicker. 2016. Range expansion of the invasive hydroid, *Cordylophora caspia* (Pallas, 1771), in Colorado River reservoirs. BioInvasions Records 5(3): 133-137.

Pucherelli S., Y. Passamanek, C. Mower. 2024. In Draft. Ultrasonic Transducer Field Test for Quagga Mussel Settlement Control. Reclamation Science and Technology Program Final Report ST-2024-20061-01.

Svoboda, Connie. 2022. “Glen Canyon Dam Fish Escapement Options”. Bureau of Reclamation, Technical Service Center, Hydraulic Laboratory Report HL-2022-02.
<https://www.usbr.gov/uc/progact/amp/twg/2022-10-13-twg-meeting/20221013-GlenCanyonDamFishEscapementOptions-508-UCRO.pdf>

U.S. Fish and Wildlife Service. 2016. “Final Biological Opinion for the Glen Canyon Dam Long-Term Experimental and Management Plan, Coconino County, Arizona”. U.S. Fish and Wildlife Service, Phoenix, Arizona, November 28, 2016. AESO/SE 02EAAZ00-2012-F-0059 and 02EAAZ00-2014-CPA-0029.

Vermeyen, Tracy. 1997. Use of Temperature Control Curtains to Control Reservoir Release Water Temperatures. Bureau of Reclamation, Technical Service Center, Hydraulic Investigations and Laboratory Services. Report R-97-09.

APPENDIX A – Subject Matter Expert Panel Members

Agency	Participant Name	Title
Bureau of Reclamation – Technical Service Center	Jason Wagner	Civil Engineer
	Connie Svoboda	Supervisory Civil Engineer (Hydraulics)
	Shanna Durham	Mechanical Engineer
	Mike Horn	Supervisory Fish Biologist
	Blake Biethman	Civil Engineer
Bureau of Reclamation – Upper Colorado Basin Region	Bill Stewart	Group Chief, Adaptive Management
	Clarence Fullard	Group Chief, Water Quality
	Kerri Pedersen	Biologist, Adaptive Management Group
	Dave Speas	Fish Biologist, Adaptive Management Group
	Chris Cutler	Manager, Water and Power Service Division
	Bob Martin	Deputy Power Manager, Power Office
U.S. Fish and Wildlife Service	Kevin McAbee	Nonnative Fish Coordinator, Upper Colorado River Endangered Fish Recovery Program
	Nathan Clifton	Hydraulic/Fish and Aquatic Organism Passage Engineer
U.S. Army Corps of Engineers	Christa Woodley	Research Biologist, Engineer Research and Development Center
National Park Service	Melissa Trammell	Fisheries Biologist
Western Area Power Administration	Craig Ellsworth	Fisheries Biologist, CRSP Management Center
U.S. Geological Survey	Toby Kock	Supervisory Research Fish Biologist, Western Fisheries Research Center
	Summer Burdick	Research Fishery Biologist, Western Fisheries Research Center

APPENDIX B – Basis of Cost Estimate Memo

Date: 7/21/2023
 Project: Colorado River Storage Project – Glen Canyon Unit, AZ
 Feature: Glen Canyon Dam – Fish Exclusion Facility Project
 Region: Upper Colorado-Basin
 Estimate Level: Appraisal
 Unit Price Level: April-2023



Glen Canyon Dam Fish Exclusion Facility Basis of Cost Estimate Memo

EXECUTIVE SUMMARY:

A basis of estimate (BOE) is an organized set of data and narrative information that explains the logic, methodology, calculations, and assumptions were used to estimate the scope of work for this feature of construction.

The estimate includes the following allowances:

- Mobilization is included with the Pay Items, since the 5% typically used will not be sufficient to cover the Mobilization for this unique project.
- Contract Cost Allowances
 - o Design contingency 20%
 - o Allowance for Procurement Strategy 5%
- Construction Contingency 25%

The use of these contingencies is described in Reclamation Directives and Standards FAC 09-01.

Description	Appraisal Alt 1 – Net Option (April 2023)	Appraisal Alt 2 – Curtain Option (April 2023)
Subtotal	\$14,125,000.00	\$14,935,000.00
Mobilization	Included in Pay Items	Included in Pay Items
Subtotal with Mobilization	\$14,125,000.00	\$14,935,000.00
Contract Cost Allowances (+/- 25%)	\$3,375,000.00	\$3,565,000.00
Contract Cost¹	\$17,500,000.00	\$18,500,000.00
Construction Contingencies (+/-25%)	\$4,500,000.00	\$4,500,000.00
Field Cost² (Apr-23)	\$22,000,000.00	\$23,000,000.00
Escalation to NTP	N/A	N/A
Field Cost with Escalation	N/A	N/A
Non-Contract Costs ³	To be determined by the appropriate responsible office	To be determined by the appropriate responsible office
Feature Construction Cost⁴	To be determined by the appropriate responsible office	To be determined by the appropriate responsible office

1) Contract Cost – The estimated cost of the contract(s) at the time of award at this Unit Price Level

2) Field Cost – Value established to accommodate construction and contract closeout

3) Non-Contract Costs – The estimated costs for Reclamation and/or service contractors to implement the work

4) Feature Construction Cost – The sum of Field Cost and Non-Contract Costs; the estimated budget value

Date: 7/21/2023
Project: Colorado River Storage Project – Glen Canyon Unit, AZ
Feature: Glen Canyon Dam – Fish Exclusion Facility Project
Region: Upper Colorado-Basin
Estimate Level: Appraisal
Unit Price Level: April-2023



Field cost for Glen Canyon Dam Fish Exclusion Facility Alt. 1 – Net Option is \$22,000,000 at Unit Price Level April 2023. The Field cost for Alt. 2 – Curtain Option is \$23,000,000 at the same Unit Price Level April 2023. Please note that escalation to NTP and non-contract costs have NOT been included in these Appraisal Level Cost Estimates and need to be considered for budgetary purposes.

The costs are based on a very preliminary design, which required multiple assumptions to be made during the preparation of the cost estimates. The netting supplier provided budgetary cost ranges for the materials only for the net, boat gate and flotation system. They did not provide design recommendations, detailed pricing, or installation costs due to the lack of information available at this time.

BACKGROUND:

The Bureau of Reclamation is investigating alternate methods to prevent fish species upstream of the dam infiltrating downstream of it. This Appraisal Design proposes to suspend either netting or “curtain” across Lake Powell in the canyon section approximately 1,500 feet upstream of the dam with the ability to move vertically with the reservoir water surface fluctuations, while still maintaining the seal against the canyon walls. The project proposes to provide approximately 1,050 feet wide by 100 feet deep net or curtain system across the canyon. This option is one among others that are being looked at to prevent the infiltration of upstream species to downstream of the dam.

BASIS OF ESTIMATE:

This cost estimate was in general prepared using detailed ‘bottom up’ costs for each item. The details combine the information provided on the Quantity Estimate Worksheets (QEWs) with site specific pricing for labor, equipment, materials and assumed production rates. The estimate was prepared with the best information available at a Unit Price Level of April-2023 and required multiple assumptions to be made.

Reference Documents

- Quantity Estimate Worksheets (QEWs) provided by Blake Biethman on May 1, 2023
- Hand drawn sketch “Canyon Wall Detail” for rock hillside netting attachments system
- Project Specifications and drawings not available at the time of estimate

Direct Costs

- Labor - based upon Davis-Bacon wage rates for Coconino County in the state of Arizona.
- Equipment rates are 2022 rates from Equipment Watch and Oceaneering 2022 diving equipment catalog.
- Materials: Supplier budgetary cost ranges for net materials (net, boat gate and flotation system only); also online pricing or best available information used.
- Production Rates: Discussions with diving industry experts for development of cost driver production rates, and estimator judgement.

Indirect Costs

- Project Duration: assumed 7 months
- Home Office G&A: 6%

Date: 7/21/2023
Project: Colorado River Storage Project – Glen Canyon Unit, AZ
Feature: Glen Canyon Dam – Fish Exclusion Facility Project
Region: Upper Colorado-Basin
Estimate Level: Appraisal
Unit Price Level: April-2023



- Markup: 10%
- Escalation During Construction: 4% annual rate
- Insurance and Bonding: 2%

ASSUMPTIONS/EXCLUSIONS:

- Estimate assumes no direct land access is available and that all work will be completed within the reservoir from equipment barges that include cranes and extensive dive work support equipment.
- Estimate assumes that a rock jetty can be established at the Wahweap Marina area and be used for mobilizing and demobilizing the barge system, the dive equipment and cranes. The rock jetty would be removed once the project has been completed.
- Estimate assumes the Wahweap Marina area can also be used for staging area for small office, parking, access for boats to move crew and materials to and from the barges at the work area by the dam.
- Per discussion with netting supplier, estimate assumes netting materials cost for net, boat gate, flotation system based budgetary cost range provided by supplier. The budgetary range did NOT include any installation costs. Estimator assumed a crew and production rates for installation of these materials.
- Netting supplier indicated that just for the actual curtain material the cost of the curtain and net material only are “about equal”; the estimates assume that. However, the estimate assumes that since the curtain is effectively a “dam” the cost for the chain weights, curtain connections and flotation system would be higher than for the net; estimate assumes the curtain flotation material costs would be double that of the net option.
- Estimates assume that rock hillside attachments for both systems are the same as shown on the “Canyon Wall Detail” sketch and in QEWs descriptions.
- The QEWs require the net or curtain systems to have allowances for reservoir water fluctuations up to 200 feet, which with the 100 feet tall net or curtain, requires the rock hillside attachments be a total of 300 feet vertically on each canyon wall.
- Estimates assume, per discussion with design team, the installation of the rock hillside attachments will be 50 feet above the reservoir water surface and 250 feet below.
- Estimates assume that divers will be required for the installation work in the water. Per discussions with a diving contractor, the underwater work assumes air diving at 0-100 feet depth working 6 days per week, 10 hours per day, and Saturation diving at 100 to 250 feet depth working 7 days per week, 24 hours per day.
- Budgetary diving costs were received from one diving contractor. These costs in addition to another diving work cost estimate completed recently were used as references for completing these estimates.
- Vertical Attachment Mechanism which attaches to the scribed net or curtain and allows the net or curtain to adjust vertically was not designed. The netting supplier declined to provide potential solutions so the system has been assumed at a plug cost per foot for materials for the net option. For the curtain option materials estimate assumes a 20% higher cost. No details have been designed or provided to complete the estimates. Divers were assumed for the in-water work while the above water work assumes working from a barge system with equipment and manlift baskets on them.

Date: 7/21/2023
Project: Colorado River Storage Project – Glen Canyon Unit, AZ
Feature: Glen Canyon Dam – Fish Exclusion Facility Project
Region: Upper Colorado-Basin
Estimate Level: Appraisal
Unit Price Level: April-2023



- No design was provided for the mooring system. The estimate used information from another project for material and installation costs with addition of diving work to set the system.

POTENTIAL COST SAVINGS:

- Consider full and open competition solicitation.

RISKS AND UNCERTAINTY:

- Project is at a preliminary design stage with limited or no details for some components that at later design stages will impact costs once more details are available.
- There are limited netting/curtain suppliers available to provide this system.
- Vertical Attachment Mechanism still requires to be designed.
- Rock Hillside Attachments still requires to be designed.

CURRENT STATUS:

The Region and Technical Services Center (TSC) will consider these two options and others to determine how to proceed to achieve the objective of reducing or preventing upstream fish species from infiltrating the downstream waters. Currently, no other milestone has been established.

CONTACTS:

Brian McLeod, Group Manager, Estimating Services Group (303) 445-3485
Tom Hanke, Senior Estimator, Estimating Services Group (303) 445-3083

APPENDIX C – Fish Exclusion Net Appraisal Cost Estimate

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 1 - Net Option		PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ					
		WOID: GCFEX		ESTIMATE LEVEL: Appraisal			
		REGION: UC		UNIT PRICE LEVEL: Apr-23			
		FILE: Z:\DO\TSC\Jobs\UC\Glen Canyon Dam\2022-PDC-Fish Escapement\APR\EST\8170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls.xlsx\GCFEX A1					
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	Alt 1-01	Fish Exclusion Netting	8150	1	LS	\$2,100,000.00	\$2,100,000.00
		Made of all Dyneema (not dyneema blend)					
		1/4" mesh grid size					
		Overall length: 1050 ft					
		Net height: 100 ft					
		The overall length is to be broken up into component sections approximately 100 ft in length to allow for replacement of individual sections. The seams need to include a system to allow a section of the net to be replaced in place within the reservoir, likely by divers.					
		Designed for water velocities up to 1.0 ft/s					
		Single direction flow					
		Needs to allow for reservoir water surface fluctuations up to 200 feet					
		Once deployed, the net will remain in service and NOT be seasonally removed					
		If a coating that protects against mussel growth is available, include it in the net cost					
		Info from a distributor is provided below:					
		https://www.pacificnettingproducts.com/wp-content/uploads/2022/03/Dyneema.pdf					
		https://www.pacificnettingproducts.com/wp-content/uploads/2022/03/Netting-Case-Studies.pdf					
	Alt 1-02	Submersible boat gate	8150	1	LS	\$125,000.00	\$125,000.00
		Located along the net to allow for boats to pass over top of the net if required.					
		This feature is similar to the one installed at Tacoma Power/ Cushman Dam, which is referenced in the netting case studies PDF above.					
	Alt 1-03	Floatation system	8150	1	LS	\$600,000.00	\$600,000.00
		Total length of floatation line: 1050 ft					
		Include hi-visibility floats					
		SUBTOTAL THIS SHEET					\$2,825,000.00
QUANTITIES			PRICES				
BY Blake Biethman		CHECKED Jason Wagner		BY T. Hanke		CHECKED B. Ahern	
DATE PREPARED 05/01/23		PEER REVIEW / DATE Jason Wagner		DATE PREPARED 07/20/23		PEER REVIEW / DATE A. Galardi	

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 1 - Net Option		PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ					
		WOID: GCFEX		ESTIMATE LEVEL: Appraisal			
		REGION: UC		UNIT PRICE LEVEL: Apr-23			
		FILE: T:\Jobs\UC\Glen Canyon Dam\2022-FDC-Fish Escapement\APR\EST\6170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls;xls\GCFEX.A2					
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	Alt 1-04	Rock hillside netting attachments	8150	1	LS	\$5,115,000.00	\$5,115,000.00
		The side attachments for the net are not typical, and a similar case study could not be found.					
		The attachments go the height of the net, plus the range the WSEL can vary. Assuming the net is 100 ft tall, plus a 200 ft WSEL range, so a total of 300 ft of attachments on each side					
		Drilling of primary rock anchors (underwater)		122	EA	Included above in Item Alt 1-04	
		Assume rock anchors drilled 3 ft deep, 1" OD					
		Vertical spacing on holes = 5 ft, 300 ft range					
		Total holes = 61 on each side = 122 total					
		Drilling of secondary rock anchors (underwater)		480	EA	Included above in Item Alt 1-04	
		Assume rock anchors drilled 5 inches deep, 3/4" OD					
		Vertical spacing on holes = 1 ft, 300 ft range					
		No holes needed where the primary anchors are placed					
		Total holes = 480					
		Primary anchors (high tension)		122	EA	Included above in Item Alt 1-04	
		Assume cable is 3/4" braided stainless cable					
		Total cable length (including embedment) = 13 ft					
		Epoxy grouted into sandstone walls					
		Secondary anchors (low tension)		480	EA	Included above in Item Alt 1-04	
		HILTI products or similar					
		1/2" diameter stainless anchors					
		Anchor length = 8", epoxy grouted					
		Threaded free end with nut					
		SUBTOTAL THIS SHEET					\$5,115,000.00
QUANTITIES				PRICES			
BY		CHECKED		BY		CHECKED	
Blake Biethman		Jason Wagner		T. Hanke		B. Ahern	
DATE PREPARED		PEER REVIEW / DATE		DATE PREPARED		PEER REVIEW / DATE	
05/01/23		Jason Wagner		07/20/23		A. Galardi	

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 1 - Net Option				PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ			
WOID: GCFEX				ESTIMATE LEVEL: Appraisal			
REGION: UC				UNIT PRICE LEVEL: Apr-23			
FILE: Z:\DO\TSC\Jobs\UC\Glen Canyon Dam\2022-PDC-Fish Escapement\APR\EST\8170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls\GCFEX A3							
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	Alt 1-05	Canyon wall scribed net. See figure	8150	1	LS	\$1,515,000.00	\$1,515,000.00
		Vertical banding bar (low tension)					
		Assume 1/16" x 2" strip stainless banding bar.					
		Length = 600 ft. Drilled every 1 ft.					
		Main net attachment line (higher tension)					
		Assume 3/4" stainless braided cable					
		Length = 600 ft					
		Mechanical T connectors to attach					
		drilled anchors to this line. 122 ea					
		Netting material					
		Assume same material as primary net					
		Area = 10' x 300 ft = 3,000 ft2 for					
		each side, 6,000 ft2 total					
	Alt 1-06	Vertical adjustment mechanism	8150	1	LS	\$2,270,000.00	\$2,270,000.00
		System that attaches to the canyon wall					
		scribed net and allows the net to					
		adjust vertically. This feature will					
		require the manufacturer to engineer					
		a site specific solution.					
	Alt 1-07	Mooring system and anchors		1	LS	\$700,000.00	\$700,000.00
		Sunken anchors and mooring system					
		Assume a minimum of 2 sunken anchors					
		to be placed upstream of the net.					
		<i>Estimator Added Item:</i>					
	Alt 1-08	Mobilization and Preparatory Work		1	LS	\$1,700,000.00	\$1,700,000.00
		SUBTOTAL THIS SHEET					\$6,185,000.00
QUANTITIES				PRICES			
BY Blake Biethman		CHECKED Jason Wagner		BY T. Hanke		CHECKED B. Ahern	
DATE PREPARED 05/01/23		PEER REVIEW / DATE Jason Wagner		DATE PREPARED 07/20/23		PEER REVIEW / DATE A. Galardi	

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 1 - Net Option SUMMARY				PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ			
				WOID: GCFEX	ESTIMATE LEVEL: Appraisal		
				REGION: UC	UNIT PRICE LEVEL: Apr-23		
				FILE: Z:\DO\TSC\Jobs\UC\Glen Canyon Dam\2022-PDC-Fish Escapement\APR\EST\8170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls.xlsx\ALT 1 - NETTING - SUMMARY			
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	1	Netting					\$2,100,000.00
	2	Boat Gate					\$125,000.00
	3	Flotation System					\$600,000.00
	4	Rock Hillside Attachments					\$5,115,000.00
	5	Canyon Wall Scribed Netting					\$1,515,000.00
	6	Vertical Adjustment Mechanism					\$2,270,000.00
	7	Mooring System and Anchors.					\$700,000.00
	8	Mobilization and Preparatory Work					\$1,700,000.00
		Subtotal (Pay Items)					\$ 14,125,000.00
		Mobilization					\$ -
		Subtotal with Mobilization					\$ 14,125,000.00
		Contract Cost Allowances (Sum of):	25%	+/-			\$ 3,375,000.00
		Design Contingencies, 20 % (+/-)					
		APS, 5 % (+/-). Type of procurement: Assumed RFP					
		Special Taxes:					
		- None					
		CONTRACT COST					\$ 17,500,000.00
		Construction Contingencies	25.0%	+/-			\$ 4,500,000.00
		FIELD COST (Price Level - April 2023)					\$ 22,000,000.00
		Escalation to Notice to Proceed (NTP)					To be determined by appropriate office
		Non-Contract Costs					To be determined by appropriate office
		CONSTRUCTION COST					To be determined by appropriate office
		NOTE: The Certified Cost Estimate Executive Summary (CCEES) Form is to be completed by the appropriate Reclamation office. Reference Deputy Commissioner's 01/18/23 email regarding the CCEES requirement.					
		Ref.: For appropriate use and terminology, see Reclamation Manual, Directives and Standards FAC; 09-01, 09-02 and 09-03.					
QUANTITIES				PRICES			
BY See previous sheets		CHECKED See previous sheets		BY THOMAS HANKE Digitally signed by THOMAS HANKE Date: 2023.07.19 17:03:13 -0600		CHECKED BRENDAN AHERN Digitally signed by BRENDAN AHERN Date: 2023.07.20 16:02:45 -0600	
DATE PREPARED See previous sheets		PEER REVIEW / DATE See previous sheets		DATE PREPARED 07/20/23		PEER REVIEW / DATE ANTHONY GALARDI Digitally signed by ANTHONY GALARDI Date: 2023.07.20 09:14:20 -0600	

APPENDIX D – Fish Exclusion Curtain Appraisal Cost Estimate

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 2 - Curtain Option		PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ					
		WOID: GCFEX		ESTIMATE LEVEL: Appraisal			
		REGION: UC		UNIT PRICE LEVEL: Apr-23			
		FILE: T:\Jobs\UC\Glen Canyon Dam\2022-PDC-Fish Escapement\APR\EST\6170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls.xlsx\GCFEX B2					
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	Alt 2-04	Rock hillside curtain attachments	8150	1	LS	\$5,115,000.00	\$5,115,000.00
		The side attachments for the curtain are not typical, and a similar case study could not be found.					
		The attachments go the height of the curtain, plus the range the WSEL can vary. Assuming the curtain is 100 ft tall, plus a 200 ft WSEL range, so a total of 300 ft of attachments on each side					
		Drilling of primary rock anchors (underwater)		122	EA	Included above in Item Alt 2-04	
		Assume rock anchors drilled 3 ft deep, 1" OD					
		Vertical spacing on holes = 5 ft, 300 ft range					
		Total holes = 61 on each side = 122 total					
		Drilling of secondary rock anchors (underwater)		480	EA	Included above in Item Alt 2-04	
		Assume rock anchors drilled 5 inches deep, 3/4" OD					
		Vertical spacing on holes = 1 ft, 300 ft range					
		No holes needed where the primary anchors are placed					
		Total holes = 480					
		Primary anchors (high tension)		122	EA	Included above in Item Alt 2-04	
		Assume cable is 3/4" braided stainless cable					
		Total cable length (including embedment) = 13 ft					
		Epoxy grouted into sandstone walls					
		Secondary anchors (low tension)		480	EA	Included above in Item Alt 2-04	
		HILTI products or similar					
		1/2" diameter stainless anchors					
		Anchor length = 8", epoxy grouted					
		Threaded free end with nut					
		SUBTOTAL THIS SHEET					\$5,115,000.00
QUANTITIES				PRICES			
BY		CHECKED		BY		CHECKED	
Blake Biethman		Jason Wagner		T. Hanke		B. Ahern	
DATE PREPARED		PEER REVIEW / DATE		DATE PREPARED		PEER REVIEW / DATE	
05/01/23		Jason Wagner		07/20/23		A. Galardi	

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 2 - Curtain Option				PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ			
WOID: GCFEX				ESTIMATE LEVEL: Appraisal			
REGION: UC				UNIT PRICE LEVEL: Apr-23			
FILE: Z:\DO\TSC\Jobs\UC\Glen Canyon Dam\2022-PDC-Fish Escapement\APR\EST\8170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls\GCFEX B3							
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	Alt 2-05	Canyon wall scribed curtain. See figure	8150	1	LS	\$1,515,000.00	\$1,515,000.00
		Vertical banding bar (low tension)					
		Assume 1/16" x 2" strip stainless banding bar.					
		Length = 600 ft. Drilled every 1 ft.					
		Main curtain attachment line (higher tension)					
		Assume 3/4" stainless braided cable					
		Length = 600 ft					
		Mechanical T connectors to attach					
		drilled anchors to this line. 122 ea					
		Curtain material					
		Assume same material as primary curtain					
		Area = 10' x 300 ft = 3,000 ft2 for					
		each side, 6,000 ft2 total					
	Alt 2-06	Vertical adjustment mechanism	8150	1	LS	\$2,350,000.00	\$2,350,000.00
		System that attaches to the canyon wall					
		scribed curtain and allows the curtain to					
		adjust vertically. This feature will					
		require the manufacturer to engineer					
		a site specific solution.					
	Alt 2-07	Mooring system and anchors		1	LS	\$700,000.00	\$700,000.00
		Sunken anchors and mooring system					
		Assume a minimum of 2 sunken anchors					
		to be placed upstream of the curtain.					
		<i>Estimator Added Item:</i>					
	Alt 2-08	Mobilization and Preparatory Work		1	LS	\$1,700,000.00	\$1,700,000.00
		SUBTOTAL THIS SHEET					\$6,265,000.00
QUANTITIES				PRICES			
BY Blake Biethman		CHECKED Jason Wagner		BY T. Hanke		CHECKED B. Ahern	
DATE PREPARED 05/01/23		PEER REVIEW / DATE Jason Wagner		DATE PREPARED 07/20/23		PEER REVIEW / DATE A. Galardi	

FEATURE: Glen Canyon Dam Fish Exclusion Facility Alt. 2 - Curtain Option SUMMARY				PROJECT: Colorado River Storage Project - Glen Canyon Unit, AZ WOID: GCFEX ESTIMATE LEVEL: Appraisal REGION: UC UNIT PRICE LEVEL: Apr-23 FILE: Z:\DO\TSC\Jobs\UC\Glen Canyon Dam\2022-PDC-Fish Escapement\APR\EST\8170\FinalEst\GlenCanyonFishExcl-Appraisal-DRAFT-WORKING.xls.xlsx\ALT 2 - CURTAIN - SUMMARY			
PLANT ACCOUNT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	1	Curtain					\$2,300,000.00
	2	Boat Gate					\$125,000.00
	3	Flotation System					\$1,130,000.00
	4	Rock Hillside Attachments					\$5,115,000.00
	5	Canyon Wall Scribed Curtain					\$1,515,000.00
	6	Vertical Adjustment Mechanism					\$2,350,000.00
	7	Mooring System and Anchors.					\$700,000.00
	8	Mobilization and Preparatory Work					\$1,700,000.00
		Subtotal (Pay Items)					\$ 14,935,000.00
		Mobilization					\$ -
		Subtotal with Mobilization					\$ 14,935,000.00
		Contract Cost Allowances (Sum of):	25%	+/-			\$ 3,565,000.00
		Design Contingencies, 20 % (+/-)					
		APS, 5 % (+/-). Type of procurement: Assumed RFP					
		Special Taxes:					
		- None					
		CONTRACT COST					\$ 18,500,000.00
		Construction Contingencies	25.0%	+/-			\$ 4,500,000.00
		FIELD COST (Price Level - April 2023)					\$ 23,000,000.00
		Escalation to Notice to Proceed (NTP)					To be determined by appropriate office
		Non-Contract Costs					To be determined by appropriate office
		CONSTRUCTION COST					To be determined by appropriate office
		NOTE: The Certified Cost Estimate Executive Summary (CCEES) Form is to be completed by the appropriate					
		Reclamation office. Reference Deputy Commissioner's 01/18/23 email regarding the CCEES requirement.					
		Ref.: For appropriate use and terminology, see Reclamation Manual, Directives and Standards FAC; 09-01, 09-02 and 09-03.					
QUANTITIES				PRICES			
BY		CHECKED		BY		CHECKED	
See previous sheets		See previous sheets		THOMAS HANKE Digitally signed by THOMAS HANKE Date: 2023.07.19 17:01:57 -0600		BRENDAN AHERN Digitally signed by BRENDAN AHERN Date: 2023.07.20 08:24 -0600	
DATE PREPARED		PEER REVIEW / DATE		DATE PREPARED		PEER REVIEW / DATE	
See previous sheets		See previous sheets		07/20/23		ANTHONY GALARDI Digitally signed by ANTHONY GALARDI Date: 2023.07.20 08:15:43 -0600	