RJH CONSULTANTS, INC.

GEOTECHNICAL AND
WATER RESOURCES ENGINEERING

LOAN FEASIBILITY AND EVALUATION REPORT

GRIZZLY RESERVOIR REHABILITATION

PITKIN COUNTY, COLORADO

Submitted to
Twin Lakes Reservoir and Canal Company
321 Main St.
Ordway, Colorado 81063

Submitted by
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Project 21125

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

SECTION 1 - INTRODUCTION

1.1 Purpose

The Twin Lakes Reservoir and Canal Company (TLRCC), located in Ordway, Colorado, owns and operates Grizzly Reservoir and the Twin Lakes Tunnel. Grizzly Reservoir (Site) is an integral component of a trans-basin diversion and collection system that stores water from the upper basin tributaries of the west slope Roaring Fork River system and transfers the stored waters to the upper basin tributaries of the east slope Arkansas River system via the Twin Lakes Tunnel that is constructed under the Continental Divide. Grizzly Reservoir Dam was originally constructed in 1933 and subsequently raised and enlarged in 1935. Twin Lakes Tunnel was constructed in 1934. Both the dam and the tunnel gates that control flow through the tunnel have had some minor upgrades subsequent to the original construction but no major rehabilitation. For both safety and operational reliability, the dam and tunnel gates require some significant upgrades and rehabilitation.

TLRCC is planning to rehabilitate the dam and Twin Lakes Tunnel gates to improve both dam safety and operational reliability. Planned improvements include a new upstream dam slope membrane liner, low-level outlet works discharge structure replacement, a new low-level outlet trashrack, and replacement of the tunnel gates and operators.

1.2 Project Location

Grizzly Reservoir Dam (DAMID 380109) is a high-hazard dam that impounds a 590-acre-foot (ac-ft) reservoir in Pitkin County, Colorado, approximately 15 miles southeast of Aspen, Colorado. The dam is located in Section 24 of T11S, R83W. The dam is a 56-foot-high earth and rockfill dam with an upstream steel face constructed on Lincoln Creek to impound and divert west slope water through the Twin Lakes Tunnel to the east slope Arkansas River Basin. The area surrounding the dam is undeveloped, steep mountainous terrain. The dam is accessed from the north via County Road 23 or from the east via the Twin Lakes Tunnel. A vicinity map of the Site is shown on Figure 1.1.

1.3 Objectives

The objectives of this report are to present alternatives for addressing dam safety concerns and operational issues associated with Grizzly Reservoir Dam and Twin Lakes Tunnel operating gates, present the concept-level design of the selected alternative, provide an opinion of probable cost of construction (OPCC), and present a proposed implementation schedule for the Grizzly Reservoir Rehabilitation Project (Project) for use in obtaining a Colorado Water Conservation Board (CWCB) Water Project Loan. The selected concept-level alternative and cost opinion presented in this report were developed to enable an evaluation of the Project's technical, construction, and permitting requirements and associated costs. The selected alternative will be refined during final design based on additional analyses specific to the selected alternative. These specific analyses may result in modifications to the concepts presented in this report. Supporting calculations for the alternative included in final design will be developed and presented in the design report that will be developed in future design phases.

1.4 Scope of Work

RJH Consultants, Inc. (RJH) performed the following scope of work:

- Collected data needed to identify site conditions and support evaluation of rehabilitation alternatives.
- Performed a limited geotechnical field investigation and prepared a Geotechnical Data Report.
- Performed an inspection of the outlet works and prepared an Outlet Inspection Memorandum.
- Performed preliminary level sizes and layouts for the outlet works rehabilitation, dam seepage and internal erosion mitigation, Twin Lakes Tunnel debris management and gate rehabilitation based on judgement, general design criteria, and experience.
- Developed concept-level design figures of the selected alternative.
- Estimated quantities of primary materials required for construction and prepared an overall OPCC to construct the Project.
- Developed a Project schedule for the design and construction of the dam and Twin Lakes Tunnel rehabilitation.
- Identified probable coordination required with federal, state, and local agencies.
- Prepared this report.

1.5 Project Personnel

The following personnel from RJH are responsible for the technical work contained in this report:

Project Manager	Michael Graber, P.E.
Project Engineer	Brena Sheridan, P.E.
Staff Engineer	Austin Yahn, E.I.

1.6 Existing Conditions

The original dam was constructed circa 1932, was subsequently raised 10 feet in height in 1935, and a 3-foot-high steel parapet wall was added across the dam crest in 1995. The low-level outlet works discharges into Lincoln Creek and was constructed through the rockfill dam embankment in 1932 and was extended 14 feet downstream in 1935.

According to the Colorado Office of the State Engineer (SEO), the dam is 792 feet long with a height of 56 feet and a crest width of 20 feet. The steel parapet wall extends approximately 630 feet along the upstream crest of the dam and ties into high ground near the right abutment. The top of the parapet wall is at approximate elevation (El.) 10,538, and the dam crest is at approximate El. 10535. The upstream slope of the dam is generally 0.5 horizontal to 1 vertical (H: V), and the downstream slope is generally 1.5H:1V. Steel facing on the upstream slope of the dam is underlain by a three-inch concrete slab to El. 10522 and underlain by rubble masonry in cement mortar for the remaining height of the dam. The majority of the embankment section is rockfill, placed up to El. 10522. Earth and rockfill were placed above this elevation and on the downstream slope during the dam raise in 1935. A 50-foot-wide concrete auxiliary spillway is located on the left abutment of the dam with invert El. 10530. The low-level outlet works is situated near the maximum section of the dam and is perpendicular to the centerline of the dam. The outlet works is a 4- by 4-foot reinforced concrete conduit with a length of approximately 120 feet and a slope of approximately 1-percent. Seepage collars are located periodically along the length of the outlet conduit. The outlet works has an 8-foot-long concrete discharge structure. Releases to Lincoln Creek are controlled through a manually operated, 4-foot by 4-foot-5-inch steel slide gate. The slide gate is mounted to a concrete headwall, and the intake structure includes a trashrack. The gate stem is mounted to the steel facing. Existing conditions of the dam and appurtenant features are shown on Figures 1 through 4 in Appendix A.

The Twin Lakes Tunnel intake structure is located on the east side of the reservoir. The reinforced concrete intake structure is 28-feet-9-inches wide with steel trashracks at the inlet and reduces to 18-feet-8-inches wide. Flow in the intake structure is divided into three separate bays. The intake structure is 7-feet-9-inches tall before it enters a 24-foot-4-inch-tall riser structure. Flow is regulated with three 4-foot-10-inch wide by 7-foot-9-inch tall electrically actuated steel slide gates. A valve house sits on top of the riser structure and houses the electric gate operators and generator. Existing conditions of the intake structure and valve house are shown on Figures 5 through 8 in Appendix A.

1.7 Dam Safety Concerns

The purpose of the rehabilitation of the dam is to address dam safety concerns associated with the corroded and thinning upstream slope steel facing, uncontrolled seepage, and operational problems with the outlet works. Identified conditions observed during previous SEO dam safety inspections and RJH site visits include the following:

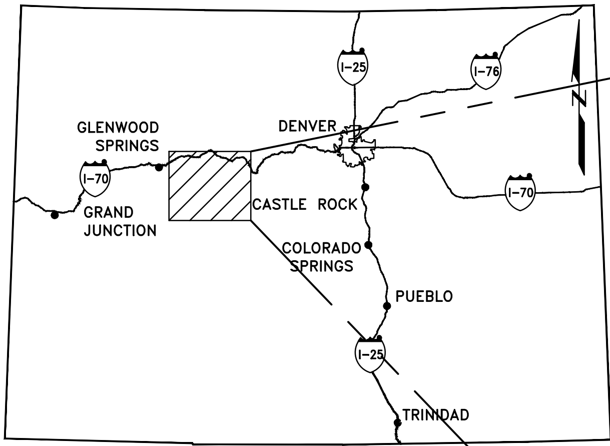
- Uncontrolled seepage extending about 20 to 30 feet to the left of the outlet works on the downstream dam slope. The seepage is generally at the downstream toe along the foundation contact.
- Minor buckling and panel seam separation of the steel facing at a few locations.
- Deterioration of the asphalt coating on the steel plate facing and corrosion and thinning of the steel plate.
- Cracks, holes, and joint separations in the concrete outlet conduit.
- Concrete surface spalling of the outlet conduit due to cavitation.
- Lack of a vent downstream of the outlet slide gate results in surging in the release flows and cavitation in the outlet conduit.
- Uncontrolled seepage flowing along the outlet tunnel exterior surface interface with the earth and rockfill embankment.

Photographs taken during the most recent reservoir draining in 2015 indicate that the existing trashrack for the outlet works has been cut. The trashrack was likely cut due to operational issues associated with the trashrack. The absence of a trashrack poses a potential dam safety concern.

1.8 Twin Lakes Tunnel Operational Issues

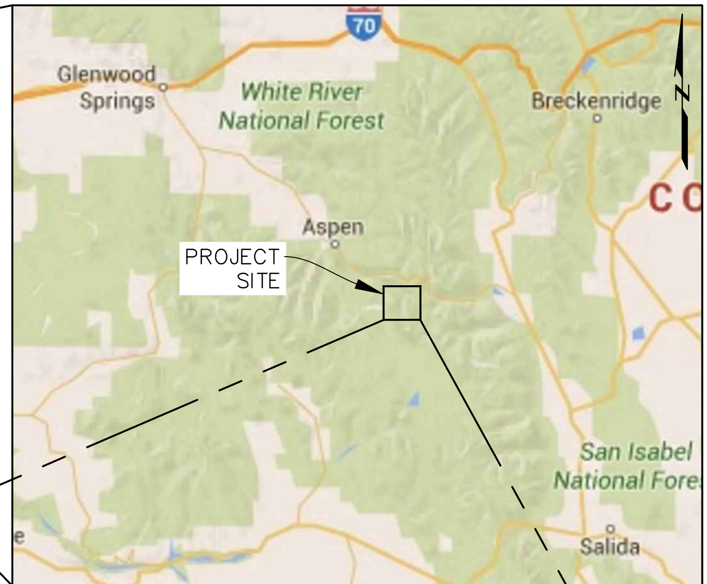
Operational issues associated with the Twin Lakes Tunnel flow control gates include significant leakage and deterioration of the three existing steel gates. The gates are over 80-years old and have exceeded their expected design and service life. The gates are difficult to operate and require significant maintenance every year.

The valve house and intake structure are located at the base of an avalanche run-out zone. Large rocks, trees, and debris are frequently deposited into the tunnel inlet channel blocking and limiting flow into the trash rack on the intake structure. Currently, avalanche deposited debris cannot be readily accessed for removal without dewatering the inlet channel by constructing a cofferdam across the intake channel. The ability to remove avalanche deposited debris in a timely and more cost-efficient manner is needed.



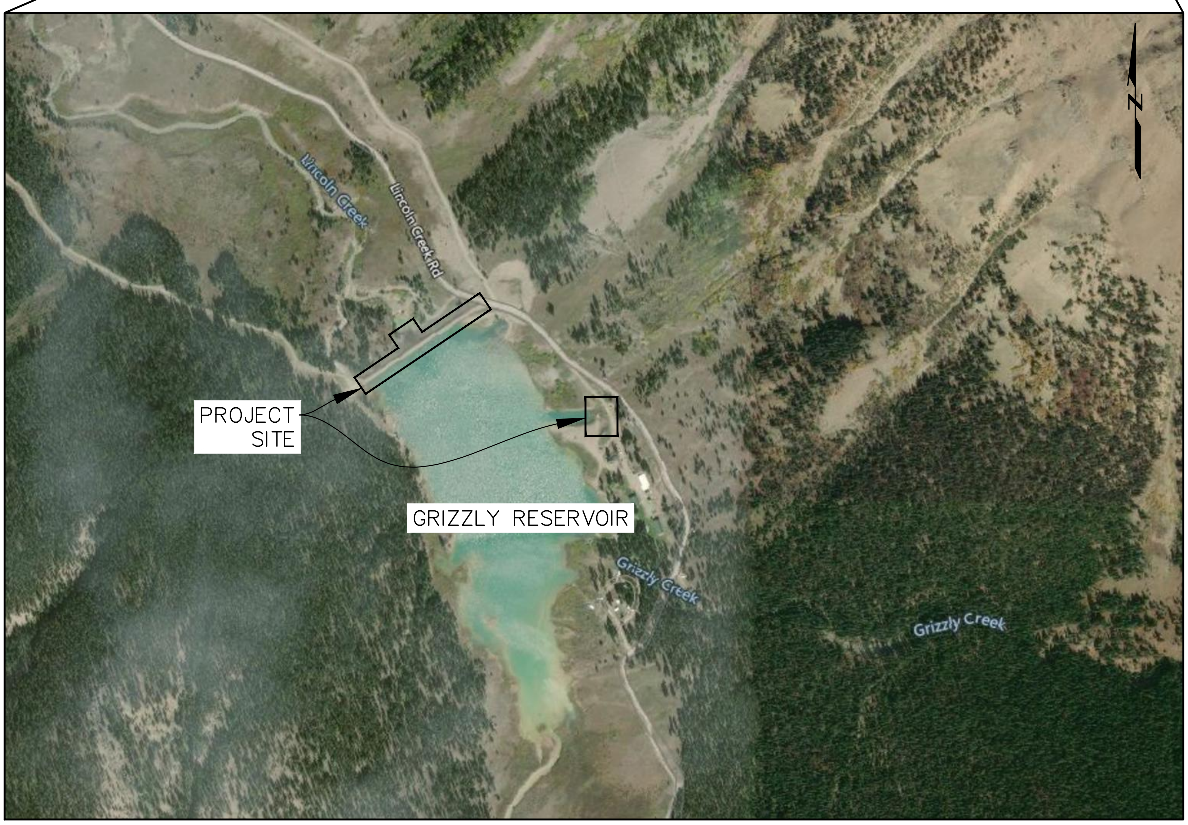
PROJECT VICINITY MAP

(NOT TO SCALE)



PROJECT LOCATION MAP

(NOT TO SCALE)



PROJECT AERIAL MAP

(NOT TO SCALE)

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	SITE LOCATION MAP
	PROJECT NO. 21125	December 2021 **Figure 1.1**

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SECTION 2 - SPONSOR

2.1 Sponsor

TLRCC is a mutual ditch and reservoir company registered in the State of Colorado. The Company originally built Twin Lakes Reservoir in Lake County in 1900, whose Arkansas River storage rights were decreed to provide supplemental water to lands irrigated under the Colorado Canal in eastern Pueblo County and Crowley County. Water supply for lands under the canal remained short even with the Twin Lakes water rights, and in 1930 water users initiated the Independence Pass Transmountain Diversion System (IPTDS), which eventually diverted water from the headwaters of the Roaring Fork River in Pitkin County to provide supplemental water for use under the Colorado Canal and storage in Twin Lakes. The proposed work at Grizzly Reservoir Dam and Twin Lakes Tunnel is located on the IPTDS system.

There are approximately 240 shareholders in TLRCC who own 49,588.965 shares of stock. TLRCC sets annual assessments to provide revenue for its financial requirements.

Articles of incorporation and bylaws will be provided at the time of the loan application.

SECTION 3 - WATER RIGHTS AND WATER DEMANDS

3.1 Water Rights and Water Demands

TLRCC has east slope storage rights at Twin Lakes with priority dates December 15, 1896, and March 29, 1897, with a total storage right of 54,452 acre-feet. These rights are generally in priority during the Winter Water storage season (November 15 through March 14) and during runoff in years with high snowpack. This water may be used for irrigation, domestic, commercial, industrial, and municipal purposes at any site in the Arkansas River basin of Colorado below the Twin Lakes Reservoir. These rights have yielded an average of 9,430 ac-ft over the past 36 years.

TLRCC's original west slope rights for the IPTDS have a priority date of August 23, 1930 and allow for diversion of up to 625 cubic feet per second (cfs) with limits based on whether Twin Lakes Reservoir has filled and if water is available in priority at Colorado Canal. This water may be used for direct flow purposes or may be stored in Twin Lakes Reservoir. A later decree, the IPTDS 1994 Supplement, allows for additional diversions even if the storage right has been met at Twin Lakes and there is water available at Colorado Canal. Total IPTDS diversions are limited to 68,000 ac-ft a single year and 570,000 ac-ft over a 10-year period. Water may be used for irrigation, domestic, commercial, industrial, municipal, and all beneficial purposes. These rights have yielded an average of 42,000 ac-ft over the past 36 years.

A summary of water yield over the past 36 years is provided in Appendix B.

SECTION 4 - DATA COLLECTION

4.1 Data Collection

Data collection included a topographic survey of the site, a dam low-level outlet works inspection and a limited subsurface investigation. The following sections describe the pertinent information obtained.

4.2 Survey

Aspen Surveyors, LLC, under contract to RJH, performed a topographic survey of the embankment dam and appurtenant site features, including the Twin Lakes Tunnel intake structure, on September 15, 2021. Existing survey monuments near the Site were not found, and the survey was not tied into a grid-reference system. The horizontal coordinate system is a local coordinate system established by Aspen Surveyors, LLC. The vertical datum is the North American Vertical Datum of 1988 (NAVD88), which was increased by 38.1 feet by RJH to generally match elevations shown on historical drawings. Two permanent and four temporary control points were established at the Site.

4.3 Outlet Works Inspection

An inspection of the outlet conduit and discharge structure was performed on September 15, 2021. The outlet conduit and stilling basin were dewatered to allow for visual inspection. The reservoir was at approximate El. 10520, and the upstream slide gate was in the closed position. Observations from the inspection include the following:

- A significant amount of seepage was noted spraying from the slide gate. The majority of the seepage appeared to be from the left lower side of the gate, looking downstream.
- The steel tunnel liner downstream of the gate was in good condition with only minor surface rust. There were no indications of recent cavitation or erosion in the steel plate liner.
- Immediately downstream of the steel plate lining, erosion of the concrete floor was observed, likely due to cavitation.
- There was seepage from nearly every tunnel joint, of varying amounts from less than 1 gallon per minute up to an estimated 5 gallons per minute.

- There were also a number of cracks and holes in the tunnel, ceiling, walls, and floor from which clear seepage flowed.
- An approximate 2-inch-wide crack was noted approximately 19-feet from the downstream end of the tunnel on the left side looking downstream.
- An approximate 1-inch-wide crack was observed in the tunnel ceiling approximately 45-feet from the downstream end of the tunnel across the entire ceiling, and a significant amount of seepage was observed from the ceiling.
- Previous crack and joint repairs to the concrete tunnel were observed at a number of locations and were in generally good condition.
- An appropriately sized air vent immediately downstream of the gate to prevent negative pressures, cavitation damage, and unstable flow in the conduit was not found.

Additional information is provided in Appendix C.

4.4 Subsurface Investigation

RJH performed a limited subsurface investigation on September 15, 2021, to develop material properties for the dam embankment and potential borrow. Three test pits were excavated on the downstream slope of the dam near the outlet works discharge structure. The test pits generally extended 3 feet below the ground surface and were 2 to 3 feet wide. Material encountered included earth and rockfill. Groundwater was not encountered. A sample of deposited sediment excavated from the reservoir was also collected to evaluate for potential borrow material. The work performed and data collected is provided in the Geotechnical Data Report in Appendix D.

Earthfill encountered in the test pits from the dam near the outlet works consisted of silty sand with gravel to poorly graded sand with gravel. Rockfill was encountered approximately 1 to 2 feet below the existing ground surface and appeared to have a maximum particle size of 4 to 6 inches.

4.5 Upstream Steel Facing Thickness

RJH collected thickness measurements of the existing upstream steel facing. RJH also performed sounding along the steel facing to estimate the presence of voids behind the steel facing. Thickness measurements and sounding were used to support the design of the geosynthetic liner system. The thickness of the steel ranged from 0.188 inch to 0.316

inch, with an average of approximately 0.25 inch. The majority of the panels on which sounding was performed appeared to have voids behind the panels. A summary of the data collected is provided in Appendix E.

SECTION 5 - ANALYSIS OF ALTERNATIVES

5.1 Alternatives

RJH developed concepts to address the dam safety concerns and operational issues associated with the outlet works, dam seepage, Twin Lakes Tunnel debris, and Twin Lakes Tunnel gates.

5.2 Outlet Works Rehabilitation Alternatives

Three alternatives were evaluated for addressing dam safety concerns associated with the outlet works and include a no action alternative, outlet works replacement, and concrete repair with vent installation.

5.2.1 Alternative 1 – No Action

Alternative 1 includes no action and would not address the dam safety issues associated with the outlet works. The concrete would continue to deteriorate, and seepage flow into the conduit would increase with an increased risk of internal erosion and potential piping failure.

5.2.2 Alternative 2 – Outlet Works Replacement

Alternative 2 includes removal of the entire outlet works and replacement of the outlet works components. Demolition of the outlet conduit would require significant excavation through the embankment section. This alternative includes the following primary components:

- Excavating and fill placement of approximately 25,000 cubic yards (cy) of embankment material.
- Removing and replacing approximately 1,300 square yards (sq. yd) of the steel facing.
- Demolishing the existing concrete outlet conduit, intake structure, and discharge structure.
- Installing a new 54-inch diameter concrete encased steel pipe.
- Installing a new concrete intake structure with a trashrack.
- Installing a new concrete discharge structure and riprap protection.

- Installing a new manually operated slide gate.

5.2.3 Alternative 3 – Outlet Works Concrete Repair and Vent and Trashrack Installation

Alternative 3 includes repairing the damaged concrete interior of the outlet works conduit, installing an 18-inch-diameter galvanized steel air vent immediately downstream of the existing slide gate, and removing and replacing the trashrack at the intake of the outlet conduit. The cracks and holes in the outlet conduit would be sealed with a moisture activated diisocyanate blended polyurethane injectable grout. The grout would be pumped under pressure through multiple drilled injection ports in the cracks and holes and would set up almost immediately when contacting water. This would provide a positive water tight seal and is considered a permanent long-term repair. Surface repairs would be made using epoxy mortar in general accordance with Guide to Concrete Repair (Reclamation, 2015). The vent would be cored through the existing outlet works, sealed with epoxy sealant, and supported on the upstream face of the dam to the dam crest. The vent would reduce cavitation damage and reduce unstable flow in the outlet works. Additional information for sizing the air vent is provided in Appendix F. The trashrack would be designed in general accordance with applicable U.S. Bureau of Reclamation and U.S. Army Corps of Engineers design criteria to meet requirements in Section 7.8.2.4 of the SEO Rules and Regulations for Dam Safety and Dam Construction (SEO, 2020)

5.2.4 Selected Alternative

Alternative 1 will not address the dam safety issues associated with the outlet works. Alternative 2 is not cost-effective because it replaces components for which significant service remains. Alternative 3 is technically feasible, constructable, addresses the identified dam safety issues, and is the most cost-effective alternative. Alternative 3 is the selected alternative. Base construction costs for comparison of Alternative 2 and Alternative 3 are provided in Table 5.1.

TABLE 5.1
COMPARISON OF THE OUTLET WORKS REHABILITATION BASE CONSTRUCTION COSTS

Alternative	Cost
Alternative 2 – Outlet Works Replacement	$3,600,000
Alternative 3 – Outlet Works Concrete Repair and Vent Installation	$200,000

5.3 Dam Seepage Mitigation

Three alternatives were evaluated for mitigating seepage and internal erosion along the outlet works conduit and addressing dam safety concerns associated with the steel facing and include a no action alternative, steel facing replacement, and geosynthetic system and filter diaphragm installation.

5.3.1 Alternative 1 – No Action

Alternative 1 includes no action and would not address the dam safety issues associated with dam seepage. The existing steel facing would continue to deteriorate, and seepage would increase with an increased risk of internal erosion and potential dam failure.

5.3.2 Alternative 2 – Steel Facing Replacement

Alternative 2 includes removing and replacing the upstream steel facing on the dam. The surface area of the steel facing on the dam is approximately 3,360 sq. yd. The steel facing would be replaced with a minimum 3/4-inch coated steel plate. Replacement of the steel facing would likely require repairing or replacing the concrete slab beneath the existing steel facing and the concrete toe wall, depending on the condition of the concrete.

5.3.3 Alternative 3 – Geosynthetic System and Filter Diaphragm

Alternative 3 includes installing a geosynthetic system over the existing steel facing and constructing a filter diaphragm near the downstream end of the outlet works. The geosynthetic system would significantly reduce seepage, and the filter diaphragm would mitigate the risk of internal erosion along the outlet conduit. To construct the filter diaphragm, a section of the outlet works conduit and discharge structure would need to be demolished and replaced at the downstream toe of the dam. Additional information on sizing the filter diaphragm and the information on the geosynthetic system is provided in Appendix G and Appendix H, respectively. This alternative would include the following primary components:

- Removal of the existing asphalt coating on the steel facing where steel components of the geomembrane system require welding.
- Welding geomembrane tensioning profiles to the steel facing.
- Installing approximately 3,360 sq. yd of geomembrane over geotextile.

- Installing geonet between the geomembrane and geotextile along the lower perimeter seal for drainage collection, which would convey water to drainage holes.
- Installing a watertight perimeter seal onto the bottom concrete toe wall and top steel crest using a stainless-steel batten bar.
- Installing shoring near the downstream dam toe to install the diaphragm filter.
- Excavating and fill placement of approximately 1,150 cy of downstream embankment material.
- Demolishing and replacing 14-feet of the existing concrete outlet works conduit and discharge structure. The new conduit and structure would be reinforced concrete similar to the existing facilities.
- Installing a two-stage filter diaphragm. The two-stage filter diaphragm would be installed at the upstream end of the new conduit and would consist of transition material and filter sand.
- Installing a drainage layer with slotted polyvinyl chloride (PVC) pipe to convey seepage to the downstream toe of the dam and discharge in Lincoln Creek.

5.3.4 Selected Alternative

Alternative 1 will not address the dam safety issues associated with uncontrolled seepage and deterioration of the existing upstream steel facing. Alternative 2 is not cost-effective because it replaces components for which significant service remains. Alternative 3 is technically feasible, constructable, addresses the identified dam safety issues, and is the most cost-effective alternative. Alternative 3 is the selected alternative. Base construction costs for comparison of Alternative 2 and Alternative 3 are provided in Table 5.2.

TABLE 5.2
COMPARISON OF DAM SEEPAGE MITIGATION BASE CONSTRUCTION COSTS

Alternative	Cost
Alternative 2 - Steel Facing Replacement	$16,500,000
Alternative 3 - Geosynthetic System and Filter Diaphragm	$3,200,000

5.4 Twin Lakes Tunnel Intake Debris Management

Three alternatives were evaluated for managing debris removal from the Twin Lakes Tunnel intake structure and include a no action alternative, installing a mechanical operated trashrack, and installing a retaining wall.

5.4.1 Alternative 1 – No Action

Alternative 1 includes no action. In the frequent event that an avalanche runs, TLRCC will lose the ability to divert water in the Twin Lakes Tunnel until the reservoir can be lowered following spring runoff and a cofferdam can be built to access the tunnel intake and debris can be removed.

5.4.2 Alternative 2 – Mechanically Operated Trash Rake

Alternative 2 includes installing a monorail-based trash rake system over the intake structure. The trash rake could either be automated or operated manually. Supports for the rail would either be attached to the existing intake structure or consist of columns embedded into existing ground. The trash rake would be operated on an overhead beam to remove debris from the existing trashracks. Debris would be dumped at the side of the structure. The trash rake has limited operational ability to remove large debris, trees, and large boulders that could be deposited in the intake channel when one or more avalanche chutes run and for this reason was not considered a viable alternative.

5.4.3 Alternative 3 – Retaining Wall

Alternative 3 includes constructing a reinforced concrete retaining wall above the intake structure and constructing an access pad to enable heavy equipment to access and clean debris from above the intake structure. Alternative 3 would include the following primary components:

- Installing a 54-foot-long reinforced concrete retaining wall. The middle 28 feet of the retaining wall would be constructed on top of the existing intake structure and have a height of 8.5 feet. The wall would step up and tie into existing ground on either side of the intake structure.
- Constructing a 15-foot-wide access bench behind the retaining wall. The 15-foot-wide bench would allow for heavy equipment to set up behind the retaining wall and clean debris from the intake structure.

- Excavating an access ramp on the south side of the intake structure to the bench.

5.4.4 Selected Alternative

Alternative 1 will not address the current reliability and operational deficiencies. Alternative 2 is not cost-effective and would require ongoing maintenance of the trash rake. Alternative 3 is technically feasible, constructable, addresses the identified operational issues, and is the most cost-effective alternative. Alternative 3 is the selected alternative. Base construction costs for comparison of Alternative 2 and Alternative 3 are provided in Table 5.3.

TABLE 5.3
COMPARISON OF THE TWIN LAKES TUNNEL DEBRIS MANAGEMENT BASE CONSTRUCTION COSTS

Alternative	Cost
Alternative 2 – Mechanically Operated Trash Rake	$100,000
Alternative 3 – Retaining Wall	$120,000

5.5 Twin Lakes Regulating Tunnel Gates

Three alternatives were evaluated for addressing operational issues associated with the Twin Lakes Tunnel regulating gates and include a no action alternative, constructing a new intake structure and valve house, and replacing the gates.

5.5.1 Alternative 1 – No Action

Alternative 1 includes no action. This option is not viable for the Twin Lakes Tunnel system to continue to operate. The gates are well past the normal expected service life and could become unreliable at any time. Replacement of these gates is necessary for continued reliable operation and critical water system deliveries.

5.5.2 Alternative 2 – New Tunnel Intake and Valve House

Alternative 2 would involve demolishing and replacing the existing valve house and intake structure to meet the original design and performance of the facility. This would require demolishing approximately 50 linear feet of the facility and 230 cy of concrete. The new valve house and intake structure would be designed to comply with current concrete and building code.

5.5.3 Alternative 3 – Replace Gates

Alternative 3 would involve demolishing the existing gates and replacement with new gates. Alternative 3 would include the following primary components:

- Demolishing the three existing steel gates and replacing with three new gates. The new gates would be 46- by 88-inch stainless steel slide gates with hydraulic actuators. The gates would be installed approximately 4 feet downstream of the existing gates.
- A new hydraulic power unit would be installed in the valve house to operate the gates and have a failsafe to allow the gates to fail in the closed position upon loss of power.
- Demolishing and replacing the roof of the valve house to allow installation of the new gates.
- Installing 30 cy of concrete to facilitate installation and operation of the gates.

5.5.4 Selected Alternative

Alternative 1 will not address the current reliability and operational deficiencies. Alternative 2 is not cost-effective because it replaces components for which significant service remains. Alternative 3 is technically feasible, constructable, addresses the identified operational issues, and is the most cost-effective alternative. Alternative 3 is the selected alternative. Base construction costs for comparison of Alternative 2 and Alternative 3 are provided in Table 5.4.

TABLE 5.4
COMPARISON OF TWIN LAKES REGULATING TUNNEL GATES BASE CONSTRUCTION COSTS

Alternative	Cost
Alternative 2 – New Intake and Valve House	$1,200,000
Alternative 3 – Replace Gates	$500,000

SECTION 6 - SELECTED ALTERNATIVE

Alternative 3 for each category are hereafter combined and described as the Project. Proposed modifications are shown on Figures 9 through 21 in Appendix A. Modifications to the outlet works will include demolition and replacement of the discharge structure and downstream 14 feet of the outlet conduit; injectable grouting of the outlet conduit and repairing damaged concrete with epoxy grout mortar; installation of an air vent; and demolition and replacement of the trashrack. Modifications to the dam will include the installation of a geosynthetic system over the existing steel facing, and the construction of a filter diaphragm and drainage filter. Modifications to the Twin Lakes Tunnel Intake will include the construction of a concrete retaining wall and demolition and replacement of the existing gates. The Project will require draining the reservoir for construction.

SECTION 7 - IMPACTS

7.1 Impacts

The proposed project will have no negative social or physical impacts, as it consists of maintenance projects to existing infrastructure and will not change the operation of the IPTDS.

The No Action alternative would have the greatest impact as it would increase the likelihood of dam failure at Grizzly Reservoir Dam in the future. Mitigation of identified dam safety problems and operational issues will provide continued safe water storage and reliable water system deliveries to the benefit of local and regional water users.

SECTION 8 - OPINION OF PROBABLE PROJECT COSTS

8.1 Opinion of Probable Project Cost (OPPC)

RJH developed a Class 4 estimate of OPPC in general accordance with American Society for Testing and Materials International (ASTM) E 2516 for the selected alternative. A Class 4 estimate is appropriate for concept-level design evaluation when the design is between 1 to 15 percent complete. The overall reliability of a Class 4 estimate is between about minus 15 to 30 percent and plus 20 to 50 percent when all costs are compared in 2022 dollars.

Cost opinions were developed and considered based on the size of the project, estimated quantities for primary work elements based on the concept-level design, and unit costs from the following sources:

- Published and non-published bid price data for similar work.
- R.S. Means Heavy Construction Cost Data 2020.
- Previous experience and judgment.

The "Base Construction Subtotal" (BCS) for each project component is the sum of the construction costs for primary work elements. The sum of the BCS, mobilization/demobilization, bonds/insurance, and permitting are defined as the "Direct Construction Cost" (DCC).

The Opinion of Probable Project Costs (OPPC) is the sum of the DCC, construction contingencies, and engineering and administration costs. A summary of quantities and our OPCC is presented in Table 8.1. Costs are presented in 2022 dollars.

This OPCC is based on the professional opinion of the costs to construct the Project as described in this report. Actual costs would be affected by a number of factors beyond current control, such as supply and demand for the types of construction required at the time of bidding and in the Project vicinity, changes in material supplier costs, changes in labor rates, the competitiveness of contractors and suppliers, changes in applicable regulatory requirements, and changes in design standards and concepts. Therefore, conditions and factors that arise as Project development proceeds through construction may result in construction costs that differ from the estimates documented in this report.

TABLE 8.1
OPINION OF PROBABLE CONSTRUCTION COSTS

Item	Description	Total Quantity	Unit	Unit Price	Extension
General Items					
1	Mobilization at 20 percent BCS	1	Lump Sum	$447,863	$447,863
2	Stripping, Clearing, and Grubbing	1	Lump Sum	$20,000	$20,000
3	Erosion Protection and Sediment Control	1	Lump Sum	$100,000	$100,000
4	Site Development	1	Lump Sum	$50,000	$50,000
5	Site Restoration	1	Lump Sum	$50,000	$50,000
6	Dewatering	1	Lump Sum	$75,000	$75,000
7	Surface Water Control	1	Lump Sum	$50,000	$50,000
8	Survey	1	Lump Sum	$150,000	$150,000
Grizzly Reservoir Dam Rehabilitation					
9	Geosynthetic Liner System	1	Lump Sum	$3,000,000	$3,000,000
10	Removal, Salvage, and Placement of Existing Riprap/Bedding	575	Square Yard	$100.00	$57,500
11	Demolition and Disposal	1	Lump Sum	$50,000	$50,000
12	Reservoir Basin Excavation	15,000	Cubic Yard	$7.00	$105,000
13	Downstream Embankment Excavation	1,250	Cubic Yard	$7.00	$8,750
14	Excavation Support	1	Lump Sum	$10,000	$10,000
15	Compacted Fill from Required Excavations	1,000	Cubic Yard	$15.00	$15,000
16	Reservoir Basin Grading	15,000	Cubic Yard	$6.00	$90,000
17	Transition Material	50	Cubic Yard	$130.00	$6,500
18	Filter Sand	200	Cubic Yard	$150.00	$30,000
19	Drain Gravel	15	Cubic Yard	$130.00	$1,950
20	Slotted Drain Pipe	30	Lineal Foot	$120.00	$3,600
21	Solid Drain Pipe	20	Lineal Foot	$115.00	$2,300
22	Existing Slide Gate Repairs	1	Lump Sum	$5,000	$5,000
23	Intake Structure and Trashrack	1	Lump Sum	$100,000	$100,000
24	18-inch Galvanized Steel Air Vent and Supports	1	Lineal Foot	$70,000	$70,000
25	Existing Concrete Pressure Grouting	5	Gallon	$5,000	$25,000
26	4- by 4-foot Reinforced Concrete Conduit	1	Lump Sum	$40,000	$40,000
27	Reinforced Concrete Outlet Structure	1	Lump Sum	$40,000	$40,000
28	All other work not listed separately	1	Lump Sum	$25,000	$25,000
Twin Lakes Tunnel Rehabilitation					
29	Demolition	1	Lump Sum	$25,000	$25,000
30	Excavation	775	Cubic Yard	$10.00	$7,750
31	Compacted Fill from Required Excavations	650	Cubic Yard	$15.00	$9,750
32	Excavation Support	1	Lump Sum	$5,000	$5,000
33	Reinforced Concrete Retaining Wall	1	Lump Sum	$100,000	$100,000
34	Structural Backfill	150	Cubic Yard	$12.00	$1,800
35	Aggregate Surfacing	15	Cubic Yard	$50.00	$750
36	Precast Concrete Curb	55	Lineal Feet	$60.00	$3,300
37	Reinforced Concrete Roof	1	Lump Sum	$50,000	$50,000
38	Slide Gate Support Concrete	1	Lump Sum	$37,500	$37,500
39	Slide Gate, HPU, and Hydraulic Cylinder	1	Lump Sum	$350,000	$350,000
40	Electrical	1	Lump Sum	$10,000	$10,000

Item	Description	Total Quantity	Unit	Unit Price	Extension
41	All other work not listed separately	1	Lump Sum	$10,000	$10,000
Base Construction Subtotal (BCS)					$5,239,313
Contingency (percent of BCS)		10 percent			$523,931
Construction Engineering		20 percent			$1,047,863
Owner Administration and Testing (percent of BCS)		2 percent			$104,786
OPINION OF PROBABLE CONSTRUCTION COSTS (April 2022)					$6,915,892.25

SECTION 9 - FINANCIAL PLAN

9.1 Loan Amount

The total estimated project cost is anticipated to be $6,900,000. Current and future annual assessments on TLRCC water shares will be used to cover annual loan payments. TLRCC understands that the final loan amount will depend on the final cost of the Project.

The final requested loan amount will be updated after construction bids are received.

9.2 Financing Sources

The Project is expected to be financed internally through the income of annual assessments. TLRCC requests a CWCB loan to cover a portion of the cost, with the balance coming from funds already on hand and the income of annual assessments. The final requested loan amount will be updated after construction bids are received.

9.3 Revenue and Expenditure Projections

A schedule of revenue and expenditures for the period of debt retirement will be updated after the construction bids are received. TLCC plans to order and purchase the slide gates, cylinders, and hydraulic power unit for the Twin Lakes Tunnel intake structure with their own reserve funds in advance of the loan application due to the long lead time required for manufacturing.

9.4 Loan Repayment Sources

Loan repayment sources will be from assessments on shareholders. Repayment of a CWCB loan will not require an increase in annual assessments; however, other new or increased expenses that may arise could necessitate an increase in assessments.

9.5 Financial Impacts

TLRCC does not see an immediate need for an increase of assessments on shareholders to cover CWCB loan obligations. TLRCC raised the assessments between 2015 and 2017 from $19.50 per share to $30.00 per share to cover expenses incurred through the U.S Bureau of Reclamation (Reclamation). Those expenses are not in the Reclamation's current 5-year forecast, and TLRCC will continue to keep the assessment rate at $30.00 per share to cover CWCB loan obligations.

9.6 Taxpayer's Bill of Rights (TABOR) Issues

TLRCC is not a government entity and is not subject to TABOR.

9.7 Collateral

The assets to be pledged as collateral will be determined at the time of the loan application.

9.8 Creditworthiness

Currently, TLRCC has 49,588.965 shares at $30.00 per share for a total 2022 budget of $1,487,668.95.

A copy of the December 31, 2018, and 2017 audit report of financial statements is provided in Appendix I.

SECTION 10 - IMPLEMENTATION SCHEDULE

A proposed project implementation schedule is presented in Table 7.1. A desired construction start date of May 2023 is scheduled.

TABLE 10.1
PROJECT IMPLEMENTATION SCHEDULE

Item	Schedule Date
Loan Application and Feasibility Study to CWCB	May 2022
Final Project Engineering Design Started	February 2022
Permitting Started	February 2022
Feasibility Study Review and Approved by CWCB	September 2022
Funding Approved by CWCB Board	TBD
Design, Plans, and Specifications Submitted to SEO	June 2022
Project Design Completed	June 2022
SEO Approved Project	August 2022
Bidding and Procurement	September 2022
All Permitting Obtained	October 2022
Contractor Award	October 202
Mobilization of Equipment and Materials	June/July 2023
Project Construction Started	July 2023
Project Construction Completed	October 2023
Project Closeout and Construction Completion Documents to the SEO	January 2024

10.1 Permitting and Institutional Feasibility

Permitting from and coordination with a number of governmental agencies will be required to construct the project. Following is a listing of the agencies and the anticipated permits that will be required.

10.1.1 State Engineers Office

The dam rehabilitation must be designed and constructed in accordance with the SEO Rules and Regulations for Dam Safety and Dam Construction (SEO, 2020). Review and approval of project designs, plans, specifications, and construction by the SEO will be required.

10.1.2 U. S. Army Corps of Engineers

It is anticipated the U.S. Army Corps of Engineers (USACE) will require a Section 404 Permit of the Federal Clean Water Act. The Pitkin County Permitting Office of USACE, Albuquerque District, will review the planned dam site modifications and verify the Project can be considered maintenance under the nationwide category of Section 404 of the Clean Water Act.

The permit will require reasonable measures be implemented to reduce harm to downstream waters. Release flows will be limited to minimize sediment transport through the outlet works, and sediment barriers in the discharge channel will be installed to filter water and store sediments.

10.1.2 United States Forest Service

Grizzly Reservoir Dam is located in the White River National Forest. Requirements for draining the reservoir will be coordinated with the Aspen-Sopris Ranger District.

10.1.2 Colorado Division of Water Resources, Colorado Parks and Wildlife, and Colorado Water Quality Control Division

Reservoir operation will need to satisfy the requirements in the Memorandum of Understanding between the *Colorado Division of Water Resources, Colorado Parks and Wildlife and the Colorado water Quality Control Division* dated April 16, 2012. A fish salvage plan may need to be initiated if there is not a sufficient dead pool to maintain fish when the reservoir is drained. Reservoir release rates will be coordinated with the senior aquatic biologist to minimize impacts.

10.1.2 Pitkin County

Coordination with Pitkin County will be required for draining the reservoir.

SECTION 11 - LIMITATIONS

The information presented in this report is suitable for concept design purposes only. The information in this report is based primarily on data obtained from review of existing documents, data, and studies for the subject site. Also, the nature and extent of variations between specific subsurface data may not become evident until construction. Timely and comprehensive observation and evaluation of actual subsurface conditions, supported by appropriate field and laboratory testing, will be critical during the construction phase. Variations in the subsurface profile described herein should be anticipated.

RJH has endeavored to conduct our professional services for this Project in a manner consistent with a level of care and skill ordinarily exercised by members of the engineering profession currently practicing in Colorado under similar conditions as this project. RJH makes no other warranty, expressed or implied.

Opinions of Probable Project Costs presented in this report are based on our professional opinion of the cost to construct the Project as described in this report. The estimated costs are based on the sources of information described herein and our knowledge of current construction cost conditions in the locality of the Project. Actual Project construction costs are affected by a number of factors beyond our control. Therefore, conditions and factors that arise as Project development proceeds through design and construction may result in construction costs that differ from the estimates documented in this report.

This report has been prepared for use by Twin Lakes Reservoir and Canal Company and for exclusive application to the Grizzly Reservoir Rehabilitation.

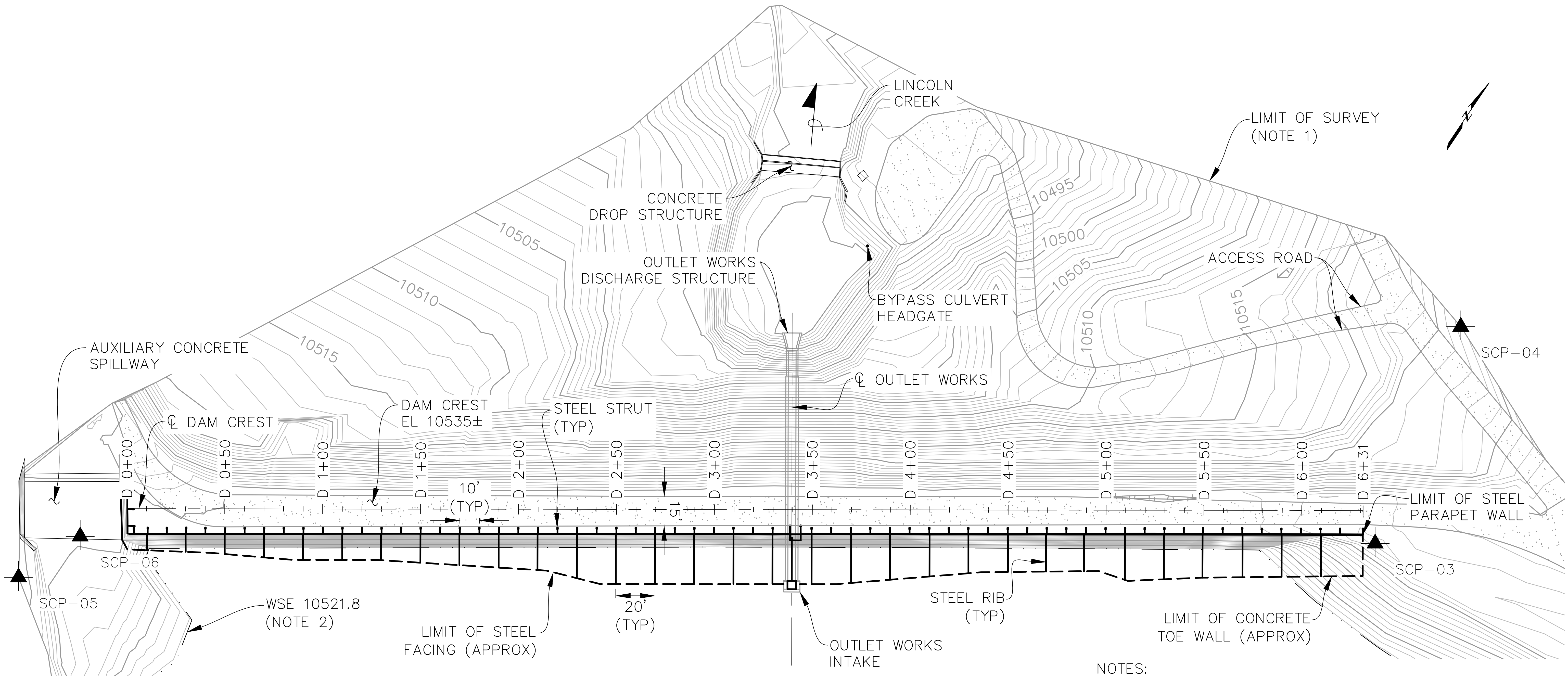
SECTION 12 - REFERENCES

Colorado Office of the State Engineer (SEO) (2007). *Rules and Regulations for Dam Safety and Dam Construction.*

U.S. Bureau of Reclamation (Reclamation) (2015). *Guide to Concrete Repair*, *Second Edition.*

APPENDIX A

CONCEPT-LEVEL FIGURES



GRIZZLY RESERVOIR
MAX NWL 10530±

0 25 50 100
SCALE IN FEET

NOTES:

1. TOPOGRAPHIC MAPPING IS FROM SURVEY PERFORMED BY ASPEN SURVEYORS, LLC ON 09/15/2021. VERTICAL DATUM IS 1988 NAVD INCREASED BY 38.1 FEET. HORIZONTAL DATUM IS LOCAL COORDINATE SYSTEM ESTABLISHED BY ASPEN SURVEYORS.
2. WATER SURFACE ELEVATION AT TIME OF SURVEY.
3. SURVEY CONTROL POINTS SET BY ASPEN SURVEYORS, LLC. SCP–01 AND SPC–02 ARE NOT SHOWN.

PRELIMINARY
NOT FOR CONSTRUCTION

SURVEY CONTROL POINTS (NOTE 3)

CONTROL POINT	NORTHING	EASTING	ELEVATION	DESCRIPTION
SCP–01	9850.56	10027.78	10522.95	TEMPORARY CONTROL POINT
SCP–02	10000.09	10000.03	10539.10	TEMPORARY CONTROL POINT
SCP–03	9991.58	9805.40	10538.41	TEMPORARY CONTROL POINT
SCP–04	10107.80	9779.78	10527.48	PERMANENT CONTROL POINT
SCP–05	9589.87	9240.86	10535.92	TEMPORARY CONTROL POINT
SCP–06	9624.79	9255.24	10530.23	PERMANENT CONTROL POINT

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

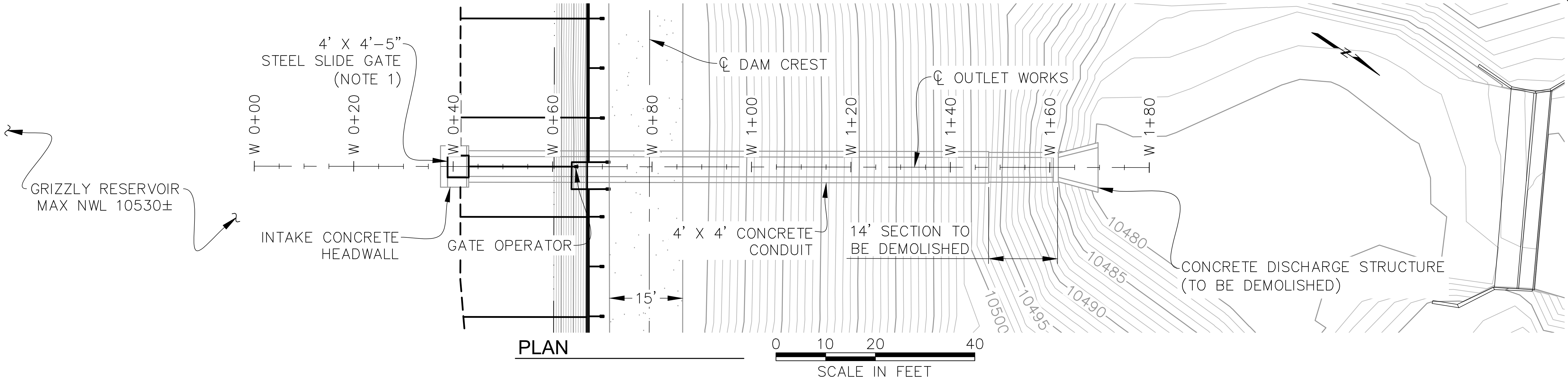
DAM - PLAN OF EXISTING CONDITIONS

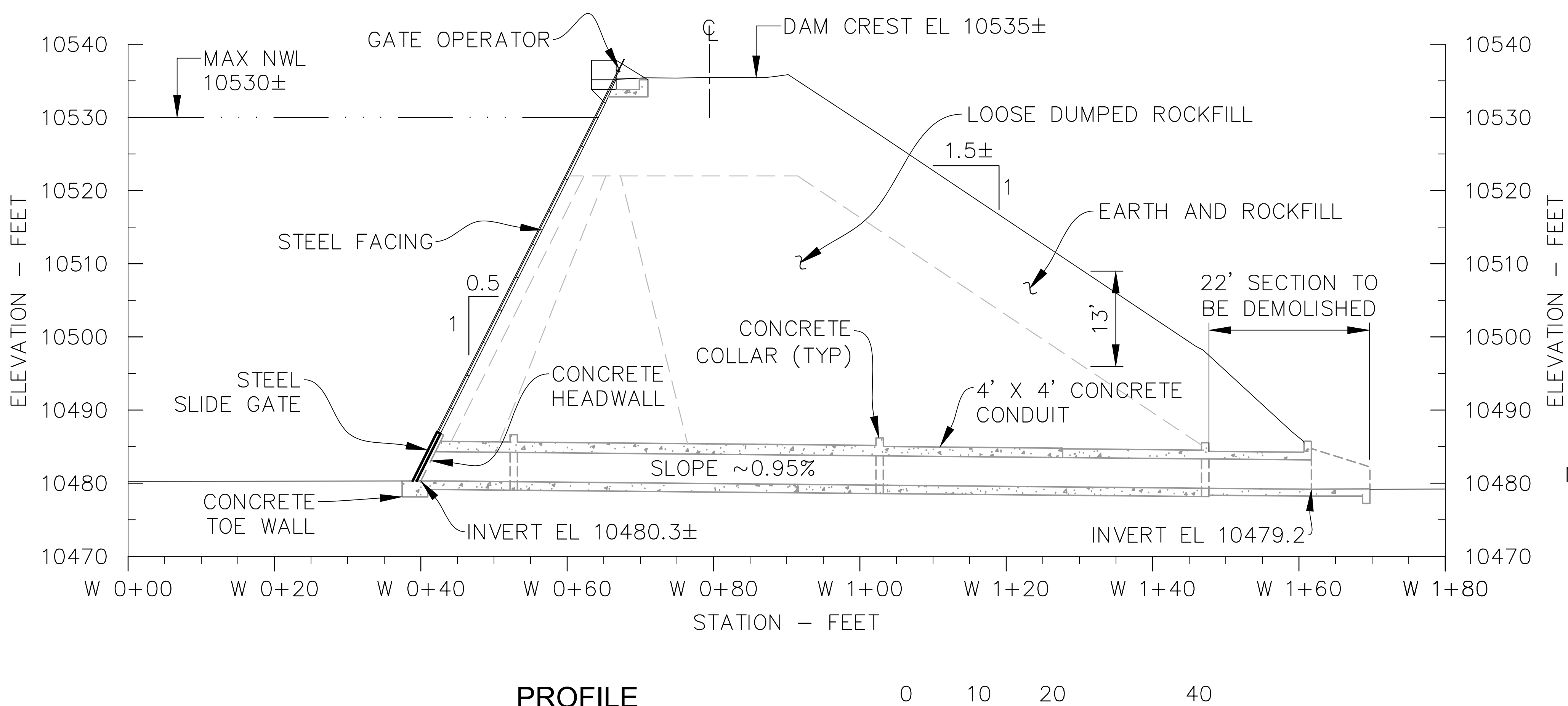
PROJECT NO. 21125

December 2021

Figure 1

P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – EXISTING_CONDITIONS.DWG 10/1/2021 9:35 AM





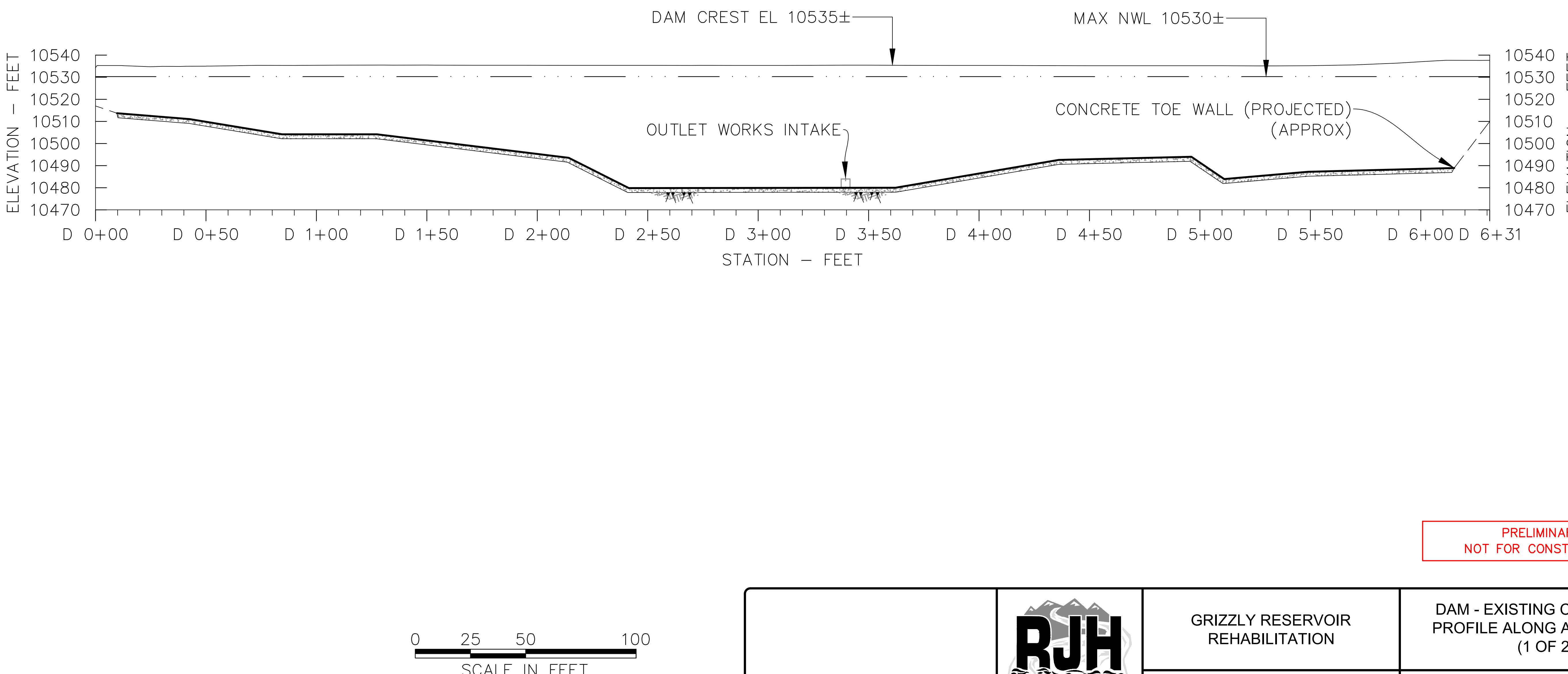
NOTES:

1. CONDITION OF SLIDE GATE TO BE VERIFIED. GATE LEAKING DURING SITE VISIT ON 09/15/2021.
2. WATER SURFACE ELEVATION AT TIME OF SURVEY ON 09/15/21.

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - OUTLET WORKS PLAN AND PROFILE OF EXISTING CONDITIONS	
	PROJECT NO. 21125	December 2021	**Figure 2**

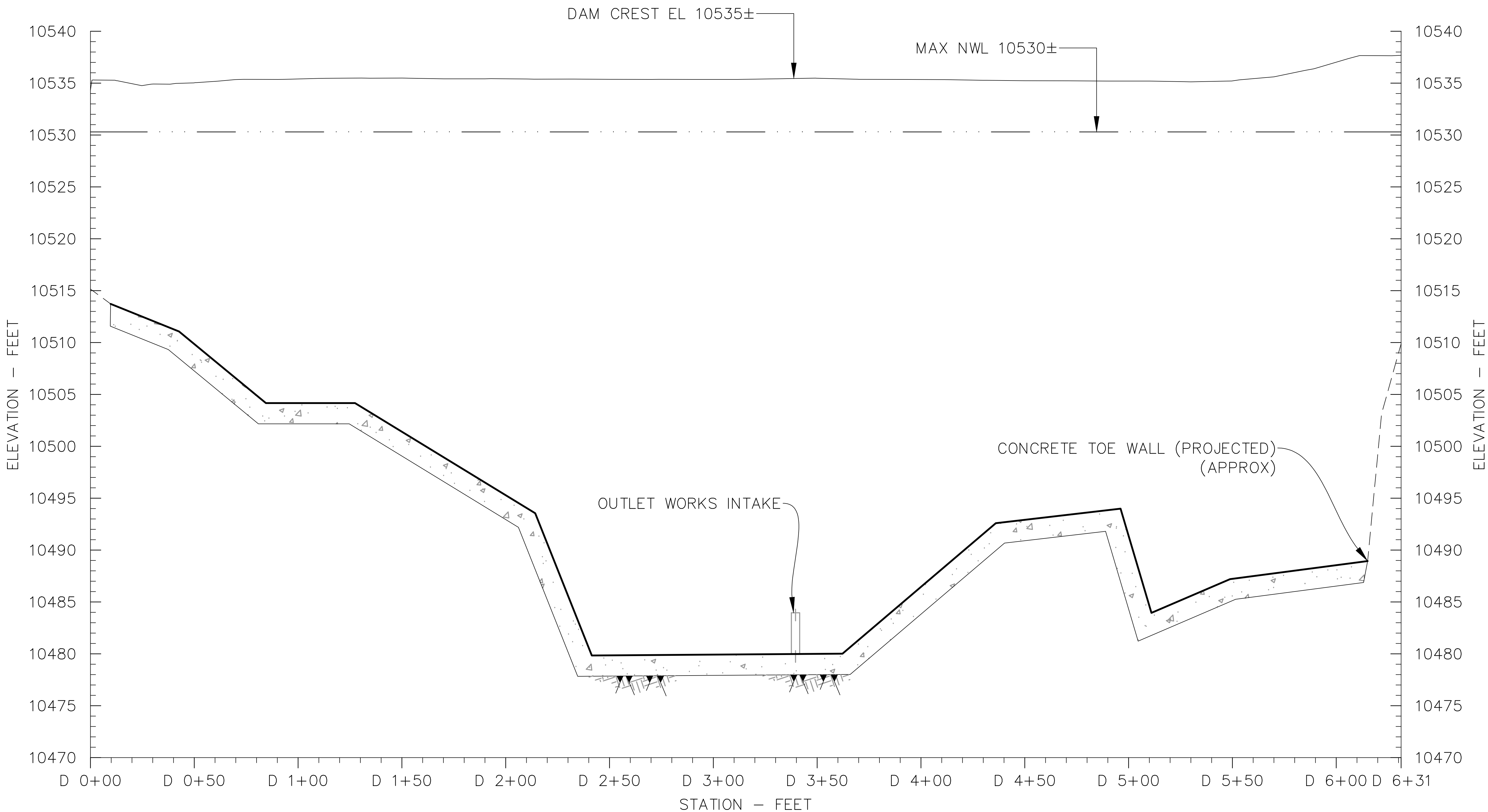
P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - EXISTING_CONDITIONS.DWG 10/1/2021 9:35 AM



PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - EXISTING CONDITIONS PROFILE ALONG AXIS OF DAM (1 OF 2)	
	PROJECT NO. 21125	December 2021	**Figure 3**

P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - EXISTING_CONDITIONS.DWG 10/1/2021 9:35 AM



PRELIMINARY
NOT FOR CONSTRUCTION

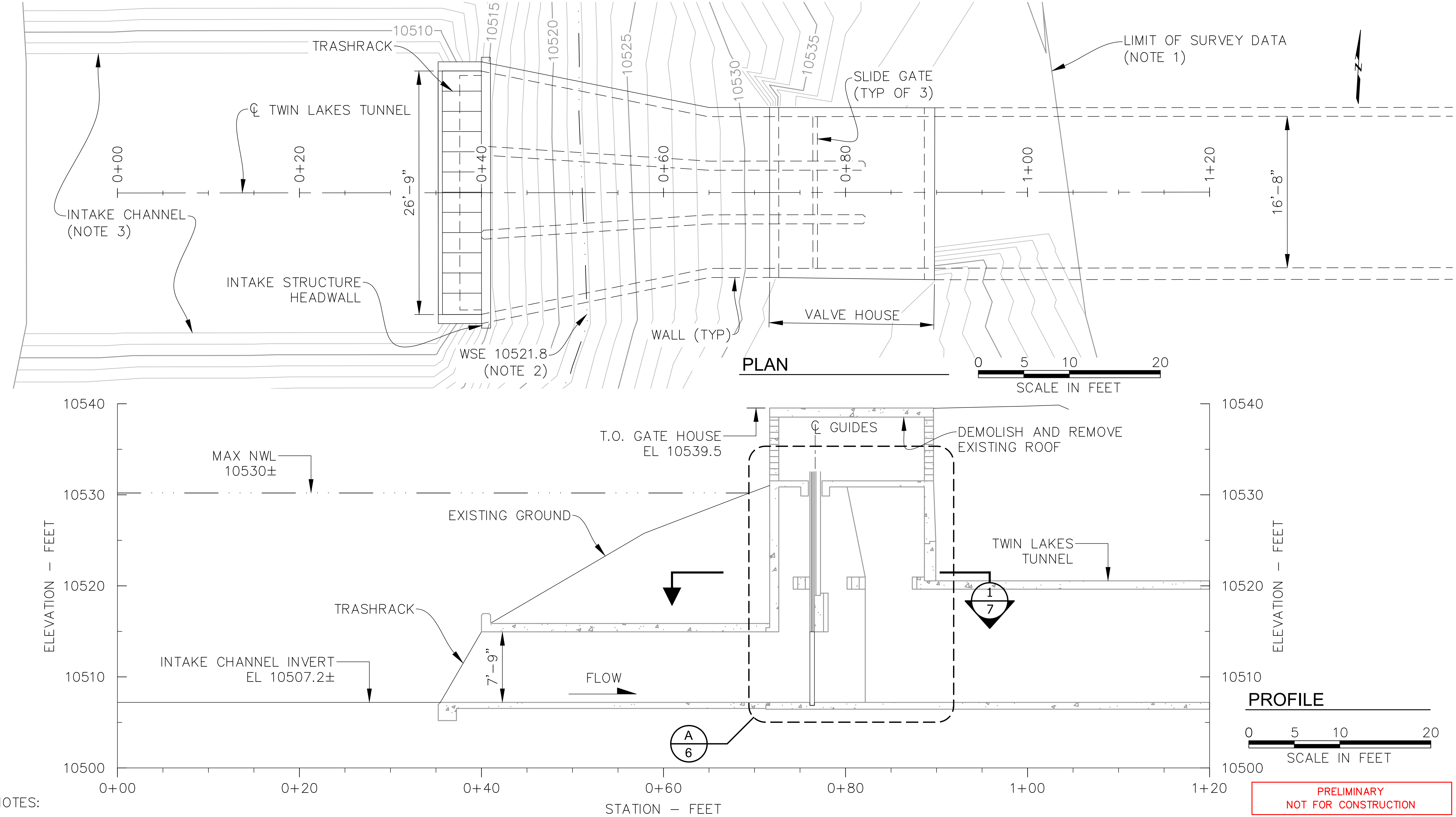
0 25 50 100 150
HORIZONTAL SCALE IN FEET

0 5 10 20 30
VERTICAL SCALE IN FEET

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - EXISTING CONDITIONS PROFILE ALONG AXIS OF DAM (2 OF 2)	
	PROJECT NO. 21125	December 2021	**Figure 4**

P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – EXISTING_CONDITIONS.DWG 10/1/2021 9:35 AM

P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - EXISTING_CONDITIONS.DWG 10/1/2021 9:35 AM

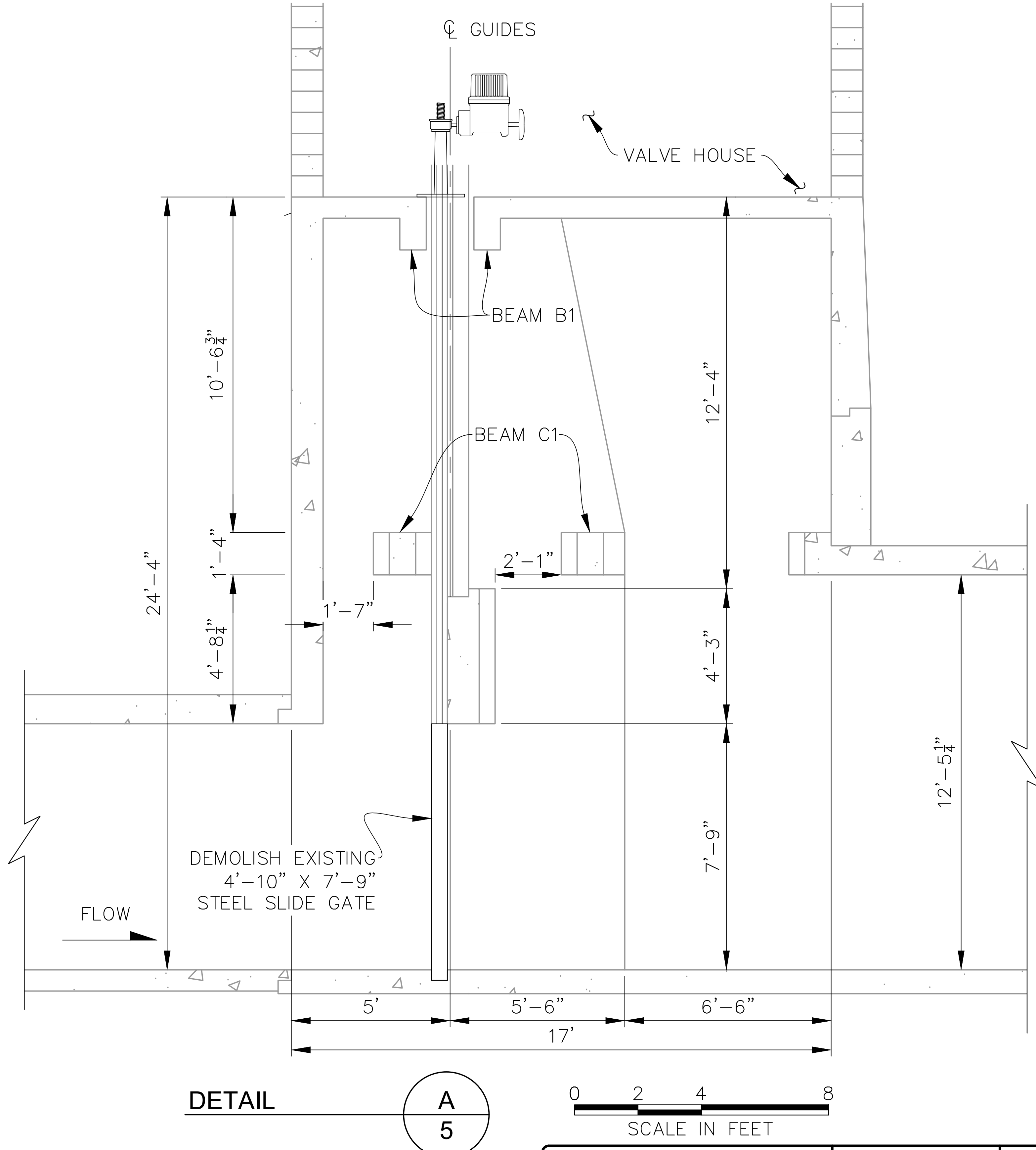


PRELIMINARY
NOT FOR CONSTRUCTION

NOTES:

1. TOPOGRAPHIC MAPPING IS FROM SURVEY PERFORMED BY ASPEN SURVEYORS, LLC ON 09/15/2021. VERTICAL DATUM IS NAVD 1988 INCREASED BY 38.1 FEET. HORIZONTAL DATUM IS LOCAL COORDINATE SYSTEM ESTABLISHED BY ASPEN SURVEYORS.
2. WATER SURFACE ELEVATION AT TIME OF SURVEY.
3. EXISTING TOPOGRAPHY APPROXIMATE BELOW WATER LINE.

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	TWIN LAKES TUNNEL - INTAKE STRUCTURE PLAN AND PROFILE OF EXISTING CONDITIONS
	PROJECT NO. 21125	December 2021 **Figure 5**



P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – EXISTING_CONDITIONS.DWG 10/1/2021 9:35 AM

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

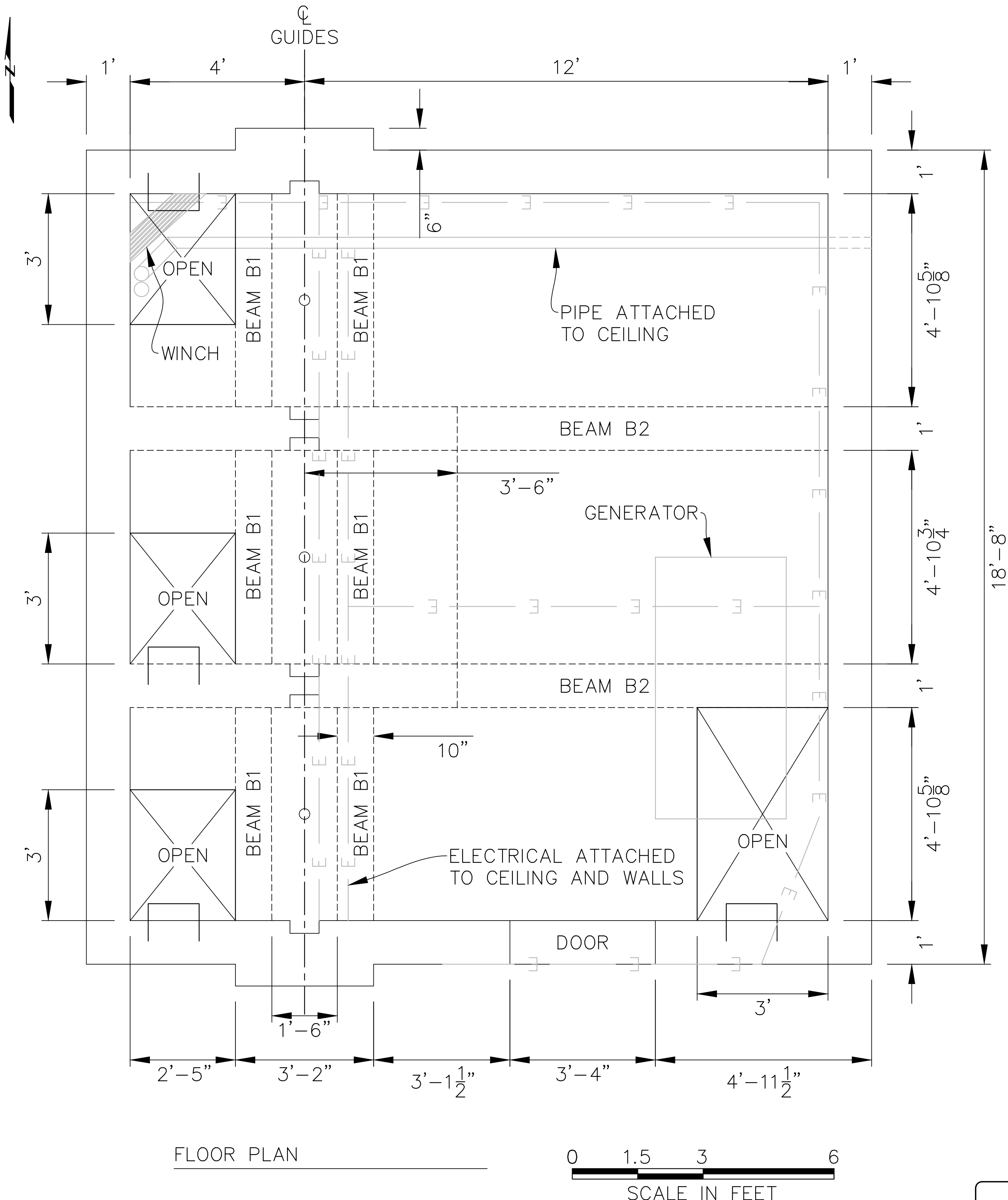
PROJECT NO. 21125

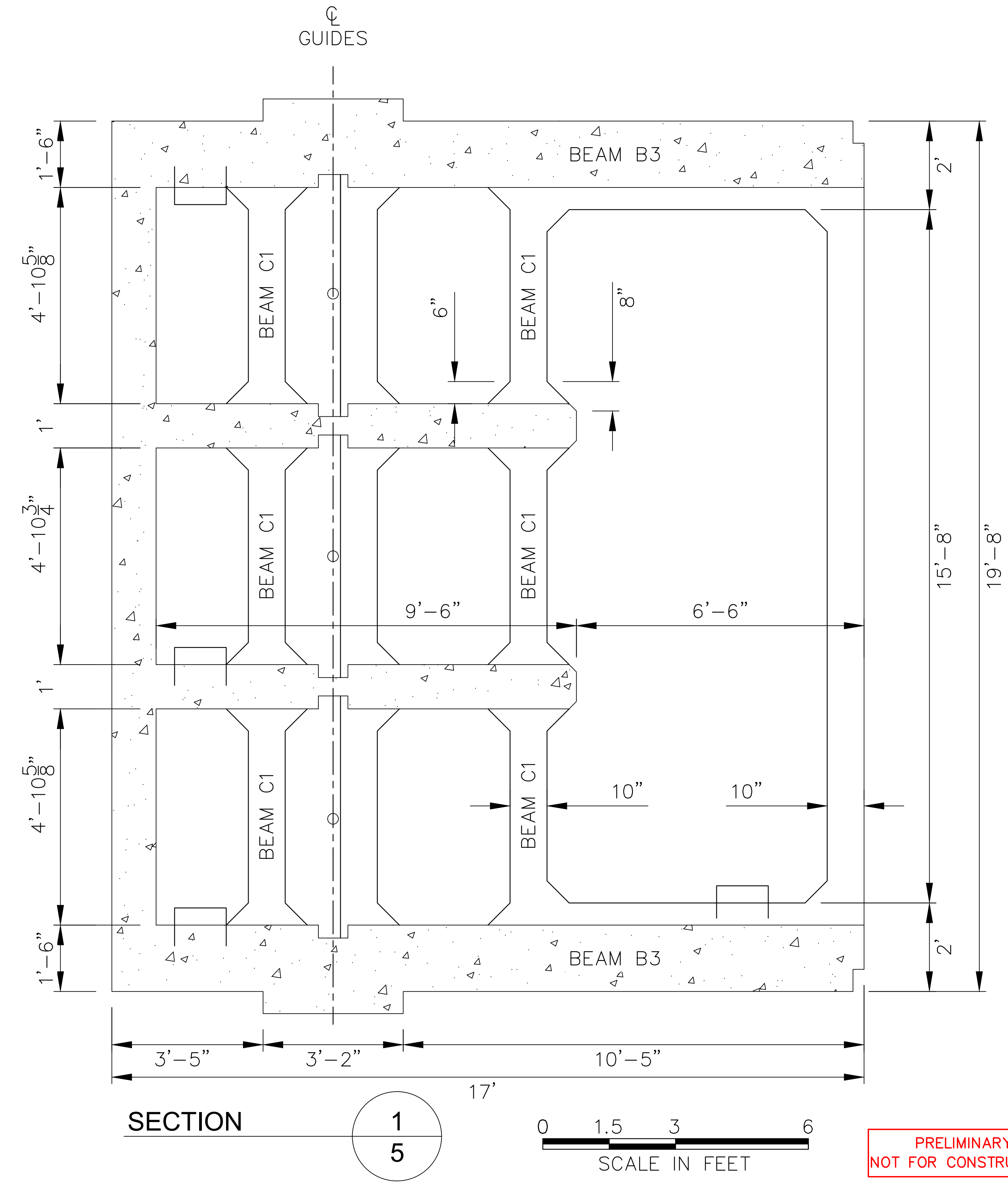
TWIN LAKES TUNNEL - EXISTING CONDITIONS INTAKE STRUCTURE PROFILE DETAIL

December 2021

Figure 6

P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - TWIN_LAKES_TUNNEL_INTAKE_EXISTING.DWG 12/10/2021 11:23 AM





PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

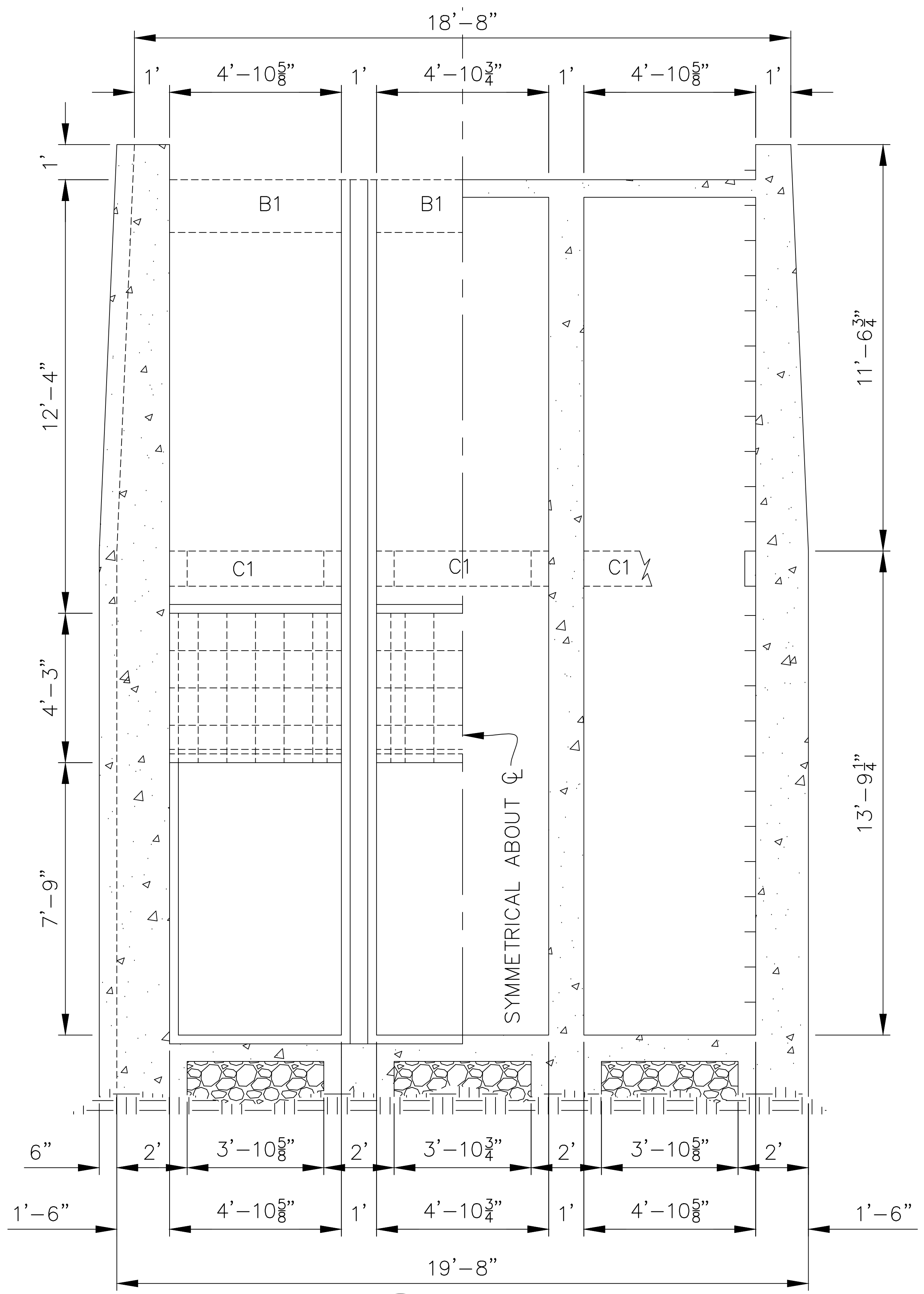
GRIZZLY RESERVOIR REHABILITATION

TWIN LAKES TUNNEL - 1934 DRAWINGS INTAKE STRUCTURE DETAILS (1 OF 2)

PROJECT NO. 21125

December 2021

Figure 7



SECTION 2/8

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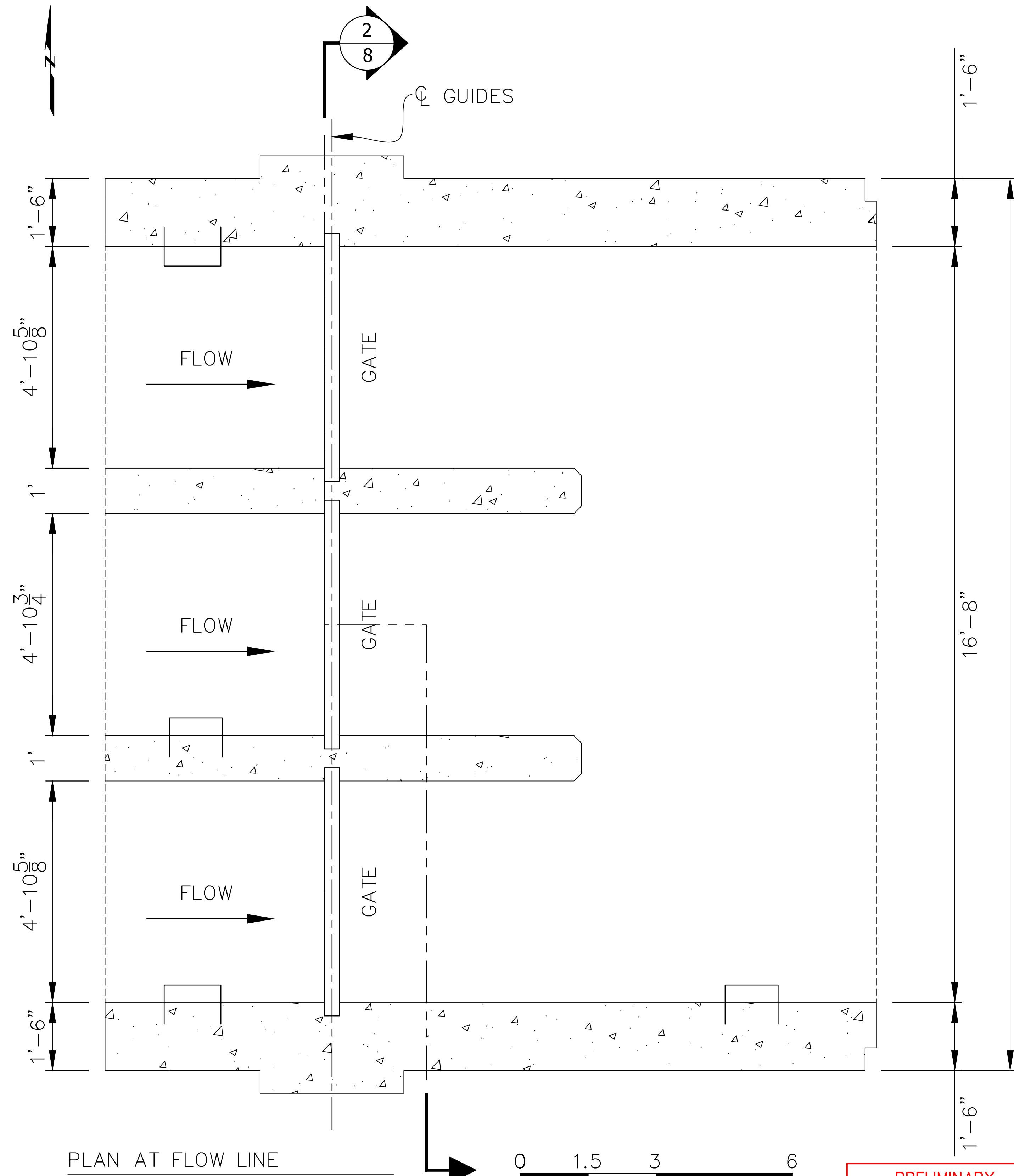

PLAN AT FLOW LINE

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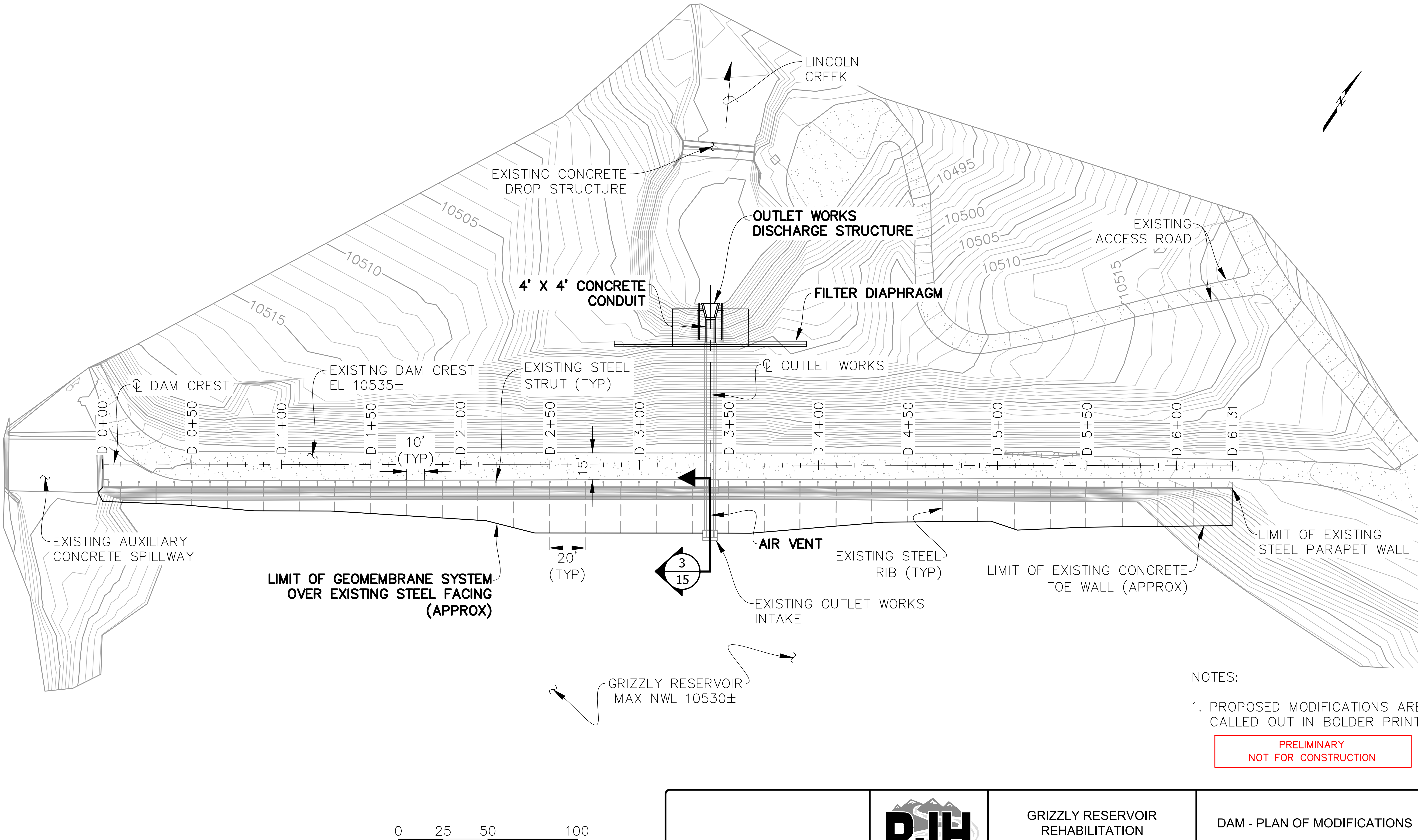
SCALE IN FEET

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	TWIN LAKES TUNNEL - 1934 DRAWINGS INTAKE STRUCTURE DETAILS (2 OF 2)	
	PROJECT NO. 21125	December 2021	**Figure 8**

P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - TWIN_LAKES_TUNNEL_INTAKE_EXISTING.DWG 12/10/2021 11:23 AM



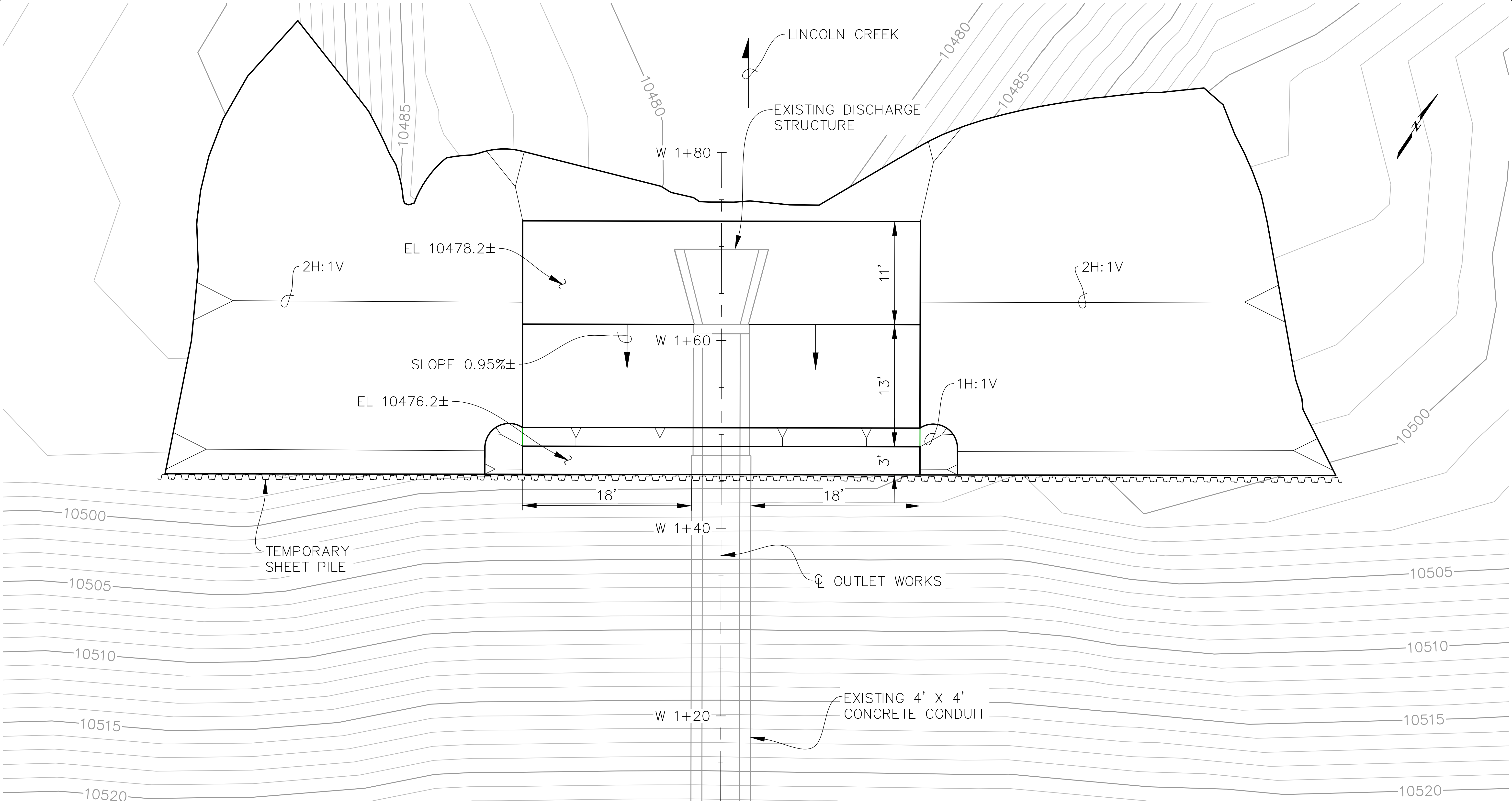
NOTES:

1. PROPOSED MODIFICATIONS ARE CALLED OUT IN BOLDER PRINT.

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - PLAN OF MODIFICATIONS	
	PROJECT NO. 21125	December 2021	Figure 9

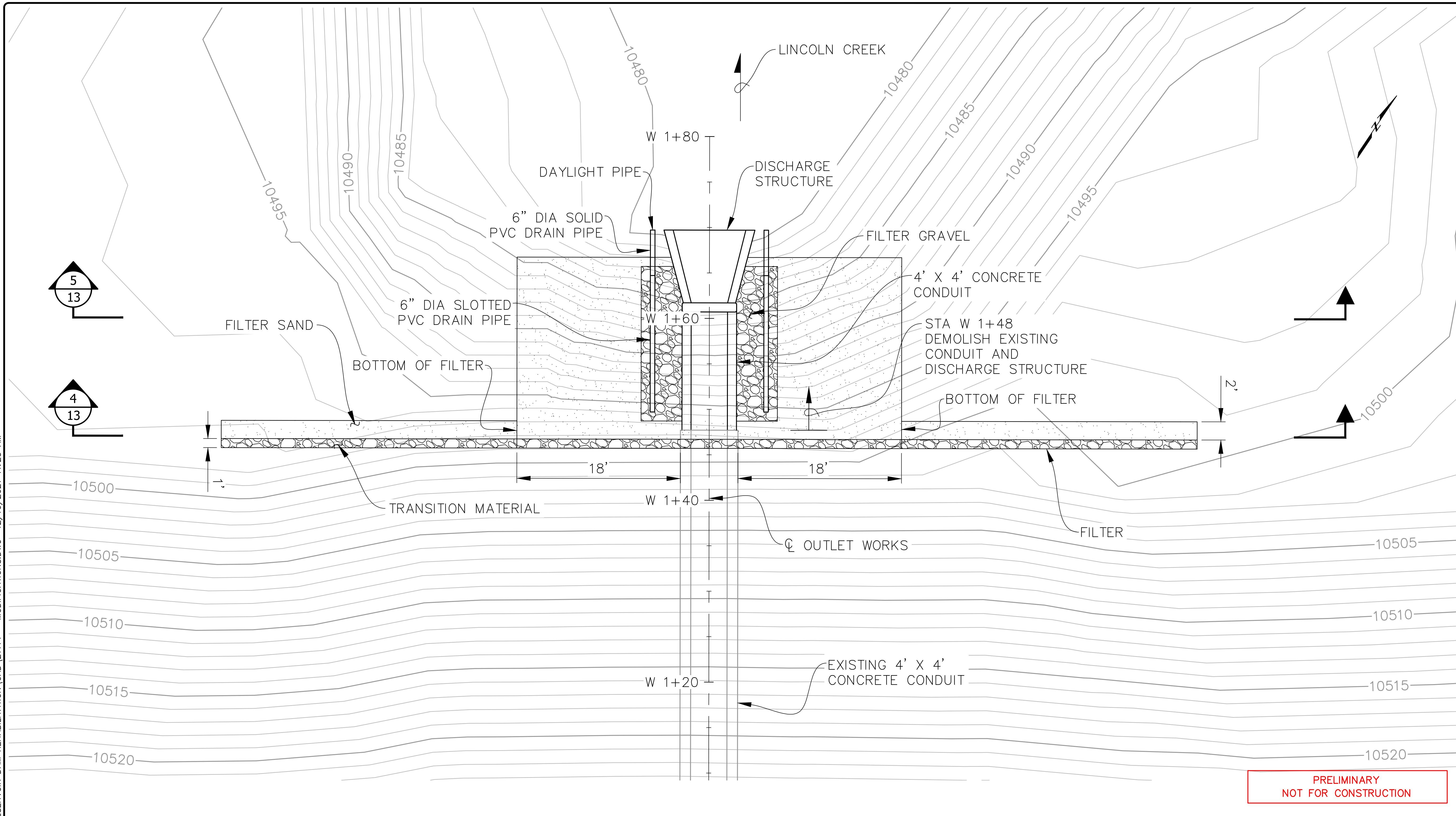
P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - MODIFICATIONS.DWG 12/10/2021 11:23 AM



PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - OUTLET WORKS EXCAVATION PLAN	
	PROJECT NO. 21125	December 2021	Figure 10

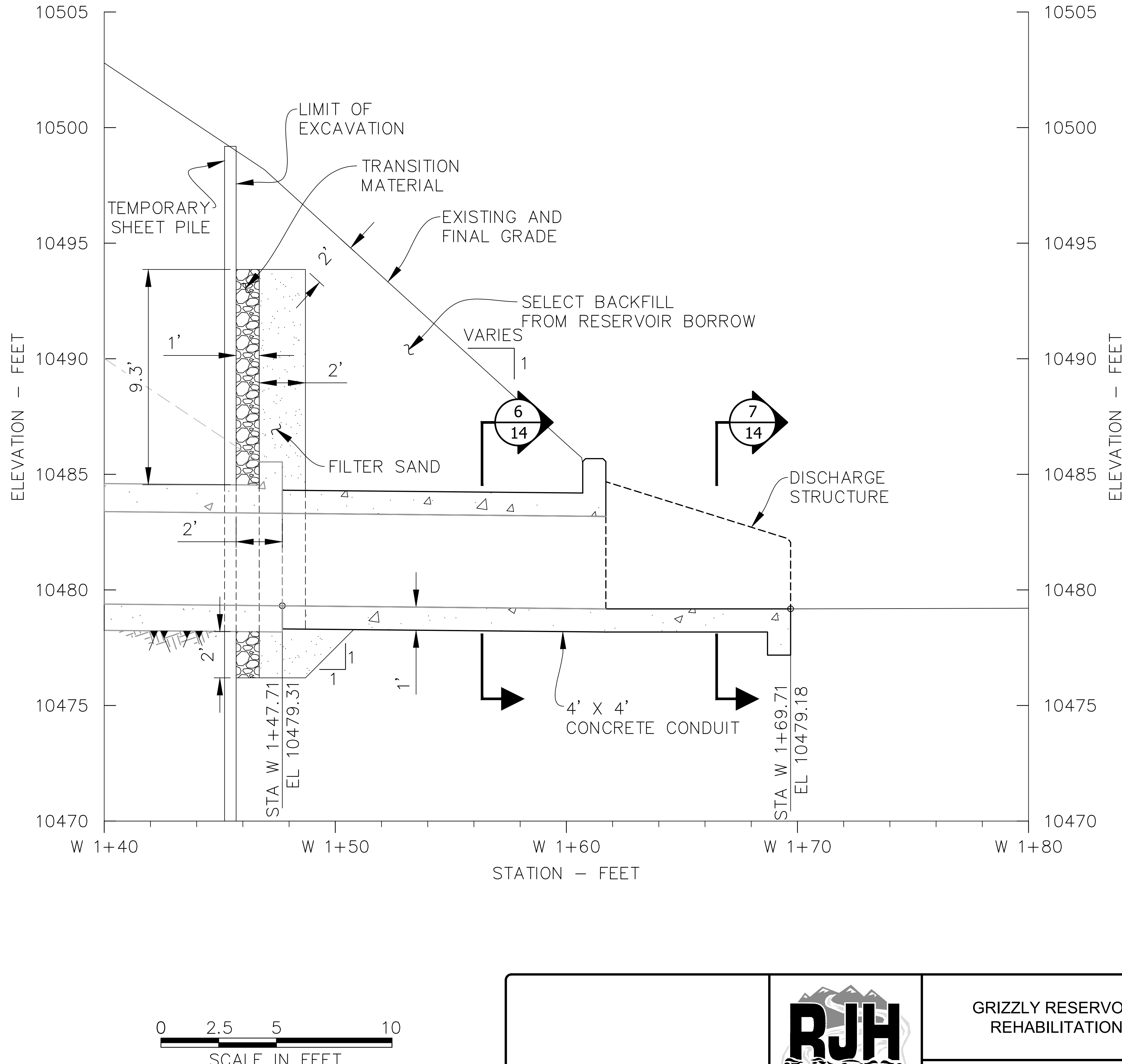
P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - EXCAVATION_PLAN.DWG 12/10/2021 11:23 AM



P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - MODIFICATIONS.DWG 12/10/2021 11:23 AM

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION	DAM - FILTER DIAPHRAGM PLAN	
PROJECT NO. 21125	December 2021	Figure 11



PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - FILTER DIAPHRAGM PROFILE	
	PROJECT NO. 21125	December 2021	**Figure 12**

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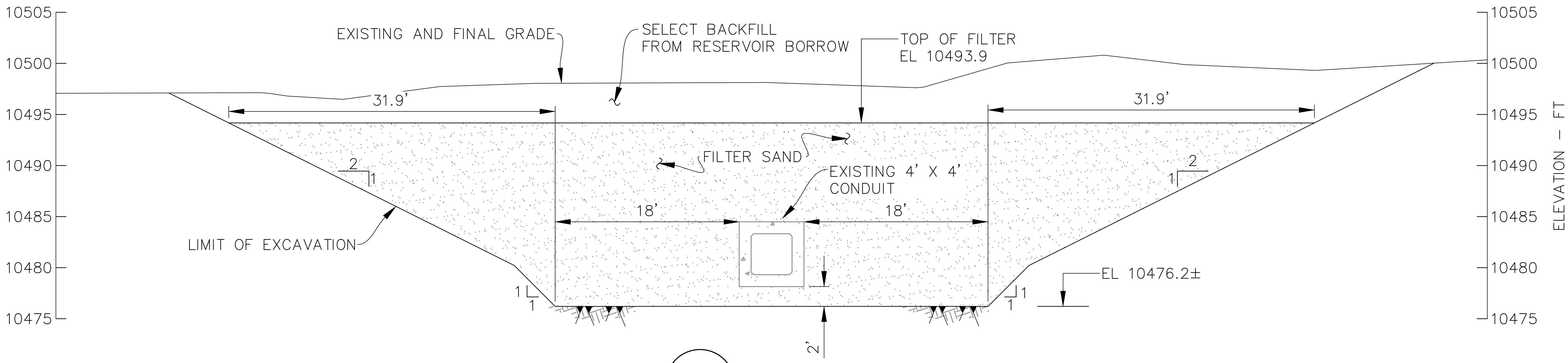
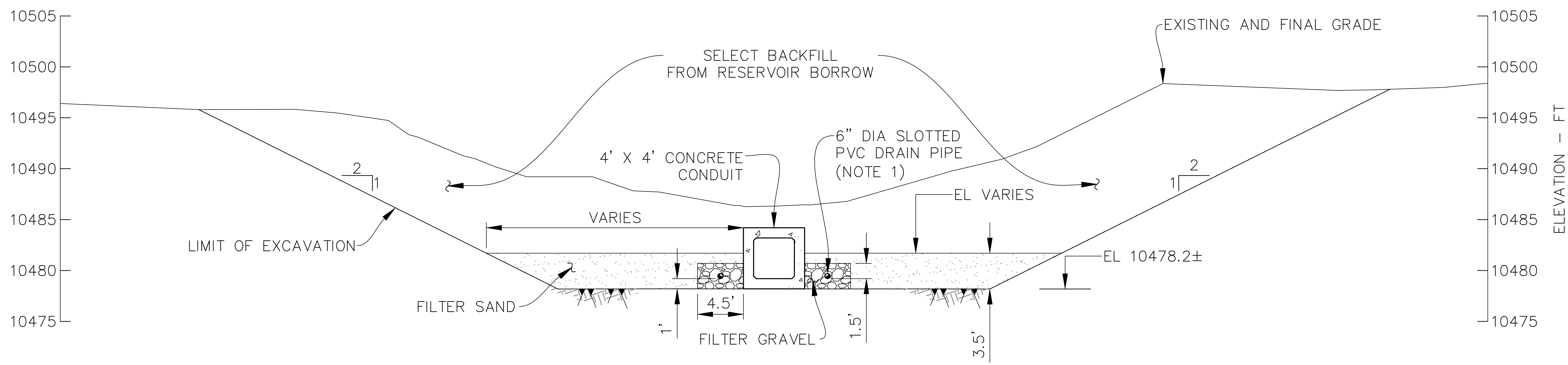


SECTION 4/11
W 1+47



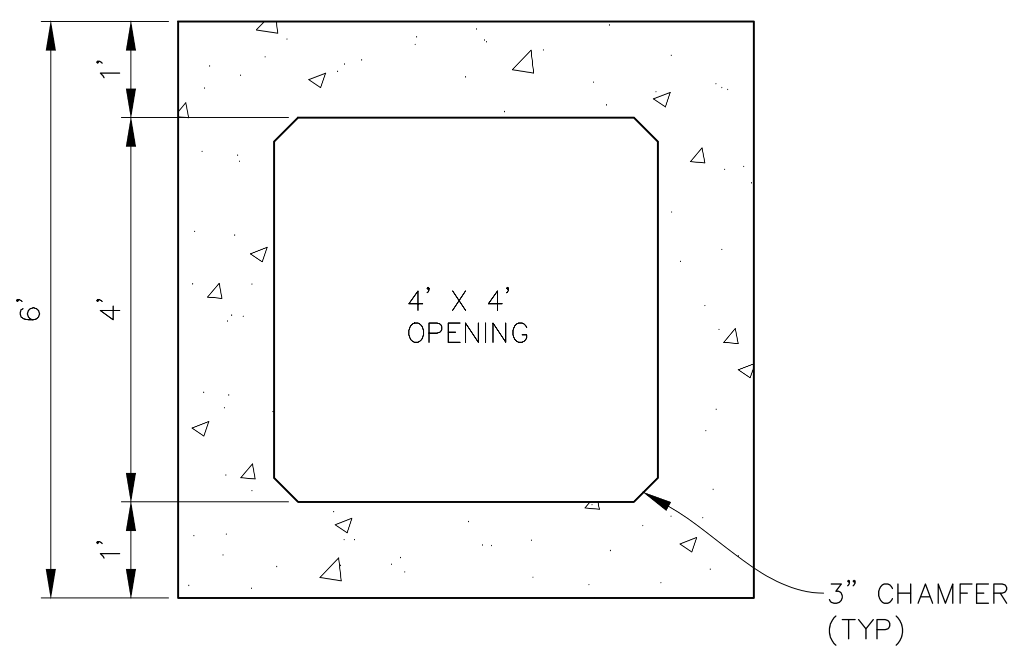
SECTION 5/11
W 1+60

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION	DAM - FILTER DIAPHRAGM SECTIONS	
PROJECT NO. 21125	December 2021	Figure 13

P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – MODIFICATIONS.DWG 12/10/2021 11:23 AM



SECTION 6/12
W 1+56

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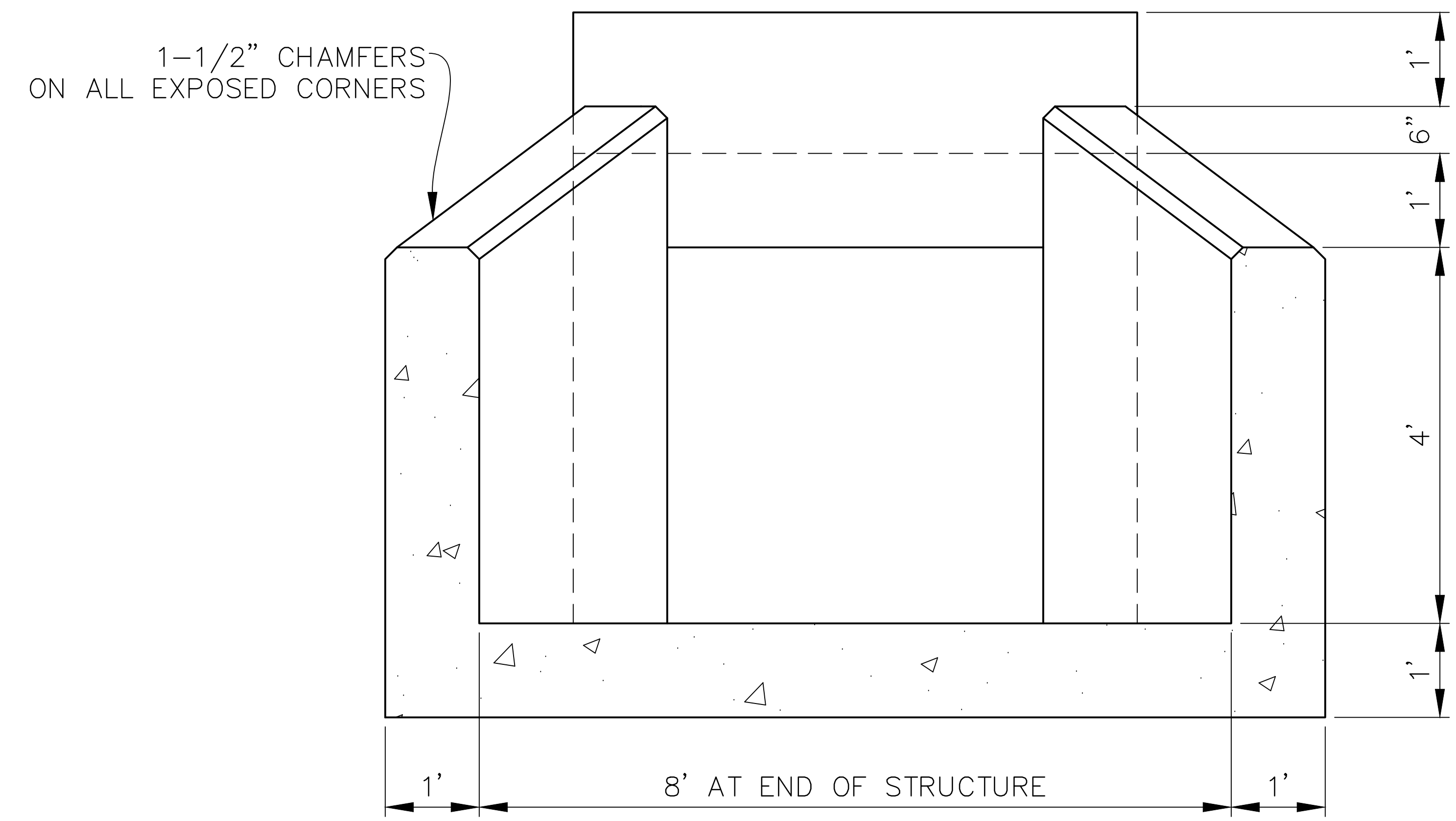


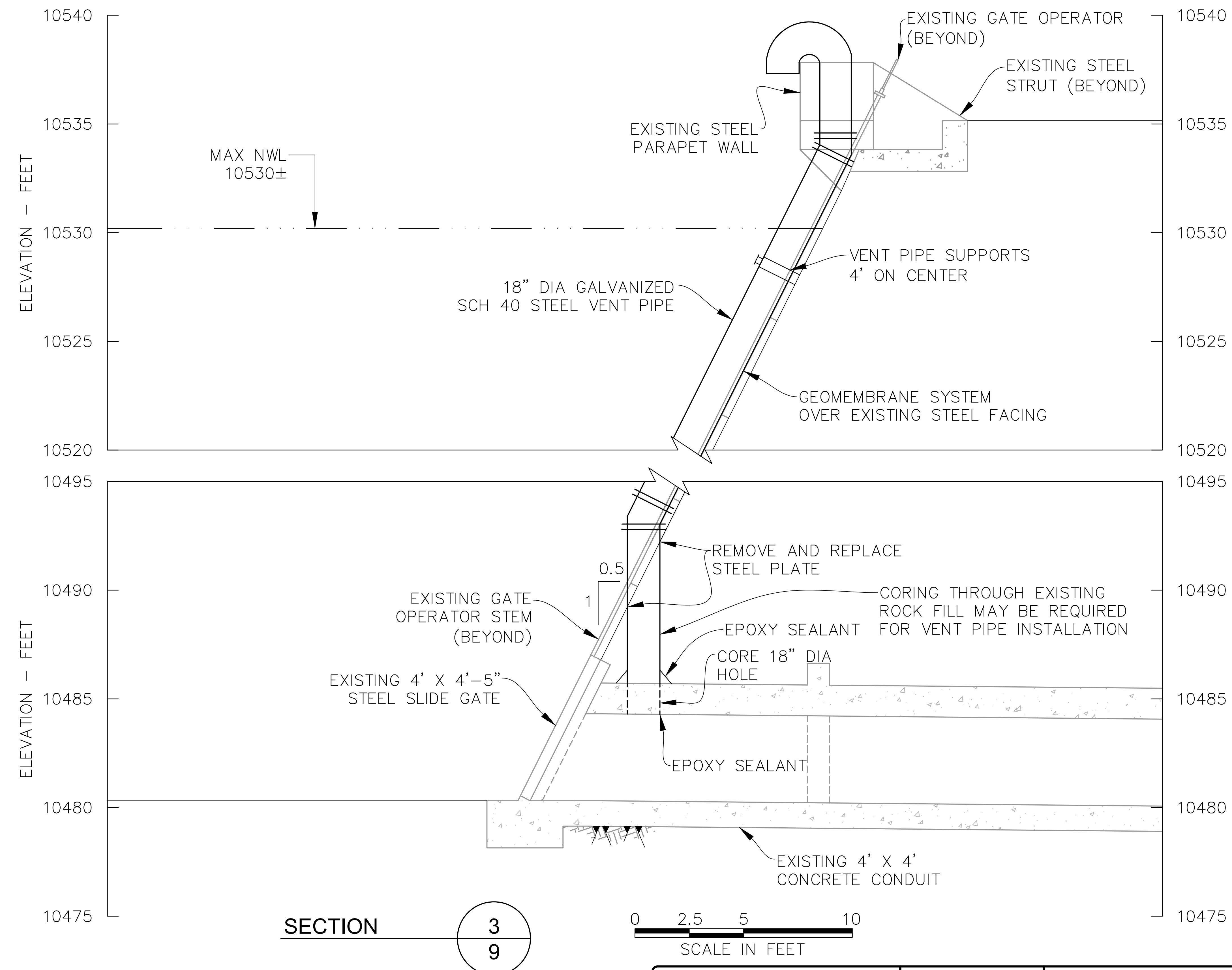
SECTION 7/12
W 1+66

0 1 2 4
SCALE IN FEET

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM -CONDUIT TYPICAL SECTIONS AND DETAILS	
	PROJECT NO. 21125	December 2021	Figure 14

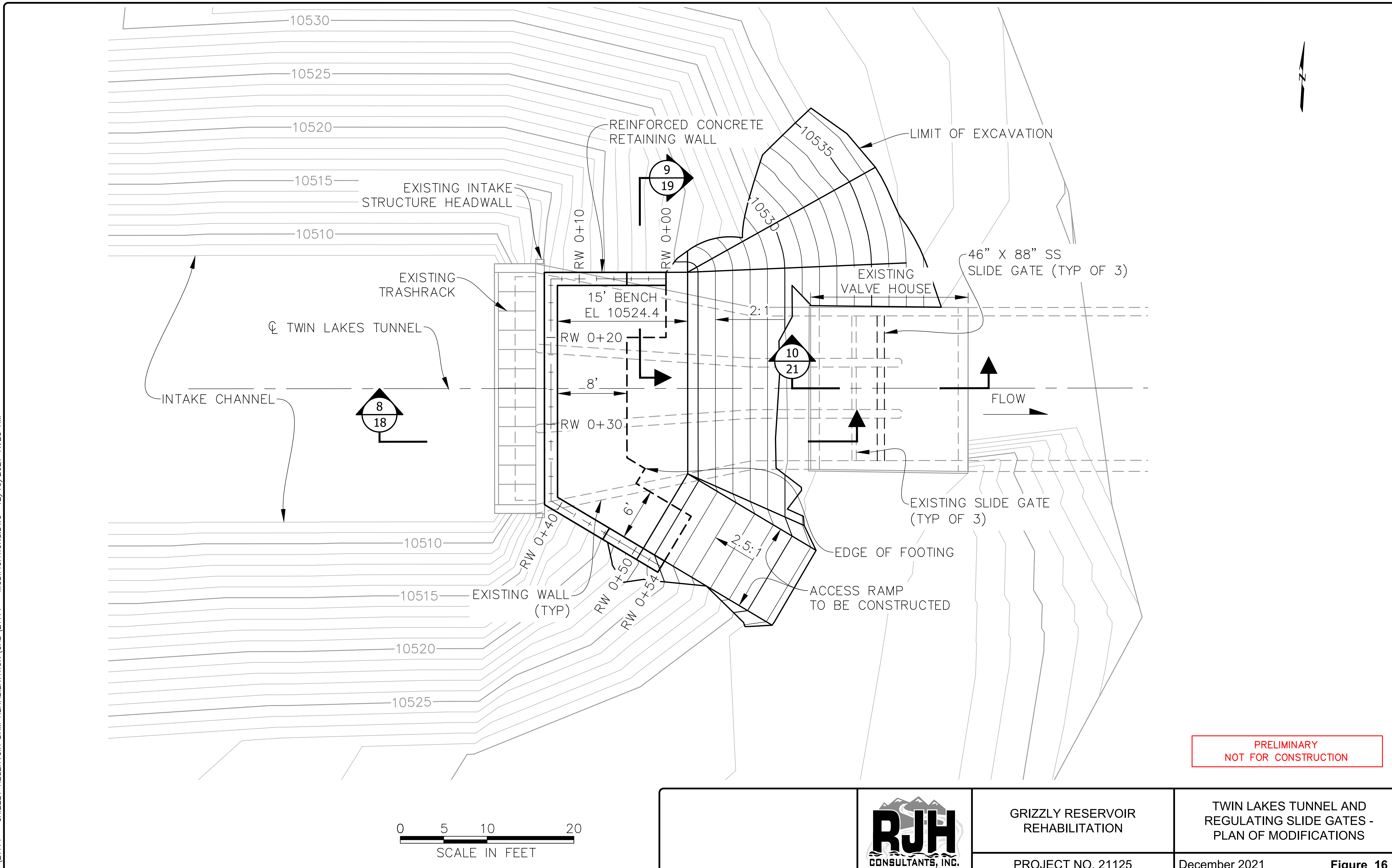
P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - MODIFICATIONS.DWG 12/10/2021 11:23 AM



PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - OUTLET WORKS AIR VENT
	PROJECT NO. 21125	December 2021 **Figure 15**

P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - MODIFICATIONS.DWG 12/10/2021 11:23 AM



RJH CONSULTANTS, INC.

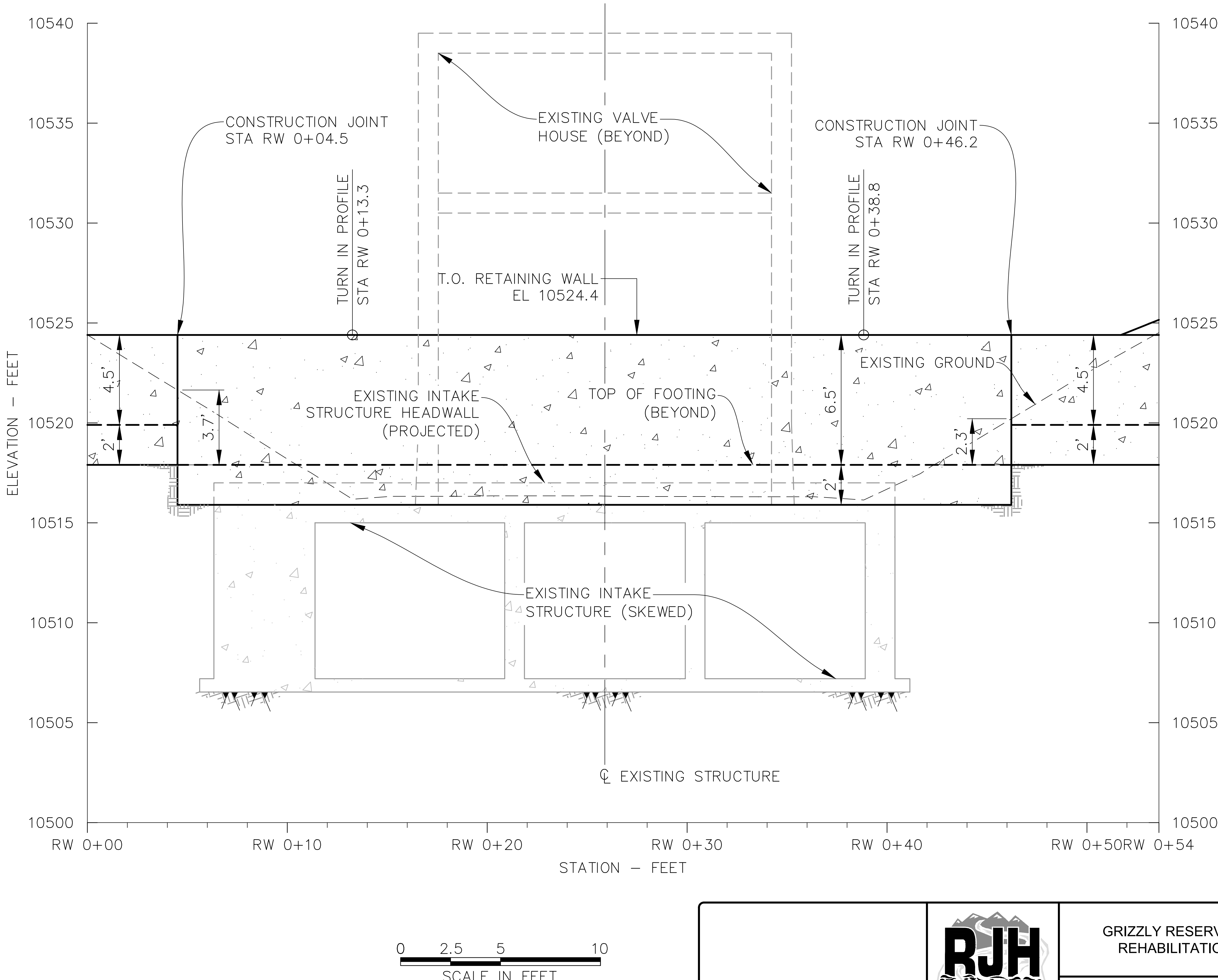
GRIZZLY RESERVOIR REHABILITATION

TWIN LAKES TUNNEL AND REGULATING SLIDE GATES - PLAN OF MODIFICATIONS

PROJECT NO. 21125

December 2021

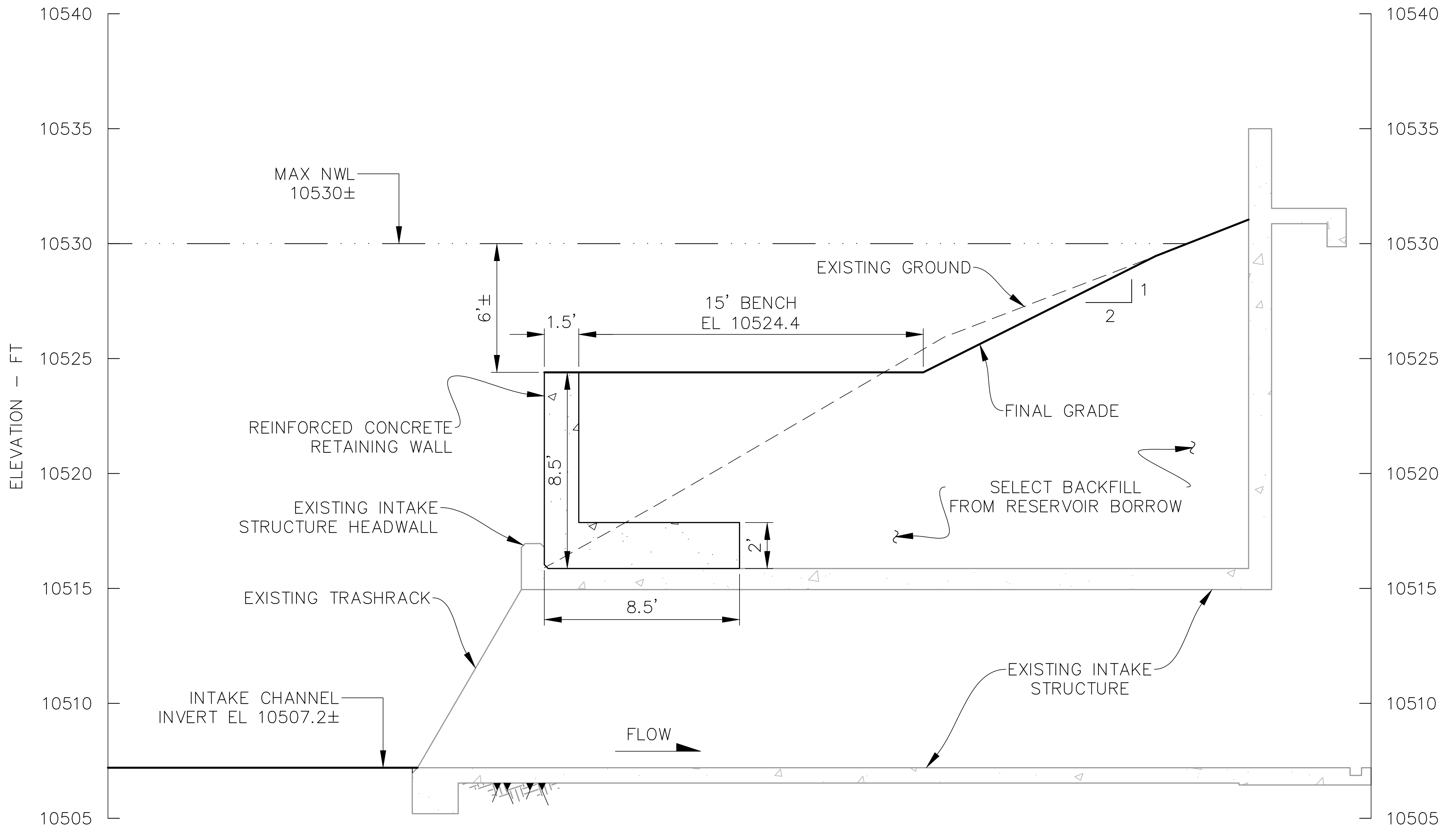
Figure 16



PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	TWIN LAKES TUNNEL - RETAINING WALL PROFILE	
	PROJECT NO. 21125	December 2021	**Figure 17**

P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – MODIFICATIONS.DWG 12/10/2021 11:23 AM



SECTION 8/16
RW 0+32

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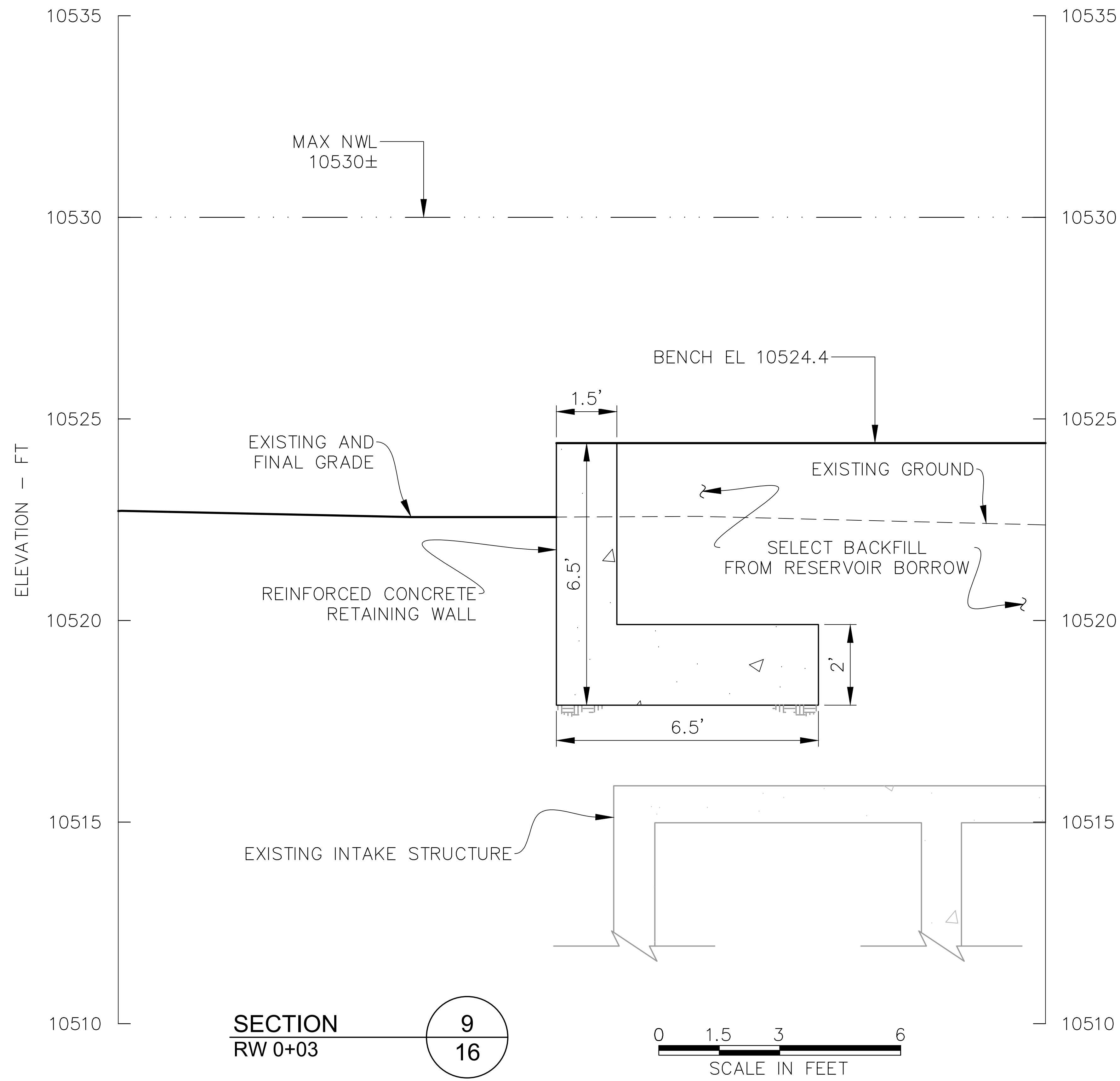
SCALE IN FEET

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION	TWIN LAKES TUNNEL - RETAINING WALL SECTION (1 OF 2)	
PROJECT NO. 21125	December 2021	**Figure 18**

P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – MODIFICATIONS.DWG 12/10/2021 11:23 AM



PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

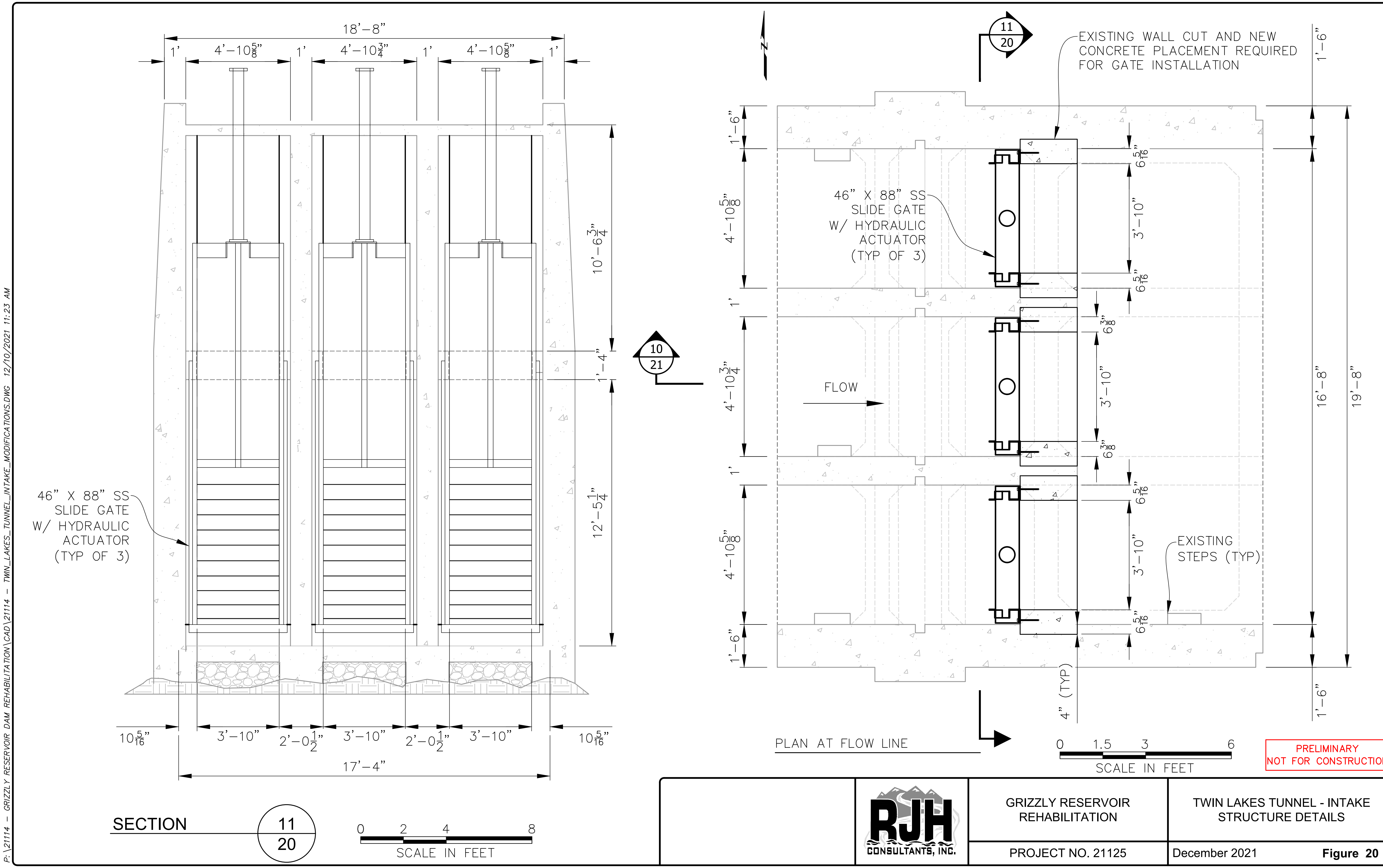
TWIN LAKES TUNNEL - RETAINING WALL SECTION (2 OF 2)

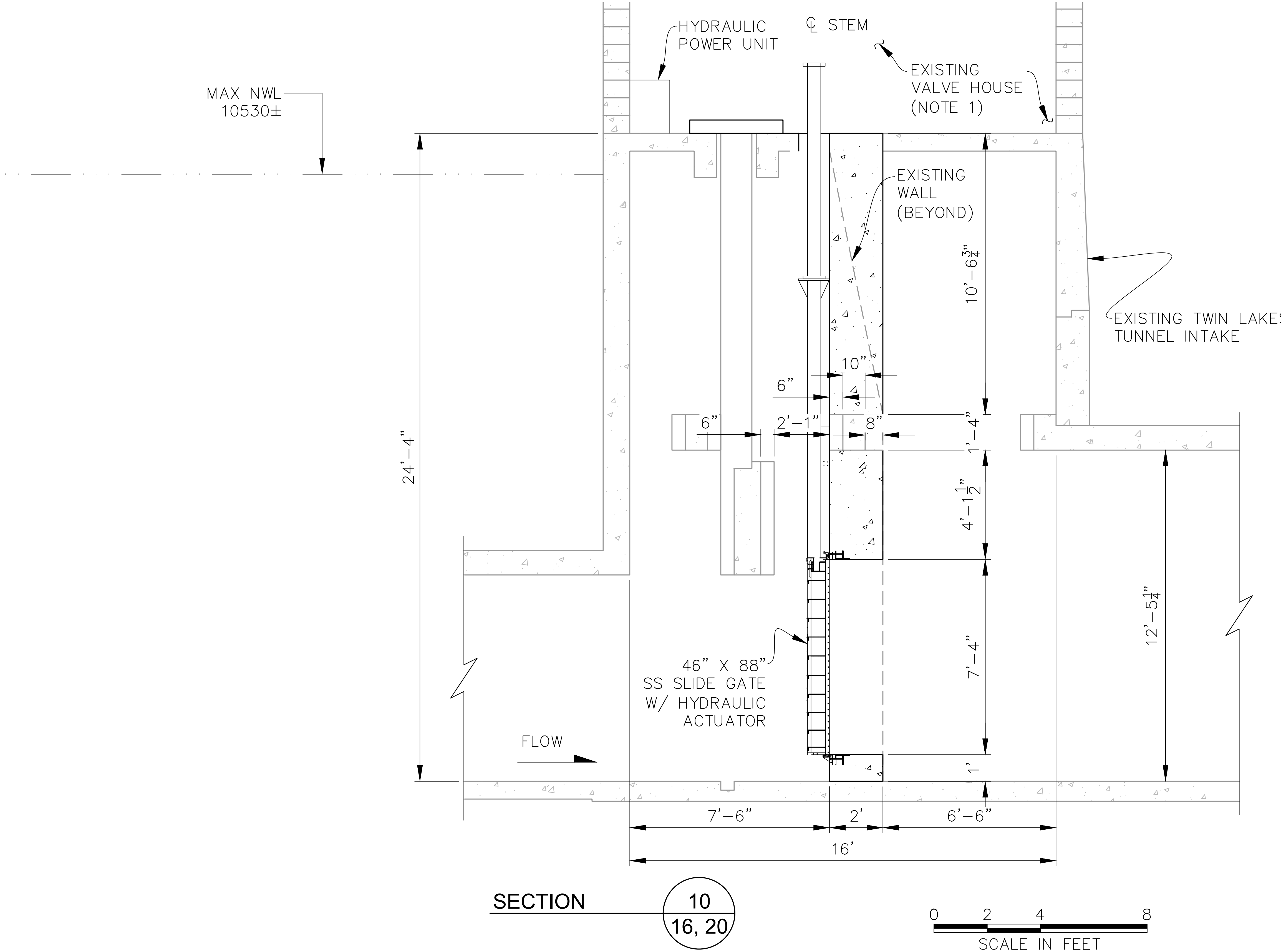
PROJECT NO. 21125

December 2021

Figure 19

P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – MODIFICATIONS.DWG 12/10/2021 11:23 AM


18'–8"
1'
4'–10 5/8"
1'
4'–10 3/4"
1'
4'–10 5/8"
1'
10'–6 3/4"
1'–4"
12'–5 1/4"
46" X 88" SS SLIDE GATE W/ HYDRAULIC ACTUATOR (TYP OF 3)
10 5/16"
3'–10"
2'–0 1/2"
3'–10"
2'–0 1/2"
3'–10"
10 5/16"
17'–4"
SECTION 11/20
0 2 4 8
SCALE IN FEET
10/21
11/20
N
EXISTING WALL CUT AND NEW CONCRETE PLACEMENT REQUIRED FOR GATE INSTALLATION
46" X 88" SS SLIDE GATE W/ HYDRAULIC ACTUATOR (TYP OF 3)
FLOW
EXISTING STEPS (TYP)
1'–6"
4'–10 5/8"
1'
4'–10 3/4"
1'
4'–10 5/8"
1'–6"
6 5/16"
3'–10"
6 5/16"
6 3/8"
3'–10"
6 3/8"
6 5/16"
3'–10"
6 5/16"
16'–8"
19'–8"
1'–6"
1'–6"
4" (TYP)
PLAN AT FLOW LINE
0 1.5 3 6
SCALE IN FEET
PRELIMINARY NOT FOR CONSTRUCTION
P:\21114 – GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 – TWIN_LAKES_TUNNEL_INTAKE_MODIFICATIONS.DWG 12/10/2021 11:23 AM
RJH CONSULTANTS, INC.
GRIZZLY RESERVOIR REHABILITATION
TWIN LAKES TUNNEL - INTAKE STRUCTURE DETAILS
PROJECT NO. 21125
December 2021
Figure 20



SECTION 10 / 16, 20

0 2 4 8
SCALE IN FEET

NOTES:

1. DEMOLISH EXISTING ROOF FOR CONSTRUCTION ACCESS. REPLACE ROOF WITH PRE-CAST OR CAST IN PLACE CONCRETE ROOF.

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

TWIN LAKES TUNNEL - GATE REPLACEMENT

PROJECT NO. 21125

December 2021

Figure 21

P:\21114 - GRIZZLY RESERVOIR DAM REHABILITATION\CAD\21114 - MODIFICATIONS.DWG 12/10/2021 11:23 AM

Appendix B

Summary of Water Yield

	= E + W Tunnel Trnsmtn	Buearu Exch Trnsmtn	Lake Creek Native	Winter Water	Now - TLRC **IPTDS Jr.** New Tunnel Trnsmtn	Colorado River Dist IPTDS Junior	TOTAL INFLOW	ENDING BALANCE	Trnsmtn Ac Ft /Share	Native Ac Ft /Share	TOTAL Ac Ft /Share
==========	===========	==========	==========	=========	=================		==========	==========	=======	=======	=======
1985-86*	49189	1545	0	3973	0		53162	45689	0.9919	0.0801	1.0721
1986-87*	18230	1941	13802	8306	0		40691	30326	0.3748	0.4458	0.8206
1987-88*	32328	1980	152	5245	0		41828	29927	0.7347	0.1088	0.8435
1988-89*	37052	1698	0	1808	0		39554	16631	0.7612	0.0365	0.7976
1989-90*	41310	1657	427	2393	0		45787	29910	0.8665	0.0569	0.9233
1990-91*	42784	1527	0	1601	0		45912	34009	0.8936	0.0323	0.9258
1991-92*	41512	1221	0	986	0		43721	38026	0.8618	0.0199	0.8817
1992-93*	62151	2345	8777	1476	0		74750	42730	1.3006	0.2068	1.5074
1993-94*	37390	1346	19673	2192	2511		63113	41024	0.8318	0.4409	1.2727
1994-95*	28777	2320	33712	2224	0		67033	50453	0.6271	0.7247	1.3518
1995-96*	33984	1777	2140	2669	770		40919	37473	0.7282	0.0970	0.8252
1996-97*	29995	1808	12663	3945	0		48411	52690	0.6413	0.3349	0.9762
1997-98*	46905	2579	6243	3812	0		59539	48201	0.9979	0.2028	1.2007
1998-99*	16371	2103	23942	2633	0		45049	43942	0.3725	0.5359	0.9084
1999-00*	41751	1695	0	3460	0		46906	33859	0.8761	0.0698	0.9459
2000-01*	45683	2142	0	2772	0		50598	44832	0.9645	0.0559	1.0203
2001-02*	20171	1484	0	2943	0		24599	35773	0.4367	0.0594	0.4960
2002-03*	44388	2424	0	2428	0		49240	42970	0.9440	0.0490	0.9930
2003-04*	34613	1259	0	3460	0		39332	33822	0.7234	0.0698	0.7932
2004-05*	49221	2976	0	3251	0		55448	36864	1.0526	0.0656	1.1181
2005-06*	53705	2962	0	4732	0		61396	44397	1.1427	0.0954	1.2381
2006-07*	53397	2974	397	6464	0		63232	48594	1.1368	0.1384	1.2751
2007-08*	64116	2989	0	5484	0		72563	42213	1.3527	0.1106	1.4633
2008-09*	58453	2972	0	3962	0		65388	45882	1.2387	0.0799	1.3186
2009-10*	46662	2954	1498	3899	0		55013	45811	1.0005	0.1088	1.1094
2010-11*	65164	2299	0	5134	0		72597	38574	1.3604	0.1035	1.4640
2011-12*	23092	1801	0	4176	0		29069	32205	0.5020	0.0842	0.5862
2012-13*	37385	2784	283	2954	0		43406	33129	0.8100	0.0653	0.8753
2013-14*	59008	2967	0	8993	1179	630	72778	42735	1.2736	0.1814	1.4676
2014-15*	16508	1866	31636	7315	0	0	57326	47053	0.3705	0.7855	1.1560
2015-16*	34053	2507	15642	4947	0	0	57149	37750	0.7373	0.4152	1.1524
2016-17*	31644	1991	17410	5007	0	0	56052	40036	0.6783	0.4520	1.1303
2017-18*	30633	2974	0	2389	0	0	35996	30681	0.6777	0.0482	0.7259
2018-19*	37564	61	15362	2877	0	0	55864	46730	0.7587	0.3678	1.1265
2019-20*	37012	2973	0	2825	0	0	42809	25808	0.8063	0.0570	0.8633
2020-21*	32883	2974	0	3059	0	0	38916	35078	0.7231	0.0617	0.7848
Blank Row											
AVERAGE:	**39863**	**2163**	**5660**	**3772**	**124**	**79**	**51532**	**39051**	**0.8486**	**0.1902**	**1.0392**
Maximum:	65164	2989	33712	8993	2511	630	74750	52690	1.3604	0.7855	1.5074
Minimum:	16371	61	0	986	0	0	24599	16631	0.3705	0.0199	0.4960

APPENDIX C

OUTLET INSPECTION MEMORANDUM

MEMORANDUM

Project 21125

TO: **Bruce Hughes, Twin Lakes Reservoir Company**

FROM: **Michael L. Graber, P.E. – RJH Consultants, Inc.**

DATE: **October 15, 2021**

RE: **Grizzly Reservoir Low Level Outlet Inspection**

Section 1 Purpose

The purpose of this memorandum is to document the findings of the outlet woks inspection performed by RJH Consultants, Inc. (RJH) for Grizzly Reservoir.

Section 2 Background

The original dam was constructed circa 1932, was subsequently raised 10 feet in height in 1935, and a 3-foot high steel parapet wall was added across the dam crest in 1995. The low-level outlet works discharges into Lincoln Creek and was constructed through the rockfill dam embankment in 1932 and extended 14 feet downstream in 1935. The outlet has a manually operated upstream slide gate that discharges into a 4-foot by 4-foot concrete tunnel that appears to have been cast in place with joints at each section. Approximately 15-feet of the tunnel immediately downstream of the gate has been lined with welded steel plate to provide erosion and cavitation protect of the concrete tunnel. The tunnel discharges at the downstream toe of the embankment into a rock lined stilling basin and then flows over a two-step drop structure into Lincoln Creek.

Section 3 Personnel

The following is a summary of key participants involved during the inspection:

Glenn Schryver	Twin Lakes Reservoir and Canal Company
Korey Kadrmas, P.E.	SEO Dam Safety Engineer
Brena Sheridan, P.E.	RJH Consultants
Austin Yahn, E.I.	RJH Consultants

Section 4 Outlet Inspection

The outlet inspection was performed on September 15, 2021. The outlet tunnel and stilling basin were dewatered to allow for visual observations. Following are the noted observations.

- Observation of the current condition, is generally similar to the conditions noted during the 2020 outlet works inspection.

- A significant amount of seepage was noted spraying from the slide gate. The majority of the seepage appeared to be from the left lower side of the gate, looking downstream.
- Immediately downstream of the steel plate lining, erosion of the concrete floor was observed.
- There was seepage from nearly every tunnel joint, of varying amounts from less than one gallon per minute up to an estimated 5 gallons per minute.
- There were also a number of cracks and holes in the tunnel, ceiling, walls and floor from which seepage flowed.
- An approximate 2-inch wide crack was noted approximately 19-feet from the downstream end of the tunnel on the left side looking downstream.
- An approximate 1-inch wide crack was observed in the tunnel ceiling approximately 45-feet from the downstream end of the tunnel across the entire ceiling and a significant amount of seepage was observed from the ceiling.
- The steel tunnel liner downstream of the gate was in good condition with only minor surface rust. There were no indications of cavitation or erosion in the steel plate liner.
- Previous crack and joint repairs to the concrete tunnel were observed at a number of locations and were in generally good condition.
- It was noted that no vent was found for the operating gate.

Section 3 Conclusions and Recommendations

Based on the observations made during the outlet inspection, RJH offers the following conclusions and recommendations:

1. The slide gate should be inspected in the summer of 2023 when the reservoir is drained for rehabilitation of the dam. Any necessary maintenance/repairs to the gate should be completed at this time.
2. Normal routine maintenance and operation of the slide gate is recommended at this time.
3. The lack of a vent on the operating gate is suspected of causing flow surges in the outflow from the discharge end of the tunnel into the stilling basin. This condition likely results in the following:
    - The submerged condition at the discharge end of the tunnel is overcome by a build-up of back flow pressure in the tunnel and then air is pulled through the top of the tunnel to the gate from the discharge end of the tunnel.
    - This condition results in surging uneven discharge flow and pressurizes the tunnel.
    - The pressurized condition in the tunnel likely forces pressurized flow from the tunnel into the embankment through the holes and cracks observed in the tunnel.
    - Pressurized flow on the outside of the conduit can over time develop into piping and backwards erosion along the conduit and a catastrophic dam failure along the outlet conduit tunnel.
    - To prevent the development of a piping condition along the outlet conduit tunnel, a two-step approach is recommended.
        1. The first step would be to effectively seal the cracks and holes in the concrete tunnel conduit with an injectable moisture activated grout.

Avanti AV-202 Multi-grout has been successfully used in other similar applications. The grout is pumped under pressure through multiple drilled injection ports in the cracks and holes and sets up almost immediately when contacting water. This provides a positive water tight seal and is considering a permanent long-term repair.

2. The second step would require the installation of a diaphragm filter approximately 14-feet from the downstream end of the tunnel. This will require removal of the discharge structure and the first joint of the tunnel which was installed as part of the dam raise in 1932. The discharge structure and tunnel would be replaced with cast-in place concrete during the dam rehabilitation. The diaphragm filter would completely envelope the tunnel conduit on all sides and is designed to intercept flow along the tunnel conduit and safely drain the flow to a daily discharge point while preventing the migration of fine-grained embankment particles that would allow a piping condition to develop. The diaphragm filter will likely consist of a two stage specifically graded sand and gravel filter with slotted drain pipe through the filter to collect the seepage.

4. The stilling basin and drop structure appear to operate as intended with no erosion or back cutting observed. Normal routine maintenance is recommended.
5. When the reservoir is drained, it is recommended that an operating gate vent be retrofitted.

Section 4 Photographs

Seepage spraying from the upstream slide gate.

Concrete erosion of the floor immediately downstream of the steel plate lining.

Flow from a joint crack on the outlet tunnel conduit ceiling.

Previous concrete repairs to the first section immediately upstream of the discharge structure.

Abraded concrete with exposed aggregate on ceiling immediately downstream of the steel lining.

Typical joint crack with clear flow.

Dewatered stilling basin looking downstream from dam crest.

APPENDIX D

GEOTECHNICAL DATA REPORT

RJH CONSULTANTS, INC.

GEOTECHNICAL AND
WATER RESOURCES ENGINEERING

GEOTECHNICAL DATA REPORT

GRIZZLY RESERVOIR REHABILITATION PROJECT

PITKIN COUNTY, COLORADO

Submitted to

Twin Lakes Reservoir and Canal Company
321 Main St.
Ordway, Colorado 81063

Submitted by

RJH Consultants, Inc.
9800 Mt. Pyramid Court, Suite 330
Englewood, Colorado 80112
303-225-4611
www.rjh-consultants.com

December 2021
Project 21125

Michael Graber, P.E.
Project Manager

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

SECTION 1 - INTRODUCTION

1.1 Purpose

This Geotechnical Data Report (Report) presents the geotechnical data collected by RJH Consultants, Inc. (RJH) at the Grizzly Reservoir Site (Site).

1.2 Scope of Work

RJH performed the following services to collect and document the geotechnical data:

- Visually classified and collected soil samples from three test pits.
- Visually classified and collected a soil sample from a sediment stockpile excavated from the reservoir.
- Performed laboratory tests on selected samples of select embankment fill and potential borrow materials.
- Prepared this Report.

The work was performed in general accordance with the Subsurface Investigation Plan Memorandum dated August 26, 2021 and approved by the Colorado Office of the State Engineer.

1.3 Authorization and Project Personnel

The work described in this Report was performed in general accordance with the agreement between the Twin Lakes Reservoir and Canal Company (Company) and RJH executed on August 18, 2021 for the Grizzly Reservoir Dam Rehabilitation Project (Project). RJH personnel responsible for the execution of this work included:

Project Manager	Michael Graber, P.E.
Project Engineer	Brena Sheridan, P.E.
Staff Engineer	Austin Yahn, E.I.

SECTION 2 - PROJECT AND SITE DESCRIPTION

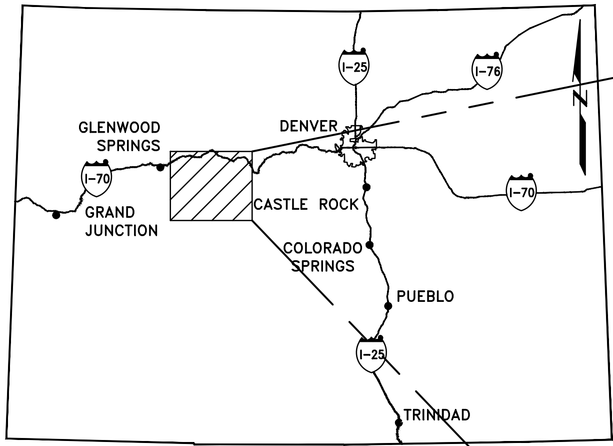
Grizzly Reservoir Dam (DAMID 380109) is a high-hazard dam that impounds a 590-acre-foot (ac-ft) reservoir located in Pitkin County, Colorado. The dam is owned and operated by the Company. The dam is a 56-foot-high rock and earth fill dam with an upstream steel face constructed on Lincoln Creek to impound and divert west slope water through the Twin Lakes Tunnel to the east slope Arkansas River Basin. The original dam construction was circa 1932, was subsequently raised 10 feet in height in 1935, and a 3-foot-high steel parapet wall was added across the dam crest in 1995. A site vicinity map is shown on Figure 2.1.

Deficiencies associated with Grizzly Reservoir Dam generally include the following:

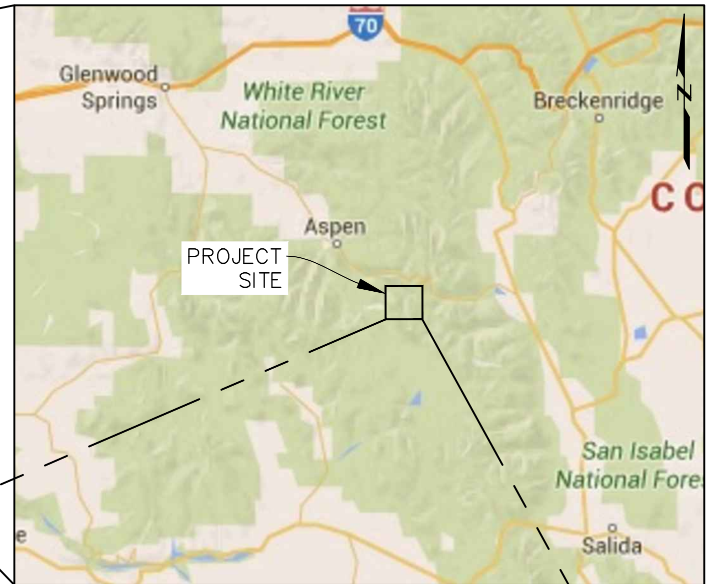
- Uncontrolled Seepage has been observed extending about 20 to 30 feet to the left of the outlet works on the downstream dam slope. The seepage is generally at the downstream toe along the foundation contact.
- In 2020, flow was observed in the right toe drain (typically dry) for the first time in a while (the Company noted it has produced flow in the past).
- The steel facing on the dam is buckling and panel seam separation has been observed at a few locations.
- The low-level outlet works has deficiencies including damage to the concrete tunnel and cavitation downstream of the slide gate.

The Project is anticipated to include:

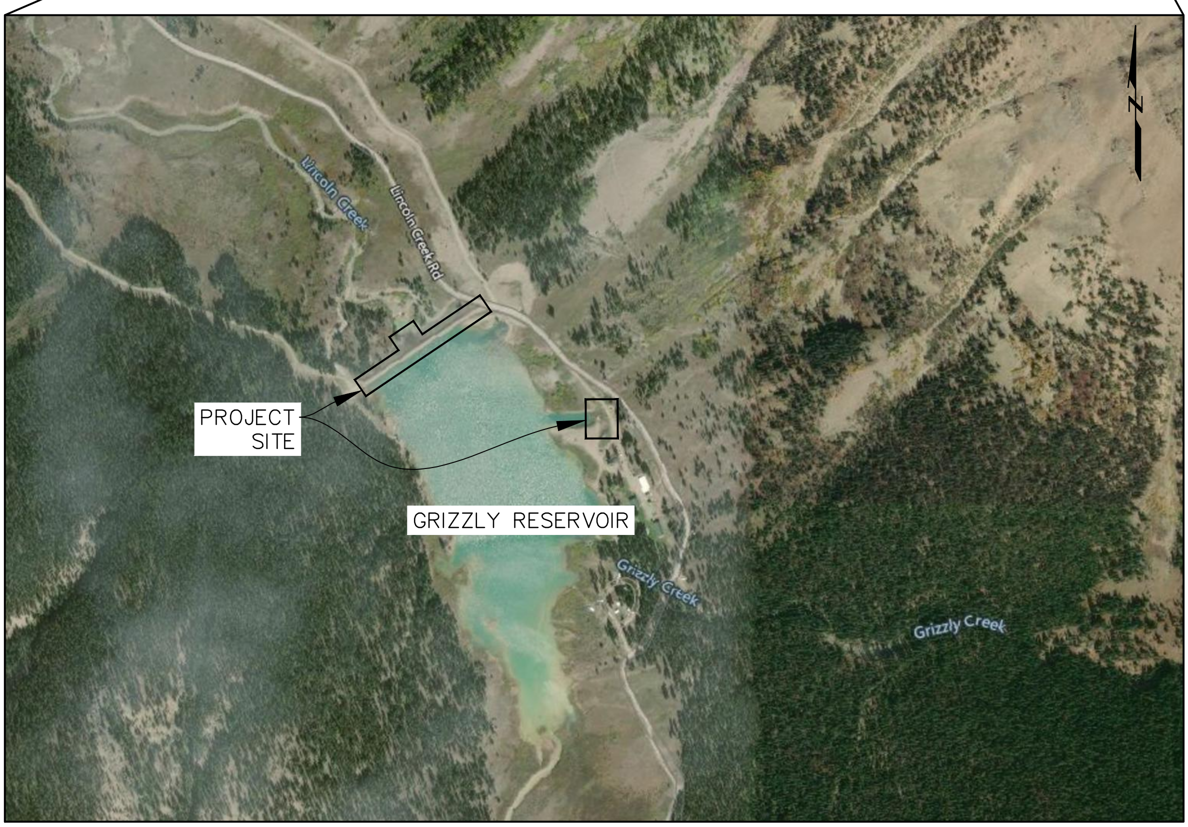
- Design and construction of a new vent immediately downstream of the outlet works upstream control gate.
- Design and construction of a diaphragm filter and blanket drain at the downstream dam toe.
- Design and construction of a membrane liner on the upstream dam face.
- Concrete repairs to the outlet tunnel conduit.
- Design and construction of a new outlet discharge structure.
- Design and construction of a new retaining wall near the Twin Lakes Tunnel Gate house.
- Replacement of slide gates for the Twin Lakes Tunnel.



PROJECT VICINITY MAP
(NOT TO SCALE)



PROJECT LOCATION MAP
(NOT TO SCALE)



PROJECT AERIAL MAP
(NOT TO SCALE)

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RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	SITE LOCATION MAP	
	PROJECT NO. 21125	December 2021	**Figure 2.1**

SECTION 3 - FIELD INVESTIGATION

3.1 General

Field investigations consisted of excavating three test pits and collection of a sample of sediment excavated from the reservoir. Test pits TP-101, TP-102, and TP-103 were excavated on September 15, 2021. A soil sample was also collected from a stockpile of sediment excavated from the reservoir.

3.2 Test Pits

The test pits were excavated by the Company. Test pits were excavated to evaluate the earthfill on the downstream slope of the embankment near the outlet tunnel discharge structure. A soil sample was also collected from a sediment stockpile from reservoir excavation to evaluate if the material is suitable for backfill. Test pits were excavated entirely through surficial soils and terminated about 3 feet below the ground surface (bgs). Test pits were generally about 3 to 5 feet long and 2 to 3 feet wide. A summary of test pits is provided in Table 3.1. Approximate test pit locations are shown on Figure 3.1.

TABLE 3.1
SUMMARY OF TEST PITS

ID	Latitude (degrees)	Longitude (degrees)	Ground Surface Elevation (ft)	Depth to Bedrock (ft)	Depth to Groundwater during Excavation (ft)	Total Depth (ft)
TP-101	39.079982	106.616551	10510	Not Encountered	Not Encountered	3
TP-102	39.079954	106.616597	10514	Not Encountered	Not Encountered	3
TP-103	39.08004	106.616416	10517	Not Encountered	Not Encountered	3
Reservoir Sediment Stockpile	39.078655	106.613736	-	-	-	-

Note:
1. Test pit locations were estimated with Gaia GPS.

Excavation was performed using a rubber-tired backhoe. Samples of soils were collected for the earthfill observed in the test pits. An RJH engineer observed the excavations, collected samples, classified the soil samples, and photographed the excavations.

Collected soil samples were packaged and transported in general accordance with American Society for Testing and Materials International (ASTM) D 4220. Samples obtained from test pits were placed in bulk bags and/or sealed plastic bags. Soil samples were classified in the field in general accordance with ASTM D 2488 (visual-manual classification). Classifications were reviewed by an experienced geological engineer for quality control. Following laboratory testing, laboratory index test results were compared to field classifications and, if necessary, modified according to ASTM D 2487 (Unified Soil Classification System (USCS)). Photographs of the test pits and reservoir sediment are provided in Appendix B.

0 60 120 240
SCALE IN FEET

NOTES:

1. LOCATIONS ESTIMATED WITH GAIA GPS.

P:\21125 – GRIZZLY RESERVOIR CWC FEASIBILITY STUDY\ENGINEERING\1003 DATA COLLECTION AND GEOTECH INVESTIGATION\REPORTING\GEOTECHNICAL_DATA_REPORT_CAD\21125-GDR_TEST_PIT_LOCATIONS.DWG 12/7/2021 3:56 PM

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION PROJECT	TEST PIT LOCATIONS
	PROJECT NO. 21125	December 2021 **Figure 3.1**

SECTION 4 - LABORATORY TESTING

Laboratory tests were performed on representative samples of soil collected during the investigation. RJH retained Advanced Terra Testing of Lakewood, Colorado to perform the laboratory testing.

Index Tests:

- Three Atterberg limit five point tests (ASTM D 4318).
- Three grain-size analysis tests (ASTM D 6913).
- One hydrometer analysis test (ASTM D 7928).
- Two moisture content tests (ASTM D 2216).
- Two standard proctor compaction tests (ASTM D 698, Method C).

Laboratory test results are summarized in Tables 4.1. Detailed laboratory test results are included in Appendix D.

TABLE 4.1
SUMMARY OF LABORATORY TEST RESULTS

Boring/Test Pit ID	Sample ID	Sample Depth Interval (ft)	General Description	Natural Moisture Content (%)	Atterberg Limits		Gradation			Standard Proctor Compaction Test	
					Liquid Limit, LL (%)	Plasticity Index, PI (%)	% Gravel (3 in. to No. 4)	% Sand (No. 4 to No. 200)	% Fines (-No. 200)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)
TP-101	Bu-2	1.5-3.0	Poorly Graded Sand with Gravel	6.1	NP	NP	32.7	62.5	4.8	-	-
TP-103	Bu-1	1.0-3.0	Silty Sand with Gravel	8.0	NP	NP	30.3	48.9	20.8(1)	125.9	9.1
Sediment Stockpile	Bu-1	-	Poorly Graded Sand with Silt and Gravel	-	NP	NP	33.1	60.5	6.4	128.2	9.4

Note:
1. Of the fines, 16.8 percent are silts and 4.0 percent are clays.

SECTION 5 - SUBSURFACE CONDITIONS

5.1 General

The subsurface conditions described in the following sections are based on data collected during the field investigation and results of laboratory testing. The subsurface material encountered in the test pits generally consisted of earthfill overlying rockfill. Vegetation at the ground surface had roots that extended approximately 1 foot into the earthfill. Information on the stratigraphic units encountered are presented in the following sections.

5.2 Earthfill

Earthfill was identified at the ground surface at test pits TP-101 and TP-103 and consisted of silty sand with gravel to poorly graded sand with gravel. The thickness was observed to range from 1.0 to 2.0 feet. Earthfill had about 50 to 60 percent fine to coarse grained sand, about 30 percent fine to coarse grained gravel, and about 5 to 20 percent non-plastic fines. The earthfill was moist and brown with occasional roots.

The earthfill encountered at test pit TP-102 appeared to be of a different source than the earthfill encountered in TP-101 and TP-103. The earthfill was visually classified as well graded gravel with silt and sand. The earthfill was gray and dry to moist. Tests were not performed on the sample collected from TP-102.

5.3 Rockfill

Rockfill was identified at test pits TP-101 and TP-103 and was encountered at approximately 1.0 to 2.0 feet bgs. The observed rockfill had a maximum particle size of about 4 to 6 inches. Samples of the rockfill were not collected.

5.4 Groundwater

Groundwater was not encountered in the test pits.

SECTION 6 - REFERENCES

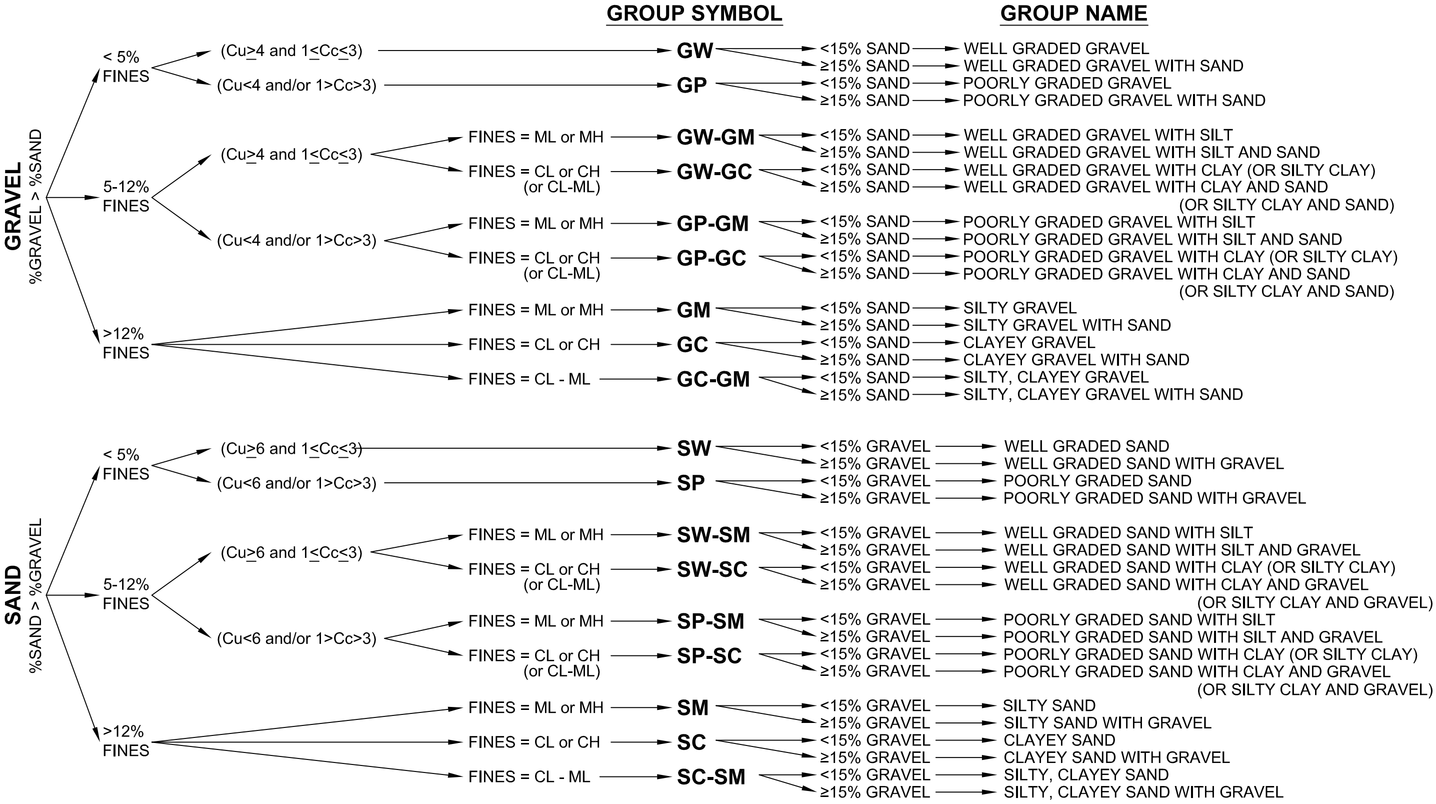
RJH Consultants, Inc. (RJH) (2021). *Grizzly Reservoir Dam (DAM ID 380109) Subsurface Investigation Plan*, August.

APPENDIX A

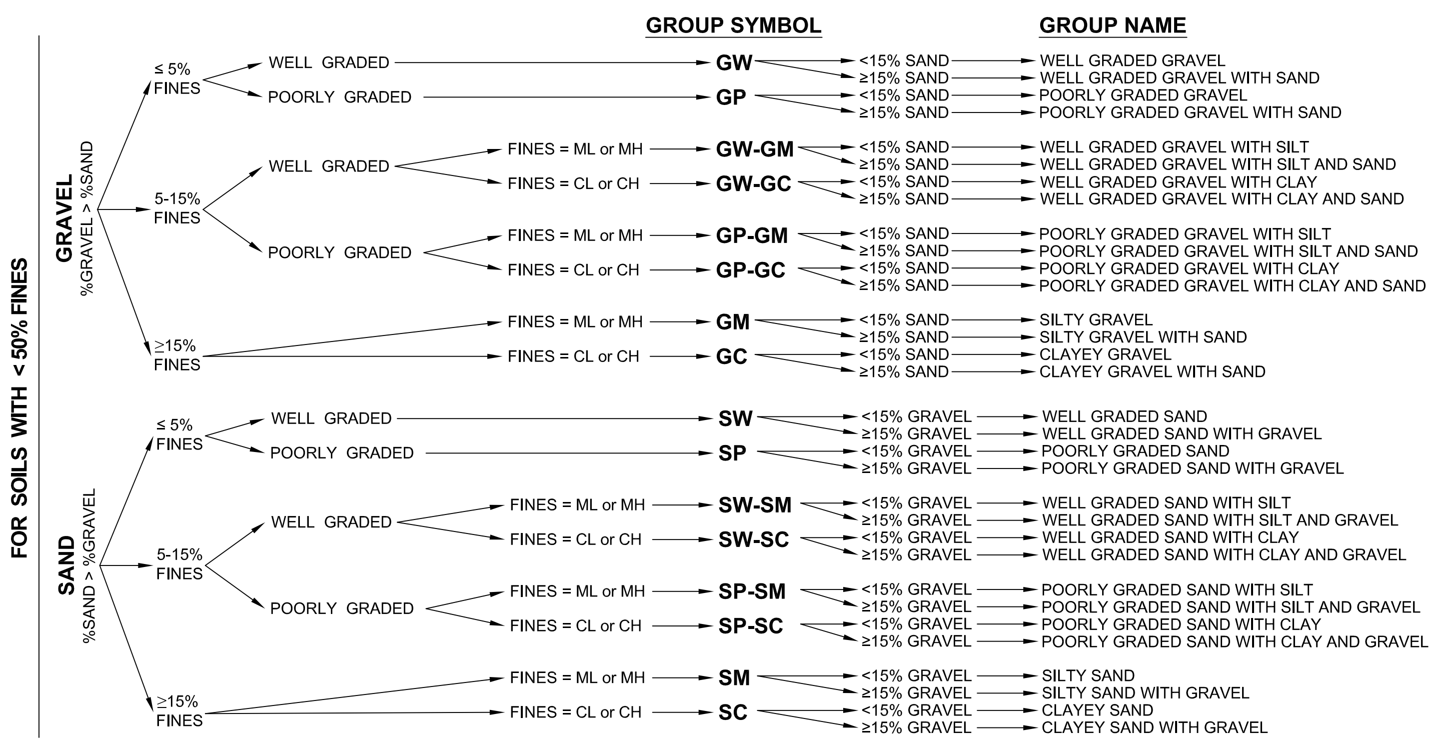
SOIL DESCRIPTORS

COARSE GRAINED SOILS
(< 50% FINES)

A) FLOWCHART APPLIED TO LABORATORY TESTED SOIL SAMPLES.
ADAPTED FROM ASTM D 2487 *CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (USCS)*.



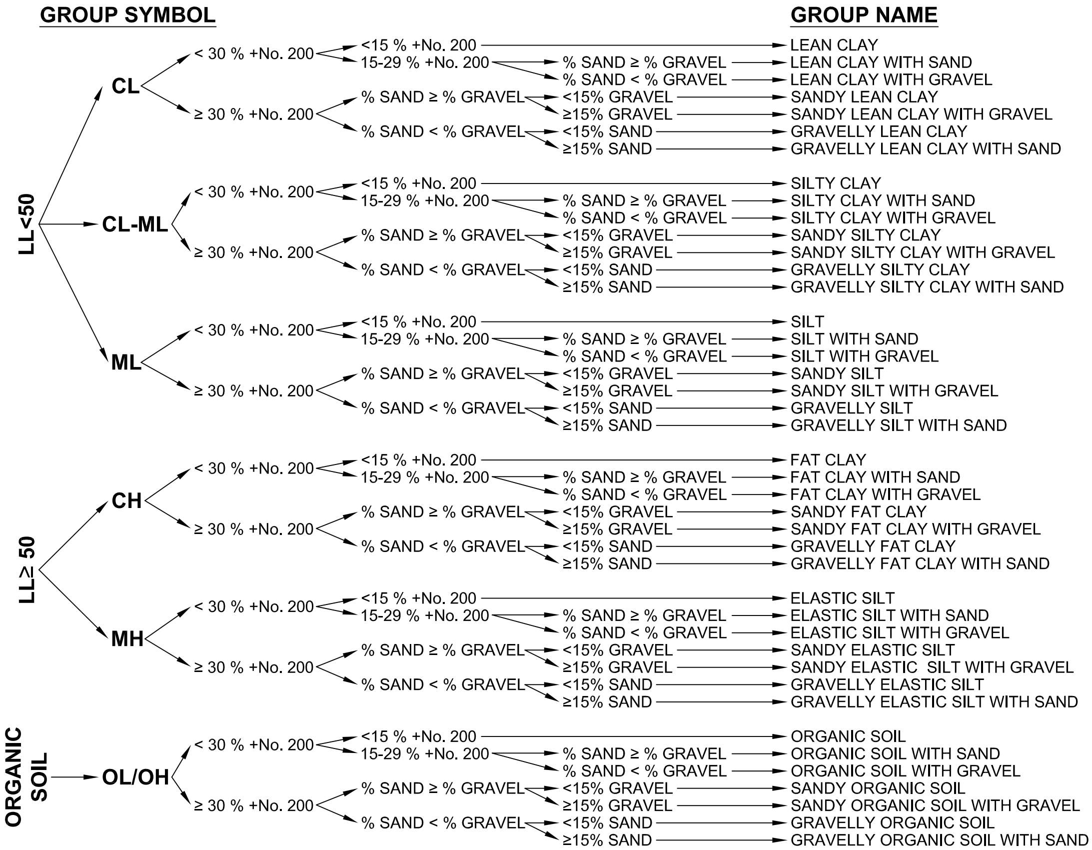
B) FLOWCHART APPLIED TO FIELD CLASSIFIED SOIL SAMPLES.
ADAPTED FROM ASTM D 2488 *DESCRIPTION AND IDENTIFICATION OF SOILS (VISUAL-MANUAL PROCEDURE)*.



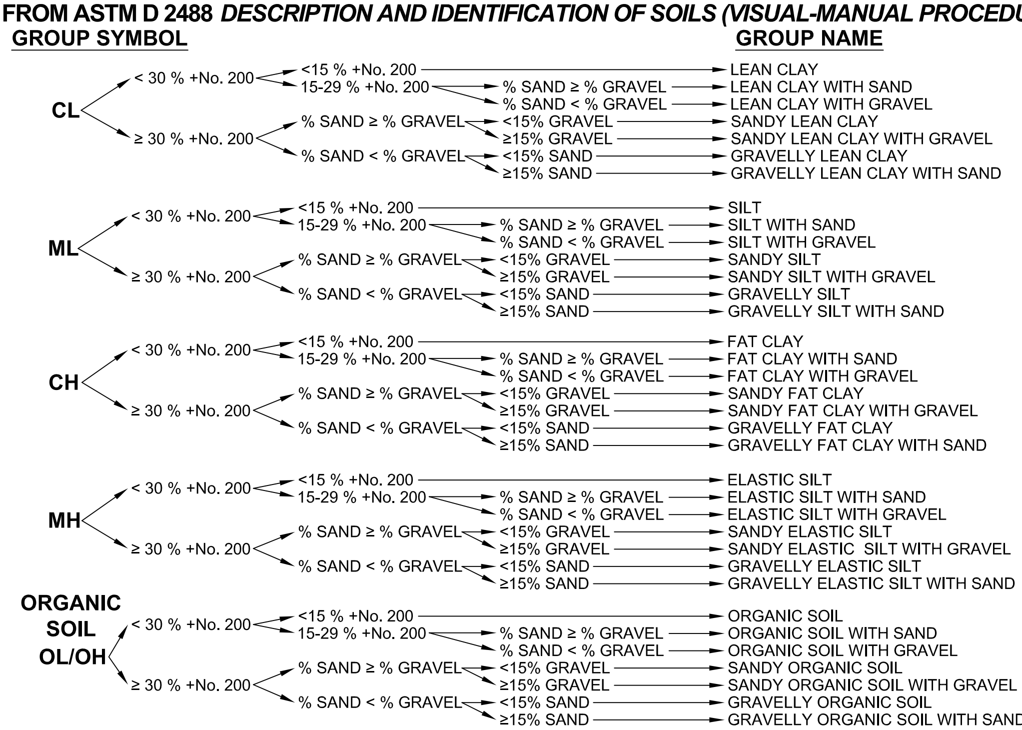
UPDATED 03-2014

FINE GRAINED SOILS
(≥ 50% FINES)

A) FLOWCHART APPLIED TO LABORATORY TESTED SOIL SAMPLES.
ADAPTED FROM ASTM D 2487 *CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (USCS)*.



B) FLOWCHART APPLIED TO FIELD CLASSIFIED SOIL SAMPLES.
ADAPTED FROM ASTM D 2488 *DESCRIPTION AND IDENTIFICATION OF SOILS (VISUAL-MANUAL PROCEDURE)*.



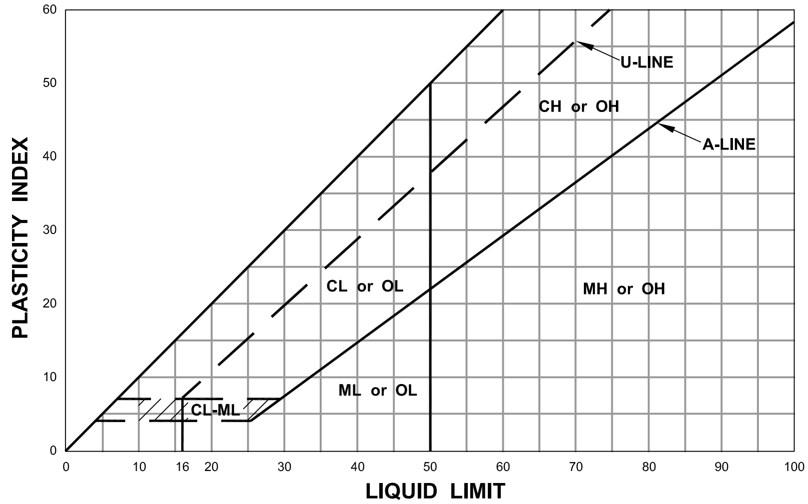
NOTE:

1. THE PLASTICITY CHART ON THE FOLLOWING PAGE WAS USED TO IDENTIFY THE GROUP SYMBOL FOR FLOWCHART A.
   A COMBINATION OF THE VISUAL MANUAL CRITERIA ON THE FOLLOWING PAGE WERE USED TO IDENTIFY THE GROUP SYMBOL FOR FLOWCHART B.

UPDATED 03-2014

SOIL PLASTICITY CHARACTERISTICS

PLASTICITY CHART



A) IDENTIFICATION OF FINES GROUP SYMBOL FROM LABORATORY TESTS.
REPRODUCED FROM ASTM D 2487 *CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (USCS)*.

B) IDENTIFICATION OF FINES GROUP SYMBOL FROM VISUAL-MANUAL CRITERIA.
REPRODUCED FROM ASTM D 2488 *DESCRIPTION AND IDENTIFICATION OF SOILS (VISUAL-MANUAL PROCEDURE).*

DRY STRENGTH	
DESCRIPTION	CRITERIA
NONE	CRUMBLES TO POWDER WHILE HANDLING.
LOW	CRUMBLES TO POWDER WITH SOME FINGER PRESSURE.
MEDIUM	BREAKS INTO PIECES OR CRUMBLES WITH CONSIDERABLE FINGER PRESSURE.
HIGH	CANNOT BE BROKEN WITH FINGER PRESSURE. BREAKS INTO PIECES BETWEEN THUMB AND HARD SURFACE.
VERY HIGH	CANNOT BE BROKEN BETWEEN THUMB AND HARD SURFACE.

DILATANCY (RESISTANCE TO SHAKING)	
DESCRIPTION	CRITERIA
NONE	NO VISIBLE CHANGE IN SPECIMEN.
SLOW	WATER APPEARS SLOWLY ON THE SURFACE OF THE SPECIMEN DURING SHAKING AND DOES NOT DISAPPEAR OR DISAPPEARS SLOWLY UPON SQUEEZING.
RAPID	WATER APPEARS QUICKLY ON THE SURFACE OF THE SPECIMEN DURING SHAKING AND DISAPPEARS QUICKLY UPON SQUEEZING.

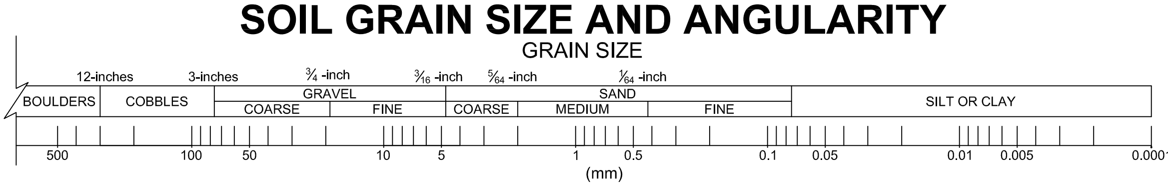
TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	
DESCRIPTION	CRITERIA
LOW	ONLY SLIGHT PRESSURE IS REQUIRED TO ROLL THE THREAD. THREAD AND LUMP ARE WEAK AND SOFT.
MEDIUM	MEDIUM PRESSURE IS REQUIRED TO ROLL THE THREAD. THREAD AND LUMP HAVE MEDIUM STIFFNESS.
HIGH	CONSIDERABLE EFFORT IS REQUIRED TO ROLL THE THREAD. THREAD AND LUMP HAVE HIGH STIFFNESS.

PLASTICITY	
DESCRIPTION	CRITERIA FOR A ⅛-INCH (3 mm) THREAD.
NON-PLASTIC	THREAD CANNOT BE ROLLED.
LOW	THREAD CAN BARELY BE ROLLED AND THE LUMP CANNOT BE FORMED WHEN DRIER THAN THE PLASTIC LIMIT.
MEDIUM	THREAD IS EASY TO ROLL AND NOT MUCH TIME IS REQUIRED TO REACH THE PLASTIC LIMIT. THE THREAD CANNOT BE RE-ROLLED SEVERAL TIMES AFTER REACHING THE PLASTIC LIMIT. THE LUMP CRUMBLES WHEN DRIER THAN THE PLASTIC LIMIT.
HIGH	IT TAKES CONSIDERABLE TIME ROLLING AND KNEADING TO REACH THE PLASTIC LIMIT. THE THREAD CAN BE RE-ROLLED SEVERAL TIMES AFTER REACHING THE PLASTIC LIMIT. THE LUMP CAN BE FORMED WITHOUT CRUMBLING WHEN DRIER THAN THE PLASTIC LIMIT.

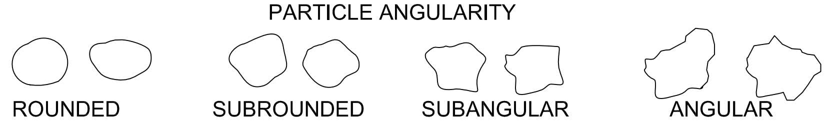
SYMBOL	DRY STRENGTH	DILATANCY	TOUGHNESS AND PLASTICITY	PLASTICITY
ML	NONE - LOW	SLOW - RAPID	LOW	LOW TO NON-PLASTIC
CL	MEDIUM - HIGH	NONE - SLOW	MEDIUM	LOW TO MEDIUM
MH	LOW - MEDIUM	NONE - SLOW	LOW TO MEDIUM	LOW TO MEDIUM
CH	HIGH - VERY HIGH	NONE	HIGH	HIGH

SOIL GRAIN SIZE AND ANGULARITY

GRAIN SIZE



PARTICLE ANGULARITY



UPDATED 03-2014

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TABLE 1.1
CRITERIA FOR DESCRIBING SOIL STRUCTURE[(1)]

Description	Criteria
Stratified	Alternating layers of varying material or color with layers greater than or equal to 1/4 inch thick (6 mm)
Laminated	Alternating layers of varying material or color with layers less than 1/4 inch thick (6 mm)
Fissured	Breaks along definite plates of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay
Homogeneous	Same color and appearance throughout

Note:
1. Modified from ASTM D 2488 *Description and Identification of Soils (Visual-Manual Procedure)* and differ from the U.S. Bureau of Reclamation *Engineering Geology Field Manual* (2001).

TABLE 1.2
RELATIVE DENSITY OF SANDS ACCORDING TO RESULTS OF STANDARD PENETRATION TEST[(1)]

Number of Blows N	Relative Density
0-4	Very Loose
5-10	Loose
11-30	Medium
31-50	Dense
Over 50	Very Dense

Note:
1. Modified from Terzaghi, Peck, and Mesri (1996).

TABLE 1.3
GUIDE FOR STIFFNESS OF FINE-GRAINED SOILS[(1)]

Description	Criteria	Estimated Unconfined Compressive Strength (TSF)
Very Soft	Extrudes between fingers when squeezed	<0.25
Soft	Molded by light finger pressure	0.25-0.50
Medium	Molded by strong finger pressure	0.50-1.00
Stiff	Readily indented by thumb or penetrated with great effort	1.00-2.00
Very Stiff	Readily indented by thumbnail	2.00-4.00
Hard	Indented with difficulty by thumbnail	>4.00

Note:
1. Reproduced from NAVFAC (1986).

TABLE 1.4
CRITERIA FOR DESCRIBING SOIL MOISTURE CONDITION(1)

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below the water table

Note:
1. Reproduced from ASTM 2488 *Description and Identification of Soils (Visual-Manual Procedure)*.

TABLE 1.5
CRITERIA FOR DESCRIBING SOIL CEMENTATION(1)(2)

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

Notes:
1. Reproduced from ASTM 2488 *Description and Identification of Soils (Visual-Manual Procedure)*.
2. The absence of cementation was not recorded on boring logs.

TABLE 1.6
CRITERIA FOR DESCRIBING SOIL REACTION WITH HCL(1)

Description	Criteria
None(2)	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

Notes:
1. Reproduced from ASTM 2488 Description and Identification of Soils (Visual-Manual Procedure).
2. The absence of a reaction was not recorded on boring logs.

ASTM D 2487 (2011). *Standard Classification of Soils for Engineering Purposes (USCS)*. June.

ASTM D 2488 (2009). *Standard Practice for Description and Identification of Soils (Visual-Manual Method*). July.

Bates, Robert C. and Jackson, Julia A. (1984). *Dictionary of Geologic Terms*, 3rd Edition.

Hunt, Roy E. (Hunt) (2005). *Geotechnical Investigation Handbook*.

Terzaghi, Karl, Peck, Ralph B., and Mesri, Gholamreza. (Terzaghi, Peck, and Mesri). (1996). *Soil Mechanics in Engineering Practice*.

U.S. Bureau of Reclamation (USBR) (2001). *Engineering Geology Field Manual*.

Appendix B

Photographs

Photograph 1: Excavation of TP-101. Roots from vegetation extended approximately 1 foot into the earth fill.

Photograph 2: Typical finer material encountered in TP-101. Poorly graded sand with gravel.

Photograph 3: View looking north from the dam crest. Excavation of TP-102.

Photograph 4: Fill encountered in TP-102.

Photograph 5: Typical rockfill encountered in TP-103.

Photograph 6: Soil on the west side of the reservoir sediment stockpile. Well graded sand with silt and gravel.

Appendix C

Laboratory Test Results

ADVANCED TERRA TESTING
833 PARFET ST UNIT A
LAKEWOOD, CO
303-232-8308 www.terratesting.com

Monday, October 18, 2021

Project Number: 2679-164

Company: RJH Consultants

Address:

City:

State:

RE: Soil Testing
Grizzly Reservoir Dam
21125

Dear Austin Yahn,

With this letter you will find a report on Soil samples assigned on 9/24/2021.

Testing was performed in accordance with standardized test methods, accepted industry practices as well as specific instructions received from you, our client. Advanced Terra Testing accepts no responsibility and makes no claims to the use or purpose of the material being tested. Furthermore, the results herein are based solely on the material received and tested. Please note that all material will be disposed of after thirty days unless other arrangements are made.

We respectfully request that sample reports be considered proprietary information and are not to be reproduced, except in full and only with prior written approval of Advanced Terra Testing. We are pleased to have been given the opportunity to perform high quality laboratory testing for your project. We sincerely hope the results herein provide you with all the information required. If you have questions or need anything further, please reach out and we will be happy to assist you.

Respectfully,

William Rausch, PE - Technical Manager

ADVANCED TERRA TESTING

Moisture
ASTM D 2216

CLIENT	RJH Consultants	JOB NO.	2679-164
PROJECT	Grizzly Reservoir Dam	LOCATION	--
PROJECT NO.	21125		

BORING NO.	TP-101	TP-103
DEPTH	1.5-3.0'	1.0-3.0'
SAMPLE NO.	Bu-2	Bu-1
DATE SAMPLED		
DATE TESTED	09/24/21	09/24/21
TECHNICIAN	BDF	BDF
DESCRIPTION		
Mass of Wet Soil and Pan (g):	1725.10	2277.30
Mass of Dry Soil and Pan (g):	1638.90	2126.20
Mass of Pan (g):	235.00	240.50
Moisture (%):	**6.1**	**8.0**

BORING NO.	
DEPTH	
SAMPLE NO.	
DATE SAMPLED	
DATE TESTED	
TECHNICIAN	
DESCRIPTION	
Mass of Wet Soil and Pan (g):	
Mass of Dry Soil and Pan (g):	
Mass of Pan (g):	
Moisture (%):	

BORING NO.	
DEPTH	
SAMPLE NO.	
DATE SAMPLED	
DATE TESTED	
TECHNICIAN	
DESCRIPTION	
Mass of Wet Soil and Pan (g):	
Mass of Dry Soil and Pan (g):	
Mass of Pan (g):	
Moisture (%):	
NOTES	

Data entry by:	LG	Date: 9/28/2021
Checked by:	SPH	Date: 09/28/21
File name:	2679164__Moisture ASTM D2216_0.xlsm	

ADVANCED TERRA TESTING

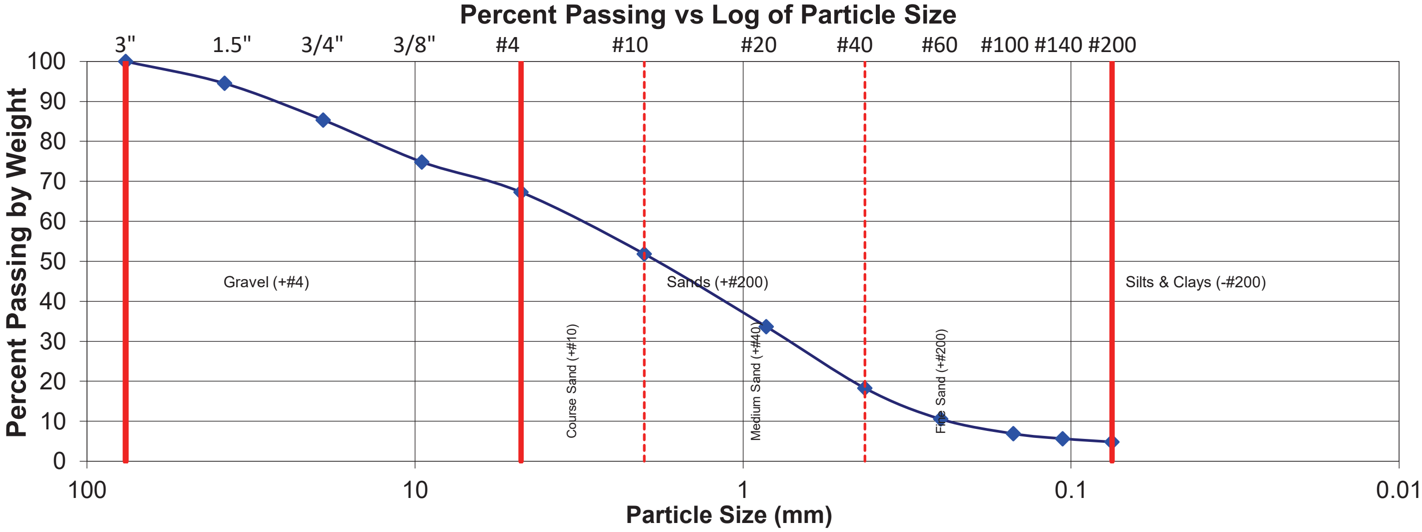
Grain Size Analysis
ASTM D 6913

CLIENT	RJH Consultants	BORING NO.	TP-101
JOB NO.	2679-164	DEPTH	1.5-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-2
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	09/28/21		
TECHNICIAN	LG		

Hygroscopic Moisture of Fines		Sample Data	
Mass Wet Pan and Soil (g):	1172.74	Total Wet Mass of Sample (g):	10888.7
Mass Dry Pan and Soil (g):	1157.92	Total Dry Mass of Sample (g):	10766.8
Mass of Pan (g):	178.21	Split Fraction:	3/8"
Moisture (%):	**1.5**	Mass of Sub-Sample Fraction (g):	999.93

Sieve Number	Sieve Size (mm)	Mass of Pan and Soil (g)	Mass of Pan (g)	Mass of Individual Retained Soil (g)	Correction Factor	Percent Passing by Weight (%)
3"	76.2	0.0	--	--	--	**--**
1.5"	38.1	590.4	--	590.4	1.00	**94.5**
3/4"	19.05	986.0	--	986.0	1.00	**85.4**
3/8"	9.53	1131.1	--	1131.1	1.00	**74.9**
#4	4.75	99.4	--	99.4	0.75	**67.3**
#10	2.00	203.4	--	203.4	0.75	**51.8**
#20	0.850	239.0	--	239.0	0.75	**33.7**
#40	0.425	202.7	--	202.7	0.75	**18.3**
#60	0.250	101.7	--	101.7	0.75	**10.5**
#100	0.150	48.1	--	48.1	0.75	**6.9**
#140	0.106	16.3	--	16.3	0.75	**5.6**
#200	0.075	10.9	--	10.9	0.75	**4.8**

Percent Passing vs Log of Particle Size



USCS Classification ASTM D 2487

Atterberg Classification:	NP	Coefficient of Curvature - C_c:	0.69
Group Symbol:	SP	Coefficient of Uniformity - C_u:	14.68
USCS Classification:	Poorly Graded Sand With Gravel		

Data entry by:	LOG	Date:	09/30/21
Checked by:	LG	Date:	10/04/21
File name:	2679164__Grain Size Analysis ASTM D6913_1.xlsm		

Grain Size Analysis
ASTM D 6913

ADVANCED TERRA TESTING

CLIENT	RJH Consultants	BORING NO.	reservoir sediment sample
JOB NO.	2679-164	DEPTH	--
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	--
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	09/28/21		
TECHNICIAN	LG		

Hygroscopic Moisture of Fines

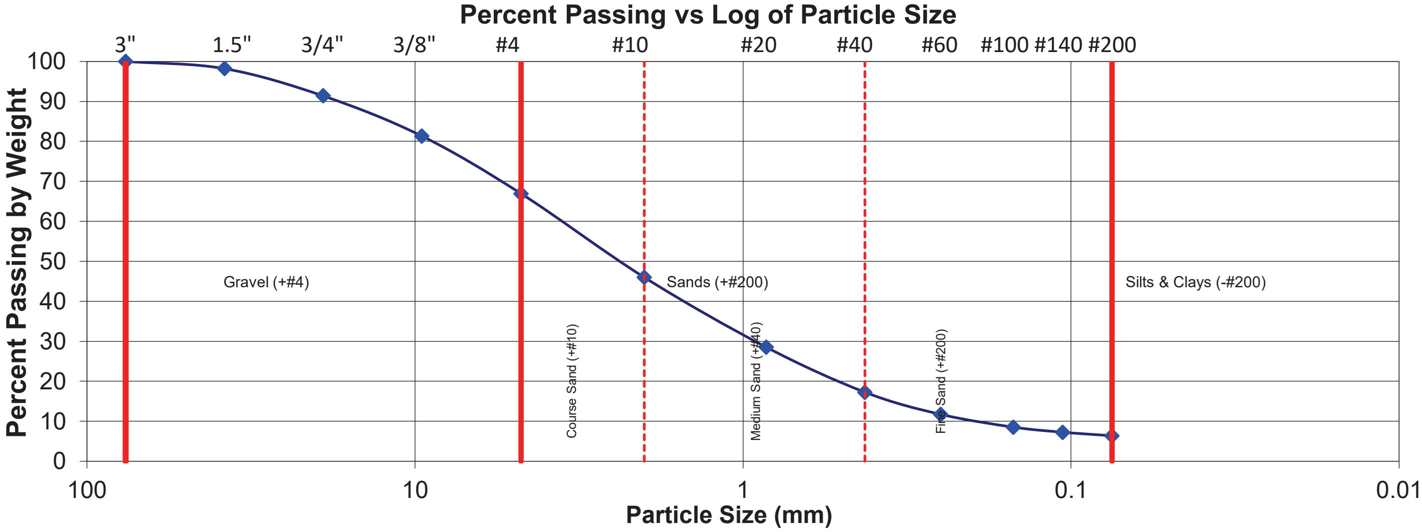
Mass Wet Pan and Soil (g): 1118.24
Mass Dry Pan and Soil (g): 1103.69
Mass of Pan (g): 264.75
Moisture (%): **1.7**

Sample Data

Total Wet Mass of Sample (g): 18583.3
Total Dry Mass of Sample (g): 18324.8
Split Fraction: 3/8"
Mass of Sub-Sample Fraction (g): 853.49

Sieve Number	Sieve Size (mm)	Mass of Pan and Soil (g)	Mass of Pan (g)	Mass of Individual Retained Soil (g)	Correction Factor	Percent Passing by Weight (%)
3"	76.2	0.0	--	--	--	**--**
1.5"	38.1	330.1	--	330.1	1.00	**98.2**
3/4"	19.05	1249.4	--	1249.4	1.00	**91.4**
3/8"	9.53	1842.6	--	1842.6	1.00	**81.3**
#4	4.75	148.4	--	148.4	0.81	**66.9**
#10	2.00	216.1	--	216.1	0.81	**46.0**
#20	0.850	180.1	--	180.1	0.81	**28.5**
#40	0.425	116.3	--	116.3	0.81	**17.3**
#60	0.250	57.1	--	57.1	0.81	**11.7**
#100	0.150	33.0	--	33.0	0.81	**8.5**
#140	0.106	13.2	--	13.2	0.81	**7.3**
#200	0.075	9.1	--	9.1	0.81	**6.4**

Percent Passing vs Log of Particle Size



USCS Classification ASTM D 2487

Atterberg Classification: NP
Coefficient of Curvature - C_c: 1.19
Group Symbol: SP-SM
Coefficient of Uniformity - C_u: 19.59
USCS Classification: Poorly Graded Sand With Silt And Gravel

Data entry by:	LOG	Date: 09/30/21
Checked by:	LG	Date: 10/04/21
File name:	2679164__Grain Size Analysis ASTM D6913_0.xlsm	

ADVANCED TERRA TESTING

Grain Size Analysis with Hydrometer
ASTM D 6913 And D 7928

CLIENT	RJH Consultants	BORING NO.	TP-103
JOB NO.	2679-164	DEPTH	1.0-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-1
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	10/11/21		
TECHNICIAN	BDF		

Hygroscopic Moisture of Fines

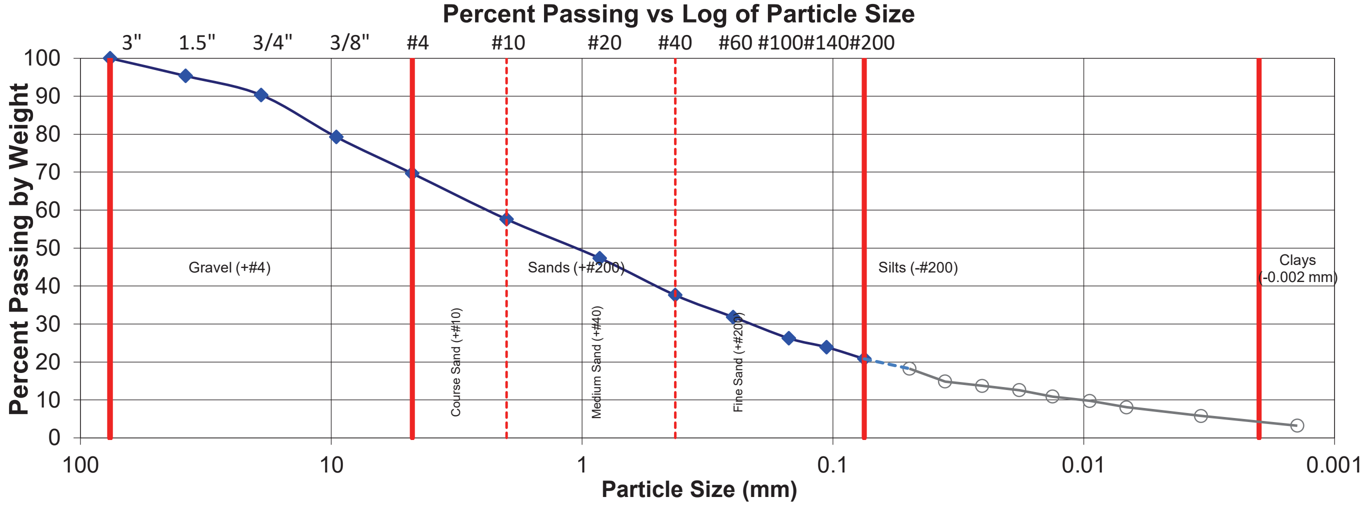
Mass Wet Pan and Soil (g): 118.02
Mass Dry Pan and Soil (g): 116.14
Mass of Pan (g): 6.81
Moisture (%): **1.7**

Sample Data

Total Wet Mass of Sample (g): 8778.1
Total Dry Mass of Sample (g): 8692.5
Split Fraction: #10 3/8"
Mass of Sub-Sample Fraction (g): 51.83 1063.20

Sieve Number	Sieve Size (mm)	Mass of Pan and Soil (g)	Mass of Pan (g)	Mass of Individual Retained Soil (g)	Correction Factor	Percent Passing by Weight (%)
3"	76.2	0.0	--	--	--	**100.0**
1.5"	38.1	403.2	--	403.2	1.00	**95.4**
3/4"	19.05	437.5	--	437.5	1.00	**90.3**
3/8"	9.53	964.3	--	964.3	1.00	**79.2**
#4	4.75	127.0	--	127.0	0.79	**69.7**
#10	2.00	159.8	--	159.82	0.792	**57.6**
#20	0.850	9.1	--	9.08	0.575	**47.3**
#40	0.425	8.6	--	8.63	0.575	**37.6**
#60	0.250	5.1	--	5.09	0.575	**31.8**
#100	0.150	5.0	--	4.95	0.575	**26.3**
#140	0.106	2.1	--	2.09	0.575	**23.9**
#200	0.075	2.7	--	2.73	0.575	**20.8**

Percent Passing vs Log of Particle Size



USCS Classification ASTM D 2487

Atterberg Classification: NP
Group Symbol: SM
USCS Classification: Silty Sand With Gravel

Coefficient of Curvature - C_c: --
Coefficient of Uniformity - C_u: --

Data entry by: KMS Date: 10/13/21
Checked by: JJA Date: 10/14/21
File name: 2679164__Grain Size with Hydrometer ASTM D6913 D7928_0.xlsm Page 1 of 2

ADVANCED TERRA TESTING

Grain Size Analysis with Hydrometer
ASTM D 6913 And D 7928

CLIENT	RJH Consultants	BORING NO.	TP-103
JOB NO.	2679-164	DEPTH	1.0-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-1
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	10/11/21		
TECHNICIAN	BDF		

Hydrometer and Flask Parameters

Hydrometer ID:	0805	Flask ID:	1192
Average Mass Offset (g/L):	9.87	Flask Volume (cm³):	1002.7
Hydrometer Bulb Volume (cm³):	56.50	Flask Surface Area (cm²):	27.82
Meniscus Correction (g/L):	1.00	Assumed Specific Gravity	2.65
H_b (cm):	24.5	Hydrometer Type:	152H
H_{cb} (cm):	6.8		
H_s (cm):	8.2	Percent Finer by Mass at 2 μm:	**4.0**

Hydrometer Data

Elapsed Time (minutes)	Hydrometer Reading (g/L)	Offset Reading (g/L)	Temperature (°C)	Effective Depth (cm)	Maximum Particle Diameter in Suspension (mm)	Percent Finer by Mass (%)
1	22.00	5.89	21.6	13.23	0.050	**18.2**
2	19.00	5.89	21.6	13.72	0.036	**14.8**
4	18.00	5.89	21.6	13.89	0.025	**13.7**
8	17.00	5.89	21.6	14.05	0.018	**12.6**
15	15.50	5.89	21.6	14.30	0.013	**10.9**
30	14.50	5.89	21.6	14.46	0.009	**9.7**
60	13.00	5.89	21.6	14.71	0.007	**8.1**
240	11.00	5.89	21.6	15.04	0.003	**5.8**
1440	9.00	6.17	20.8	15.37	0.001	**3.2**

NOTES:

File name: 2679164__Grain Size with Hydrometer ASTM D6913 D7928_0.xlsm

Page 2 of 2

Atterberg Limits
ASTM D 4318

ADVANCED TERRA TESTING

CLIENT	RJH Consultants	BORING NO.	TP-101
JOB NO.	2679-164	DEPTH	1.5-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-2
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	SAMPLED BY	--
DATE TESTED	09/30/21	DESCRIPTION	--
TECHNICIAN	LOG		

Plastic Limits

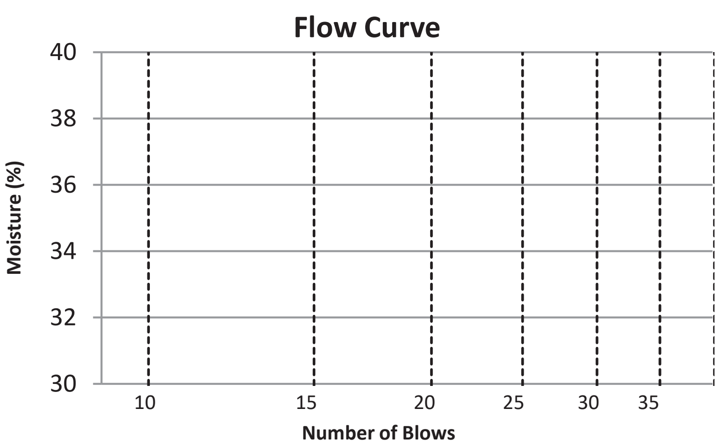
Mass of Wet Pan and Soil (g):	
Mass of Dry Pan and Soil (g):	
Mass of Pan (g):	
Moisture (%)	
	Non-Plastic

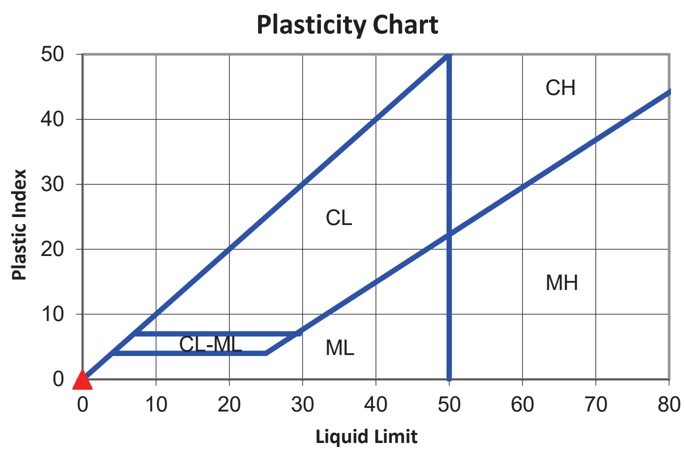
Liquid Limits

Number of Blows	
Mass of Wet Pan and Soil (g):	
Mass of Dry Pan and Soil (g):	
Mass of Pan (g):	
Moisture (%)	
Corrected Moisture (%)	Non-Plastic

Plastic Index

Plastic Limit:	--	Atterberg Classification:	NP
Liquid Limit:	--	Method:	A
Plastic Index:	--		





NOTES	

Data entry by:	LOG	Date: 09/30/21
Checked by:	LG	Date: 10/04/21
File name:	2679164__Atterberg ASTM D4318_1.xlsm	

ADVANCED TERRA TESTING

Atterberg Limits
ASTM D 4318

CLIENT	RJH Consultants	BORING NO.	reservoir sediment stockpile
JOB NO.	2679-164	DEPTH	--
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	--
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	SAMPLED BY	--
DATE TESTED	09/30/21	DESCRIPTION	--
TECHNICIAN	LOG		

Plastic Limits

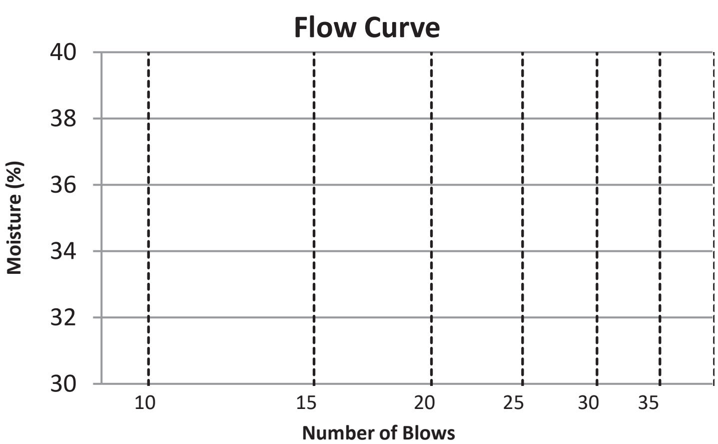
Mass of Wet Pan and Soil (g):	
Mass of Dry Pan and Soil (g):	
Mass of Pan (g):	
Moisture (%)	Non-Plastic

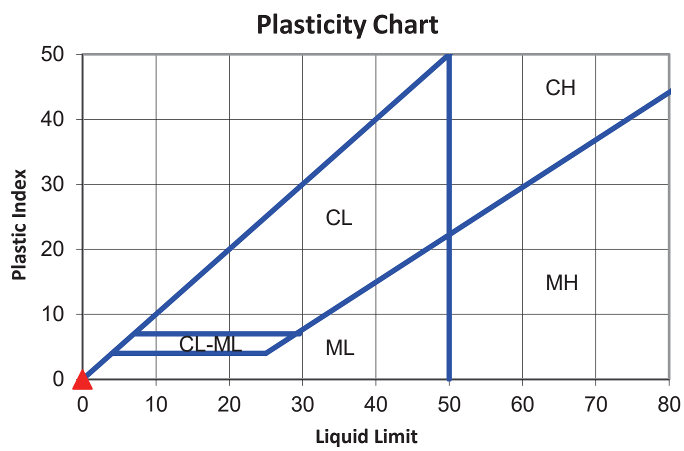
Liquid Limits

Number of Blows	
Mass of Wet Pan and Soil (g):	
Mass of Dry Pan and Soil (g):	
Mass of Pan (g):	
Moisture (%)	
Corrected Moisture (%)	Non-Plastic

Plastic Index

Plastic Limit:	--	Atterberg Classification:	NP
Liquid Limit:	--	Method:	A
Plastic Index:	--		





NOTES

Data entry by:	LOG	Date: 09/30/21
Checked by:	LG	Date: 10/04/21
File name:	2679164__Atterberg ASTM D4318_2.xlsm	

ADVANCED TERRA TESTING

Atterberg Limits
ASTM D 4318

CLIENT	RJH Consultants	BORING NO.	TP-103
JOB NO.	2679-164	DEPTH	1.0-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-1
PROJECT NO.	21125	DATE SAMPLED	--
LOCATION	--	SAMPLED BY	--
DATE TESTED	09/30/21	DESCRIPTION	--
TECHNICIAN	JJA		

Plastic Limits

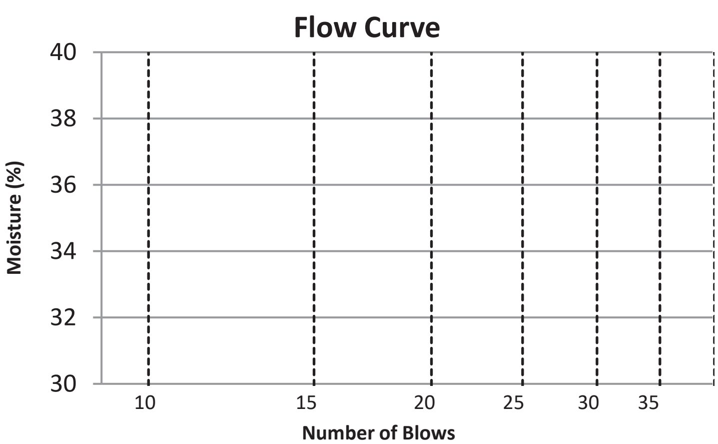
Mass of Wet Pan and Soil (g):	
Mass of Dry Pan and Soil (g):	
Mass of Pan (g):	
Moisture (%)	Non-Plastic

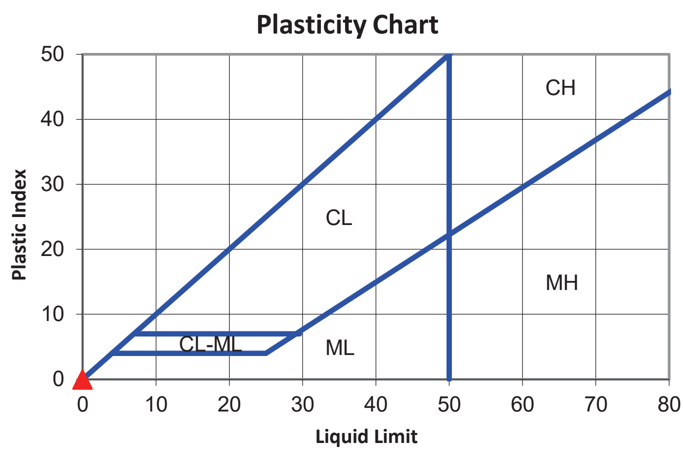
Liquid Limits

Number of Blows	
Mass of Wet Pan and Soil (g):	
Mass of Dry Pan and Soil (g):	
Mass of Pan (g):	
Moisture (%)	
Corrected Moisture (%)	Non-Plastic

Plastic Index

Plastic Limit:	--	Atterberg Classification:	NP
Liquid Limit:	--	Method:	A
Plastic Index:	--		





NOTES

Data entry by:	JJA	Date: 09/30/21
Checked by:	LOG	Date: 09/30/21
File name:	2679164__Atterberg ASTM D4318_0.xlsm	

Laboratory Compaction Characteristics

ASTM D698

ADVANCED TERRA TESTING

CLIENT	RJH Consultants	BORING NO.	Reservoir Sediment Stockpile
JOB NO.	2679-164	DEPTH	--
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	--
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	10/04/21		
TECHNICIAN	LG		

Laboratory Compaction Characteristics

Hygroscopic Moisture

Mass of Wet Pan and Soil (g):	1118.24
Mass of Dry Pan and Soil (g):	1103.69
Mass of Pan (g):	264.75
Moisture (%):	1.7

Rock Correction ASTM D 4718

Method:	B
Course Fraction (%):	19.7
Rock Correction Applied:	YES
Mass of Dry Aggregate (g):	3966.9
Mass of SSD Aggregate (g):	3507.4
Mass of Aggregate in Water (g):	2130.8
Rock Specific Gravity:	2.88
Zero Air Voids Specific Gravity:	2.65

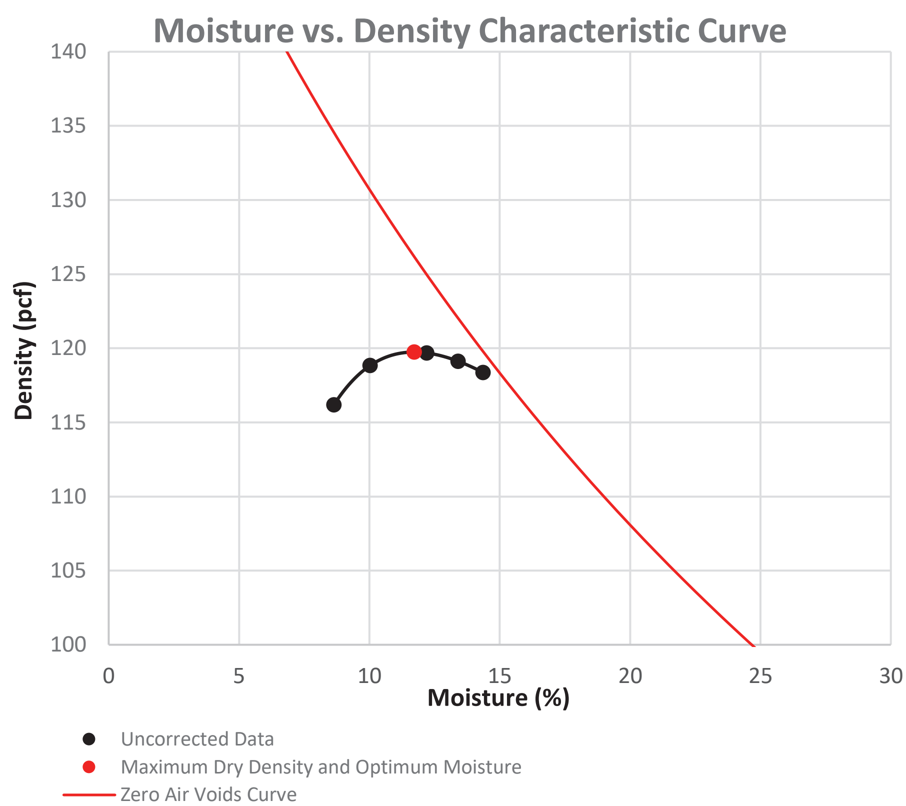
Optimum Dry Density and Moisture

Uncorrected

Dry Density (pcf):	**119.7**
Dry Density (kg/m³):	**1918**
Moisture (%):	**11.7**

Corrected

Dry Density (pcf):	**128.2**
Dry Density (kg/m³):	**2053**
Moisture (%):	**9.4**



Sample Number:	1	2	3	4	5
Mass of Wet Pan and Soil (g):	221.77	240.67	414.53	380.93	291.54
Mass of Dry Soil and Pan (g):	204.67	219.34	363.37	340.29	257.87
Mass of Pan (g);	6.72	6.69	6.91	7.14	6.69
Moisture (%):	8.6	10.0	14.4	12.2	13.4
Mass of Wet Soil and Mold (g):	6483.2	6551.8	6621.4	6605.1	6617.3
Mass of Mold (g):	4574.8	4574.8	4574.8	4574.8	4574.8
Wet Density (pcf):	126.2	130.8	135.4	134.3	135.1
Dry Density (pcf):	116.2	118.8	118.4	119.7	119.1
Wet Density (kg/m³):	2022	2095	2168	2151	2164
Dry Density (kg/m³):	1861	1904	1896	1917	1908

Data entry by: LG Date: 10/15/21
Checked by: KMS Date: 10/15/21
File name: 2679164__compaction ASTM D698 D1557_0.xlsm

Laboratory Compaction Characteristics

ASTM D698

CLIENT	RJH Consultants	BORING NO.	TP 103
JOB NO.	2679-164	DEPTH	1-3'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-1
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	10/13/21		
TECHNICIAN	LG		

Laboratory Compaction Characteristics

Hygroscopic Moisture

Mass of Wet Pan and Soil (g):	420.26
Mass of Dry Pan and Soil (g):	413.08
Mass of Pan (g):	6.68
Moisture (%):	1.8

Rock Correction ASTM D 4718

Method:	B
Course Fraction (%):	22.3
Rock Correction Applied:	YES
Mass of Dry Aggregate (g):	1906.3
Mass of SSD Aggregate (g):	1919.6
Mass of Aggregate in Water (g):	1179.6
Rock Specific Gravity:	2.58
Zero Air Voids Specific Gravity:	2.65

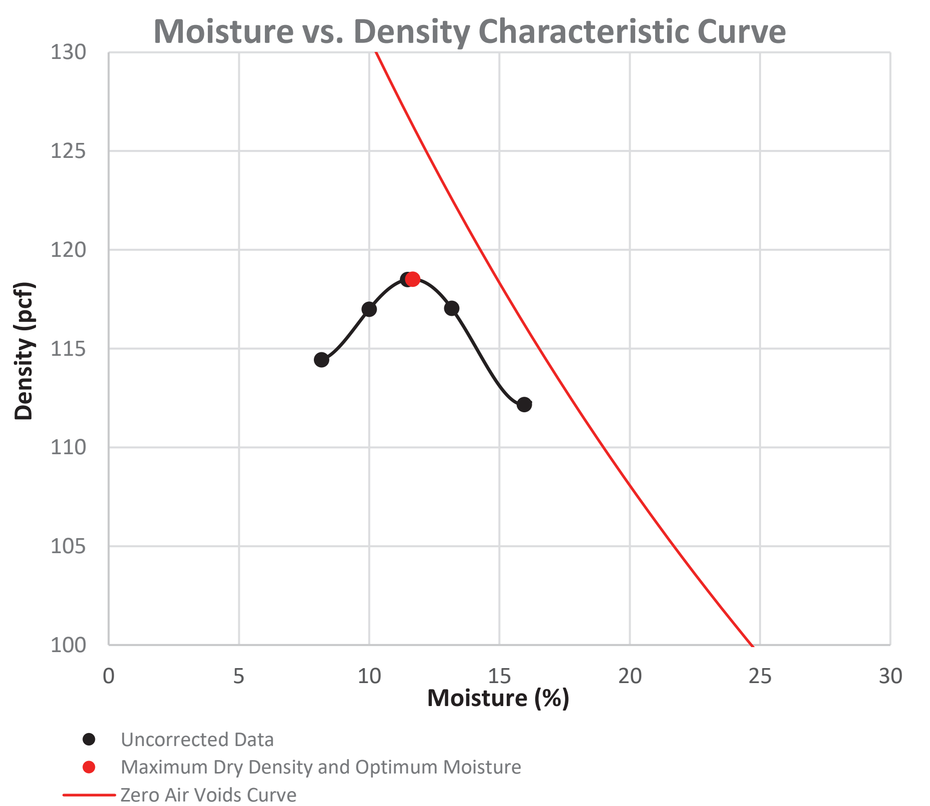
Optimum Dry Density and Moisture

Uncorrected

Dry Density (pcf):	**118.5**
Dry Density (kg/m³):	**1899**
Moisture (%):	**11.7**

Corrected

Dry Density (pcf):	**125.9**
Dry Density (kg/m³):	**2017**
Moisture (%):	**9.1**



Sample Number:	1	2	3	4	5
Mass of Wet Pan and Soil (g):	221.64	212.03	291.68	290.94	289.96
Mass of Dry Soil and Pan (g):	202.11	190.91	258.53	251.81	268.59
Mass of Pan (g);	6.71	6.83	6.70	6.59	6.97
Moisture (%):	10.0	11.5	13.2	16.0	8.2
Mass of Wet Soil and Mold (g):	6520.8	6572.5	6577.8	6541.9	6446.9
Mass of Mold (g):	4575.2	4575.2	4575.2	4575.2	4575.2
Wet Density (pcf):	128.7	132.1	132.5	130.1	123.8
Dry Density (pcf):	117.0	118.5	117.0	112.2	114.4
Wet Density (kg/m³):	2061	2116	2122	2084	1983
Dry Density (kg/m³):	1874	1898	1875	1797	1833

Data entry by:	LG	Date: 10/14/21
Checked by:	WAR	Date: 10/18/21
File name:	2679164__compaction ASTM D698 D1557_1.xlsm	

APPENDIX E

UPSTREAM STEEL FACING THICKNESS MEASUREMENTS

MEMORANDUM

Project 21125

TO:	**John Wilkes, President - CARPI, USA**
FROM:	**Michael Graber, P.E. - RJH Consultants, Inc.**
DATE:	**October 22, 2021**
RE:	**Grizzly Reservoir Dam (DAMID 380109)** **Steel Facing Thickness Measurements and Sounding**
CC:	**Bruce Hughes – Twin Lakes Reservoir and Canal Company**

Purpose

The purpose of this memorandum is to summarize the data collected during the site visit of Grizzly Reservoir Dam (Site) on Wednesday, October 20, 2021. Thickness measurements of the steel facing were obtained at 18 panels. Sounding was also performed on the panels where thickness measurements were obtained.

Weather

AM: High 30's, Sunny
PM: Low to Mid 50's, Sunny

Personnel Onsite

Personnel who were onsite are summarized in the table below. RJH Consultants, Inc. (RJH) arrived to the Site at approximately 10:00 a.m. and left at approximately 3:30 p.m.

Company	Personnel (Title)
RJH	Michael Graber, P.E. (Project Manager) Matt Kull, E.I. (Staff Engineer) Austin Yahn, E.I. (Staff Engineer)
Twin Lakes Reservoir and Canal Company	Glenn Schryver

Site Conditions

The reservoir pool of Grizzly Reservoir was approximately 14 vertical feet below the crest of the dam.

Data Collection

- The upstream slope of the dam was accessed using a ladder and personal fall arrest system with a lifeline in general accordance with RJH's Health and Safety Plan and Occupational Safety and Health Administration (OSHA) guidelines.

- Thickness measurements were obtained using a Reed Instruments TM-8811 ultrasonic thickness gauge.
- Coating and rust on the steel facing were removed with an angle grinder at the measurement locations to ensure a clean surface prior to measurement.
- The thickness of the steel facing was generally consistent, ranging from 0.188 inch to 0.316 inch. The average thickness of the steel facing was approximately 1/4 inch with a standard deviation of 0.04 inch.
- Sounding was performed with a 5-pound sledge hammer on the panels where thickness measurements were obtained.
- The majority of all panels appeared to have voids behind the panel. Random areas without voids were observed on some of the panels.

Discussions

- RJH asked Glenn Shryver (Twin Lakes Reservoir and Canal Company) the maximum capacity of the outlet conduit. Glenn said that a maximum flowrate of about 400 cubic feet per second could be released through the conduit.

Attachments: Attachment A - Steel Facing Thickness Measurement Data
Attachment B - Steel Facing Thickness Measurement Locations
Attachment C - Photographs

MLG/mme

ATTACHMENT A

STEEL FACING THICKNESS MEASUREMENT DATA

Steel Facing Thickness Measurements

Measurement Location ID	Thickness (in)	Average Panel Thickness (in)	Distance from Rib (ft)	Horizontal Distance from Crest (ft)	Vertical Distance from Crest (ft)	Distance from Crest along Slope (ft)	Sounding Information
P01-01	0.263	0.271	3.6R	4.2	8.3	9.3	Hollow
P01-02	0.278		3.1R	5.6	11.2	12.5	
P02-01	0.188	0.191	4.7L	0.9	1.8	2.0	Mostly hollow, solid area ~1 ft above water line
P02-02	0.193		4.7L	5.9	11.9	13.3	
P03-01	0.193	0.191	5.1L	1.8	3.6	4.0	Hollow
P03-02	0.189		5.1L	5.4	10.7	12.0	
P04-01	0.198	0.195	4.4L	1.8	3.6	4.0	Mostly hollow
P04-02	0.195		4.4L	4.7	9.4	10.5	
P04-03	0.191		4.4L	5.9	11.7	13.1	
P05-01	0.278	0.281	9.6L	2.0	4.0	4.5	Hollow
P05-02	0.278		9.6L	4.7	9.4	10.5	
P05-03	0.287		9.6L	5.8	11.6	13.0	
P06-01	0.278	0.276	10.5L	1.1	2.2	2.5	Mostly hollow, one solid area ~ 1.5 ft above water line, top 4 ft solid
P06-02	0.282		10.5L	4.0	8.0	9.0	
P06-03	0.268		10.5L	5.8	11.6	13.0	
P07-01	0.263	0.274	10.5L	1.3	2.7	3.0	Hollow
P07-02	0.278		10.5L	4.0	8.0	9.0	
P07-03	0.282		10.5L	5.6	11.2	12.5	
P09-01	0.263	0.274	9.5L	1.2	2.4	2.7	Hollow
P09-02	0.278		9.5L	3.0	5.9	6.6	
P09-03	0.282		9.5L	6.1	12.3	13.7	

Steel Facing Thickness Measurements

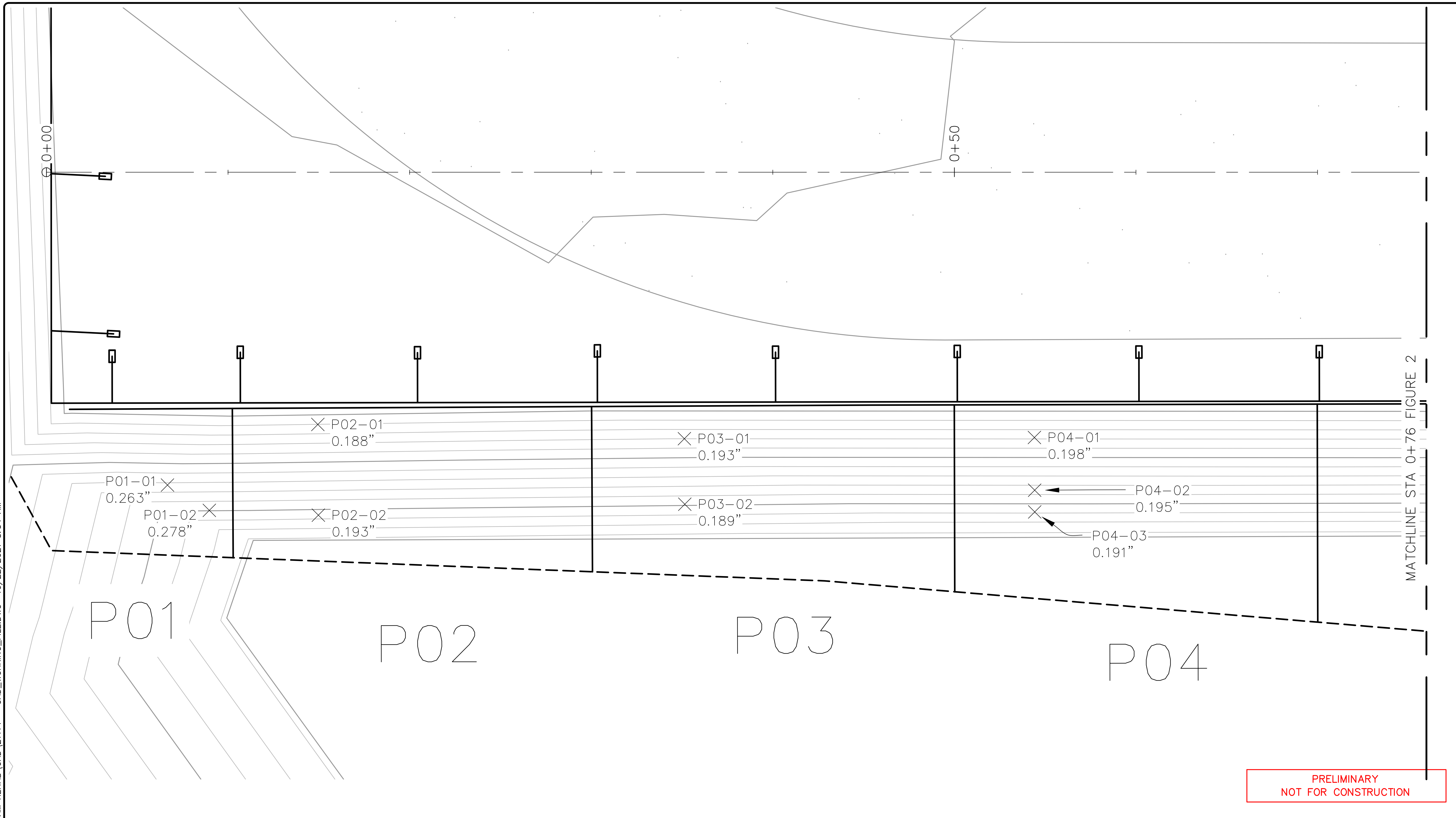
Measurement Location ID	Thickness (in)	Average Panel Thickness (in)	Distance from Rib (ft)	Horizontal Distance from Crest (ft)	Vertical Distance from Crest (ft)	Distance from Crest along Slope (ft)	Sounding Information
P11-01	0.287	0.294	8.8L	1.3	2.7	3.0	Mostly hollow, one solid area ~1 ft above water line on left side of ladder
P11-02	0.282		8.8L	3.0	6.0	6.7	
P11-03	0.312		8.8L	6.3	12.5	14.0	
P13-01	0.273	0.287	9.4L	1.3	2.5	2.8	Hollow
P13-02	0.273		9.4L	3.2	6.4	7.2	
P13-03	0.316		9.4L	6.1	12.2	13.6	
P15-01	0.263	0.270	9.6L	1.3	2.7	3.0	Hollow
P15-02	0.268		9.6L	3.0	6.1	6.8	
P15-03	0.278		9.6L	6.1	12.3	13.7	
P17-01	0.198	0.226	10.6L	1.3	2.7	3.0	Mostly hollow, one solid area near center of panel
P17-02	0.203		10.6L	3.9	7.9	8.8	
P17-03	0.278		10.6L	6.4	12.7	14.2	
P19-01	0.203	0.240	9.3L	0.9	1.8	2.0	Hollow
P19-02	0.203		9.3L	3.4	6.8	7.6	
P19-03	0.314		9.3L	6.1	12.2	13.6	
P21-01	0.227	0.250	10.5L	2.0	4.0	4.5	Hollow
P21-02	0.242		10.5L	4.5	8.9	10.0	
P21-03	0.282		10.5L	6.0	12.1	13.5	
P23-01	0.203	0.221	10.5L	1.8	3.6	4.0	Hollow
P23-02	0.193		10.5L	4.0	8.0	9.0	
P23-03	0.268		10.5L	6.0	12.1	13.5	

Steel Facing Thickness Measurements

Measurement Location ID	Thickness (in)	Average Panel Thickness (in)	Distance from Rib (ft)	Horizontal Distance from Crest (ft)	Vertical Distance from Crest (ft)	Distance from Crest along Slope (ft)	Sounding Information
P25-01	0.191	0.220	10.5L	2.2	4.5	5.0	Mostly hollow, one solid area
P25-02	0.188		10.5L	4.2	8.5	9.5	
P25-03	0.282		10.5L	5.8	11.6	13.0	
P27-01	0.208	0.225	10.0L	1.8	3.6	4.0	Mostly hollow, one solid area
P27-02	0.188		10.0L	4.0	8.0	9.0	
P27-03	0.278		10.0L	5.8	11.6	13.0	
P30-01	0.203	0.230	2.0L	1.8	3.6	4.0	Hollow
P30-02	0.200		2.0L	4.0	8.0	9.0	
P30-03	0.287		2.0L	6.0	12.1	13.5	

ATTACHMENT B

STEEL FACING THICKNESS MEASUREMENT LOCATIONS



RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

STEEL THICKNESS MEASUREMENT LOCATIONS

PROJECT NO. 21125

October 2021

Figure 1

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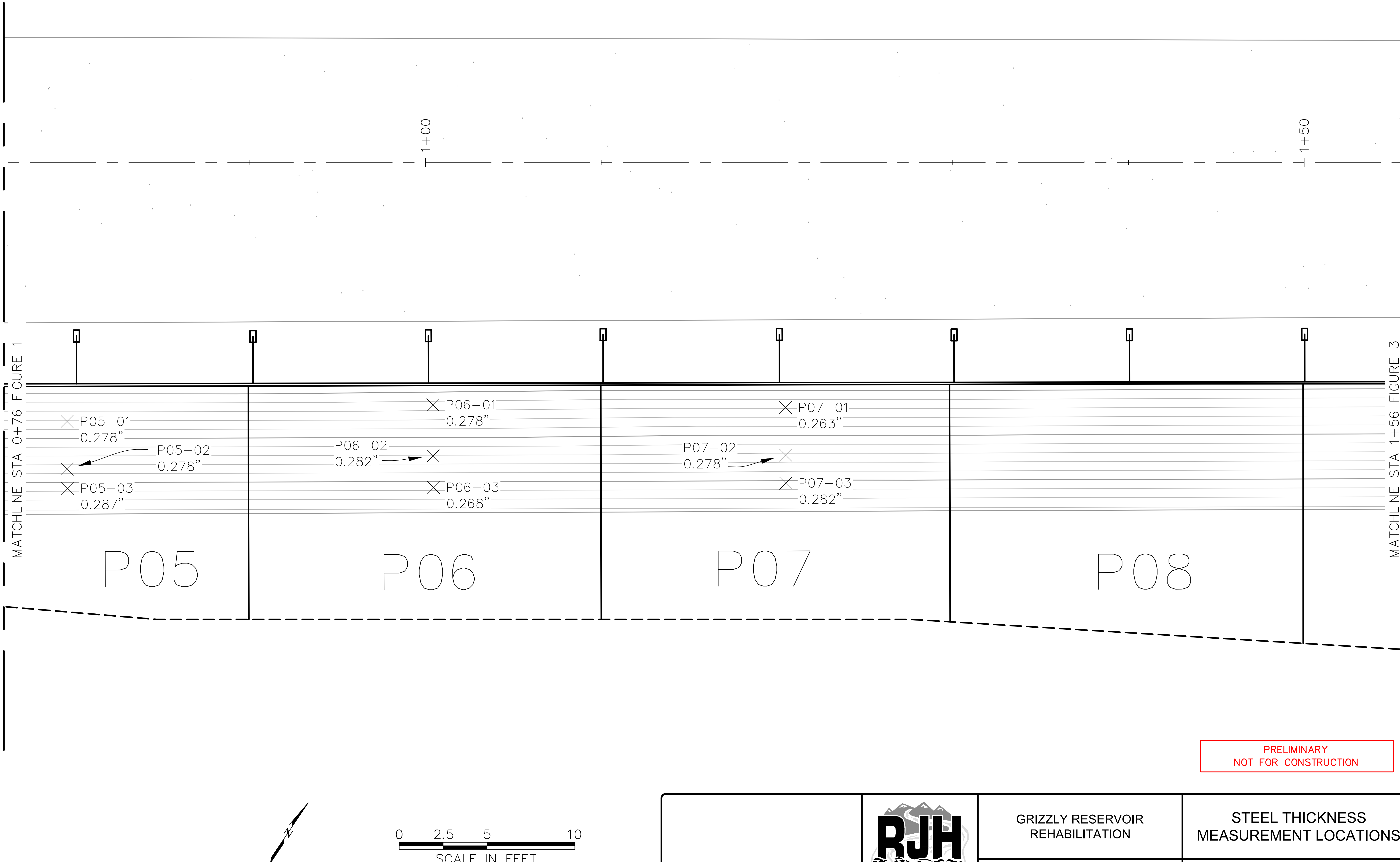

PRELIMINARY
NOT FOR CONSTRUCTION

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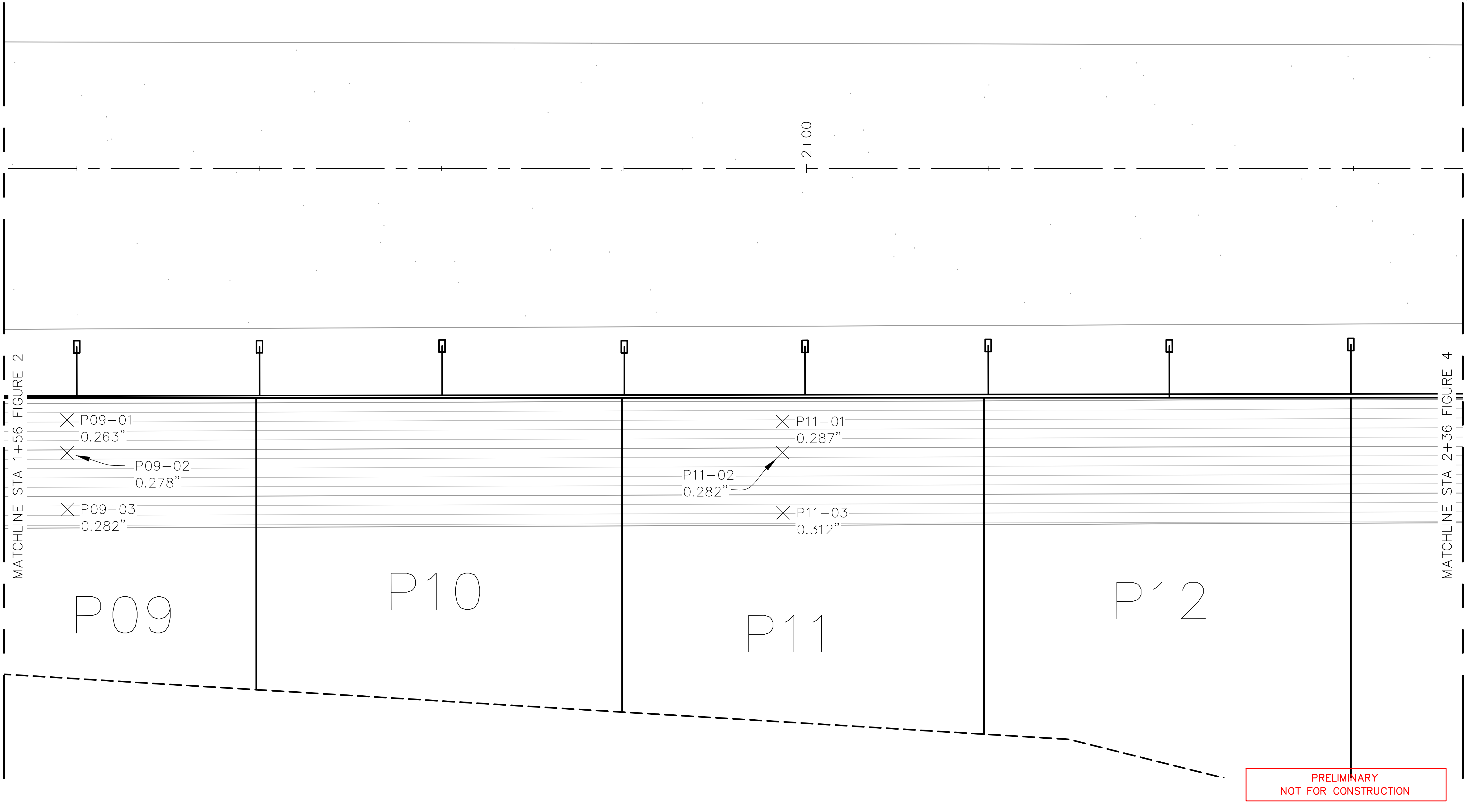
RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	STEEL THICKNESS MEASUREMENT LOCATIONS	
	PROJECT NO. 21125	October 2021	**Figure 2**



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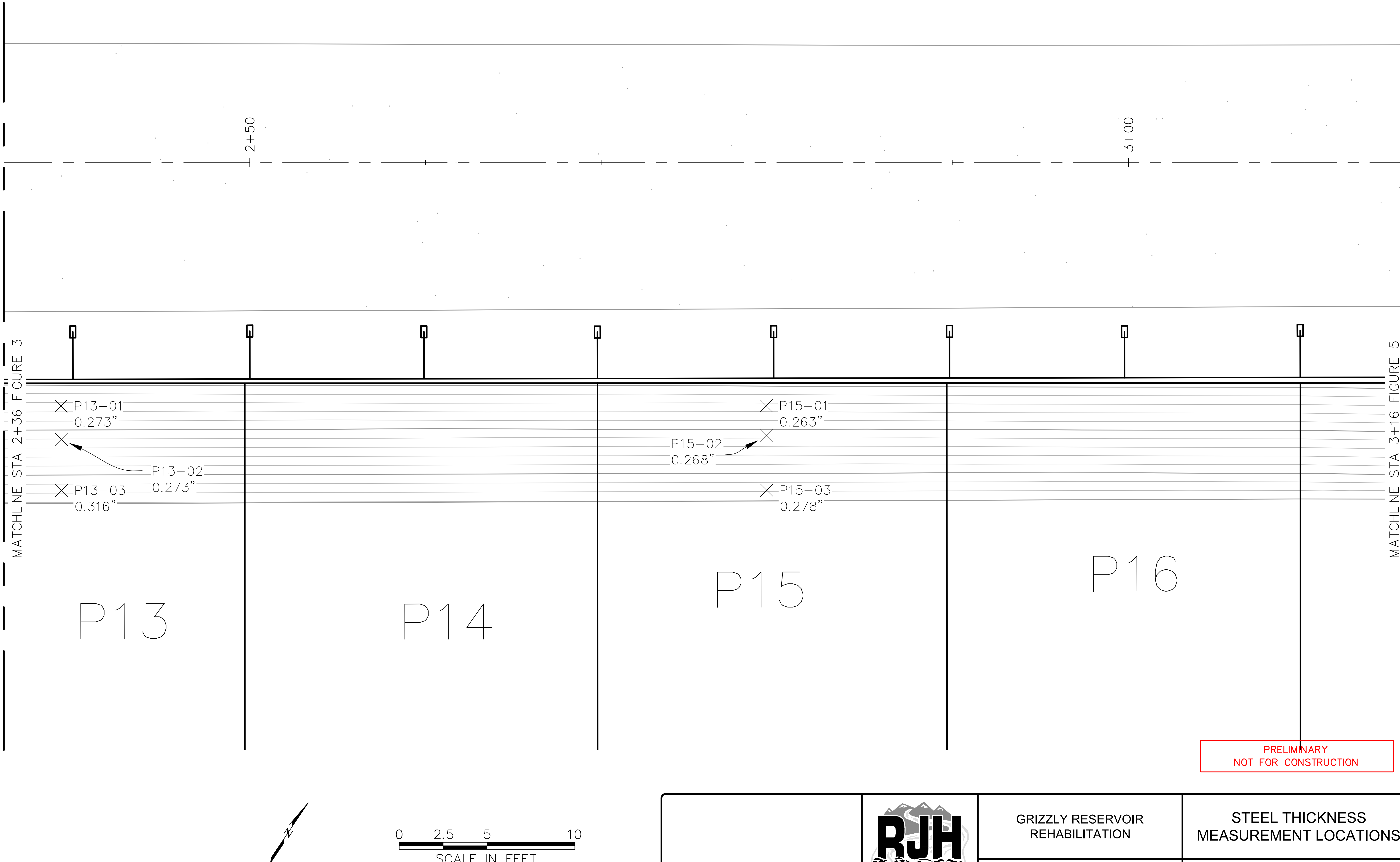
RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	STEEL THICKNESS MEASUREMENT LOCATIONS
	PROJECT NO. 21125	October 2021 **Figure 3**



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RJH CONSULTANTS, INC.

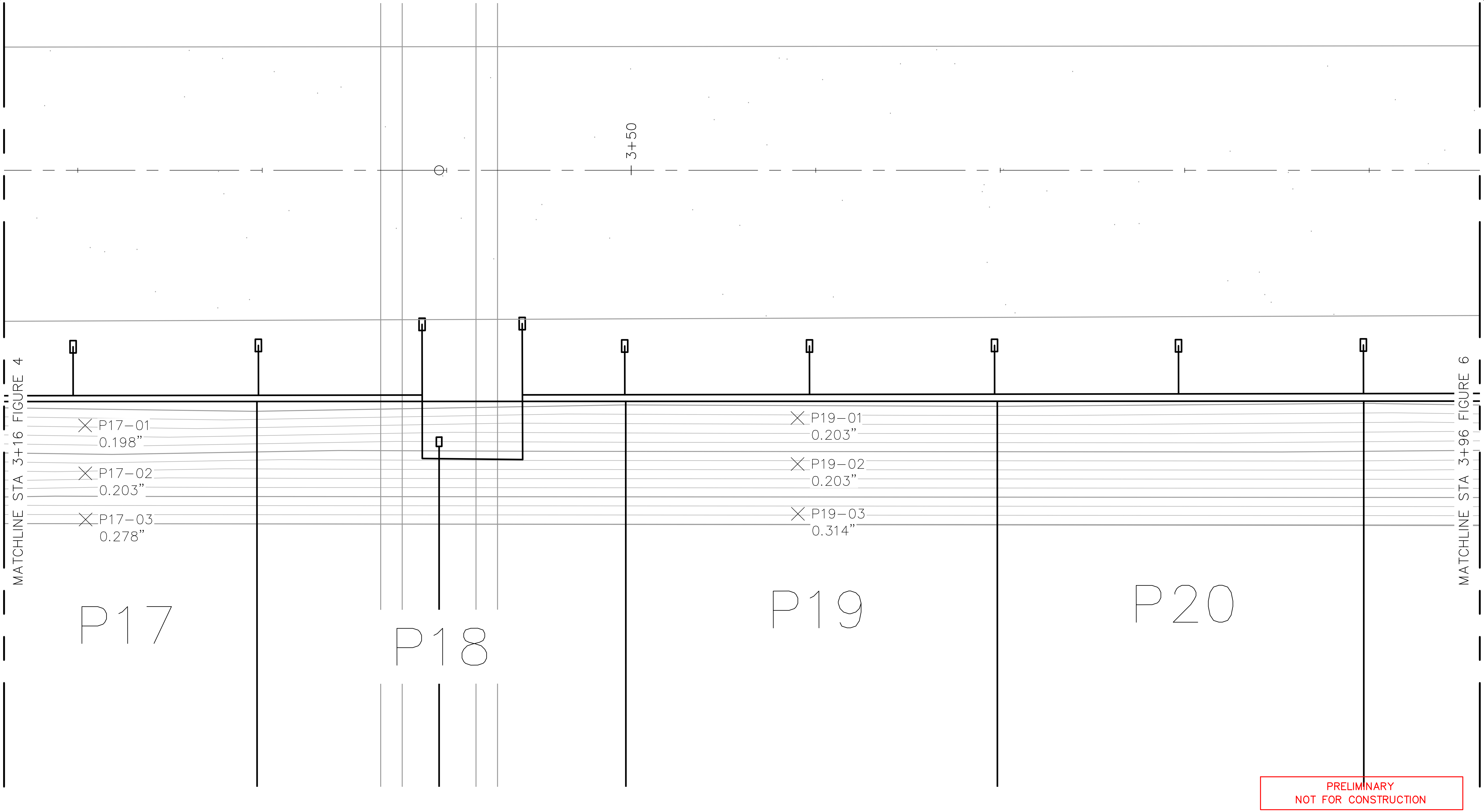
GRIZZLY RESERVOIR REHABILITATION

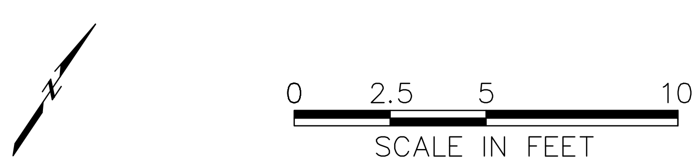
PROJECT NO. 21125

STEEL THICKNESS MEASUREMENT LOCATIONS

October 2021

Figure 4





RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

STEEL THICKNESS MEASUREMENT LOCATIONS

PROJECT NO. 21125

October 2021

Figure 5

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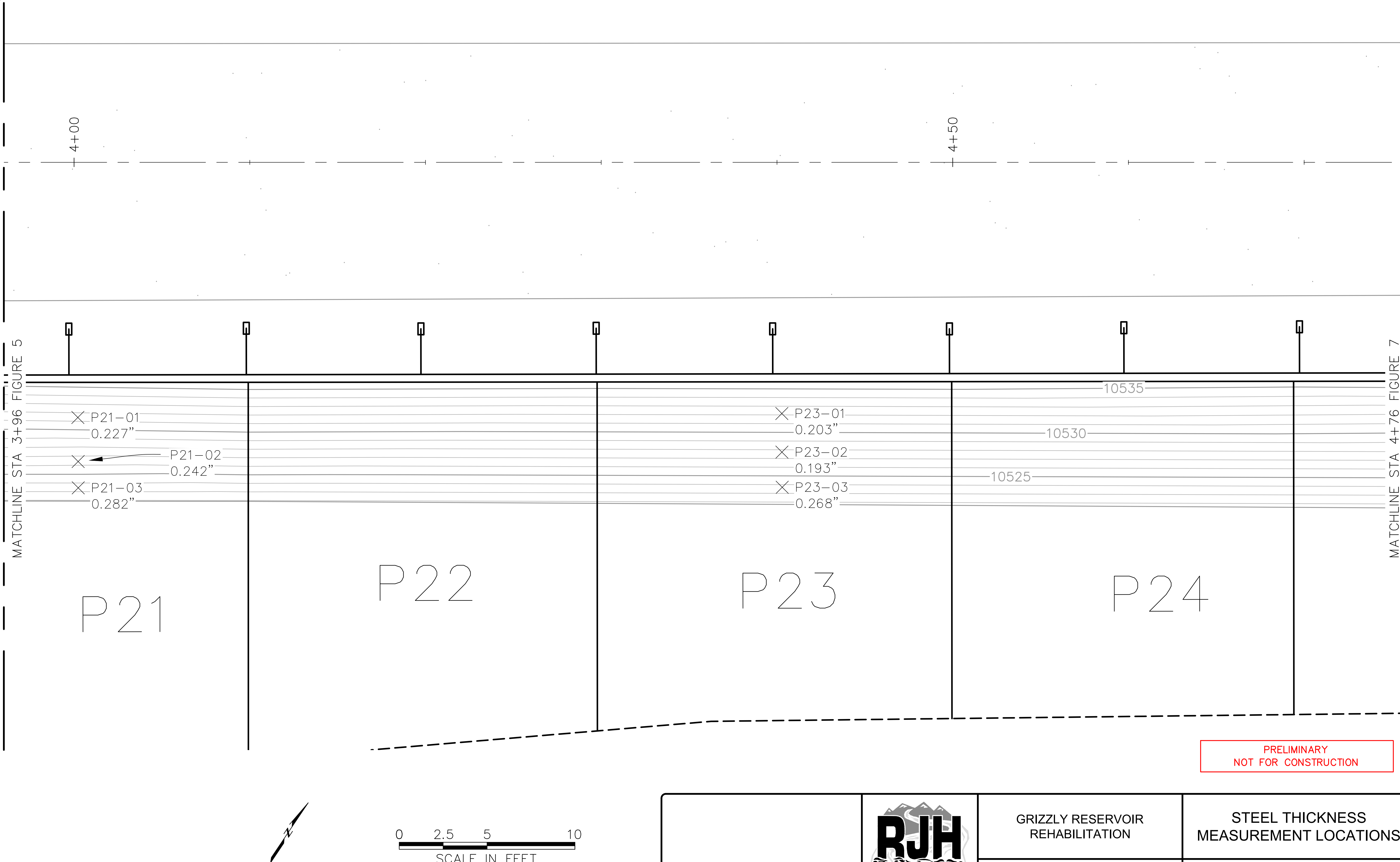

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

STEEL THICKNESS MEASUREMENT LOCATIONS

PROJECT NO. 21125

October 2021

Figure 6

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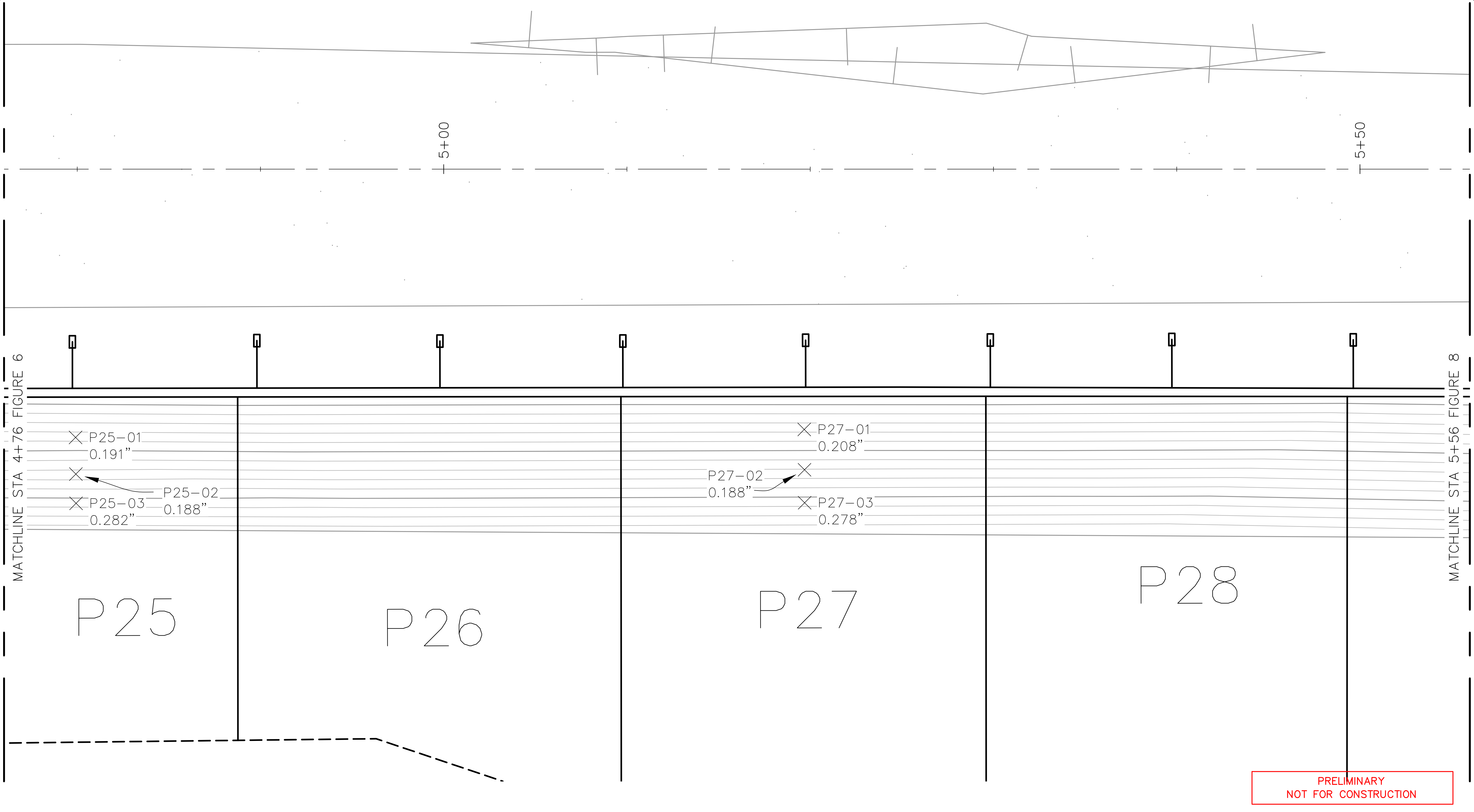

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RJH CONSULTANTS, INC.

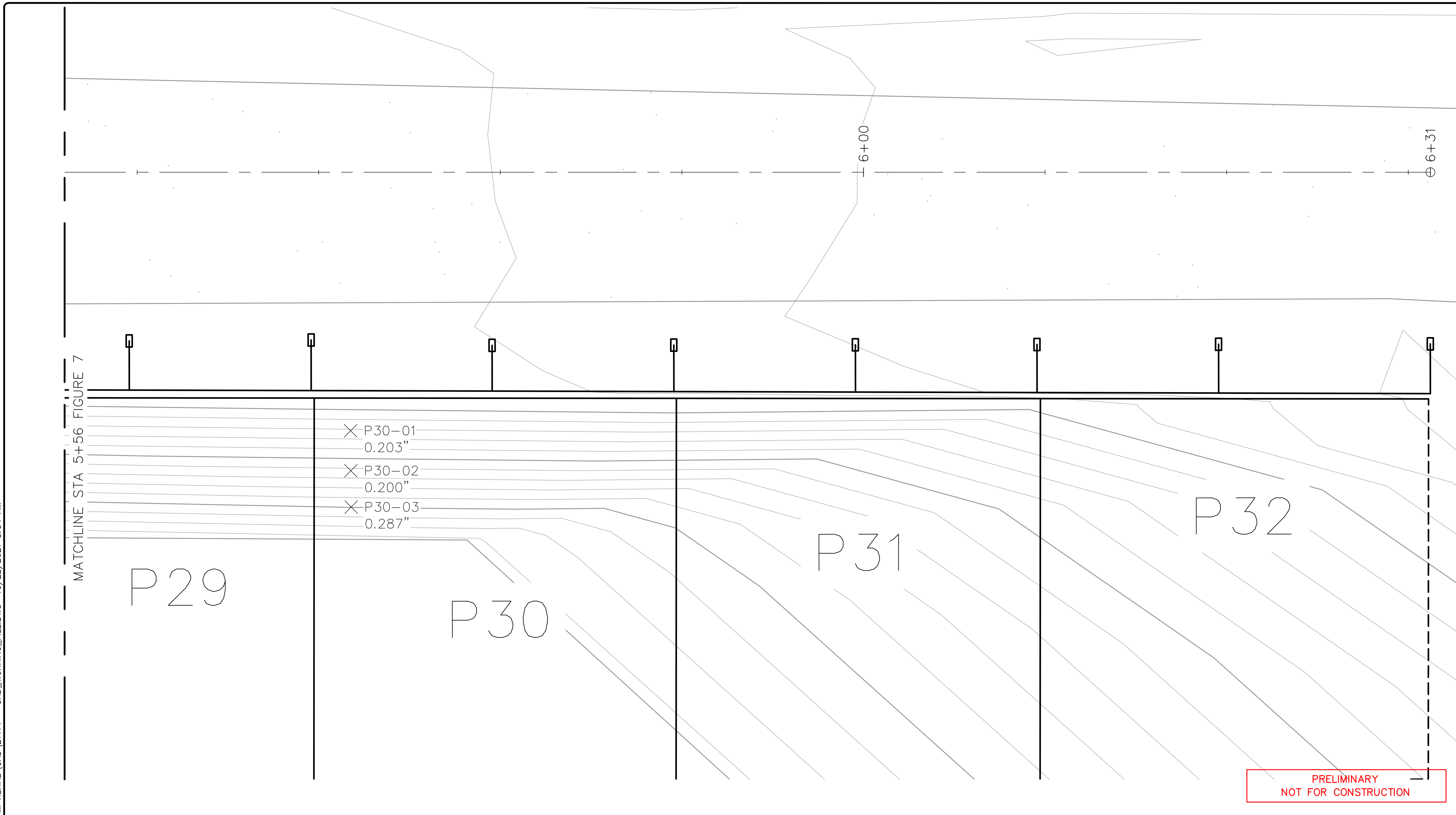
GRIZZLY RESERVOIR REHABILITATION

PROJECT NO. 21125

STEEL THICKNESS MEASUREMENT LOCATIONS

October 2021

Figure 7



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RJH CONSULTANTS, INC.

GRIZZLY RESERVOIR REHABILITATION

PROJECT NO. 21125

STEEL THICKNESS MEASUREMENT LOCATIONS

October 2021

Figure 8

ATTACHMENT C

PHOTOGRAPHS

Photograph 1: View looking north at panel P01. RJH removed coating from the steel facing prior to obtaining measurements.

Photograph 2: View looking east near Station 0+15. RJH accessed the steel facing with a ladder and personal fall arrest system with a lifeline. The ladder and lifeline were anchored separately to the roll cage of a side-by-side.

Photograph 3: View looking east near Station 2+80.

Photograph 4: View looking north near the gate operator.

Photograph 5: View looking east near the gate operator.

Photograph 6: Gate operator supports.

Photograph 7: View looking east from the auxiliary spillway. RJH obtains thickness measurements.

APPENDIX F

AIR VENT SIZING

Purpose

Evaluate the outlet works rating curve for the existing 4'-0" square concrete box outlet conduit.

References:

1. Use T.W. Sturm Open Channel Hydraulics (2001).
2. Use FHWA HDS-5 Hydraulic Design of Highway Culverts (2012).
3. Use USBR Small Dams (1987).
4. Use Brater & King Handbook of Hydraulics (1996).
5. Grizzly Reservoir Design Plans (1932, 1933, 1935)
6. ~~Engineer's Inspection Report, SEO (2018)~~

Analysis:

- Evaluate flow conditions for unsubmerged inlet control, submerged inlet control, and outlet control.
- Use Federal Highway Administrations Culvert Equations for inlet control.
- Use Energy Equation for outlet control.
- Pertinent Dam Information:

Dam Crest Elev:	10535	ft √
Normal High Water Level (NHWL):	10530	ft √
Outlet Pipe Inlet Invert:	10480.3	ft √
Outlet Pipe Outlet Invert:	10479.2	ft √

1. Unsubmerged Inlet Control

$$\frac{HW_i}{D} = \frac{H_c}{D} + K\left[\frac{Q}{AD^{0.5}}\right]^M + K_s S \quad [1]$$

Where:

HW_i=	Headwater height above inlet invert (ft)		
D=	Interior height of culvert barrel (ft) =	4.00	*4'-0" Concrete Box Culvert* √
H_c=	Specific head at critical depth (ft), where,	$H_c = d_c + \frac{V_c^2}{2g}$	
K=	Constant from FHWA =	0.061 √	(Reference 2, Pg 8)
M=	Constant from FHWA =	0.75 √	
Q=	Discharge (cfs)	*unknown*	
A=	Full cross-sectional area of culvert (sf) =	16.00 √	
K_s=	Slope Correction Factor =	-0.5	
S=	Culvert barrel slope (ft/ft) =	0.0092 √	(Reference 5, Pg 11-13)

Invert EL.= 10480.3 *(inlet)* √

- Solve for critical depth (dc) by setting Froude number (Fr) equal to 1:

$$F_r = \frac{Q^2 B_C}{g A_c^3}$$

$$\text{Water Surface Elevation (W.S.E.)} = \text{Pipe Invert Elevation} + HW_i$$

▪ Determine the flow rate for varying headwater heights above the culvert inlet inverts:

Unsubmerged Inlet Control							
Q (cfs)	d_c (ft)[(1)]	B_c (ft)	A_c (sf)	Fr	H_c (ft)	HW_i (ft)	W.S.E. (ft)
0.0	0.0	4.0	0.1	0.0	0.0	0.0	10480.3
6.0	0.4	4.0	1.6	1.0	0.6	0.7	10481.0
23.0	1.0	4.0	4.0	1.0	1.5	1.7	10482.0
46.0	1.6	4.0	6.4	1.0	2.4	2.7	10483.0
73.0	2.2	4.0	8.7	1.0	3.3	3.7	10484.0

(1) Solved by setting Fr=1.

2. Submerged Inlet Control

$$\frac{HW_i}{D} = c\left[\frac{Q}{AD^{0.5}}\right]^2 + Y + K_s S$$

Where:

HW_i= Headwater height above inlet invert (ft)
D= Interior height of culvert barrel (ft) = 4.00
c= Constant from FHWA = 0.0423 Reference 2, Pg 8
Q= Discharge (cfs) *unknown*
A= Full cross sectional area of culvert (sf) = 16.00
Y= Constant from FHWA = 0.82 Reference 2, Pg 8
K_s= Slope Correction Factor = -0.5
S= Culvert barrel slope (ft/ft) = 0.0092

▪ Determine the flow rate for varying headwater heights above the culvert inlet:

Submerged Inlet Control		
Q (cfs)	Hwi (ft)	W.S.E. (ft)
93.3	4.7	10485.0
121.5	5.7	10486.0
144.3	6.7	10487.0
163.9	7.7	10488.0
181.4	8.7	10489.0
197.4	9.7	10490.0
212.2	10.7	10491.0
226.0	11.7	10492.0
239.0	12.7	10493.0
251.3	13.7	10494.0
263.1	14.7	10495.0
274.4	15.7	10496.0
285.2	16.7	10497.0
295.6	17.7	10498.0
305.7	18.7	10499.0
315.4	19.7	10500.0
324.9	20.7	10501.0
334.0	21.7	10502.0
343.0	22.7	10503.0
351.7	23.7	10504.0

Client: Grizzly Reservoir
Subject: Outlet Works - Rating Curve

Project: 21125
Prepared By: BES
Checked By:
Approved By: MLG

Page: 3/13
Date: 12/06/21
Date:
12/09/2021

√	√	√	
360.2	24.7	10505.0	
368.5	25.7	10506.0	
376.6	26.7	10507.0	
384.6	27.7	10508.0	
392.4	28.7	10509.0	
400.0	29.7	10510.0	
407.5	30.7	10511.0	
414.9	31.7	10512.0	
422.1	32.7	10513.0	
429.2	33.7	10514.0	
436.2	34.7	10515.0	
443.1	35.7	10516.0	
449.9	36.7	10517.0	
456.5	37.7	10518.0	
463.1	38.7	10519.0	
469.6	39.7	10520.0	
476.0	40.7	10521.0	
482.3	41.7	10522.0	
488.6	42.7	10523.0	
494.7	43.7	10524.0	
500.8	44.7	10525.0	
506.8	45.7	10526.0	
512.7	46.7	10527.0	
518.6	47.7	10528.0	
524.4	48.7	10529.0	
530.1	49.7	10530.0	NHWL
535.8	50.7	10531.0	
541.4	51.7	10532.0	
547.0	52.7	10533.0	
552.5	53.7	10534.0	
557.9	54.7	10535.0	Dam Crest

3. Outlet Control

$$z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + H_L \quad [9]$$

Where:

z_i= Elevation above datum (ft)
P_i= Pressure head (psi)
γ= Unit Weight of Water (pcf)
v_i= Velocity (fps)
g= Gravitational Constant = 32.2 fps
H_L= Headloss (ft)

$$H_L = \left[\sum K_i + 29.1n^2\left(\frac{L}{r^{4/3}}\right)\right]\frac{v^2}{2g} \quad [10]$$

Where:

K_i= Minor Headloss Coefficients
n= Manning's coefficient
L= Culvert length (ft)
B = Square culvert height and width (ft)
r= Hydraulic Radius = $B^2/4B$ √
v= Velocity (fps)
H_m= Minor Headloss (ft)
H_f= Friction Headloss (ft)

Loss Type	Length (ft)	Manning n	Minor Loss K	B (ft)	Area (ft)
Pipe Entrance	--	--	0.5 √	4.00	16.00
4'-0" Square Concrete Box Culvert ("Pipe")	130 √	0.015 √	--	4.00	16.00
Pipe Exit	--	--	1.0 √	4.00	16.00

Tailwater Elevation: 10481.2 ft Pipe springline √

- Determine the flow rate for varying water heights above the culvert inlet:

Outlet Control			√	√
Q (cfs) √	H_f (ft) √	H_m (ft) √	Tailwater El.	W.S.E. (ft)
163.2	1.38	2.4	10481.2	10485.0
183.5	1.74	3.1	10481.2	10486.0
201.7	2.10	3.7	10481.2	10487.0
218.4	2.46	4.3	10481.2	10488.0
233.9	2.82	5.0	10481.2	10489.0
248.4	3.19	5.6	10481.2	10490.0
262.1	3.55	6.3	10481.2	10491.0
275.2	3.91	6.9	10481.2	10492.0
287.6	4.27	7.5	10481.2	10493.0
299.6	4.63	8.2	10481.2	10494.0
311.1	5.00	8.8	10481.2	10495.0
322.1	5.36	9.4	10481.2	10496.0
332.9	5.72	10.1	10481.2	10497.0

Client: Grizzly Reservoir
Subject: Outlet Works - Rating Curve

Project: 21125
Prepared By: BES
Checked By:
Approved By: MLG

Page: 5/13
Date: 12/06/21
Date: 12/09/2021

343.2	6.08	10.7	10481.2	10498.0	
353.3	6.44	11.4	10481.2	10499.0	
363.1	6.81	12.0	10481.2	10500.0	
372.6	7.17	12.6	10481.2	10501.0	
381.9	7.53	13.3	10481.2	10502.0	
391.0	7.89	13.9	10481.2	10503.0	
399.8	8.25	14.5	10481.2	10504.0	
408.5	8.62	15.2	10481.2	10505.0	
417.0	8.98	15.8	10481.2	10506.0	
425.3	9.34	16.5	10481.2	10507.0	
433.5	9.70	17.1	10481.2	10508.0	
441.5	10.06	17.7	10481.2	10509.0	
449.4	10.43	18.4	10481.2	10510.0	
457.1	10.79	19.0	10481.2	10511.0	
464.7	11.15	19.6	10481.2	10512.0	
472.2	11.51	20.3	10481.2	10513.0	
479.6	11.87	20.9	10481.2	10514.0	
486.8	12.24	21.6	10481.2	10515.0	
494.0	12.60	22.2	10481.2	10516.0	
501.0	12.96	22.8	10481.2	10517.0	
508.0	13.32	23.5	10481.2	10518.0	
514.8	13.68	24.1	10481.2	10519.0	
521.6	14.05	24.8	10481.2	10520.0	
528.3	14.41	25.4	10481.2	10521.0	
534.9	14.77	26.0	10481.2	10522.0	
541.4	15.13	26.7	10481.2	10523.0	
547.8	15.49	27.3	10481.2	10524.0	
554.2	15.86	27.9	10481.2	10525.0	
560.5	16.22	28.6	10481.2	10526.0	
566.7	16.58	29.2	10481.2	10527.0	
572.9	16.94	29.9	10481.2	10528.0	
578.9	17.30	30.5	10481.2	10529.0	
585.0	17.67	31.1	10481.2	10530.0	NHWL
590.9	18.03	31.8	10481.2	10531.0	
596.8	18.39	32.4	10481.2	10532.0	
602.7	18.75	33.0	10481.2	10533.0	
608.5	19.11	33.7	10481.2	10534.0	
614.2	19.48	34.3	10481.2	10535.0	Dam Crest

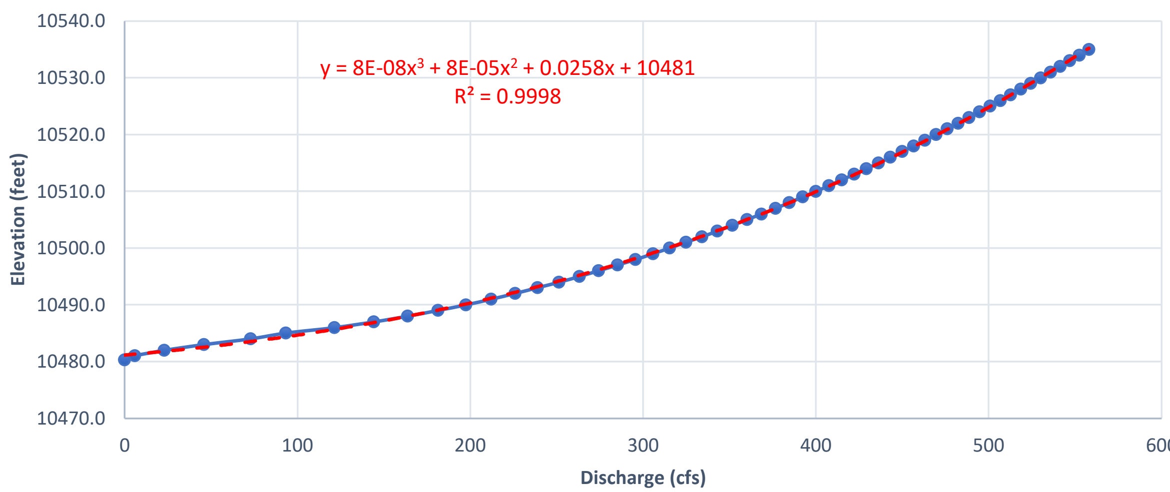
Results:

Rating Curve Table

Height (ft)	(ft)	(cfs)	Inlet Control Q	Inlet Control	Control Q
0.0	**10480.3**	**0.0**	0	---	---
1.0	**10481**	**6.0**	6.0	---	---
2.0	**10482**	**23.0**	23.0	---	---
3.0	**10483**	**46.0**	46.0	---	---
4.0	**10484**	**73.0**	73.0	---	---
5.0	**10485**	**93.3**	---	93.3	163.2
6.0	**10486**	**121.5**	---	121.5	183.5
7.0	**10487**	**144.3**	---	144.3	201.7
8.0	**10488**	**163.9**	---	163.9	218.4
9.0	**10489**	**181.4**	---	181.4	233.9
10.0	**10490**	**197.4**	---	197.4	248.4
11.0	**10491**	**212.2**	---	212.2	262.1
12.0	**10492**	**226.0**	---	226.0	275.2
13.0	**10493**	**239.0**	---	239.0	287.6
14.0	**10494**	**251.3**	---	251.3	299.6
15.0	**10495**	**263.1**	---	263.1	311.1
16.0	**10496**	**274.4**	---	274.4	322.1
17.0	**10497**	**285.2**	---	285.2	332.9
18.0	**10498**	**295.6**	---	295.6	343.2
19.0	**10499**	**305.7**	---	305.7	353.3
20.0	**10500**	**315.4**	---	315.4	363.1
21.0	**10501**	**324.9**	---	324.9	372.6
22.0	**10502**	**334.0**	---	334.0	381.9
23.0	**10503**	**343.0**	---	343.0	391.0
24.0	**10504**	**351.7**	---	351.7	399.8
25.0	**10505**	**360.2**	---	360.2	408.5
26.0	**10506**	**368.5**	---	368.5	417.0
27.0	**10507**	**376.6**	---	376.6	425.3
28.0	**10508**	**384.6**	---	384.6	433.5
29.0	**10509**	**392.4**	---	392.4	441.5
30.0	**10510**	**400.0**	---	400.0	449.4
31.0	**10511**	**407.5**	---	407.5	457.1
32.0	**10512**	**414.9**	---	414.9	464.7
33.0	**10513**	**422.1**	---	422.1	472.2
34.0	**10514**	**429.2**	---	429.2	479.6
35.0	**10515**	**436.2**	---	436.2	486.8
36.0	**10516**	**443.1**	---	443.1	494.0
37.0	**10517**	**449.9**	---	449.9	501.0
38.0	**10518**	**456.5**	---	456.5	508.0
39.0	**10519**	**463.1**	---	463.1	514.8
40.0	**10520**	**469.6**	---	469.6	521.6
41.0	**10521**	**476.0**	---	476.0	528.3
42.0	**10522**	**482.3**	---	482.3	534.9

43.0	**10523**	**488.6**	---	488.6	541.4	
44.0	**10524**	**494.7**	---	494.7	547.8	
45.0	**10525**	**500.8**	---	500.8	554.2	
46.0	**10526**	**506.8**	---	506.8	560.5	
47.0	**10527**	**512.7**	---	512.7	566.7	
48.0	**10528**	**518.6**	---	518.6	572.9	
49.0	**10529**	**524.4**	---	524.4	578.9	
50.0	**10530**	**530.1**	---	530.1	585.0	NHWL
51.0	**10531**	**535.8**	---	535.8	590.9	
52.0	**10532**	**541.4**	---	541.4	596.8	
53.0	**10533**	**547.0**	---	547.0	602.7	
54.0	**10534**	**552.5**	---	552.5	608.5	
55.0	**10535**	**557.9**	---	557.9	614.2	Dam Crest

Figure 1
Rating Curve - Upstream Control



AJY 12/6/21

MLG 12/09/2021

8/13

Table A.1. Constants for Inlet Control Equations for Charts in Appendix G.

Chart No	Shape and Material	Nomograph Scale	Inlet Configuration	Equation Form	Unsubmerged K	Unsubmerged M	Submerged c	Submerged Y	References
1	Circular Concrete	1	Square edge w/headwall	1	0.0098	2.0	0.0398	0.67	1, 2
1	Circular Concrete	2	Groove end w/headwall	1	0.0018	2.0	0.0292	0.74	1, 2
1	Circular Concrete	3	Groove end projecting	1	0.0045	2.0	0.0317	0.69	1, 2
2	Circular CM	1	Headwall	1	0.0078	2.0	0.0379	0.69	1, 2
2	Circular CM	2	Mitered to slope	1	0.0210	1.33	0.0463	0.75	1, 2
2	Circular CM	3	Projecting	1	0.0340	1.50	0.0553	0.54	1, 2
3	Circular	A	Beveled ring, 45° bevels	1	0.0018	2.50	0.0300	0.74	2
3	Circular	B	Beveled ring, 33.7° bevels*	1	0.0018	2.50	0.0243	0.83	2
8	Rect. Box Concrete	1	30° to 75° wingwall flares	1	0.026	1.0	0.0347	0.81	1, 3
8	Rect. Box Concrete	2	90° and 15° wingwall flares	1	0.061	0.75	0.0400	0.80	1, 3
√ 8	Rect. Box Concrete	3	0° wingwall flares	1	0.061	0.75	0.0423	0.82	1, 3
9	Rect. Box Concrete	1	45° wingwall flare d = .043D	2	0.510	0.667	0.0309	0.80	3
9	Rect. Box Concrete	2	18° to 33.7° wingwall flare d = .083D	2	0.486	0.667	0.0249	0.83	3
10	Rect. Box Concrete	1	90° headwall w/3/4" chamfers	2	0.515	0.667	0.0375	0.79	3
10	Rect. Box Concrete	2	90° headwall w/45° bevels	2	0.495	0.667	0.0314	0.82	3
10	Rect. Box Concrete	3	90° headwall w/33.7° bevels	2	0.486	0.667	0.0252	0.865	3
11	Rect. Box Concrete	1	3/4" chamfers; 45° skewed headwall	2	0.545	0.667	0.04505	0.73	3
11	Rect. Box Concrete	2	3/4" chamfers; 30° skewed headwall	2	0.533	0.667	0.0425	0.705	3
11	Rect. Box Concrete	3	3/4" chamfers; 15° skewed headwall	2	0.522	0.667	0.0402	0.68	3
11	Rect. Box Concrete	4	45° bevels; 10°-45° skewed headw.	2	0.498	0.667	0.0327	0.75	3
12	Rect. Box 3/4" chamf. Conc.	1	45° non-offset wingwall flares	2	0.497	0.667	0.0339	0.803	3
12	Rect. Box 3/4" chamf. Conc.	2	18.4° non-offset wingwall flares	2	0.493	0.667	0.0361	0.806	3
12	Rect. Box 3/4" chamf. Conc.	3	18.4° non-offset wingwall flares 30° skewed barrel	2	0.495	0.667	0.0386	0.71	3
13	Rect. Box Top Bev. Conc.	1	45° wingwall flares - offset	2	0.497	0.667	0.0302	0.835	3
13	Rect. Box Top Bev. Conc.	2	33.7° wingwall flares - offset	2	0.495	0.667	0.0252	0.881	3
13	Rect. Box Top Bev. Conc.	3	18.4° wingwall flares - offset	2	0.493	0.667	0.0227	0.887	3
55	Circular	1	Smooth tapered inlet throat	2	0.534	0.555	0.0196	0.90	4
55	Circular	2	Rough tapered inlet throat	2	0.519	0.64	0.0210	0.90	4
56	Ellipital Face	1	Tapered inlet-beveled edges	2	0.536	0.622	0.0368	0.83	4
56	Ellipital Face	2	Tapered inlet-square edges	2	0.5035	0.719	0.0478	0.80	4
56	Ellipital Face	3	Tapered inlet-thin edge projecting	2	0.547	0.80	0.0598	0.75	4
57	Rectangular Concrete	1	Tapered inlet throat	2	0.475	0.667	0.0179	0.97	4
58	Rectangular Concrete	1	Side tapered-less favorable edges	2	0.56	0.667	0.0446	0.85	4
58	Rectangular Concrete	2	Side tapered-more favorable edges	2	0.56	0.667	0.0378	0.87	4
59	Rectangular Concrete	1	Slope tapered-less favorable edges	2	0.50	0.667	0.0446	0.65	4
59	Rectangular Concrete	2	Slope tapered-more favorable edges	2	0.50	0.667	0.0378	0.71	4

[1]Bossy 1963, [2]FHWA 1974, [3]NBS 5th, [4]HEC 13

Table C.2. Entrance Loss Coefficients.

Outlet Control, Full or Partly Full Entrance Head Loss

$$H_e = K_e \left[\frac{V^2}{2g} \right]$$

Type of Structure and Design of Entrance	Coefficient K_e
• Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end	0.2
Square-edge	0.5
Rounded (radius = D/12	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7^0 or 45^0 bevels	0.2
Side- or slope-tapered inlet	0.2
• Pipe. or Pipe-Arch. Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7^0 or 45^0 bevels	0.2
Side- or slope-tapered inlet	0.2
• Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5 √
Rounded on 3 edges to radius of D/12 or B/12 or beveled edges on 3 sides	0.2
Wingwalls at 30^0 to 75^0 to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of D/12 or beveled top edge	0.2
Wingwall at 10^0 to 25^0 to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

*Note: "End Sections conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet.

TABLE 7.14 Values of n to Be Used with Manning Formula

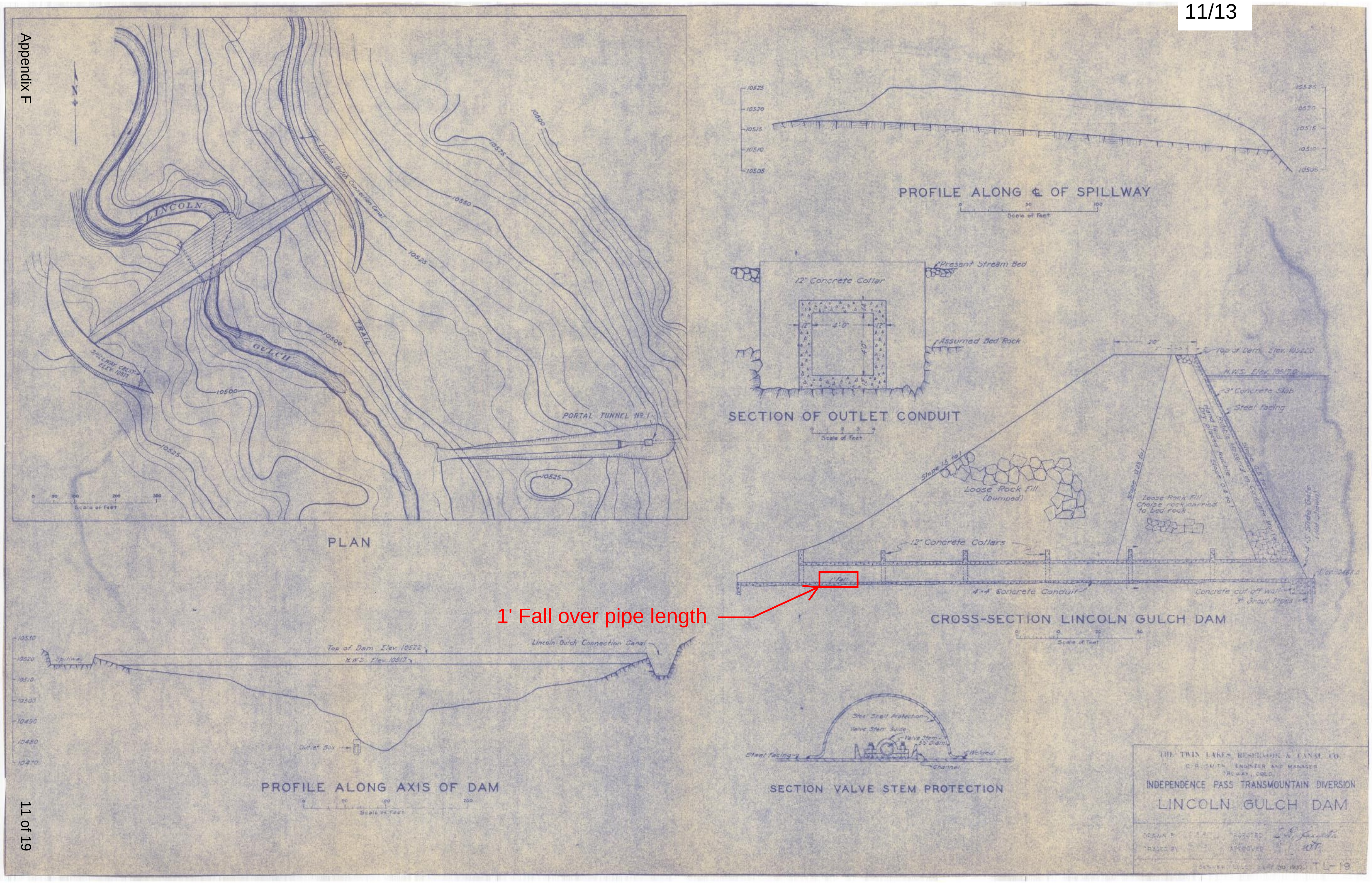
Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Smooth brass and glass pipe	0.009	0.010	0.011	0.013
Smooth lockbar and welded "OD" pipe	0.010	0.011*	0.013*	
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Vitrified sewer pipe	0.010 0.011	0.013*	0.015	0.017
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Glazed brickwork	0.011	0.012	0.013*	0.015
Brick in cement mortar, brick sewers	0.012	0.013	0.015*	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	✓ 0.015* ok	0.016
Wood stave pipe	0.010	0.011	0.012	0.013
Plank flumes:				
Planed	0.010	0.012*	0.013	0.014
Unplaned	0.011	0.013*	0.014	0.015
With battens	0.012	0.015*	0.016	
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Dressed-ashlar surface	0.013	0.014	0.015	0.017
Semicircular metal flumes, smooth	0.011	0.012	0.013	0.015
Semicircular metal flumes, corrugated	0.0225	0.025	0.0275	0.030
Canals and ditches:				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033*	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged earth channels	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides	0.028	0.030*	0.033*	0.035
Natural stream channels:				
(1) Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
(2) As (1), but some weeds and stones	0.030	0.033	0.035	0.040
(3) Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
(4) As (3), lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
(5) As (3), some weeds and stones	0.035	0.040	0.045	0.050
(6) As (4), stony sections	0.045	0.050	0.055	0.060
(7) Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
(8) Very weedy reaches	0.075	0.100	0.125	0.150

*Values commonly used in design.

Brater (1996)

AJY 12/6/21
MLG 12/09/2021

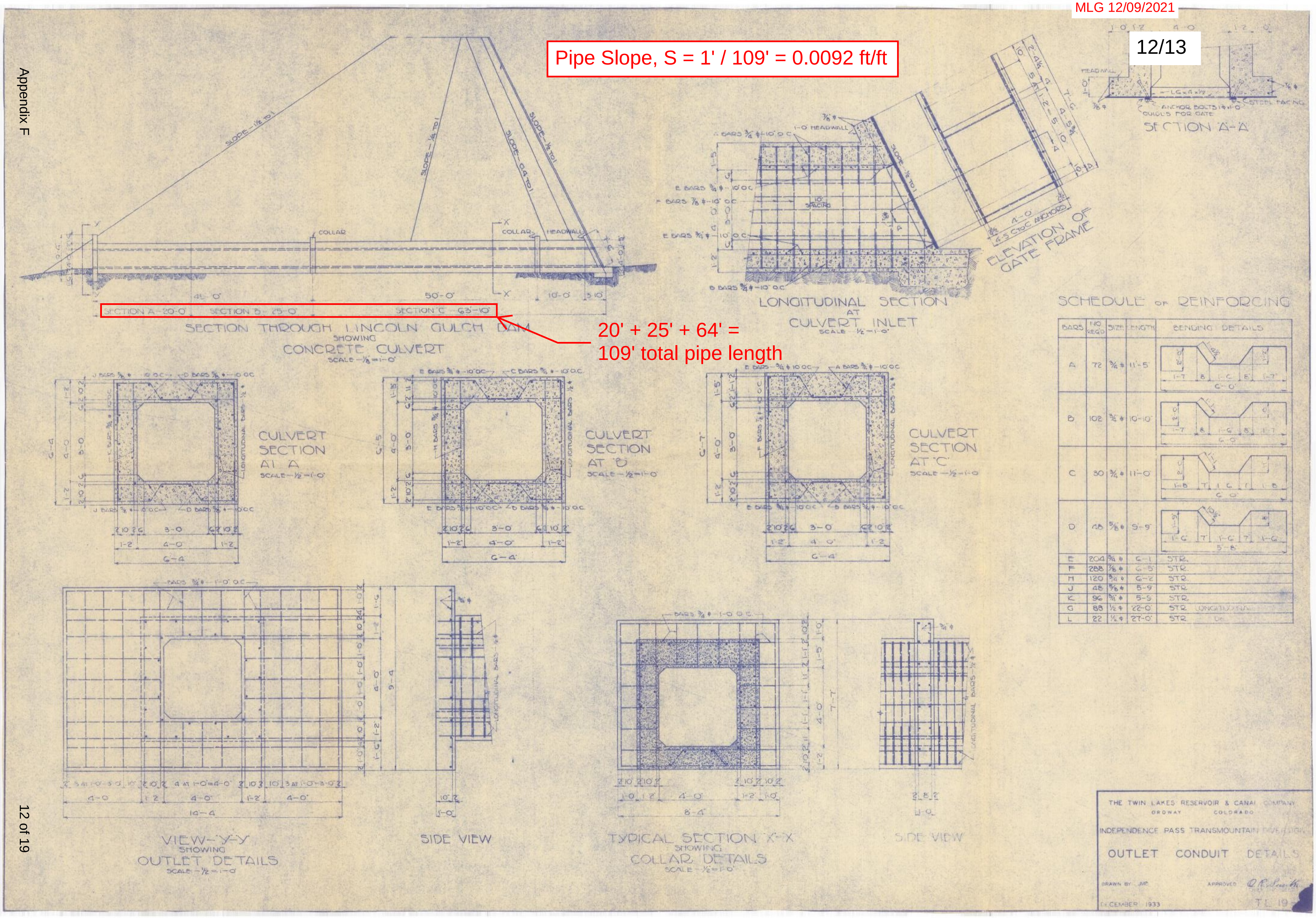
11/13

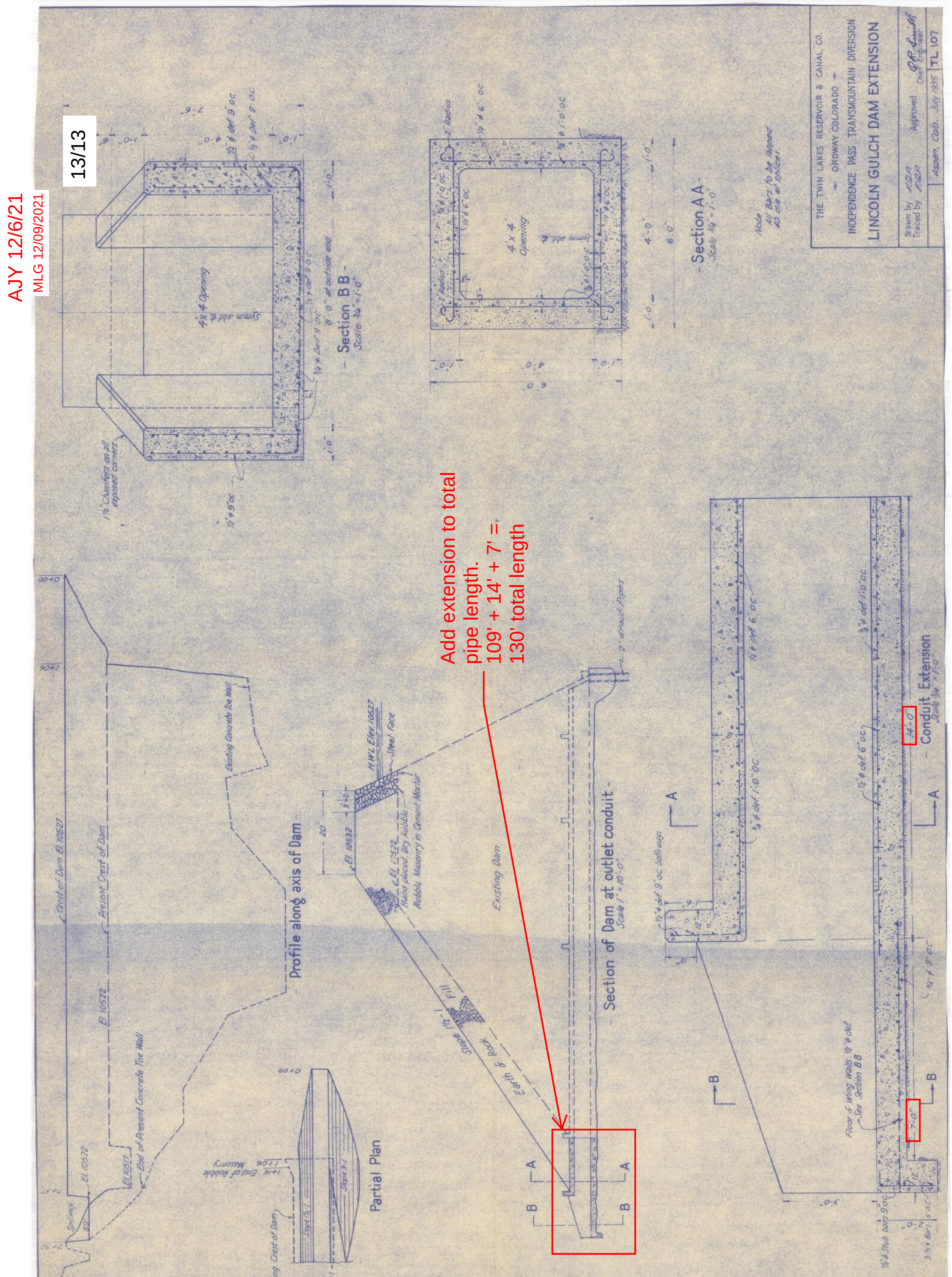


AJY 12/6/21

MLG 12/09/2021

12/13





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13/13
THE TWIN LAKES RESERVOIR & CANAL CO.
— ORDWAY COLORADO —
INDEPENDENCE PASS TRANSMOUNTAIN DIVERSION
LINCOLN GULCH DAM EXTENSION
Drawn by
Traced by
Approved
Chief Engineer
Aspen, Colo. July 1935
TL 107
- Section B B -
Scale 3/4" = 1'-0"
4x4 Opening
Symm abt ℄
1½" Chamfers on all exposed corners
8'-0" at outside end
- Section A A -
Scale 3/4" = 1'-0"
4' x 4' Opening
Note
All Bars to be lapped 40 dia at splices.
Profile along axis of Dam
Crest of Dam El 10527
Present Crest of Dam
El 10522
End of Present Concrete Toe Wall
Existing Concrete Toe Wall
Spillway
Partial Plan
Existing Crest of Dam
End of Rubble Masonry
- Section of Dam at outlet conduit -
Scale 1" = 10'-0"
H.W.L. Elev. 10527
Steel Face
Hand placed Dry rubble
Rubble Masonry in Cement Mortar
Existing Dam
Earth & Rock Fill
2" Grout Pipes
Add extension to total pipe length.
109' + 14' + 7' =
130' total length
- Conduit Extension -
Scale 3/4" = 1'-0"
14'-0"
7'-0"
Floor & Wing Walls ½"φ def. See Section BB

Purpose:

Update the RJH rating curve analysis to find the outlet works capacity with the slide gate 75% open at normal pool. This flow will be used to size the air vent.

References:

1. Use T.W. Sturm Open Channel Hydraulics (2001).
2. Use USBR Small Dams (1987).
3. Use Brater & King Handbook of Hydraulics (1996).
4. Western Dam Engineering, Technical Note. Volume 1, Issue 2. July 2013.

Analysis:

- **Use the energy equation.**

Outlet Control

$$z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + H_L \quad [1]$$

Where:

z_i= Elevation above datum (ft)
P_i= Pressure head (psi)
γ= Unit Weight of Water (pcf)
v_i= Velocity (fps)
g= Gravitational Constant = 32.2 fps
H_L= Headloss (ft)

$$H_L = \left[\sum K_i + 29.1n^2\left(\frac{L}{r^{4/3}}\right)\right]\frac{v^2}{2g} \quad [2]$$

Where:

K_i= Minor Headloss Coefficients
n= Manning's coefficient
L= Pipe length (ft)
r= Hydraulic Radius = ~~D/4~~ A/P = (B^2)/(4B)
v= Velocity (fps)
H_m= Minor Headloss (ft)
H_f= Friction Headloss (ft)

calculations used this value

Loss Type	Length (ft)	Manning n	Minor Loss K	B (ft)	Area (ft)	
Pipe Entrance	--	--	0.5	4.00	16.00	
Slide Gate, 75% Open			0.7	4.00	16.00	Use Fig. 14.22, Pg. 3
4'-0" Square Concrete Box Culvert ("Pipe")	130	0.015	--	4.00	16.00	
Pipe Exit	--	--	1.0	4.00	16.00	

- Determine the flow rate for varying water heights above the culvert inlet inverts:

Outlet Control					
Q (cfs)	H_f (ft)	H_m (ft)	Tailwater El.	W.S.E. (ft)	
513.5	13.61	35.2	10481.2	10530.0	NHWL

- **Size the air vent using the procedure and recommendations in Reference 4. (Pg. 4)**

Criteria:

The maximum design velocity of air in the air vent is 100 fps. √

The slide gate is 75% open. √

The outlet pipe is under maximum design head (NHWL in Reservoir).

A_d = 16 √ ft^2

A_{wp} = 12 √ ft^2 pg. 6

Q_w = 513.5 √ cfs

$Q_a = V_a * A_a$

V_a = 100 √ fps < Air velocity

A_a = Unknown < Area of air vent pipe

$$\left(\frac{Q_a}{Q_w}\right) = \frac{A_d}{A_{wp}} - 1$$

where:

$\left(\frac{Q_a}{Q_w}\right)$ = Air Demand Ratio

Q_a = Volume Flow Rate of Air

Qw = Volume Flow Rate of Water

A_d = Cross Sectional Area of Conduit

A_{wp} = Maximum Cross Sectional Area of Water in Conduit

Solve for Aa, and ultimately the required air vent diameter.

A_a = 1.71 √ ft^2

D_a = 1.48 √ ft < Diameter of air vent pipe

D_a = 17.7 √ in

Select an 18-inch diameter vent pipe. √

Method assumes that no hydraulic jump occurs in the conduit downstream of the slide gate.

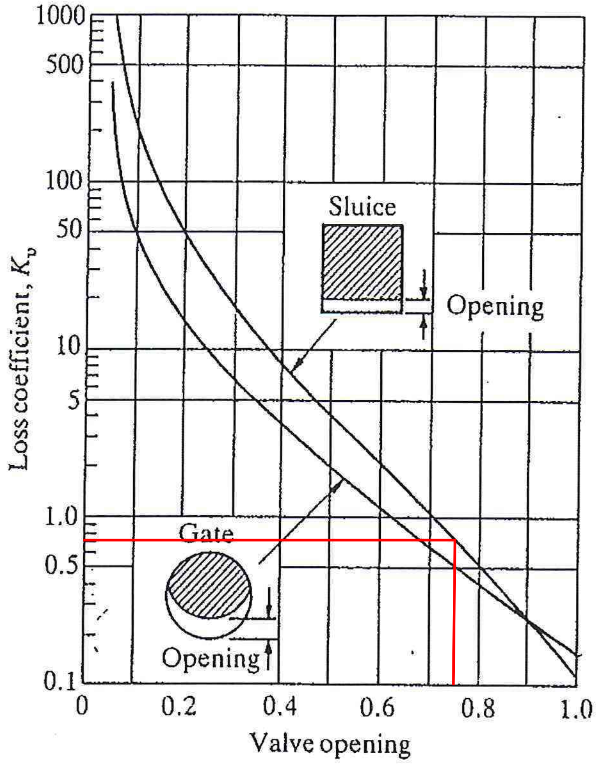

Fig. 14.22. Gate and sluice valve loss coefficients (seat area = pipe area)

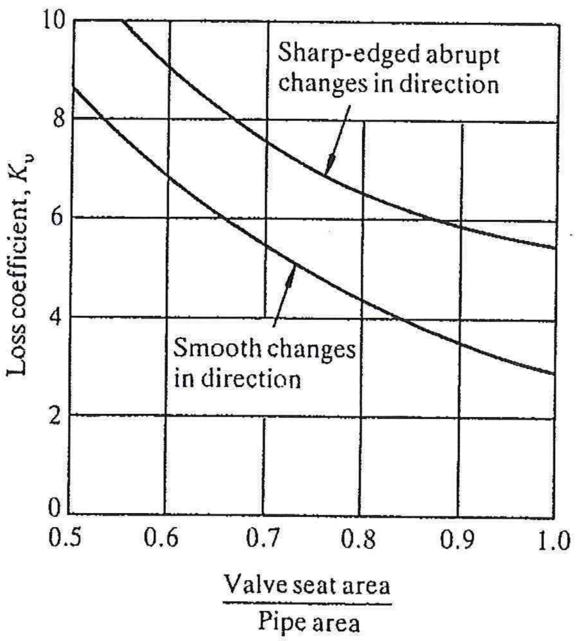

Fig. 14.23. Approximate loss coefficients for fully open globe valves

(Miller 1990)

Western Dam Engineering
Technical Note

Fortunately, for small to medium size dams where air vents are likely not nearly as costly as for large dams, a conservative design approach summarized below can be employed, wherein the air vent is oversized, negating the need for rigorous hydraulic analysis or model studies to account for all the variables. In cases where cost is a more significant issue, such as for low budget projects or for larger or more complex dams, a number of references describing alternate methodologies are provided below.

A Generalized, Conservative Design Approach

For flow in gated closed conduits with free surface open channel flow conditions (i.e., jet flow and air drag flow), the following equation, obtained from the 1980 publication *Air-Water Flow in Hydraulic Structures* (See references for full citation.) may be used to calculate maximum theoretical airflow rate:

$$\left(\frac{Q_a}{Q_w}\right) = \frac{A_d}{A_{wp}} - 1$$

where:

$\left(\frac{Q_a}{Q_w}\right)$ = Air Demand Ratio

Q_a = Volume Flow Rate of Air

Qw = Volume Flow Rate of Water

A_d = Cross Sectional Area of Conduit

A_{wp} = Maximum Cross Sectional Area of Water in Conduit

Ideally, a conduit water surface profile should be calculated for a range of gate opening heights to arrive at A_{wp}. Alternatively, A_{wp} can be approximated from the water surface profile corresponding to a gate opening of 75 percent under maximum design head, as studies have shown that maximum air demand typically occurs at/near 75 percent gate opening and maximum design head. As a rough check, the design engineer should verify that the maximum volume flow rate of air is approximately equal to the maximum flow rate of water.

For cases where the water surface profile indicates that a hydraulic jump will occur, the following equation from *Air-Water Flow in Hydraulic Structures* may be used:

$$\left(\frac{Q_a}{Q_w}\right) = 0.0066(F_r - 1)^{1.4}$$

where:

F_r = Froude Number Upstream of the Hydraulic Jump *(Note: F_r is a dimensionless index of flow regime (i.e., subcritical or supercritical)).*

In a circular pipe, F_r can be calculated from the flow depth *y* by using the following equation:

$$F = \frac{V}{(gy_e)^{1/2}}$$

where:

V = Mean Flow Velocity

g = Gravitational Constant

y_e = Effective Depth = A/T

A = Cross Sectional Area of the Water in the Conduit

T = Top Width of Flow Passage = $2[y(D-y)]^{1/2}$

D = Conduit Diameter

Y = Flow Depth

After Q_a is calculated, a maximum design air velocity can be selected, and the cross sectional area and diameter of the air vent can be calculated. An example calculation using this design method is provided at the end of this article.

As a side note, the Bureau of Reclamation conservatively designs their outlet conduits so that a hydraulic jump will theoretically never occur, while the U.S. Army Corps of Engineers (USACE) allows hydraulic jumps in outlet conduits at their dams.

Alternative Design Methodologies

The 1980 USACE *Engineering Manual Hydraulic Design of Reservoir Outlet Works* (EM 1110-2-1602), together with "Hydraulic Design Criteria" 050-1 and 050-2, present a method of estimating air demand and sizing the air vent based on an envelope design curve that was developed from outlet works air demand data from 5 different dams with heads ranging from 24 to

370 feet. The method relates Froude number and air demand ratio and is generally applicable for slide and tractor gates operating in rectangular gate chambers. The envelop design curve may underestimate air demand in some cases, such as for Beltzville Dam, where actual air demand was 5 times higher than the air demand derived from the design envelop curve. This illustrates the necessity for the designer to check the limitations and applicability of a given method to ensure the specifics of their projects are consistent with the methods being employed. A spreadsheet that employs this design method is attached to this document.

The 2011 paper titled, *Determining Air Demand for Small- to Medium-Sized Embankment Dam Low-Level Outlet Works* presents a design method for estimating air demand and sizing the air vent based on laboratory-scale low-level outlet tests with an inclined gated inlet on a 3H:1V slope. The design methodology presents a series of design curves that relate gate geometry (and corresponding discharge coefficient), driving head, gate opening (10, 30, 50, 60, 70, and 90 percent), and air demand ratio. The design method uses an envelope curve of all the observed model data; with the limitation that parameters such as conduit length and air vent geometry (and associated head losses) were not considered in the model, and the method may not be applicable for gates with inclinations different than 3H:1V.

The 2008 thesis titled, *Air Demand in Free Flowing Gated Conduits* summarizes empirical design methodologies developed by previous researchers, and presents observations on significant parameters developed from a laboratory model study. The parameters studied included: Froude number, ratio of head to gate opening, surface water roughness, conduit length, and conduit slope. A possible limitation of this study is that the model air velocity measurements were not sufficiently detailed to draw conclusions.

Air Vent Design Criteria and Guidelines

The following criteria and guidelines are commonly employed in air vent design practice:

- Limit maximum air flow velocity in the air vent to approximately 100 feet/second by increasing the vent size as necessary; above this velocity an objectionable, whistling noise occurs that can be damaging to hearing.
- For safety reasons, keep children away from vent openings, and place personnel barriers around vents if the air velocity is expected to exceed approximately 50 feet/second.
- A minimum air vent diameter of 4 inches should be used for all cases to facilitate vent cleaning and maintenance.
- For valves, the air vent is typically located upstream from the point where the water jet impinges on the conduit walls.
- If the air vent is of sufficient size to interrupt rebar in the conduit wall, use a series of smaller, side-by-side air vents.
- Install an air vent through HDPE and CIPP pipe liners if there is susceptibility to internal vacuum pressures and liner collapse.
- If steel vent pipes are used and will be in contact with corrosive soils, design appropriate cathodic protection, or use a protective coating or wrap.
- A typical configuration for the end (open to atmosphere) of the air vent is to include a 90 degree elbow (see **Figure 4**) with an expanded or bell-mouth opening oriented away from the prevailing winds, with a stainless steel screen over the opening, which will help prevent debris from entering the vent, and help prevent water from entering the pipe, which could result in freezing blockage during the winter.
- Avoid air vent design features that could result in large head losses such as a small-mesh steel screen, or an excessive number of vent pipe bends.
- Take precautions against small objects (e.g., rodents, clipboards, etc.) getting sucked into the vent and creating a potential blockage; periodically inspect the air vent to ensure air is flowing freely through it and that there are no

blockages, corrosion, or structural damage that may affect performance.

- For cases where it is not possible for an air vent to have direct connection to the atmosphere, such as for control gates located in outlet works tunnels, air demand must be supplied by an air duct above the free surface of the flowing water, and the hydraulic design should ensure flow never rises to the level of the air duct.

Figure 4: Typical outlet works air vent for a small dam

It is also important to point out that there are several outlet works hydraulic flow issues that are commonly misattributed to insufficient air vent size, but are actually associated with inadequate hydraulic design or operations errors. These include surging, structural damage due to filling the pipe too rapidly, and bi-stable flow in the conduit.

References (with Links where available)

- Air-Water Flow in Hydraulic Structures, A Water Resources Technical Publication, Engineering Monograph No. 41, United States Department of the Interior, Water and Power Resources Service, by Henry T. Falvey, Engineering and Research Center, Denver, CO, December 1980.
- *Cavitation in Chutes and Spillways*, A Water Resources Technical Publication, Engineering Monograph No. 42, United States Department of the Interior, Bureau of Reclamation, by Henry T. Falvey, Research Engineer, Denver, CO, April 1990.
- *Air Demand in Free Flowing Gated Conduits*, D. Peter Oveson, A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Civil and Environmental Engineering, Utah State Engineering, Logan, Utah, 2008.
- *Determining Air Demand for Small- to Medium-Sized Embankment Dam Low-Level Outlet Works*, Journal of Irrigation and Drainage Engineering, American Society of Civil Engineers, B.P. Tullis, and J. Larchar, December 2011.
- Hydraulic Design of Reservoir Outlet Works, EM 1110-2-1602, U.S. Army Corps of Engineers, October 15, 1980 ; together with HDC 050-1 and HDC-050-2.

Air vent sizing example using method from the 1980 publication *Air-Water Flow in Hydraulic Structures:*

Given:

0.75 of conduit diameter

- Conduit diameter = 2 feet
- Maximum water depth in conduit corresponding to 75% gate opening = 1.5 feet
- Volume flow rate of water (Q_w) = 50 ft^3/s

Calculate:

$$A_d = \pi\frac{D^2}{4} = \pi\frac{2^2}{4} = 3.14\text{ ft}^2$$

A_{wp} = 2.53 ft^2 *(obtained from table typically found in hydraulic textbooks that provides numerical values for area, wetted perimeter, and hydraulic radius for a partially filled circular pipe)*

$$\left(\frac{Q_a}{Q_w}\right) = \frac{A_d}{A_{wp}} - 1 = \frac{3.14}{2.53} - 1 = 0.24$$

$$Q_a = 0.24 * Q_w = 0.24*50\text{ ft}^3\text{/s} = 12\text{ ft}^3\text{/s}$$

Setting maximum velocity at 100 ft/s,

$$A = Q/V = (12\text{ ft}^3\text{/s})/(100\text{ ft/s}) = 0.12\text{ ft}^2 = 17.3\text{ in}^2$$

$$D_{pipe} = \sqrt{\frac{4*A}{\pi}} = \sqrt{\frac{4*17.3}{\pi}} = 4.7\text{ inches}$$

Increase D_{pipe} to commonly available pipe size of 6 inches.

Appendix G

Filter Diaphragm

Purpose:

Develop filter gradation bands for the finer material in TP-103 and reservoir borrow material based on NRCS filter compatibility criteria. Based on the aforementioned gradation bands, develop filter gradation bands for the transition/filter gravel material and estimate the ~~required~~ maximum perforation or slot sizes for the collector drain pipe.

References:

1. RJH Consultants, Inc. (RJH) (2021). *Grizzly Reservoir Rehabilitation*. Concept drawings dated November 2021. RJH project filepath: P:\21125 - Grizzly Reservoir CWC Feasibility Study\CAD\PDF\ 211125_21-11-22 - Grizzly Reservoir Dam Rehabilitation CWCB Feasibility Study.pdf.
2. Natural Ressources Conservation Service (NRCS) (2017). *Part 633 Soils Engineering National Engineering Handbook: Chapter 26 – Gradation Design of Sand and Gravel Filters*. August.
3. ASTM C33/C33M -13. *Standard Specification for Concrete Aggregates.* ASTM International, West Conshohocken, PA.
4. Federal Emergency Management Agency (FEMA) (2011). *Filters for Embankment Dams, Best Practices for Design and Construction*. October.
5. Advanced Terra Testing (ATT) (2021). RE: Soil Testing, Grizzly Reservoir Dam, 21125. Lakewood, CO.

Results:

Assuming the finer content of the material in TP-103 as the base soil:

- Filter Sand Gradation Band – See page 8 ✓
- Acceptable Filter Sand Gradation – ASTM C33 No. 89 Concrete Aggregate ✓
- Transition Material/Filter Gravel Gradation Band – See page 15 ✓
- Acceptable Transition Material/Filter Gravel Gradation – ASTM C33 No. 3 Concrete Aggregate ✓
- Maximum Perforation or Slot Size – 15.1 mm ok
-

Assuming the select reservoir borrow as the base soil:

- Filter Sand Gradation Band – See page 22 ✓
- Acceptable Filter Sand Gradation – ASTM C33 No. 467 Concrete Aggregate ✓
- Transition Material/Filter Gravel Gradation Band – See page 29 ✓
- Acceptable Transition Material/Filter Gravel Gradation – ASTM C33 No. 1 Concrete Aggregate
- Maximum Perforation or Slot Size – 36.2 mm ok

The acceptable gradations above are preliminary gradation estimates. The gradation will be refined based on locally or readably available material.

partially within filter band gradation limits

Analysis:

1 – "Filter Sand 1" Compatible with TP-103

The filter sand shown on Figure 11 on page 31 could be required to be filter compatible with the finer material content observed in the rockfill of the embankment. TP-103 had the greatest fine content of the test pits excavated near the downstream toe of the dam.

Migration of the finer content of the rockfill may not ~~be~~ cause any slope stability or piping concerns because the strength of the embankment is attained through the rockfill and seepage is limited by the upstream steel facing on the dam. ok

The filter compatibility results for the material encountered in TP-103 is presented herein for future design considerations.

Step 1: Plot the gradation curves of the base soil material.

The gradation curve of the base soil material (TP-103) is shown on page 6, which was developed from the Advanced Terra Tech test results (pages 62-63). The fines in the base soil are assumed to be non-disperive.

Step 2: Determine if the gradation curve should be regraded.

As shown on the gradation curve, the soil has 69.7% passing the No. 4 sieve.

The information in FEMA (2011) for determining if the gradation curve should be regraded is provided below: If base soil contains more than 15% fines, then regrade (Figure 5-4 on page 52).

<u>Estimate the coefficient of uniformity:</u>

$C_u = d_{60}/d_{10}$

By linear interpolation, $d_{60} = 2.545$ mm

By liner interpolation, $d_{10} = 0.0100$ mm

$C_u = 255$

<u>Estimate the coefficient of curvature:</u>

$C_z = d_{30}^2/(d_{60}*d_{10})$

By linear interpolation, $d_{30} = \cancel{0}0.21727$ mm

$C_z = 1.85$

By FEMA Figure 5-4 (page 52), because C_u is greater than 6, the soil is broadly graded and requires the gradation curve to be adjusted. Based on Figure 5-4, as long as one of the three criteria in Step 2b is no, then we proceed to regrade. Did not have to calc Cu and Cz.

NRCS presents the results of Sherard (1979) and Chapuis (1992) for estimating if the soil is broadly graded (pages 40-41). A soil is considered broadly graded if the gradation curve slope is flatter than 20 to 25 percent (i.e., the instability line). As shown on the gradation curve, the upper portions of the original base soil gradation curve are flatter than the instability line, and the remainder of the gradation curve is relatively flat. ok

Based on the information presented in FEMA (2011) and NRCS (2017), the original base soil gradation curve was adjusted and re-graded to the No. 4 sieve.

Step 3: Prepare adjusted re-graded gradation curve.

The gradation curve was adjusted in general accordance with NRCS Part 633.2605 (page 37).

The adjusted re-graded gradation curve is shown on page 6.

Step 4: Determine the base soil category based on percent passing the No. 200 sieve.

By NRCS Table 26-1, the re-graded base soil category is category 3.

Step 5: Estimate the maximum 15-percent passing particle size for the filter.

By NRCS Table 26-2, for Base Soil Category 3:

$$D_{15,max} \leq \left(\frac{40-A}{40-15}\right)[(4 \times d_{85}) - 0.7\ mm] + 0.7\ mm$$

where A = percent passing the No. 200 sieve after regrading = 29.8%

By linear interpolation of adjusted gradation curve, d_{85} = 2.3739 mm

$D_{15,max}$ = 4.2737 mm ok. 4.288 with rounded numbers.

Step 6: Estimate the minimum 15-percent passing particle size for the filter.

By NRCS Part 633.2605 (page 37), the minimum D_{15} particle size is the greater of:

- 0.1 mm
- 1/5 the maximum D_{15} particle size

$D_{15,min} >= D_{15,max}/5$ = 0.85474 mm

Step 7: Establish the minimum and maximum 60-percent passing particle sizes for the filter band.

Minimum D_{60} for the filter band:

By NRCS Part 633.2605 (pages 37-38):

$D_{60,min} = D_{15,max} = 4.2737$ mm ✓

Maximum D_{60} for the filter band:

$D_{60,max} = 5*D_{60,min} = 21.369$ mm ✓

Step 8: Determine the maximum particle size and percent passing the No. 200 sieve.

NRCS recommends a maximum particle size of 2 inches, which was used as an upper bound in constructing the filter band. ✓

To limit the percent fines in the filter, the maximum percent passing the No. 200 sieve was assumed 5-percent in accordance with guidance by NRCS (NRCS, 2017). ✓

Step 9: Estimate the maximum 90-percent passing size for the filter band.

Assuming a coefficient of uniformity of 6, the minimum D_{10} particle size is:

$D_{10,min} = D_{15,min}/1.2 = 0.71228$ mm ✓

By Table 26-3, the maximum D_{90} particle size is 25 mm. ✓

Step 10/12: Estimate the filter band.

The filter band is shown on page 8. The filter band was adjusted in general accordance with Appendix 26A-12 (NRCS, 2017). ok

The finer side of the filter band generally aligns with the particle sizes estimated through the steps above. The nominal maximum particle size for the finer side was assumed 3/8-inch. The coarser side of the filter also generally aligns with the particle sizes estimated through the steps above. The maximum D_{60} band was slightly shifted to a finer material.

Standard sieve closest to bandwidth = 5.

It was ensured that $2<C_u<6$ to mitigate against a broadly graded filter band. ✓

Recommended filter sand material.

A possible filter sand material that plots within the filter band is No. 89 Concrete Aggregate as shown on page 8. The gradation of No. 89 Concrete Aggregate is provided in the table on page 47. The selection of filter sand is anticipated to changed based on investigation of local available sand and aggregate as design progresses. ✓

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MLG 12/09/2021

TP-103 Base Soil Gradation and Properties

Gradation Data

Sieve Number	Sieve Size (mm)	TP-103 (Original) Percent Passing by Weight (%)	TP-103 (adjusted) Percent Passing by Weight (%)
3"	76.200	100.0	
1.5"	38.100	95.4	
3/4"	19.050	90.3	
3/8"	9.530	79.2	
#4	4.750	69.7	100.0
#10	2.000	57.6	82.6
#20	0.850	47.3	67.9
#40	0.425	37.6	53.9
#60	0.250	31.8	45.6
#100	0.150	26.3	37.7
#140	0.106	23.9	34.3
#200	0.075	20.8	29.8
Hydrometer	0.050	18.2	26.1
	0.036	14.8	21.2
	0.025	13.7	19.7
	0.018	12.6	18.1
	0.013	10.9	15.6
	0.009	9.7	13.9
	0.007	8.1	11.6
	0.003	5.8	8.3
	0.001	3.2	4.6

Base Soil Select Particle Sizes

Percent Passing by Weight	Nominal Grain Size Diameter, mm
Base Soil d_{85} (adjusted gradation)	
85	2.37386
Base Soil d_{15} (adjusted gradation)	
15	0.012
Base Soil d_{60} (Original)	
60	2.545
Base Soil d_{10} (original)	
10	0.010
Base Soil d_{30} (original)	
30	0.217

Coefficinet of Uniforminaty and Curvature

C_u	254.55
C_z	1.85

TP-103 Base Soil Gradation and Properties

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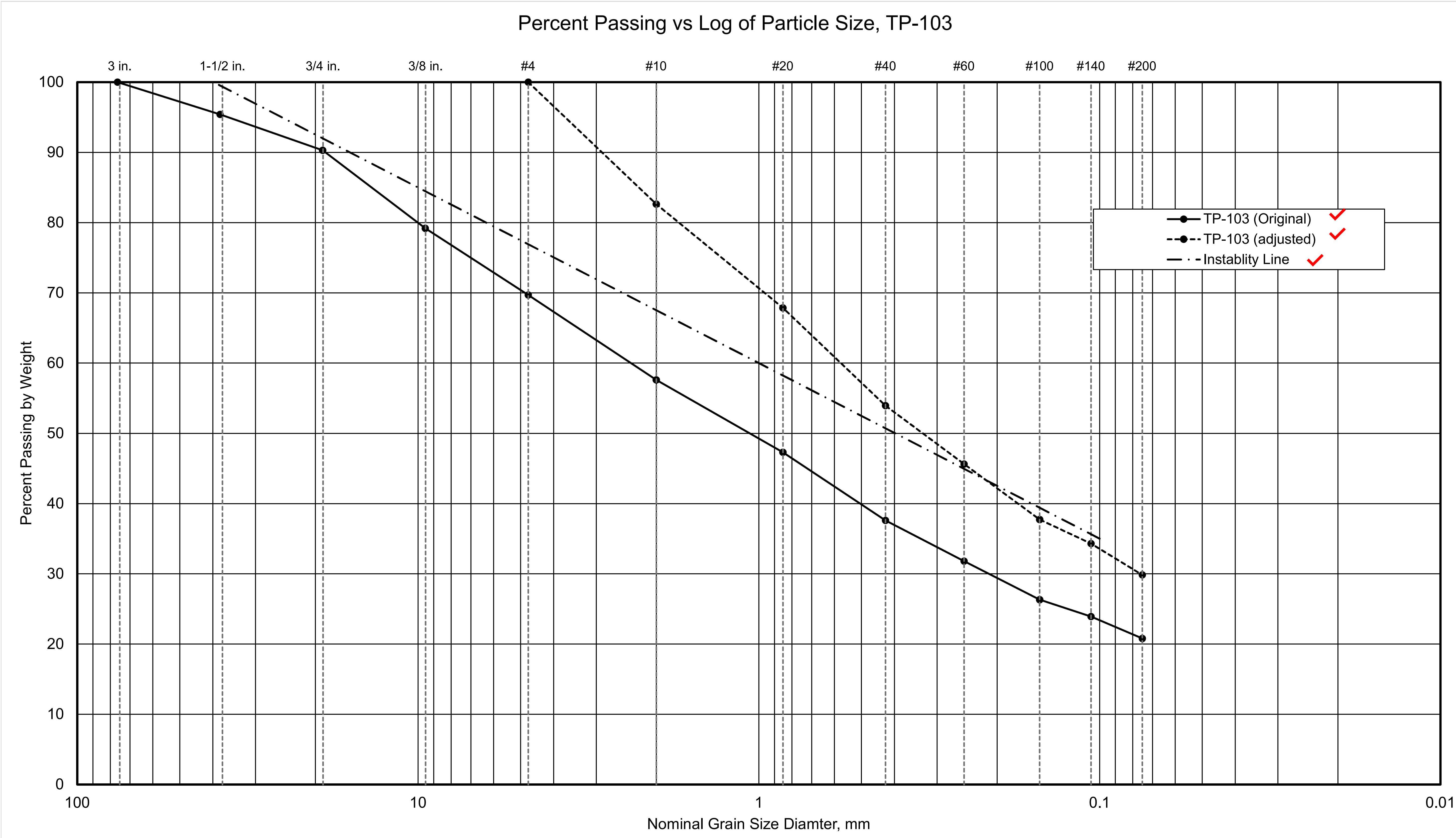
MLG 12/09/2021



TP-103 Filter Gradation Band "Filter Sand 1"

Filter Band Select Particle Sizes (NRCS)

NRCS Step	Particle Size	Percent Passing by Weight	Nominal Grain Size Diameter, mm
Step 5	Max D_{15}	15	4.2737
Step 6	Min D_{15}	15	0.85474
Step 7	Max D_{60}	60	21.369
	Min D_{60}	60	4.2737
Step 8	Max D_{100}	100	50.00
	Min D_{5}	5	0.075
Step 9	Min D_{10}	10	0.71228
	Max D_{90}	90	25.00

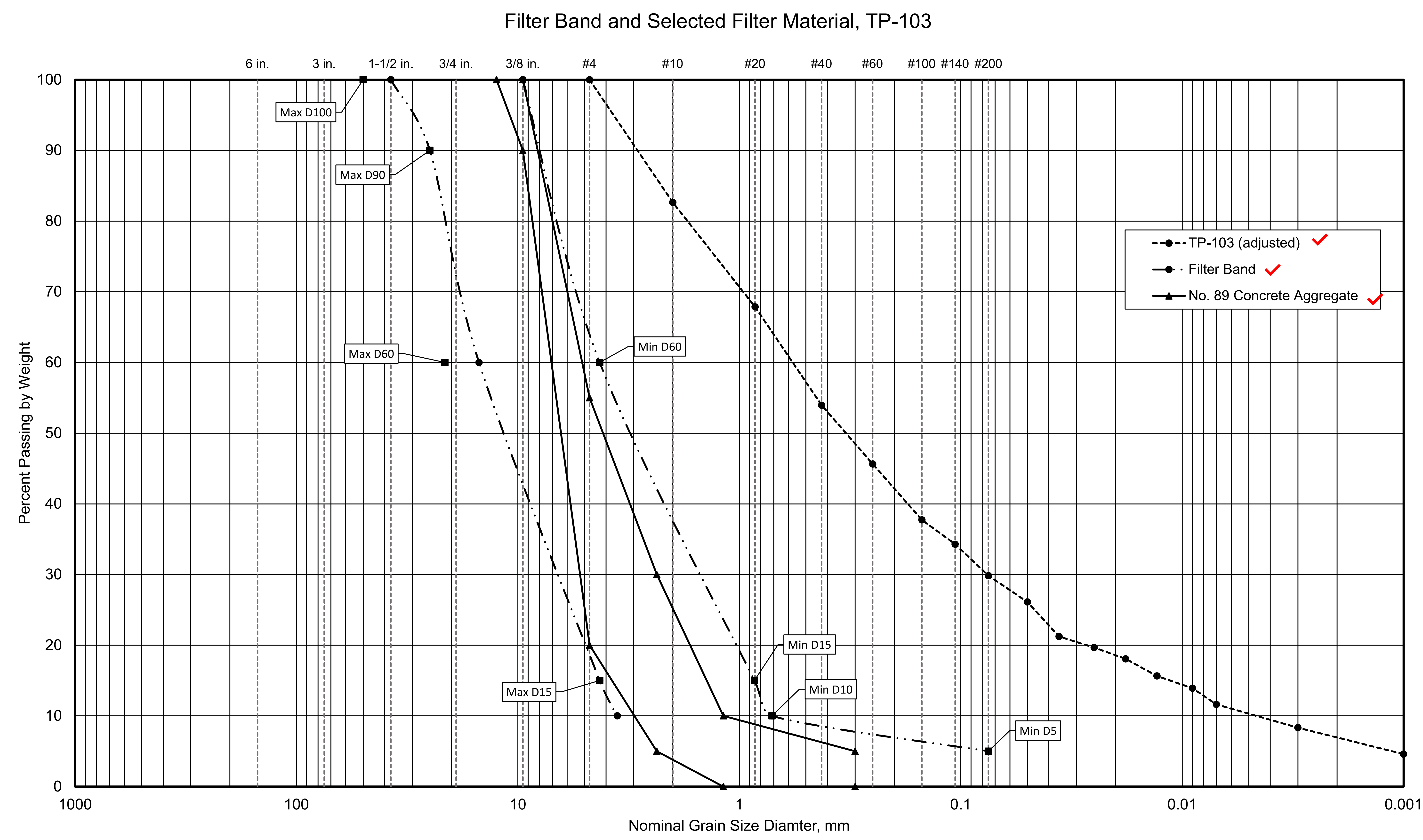
Proposed Filter Band

Percent Passing (%)	Minimum Particle Size (mm)	Maximum Particle Size (mm)
100	9.50	37.50
90	#N/A	25.00
60	4.27	15.00
15	0.85	4.27
10	0.71	3.56
5	0.075	#N/A
0	#N/A	#N/A

adjusted

12/06/21 CLS
MLG 12/09/2021

TP-103 Filter Gradation Band "Filter Sand 1"



2 – Transition Material/Filter Gravel Compatible with Filter Sand 1

Transition material and filter gravel are anticipated to be required as shown on Figure 11 on page 31. The purpose of this section is to investigate the transition material and filter gravel that are compatible with Filter Sand 1, determined in Section 1.

Step 1: Plot the gradation curves of the base soil material.

The gradation curve of the base soil material was assumed to be the same as the finer side of the filter band. The gradation curve is shown on page 13. ok

Step 2: Determine if the gradation curve should be regraded.

Base material has <15% fines, is not gap graded and is not broadly graded.

As shown on the gradation curve, the soil about 65% passing the No. 4 sieve; however, the material does not require regrading because the coefficient of uniformity and curvature are within acceptable limits and the curve is generally steeper than the line of instability as shown on pages 12 and 13.

Step 3: Prepare adjusted re-graded gradation curve.

The gradation curve does not require adjustment in general accordance with NRCS Part 633.2605 (page 37).

Step 4: Determine the base soil category based on percent passing the No. 200 sieve.

By NRCS Table 26-1, the re-graded base soil category is category 4.

Step 5: Estimate the maximum 15-percent passing particle size for the filter.

By NRCS Table 26-2, for Base Soil Category 4:

$D_{15,max} <= 4*d_{85}$

By linear interpolation of adjusted gradation curve, $d_{85} = 7.540$ mm

$D_{15,max} = 30.161$ mm

Step 6: Estimate the minimum 15-percent passing particle size for the filter.

By NRCS Part 633.2605 (page 37), the minimum D_{15} particle size is the greater of:

- 0.1 mm
- 1/5 the maximum D_{15} particle size

$D_{15,min} >= D_{15,max}/5 = 6.0321$ mm

Step 7: Establish the minimum and maximum 60-percent passing particle sizes for the filter band.

Minimum D_{60} for the filter band:

By NRCS Part 633.2605 (pages 37-38):

$D_{60,min} = D_{15,max} = 30.616$ mm

Maximum D_{60} for the filter band:

$D_{60,max} = 5*D_{60,min} = 150.80$ mm ok. 153.1 mm with rounded numbers.

Step 8: Determine the maximum particle size and percent passing the No. 200 sieve.

NRCS recommends a maximum particle size of 2 inches. A maximum particle size of 3 inches was used in the filter band, which is the maximum size that USACE allows (FEMA, 2011). ok

To limit the percent fines in the filter, the maximum percent passing the No. 200 sieve was assumed 3-percent, which is less than the 5 percent allowed by NRCS (NRCS, 2017). ok

Step 9: Estimate the maximum 90-percent passing size for the filter band.

Assuming a coefficient of uniformity of 6, the minimum D_{10} particle size is:

Could assume a CU of 2 resulting in maxD90 of 60 mm. max D90 would still be smaller than maxD60 but the curve looks a little better.

$D_{10,min} = D_{15,min}/1.2 = 5.0268$ mm

By Table 26-3, the maximum D_{90} particle size is 50 mm.

Step 10/12: Estimate the filter band.

The filter band is shown on page 15. The filter band was adjusted in general accordance with Appendix 26A-12 (NRCS, 2017).

Because the maximum D_{90} particle size was less than the maximum D_{60} particle size, the limits determined through the NRCS steps could not be used to create the maximum filter band; therefore, the filter band was estimated while keeping the band within the limits created through the steps while ensuring $2<C_u<6$ to mitigate against a broadly graded filter band.

Step 11: Collector Pipe Perforation/Slot Sizing

Perforation/slot sizes were estimated using the finer side of the filter band. By NRCS (2017), the perforations or slots should be no larger than the smaller of:

- Half the D_{85} of the fine side of the filter
- The D_{50} size of the fine side of the filter

max D60 is considered a control point for the upper limit. I would have changed a different particle size. You might be able to adjust min D60 which will change maxD60 by assuming CU<6 (step 7), but I'm not positive. Your current adjustment ensures the curve is finer than or equal to max D90 which is good.

		Project	21125	Page	
		Date	12/03/21	By	AJY
Client	Twin Lakes Reservoir and Canal Co.	Checked	12/06/21	By	CLS
Subject	Filter Diaphragm Filter Compatibility	Approved	MLG		12/09/2021

By linear interpolation of the fine side of the filter band, D_{85} = 30.16 mm

Consider using D85/2 and D50 of fine side of No. 3 concrete aggregate not values from lower limits of filter band.

Perforation/Slot Size = $D_{85}/2$ = 15.1 mm

By linear interpolation of the fine side of the filter band, D_{50} = 24.8 mm ✓

Therefore, the perforations should be no larger than 15.1 mm. ok.

Recommended transition material/filter gravel.

A possible filter ~~sand~~ material that plots within the filter band is No. 3 Concrete Aggregate as shown on page 15. The gradation of No. 3 Concrete Aggregate is provided in the table on page 47. The selection of filter ~~sand~~ is anticipated to changed based on investigation of local available sand and aggregate as design progresses. ✓

material

"Filter Sand 1" Finer Gradation Band Properties

Filter Sand 1 Finer Band Gradation

Sieve Size (mm)	Filter Sand 1
	Percent Passing by Weight (%)
9.500	100.0
4.274	60.0
0.855	15.0
0.712	10.0
0.075	5.0

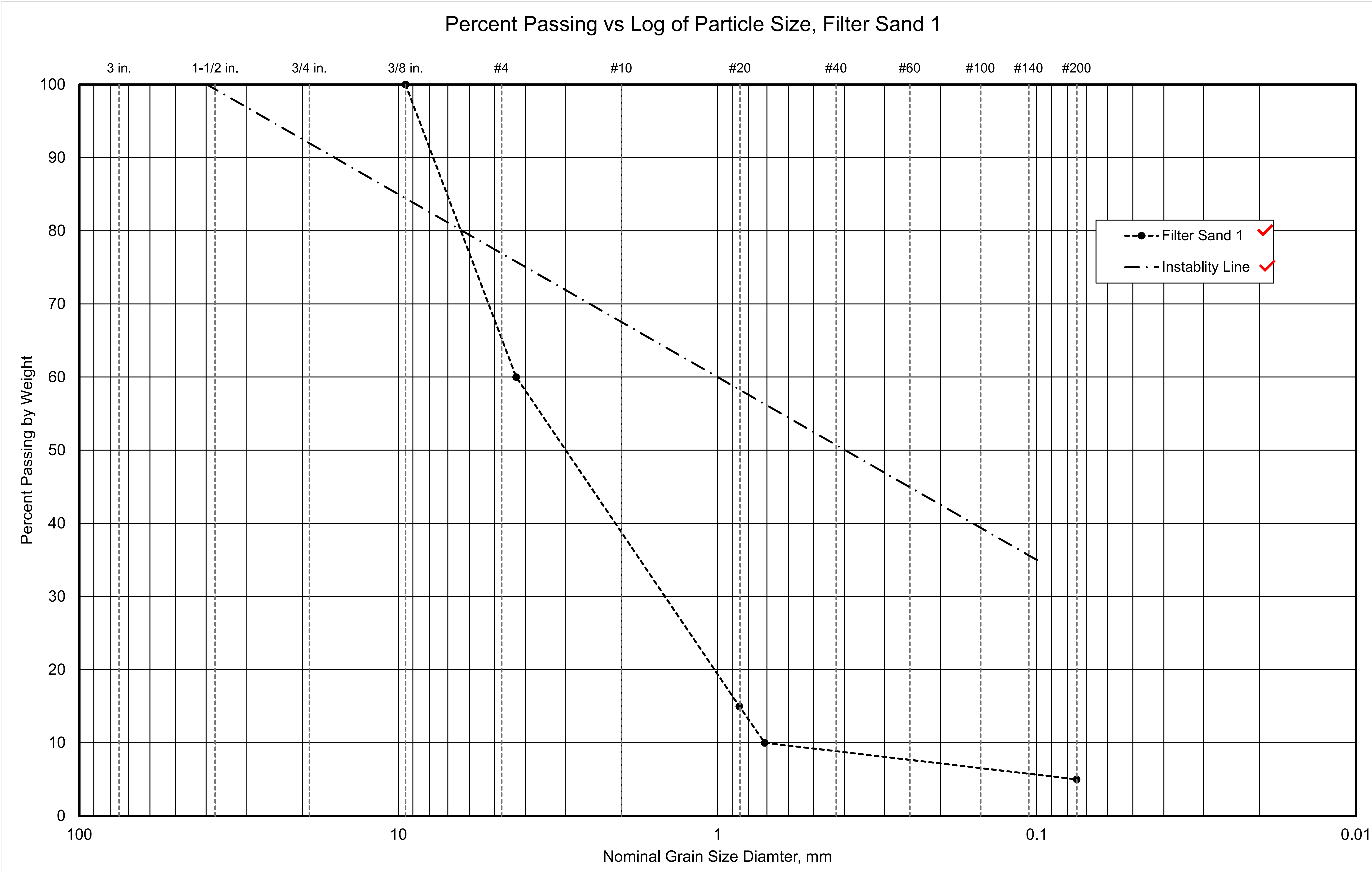
Base Soil Select Particle Sizes

Base Soil d_{85} (adjusted gradation)	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
85	7.540
Base Soil d_{15} (adjusted gradation)	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
15	0.855
Base Soil d_{60} (Original)	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
60	4.274
Base Soil d_{10} (original)	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
10	0.712
Base Soil d_{30} (original)	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
30	1.994

Coefficinet of Uniforminaty and Curvature

C_u	6.00
C_z	1.31

"Filter Sand 1" Finer Gradation Band Properties



12/06/21 CLS
MLG 12/09/2021

"Filter Sand 1" Gradation Band

Filter Band Select Particle Sizes (NRCS)

NRCS Step	Particle Size	Percent Passing by Weight	Nominal Grain Size Diameter, mm
Step 5	Max D_{15}	15	30.1606
Step 6	Min D_{15}	15	6.03211
Step 7	Max D_{60}	60	150.803
	Min D_{60}	60	30.1606
Step 8	Max D_{100}	100	50.00 76.2
	Min D_{5}	5 3	0.075
Step 9	Min D_{10}	10	5.02676
	Max D_{90}	90	50.00

✓

Proposed Filter Band

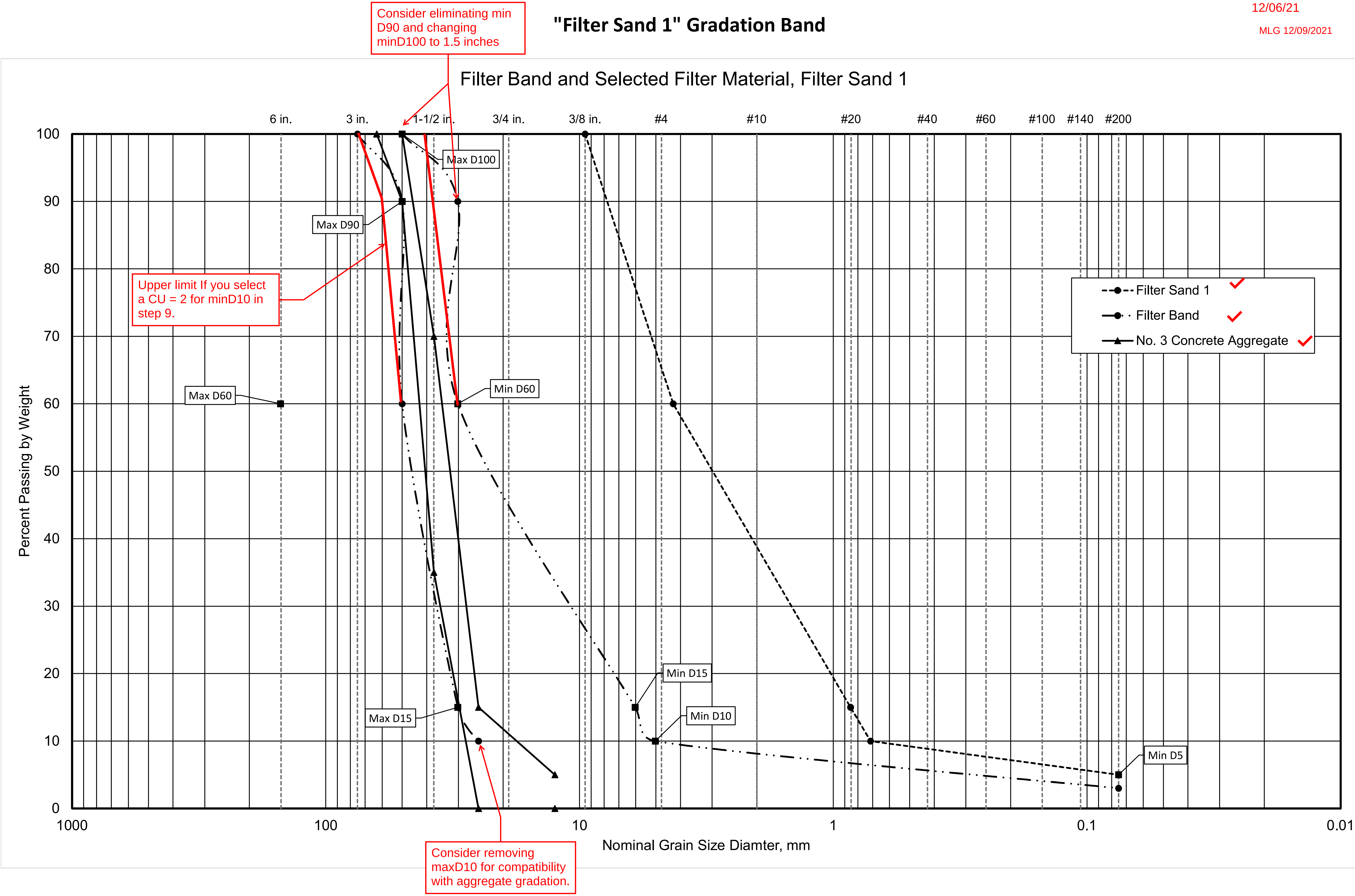
Percent Passing (%)	Minimum Particle Size (mm)	Maximum Particle Size (mm)
100	50.00	75.00
90	30.16	50.00
60	30.16	50.00
15	6.03	30.16
10	5.03	25.00
3	0.075	#N/A
0	#N/A	#N/A

✓ ✓

adjusted

band width of 5 and CU of 2

"Filter Sand 1" Gradation Band



3 – "Filter Sand 2" Compatible with Reservoir Borrow Material

The filter sand is required to be filter compatible with the reservoir borrow material because select reservoir borrow material is anticipated to be placed above the filter sand, as shown on Figure 11 on page 31.

Step 1: Plot the gradation curves of the base soil material.

The gradation curve of the base soil material (reservoir borrow material) is shown on page 20, which was developed from the Advanced Terra Tech test results (page 61). The fines in the base soil are assumed to be non-disperive.

Step 2: Determine if the gradation curve should be regraded.

As shown on the gradation curve, the soil has 66.9% passing the No. 4 sieve.

The information in FEMA (2011) for determining if the gradation curve should be regraded is provided below:

Estimate the coefficient of uniformity:

$C_u = d_{60}/d_{10}$

By linear interpolation, $d_{60} = 3.8421$ mm

By liner interpolation, $d_{10} = 0.19688$ mm

$C_u = 19.5$

Estimate the coefficient of curvature:

$C_z = d_{30}^2/(d_{60}*d_{10})$

By linear interpolation, $d_{30} = 0.94857$ mm

$C_z = 1.19$

By FEMA Figure 5-4 (page 56), because C_u is greater than 6, the soil is broadly graded and requires the gradation curve to be adjusted.

NRCS presents the results of Sherard (1979) and Chapuis (1992) for estimating if the soil is broadly graded (pages 40-41). A soil is considered broadly graded if the gradation curve slope is flatter than 20 to 25 percent (i.e., the instability line). As shown on the gradation curve, the upper portions of the original base soil gradation curve are approximately parallel to the instability line. ok

Based on the information presented in FEMA (2011) and NRCS (2017), the original base soil gradation curve was adjusted and re-graded to the No. 4 sieve.

Step 3: Prepare adjusted re-graded gradation curve.

The gradation curve was adjusted in general accordance with NRCS Part 633.2605 (page 37).

The adjusted re-graded gradation curve is shown on page 20.

Step 4: Determine the base soil category based on percent passing the No. 200 sieve.

By NRCS Table 26-1, the re-graded base soil category is category 4.

Step 5: Estimate the maximum 15-percent passing particle size for the filter.

By NRCS Table 26-2, for Base Soil Category 4:

$D_{15,max} <= 4*d_{85}$

By linear interpolation of adjusted gradation curve, $d_{85} = 3.4296$ mm

$D_{15,max} = 13.718$ mm

Step 6: Estimate the minimum 15-percent passing particle size for the filter.

By NRCS Part 633.2605 (page 37), the minimum D_{15} particle size is the greater of:

- 0.1 mm
- 1/5 the maximum D_{15} particle size

$D_{15,min} >= D_{15,max}/5 = 2.7437$ mm

Step 7: Establish the minimum and maximum 60-percent passing particle sizes for the filter band.

Minimum D_{60} for the filter band:

By NRCS Part 633.2605 (page 37):

$D_{60,min} = D_{15,max} = 13.718$ mm

Maximum D_{60} for the filter band:

$D_{60,max} = 5*D_{60,min} = 68.592$ mm

Step 8: Determine the maximum particle size and percent passing the No. 200 sieve.

NRCS recommends a maximum particle size of 2 inches. A maximum particle size of 3 inches was used in the filter band, which is the maximum size that USACE allows (FEMA, 2011). ok

To limit the percent fines in the filter, the maximum percent passing the No. 200 sieve was assumed 3-percent, which is less than the 5 percent allowed by NRCS (NRCS, 2017). ok

Step 9: Estimate the maximum 90-percent passing size for the filter band.

Assuming a coefficient of uniformity of 6, the minimum D_{10} particle size is:

Could assume a CU of 2 resulting in maxD90 of 50 mm. max D90 would still be smaller than maxD60 but the curve looks a little better.

$D_{10,min} = D_{15,min}/1.2 = 2.2864$ mm

By Table 26-3, the maximum D_{90} particle size is 40 mm.

Step 10/12: Estimate the filter band.

The filter band is shown on page 22. The filter band was adjusted in general accordance with Appendix 26A-12 (NRCS, 2017).

Because the maximum D_{90} particle size was less than the maximum D_{60} particle size, the limits determined through the NRCS steps could not be used to create the maximum filter band; therefore, the filter band was estimated while keeping the band within the limits created through the steps while ensuring $2<C_u<6$ to mitigate against a broadly graded filter band.

Recommended filter sand material.

A possible filter sand material that plots within the filter band is No. 467 Concrete Aggregate as shown on page 22. The gradation of No. 467 Concrete Aggregate is provided in the table on page 47. The selection of filter sand is anticipated to changed based on investigation of local available sand and aggregate as design progresses.

max D60 is considered a control point for the upper limit. I would have changed a different particle size. You might be able to adjust min D60 which will change maxD60 by assuming CU<6 (step 7), but I'm not positive. Your current adjustment ensures the curve is finer than or equal to max D90 which is good.

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MLG 12/09/2021

Reservoir Borrow Base Soil Gradation and Properties

Gradation Data

e Num	Sieve Size (mm)	Reservoir Borrow (Original) Percent Passing by Weight (%)	Reservoir Borrow (adjusted) Percent Passing by Weight (%)
3"	76.200	100.0	
1.5"	38.100	98.2	
3/4"	19.050	91.4	
3/8"	9.530	81.3	
#4	4.750	66.9	100.0
#10	2.000	46.0	68.8
#20	0.850	28.5	42.6
#40	0.425	17.3	25.9
#60	0.250	11.7	17.5
#100	0.150	8.5	12.7
#140	0.106	7.3	10.9
#200	0.075	6.4	9.6
Hydrometer	0.050		
	0.036		
	0.025		
	0.018		
	0.013		
	0.009		
	0.007		
	0.003		
	0.001		

Base Soil Select Particle Sizes

Percent Passing by Weight	Nominal Grain Size Diameter, mm
Base Soil d_{85} (adjusted gradation)	
85	3.43
Base Soil d_{15} (adjusted gradation)	
15	0.198
Base Soil d_{60} (Original)	
60	3.842
Base Soil d_{10} (original)	
10	0.197
Base Soil d_{30} (original)	
30	0.949

Coefficinet of Uniforminaty and Curvature

C_u	19.52
C_z	1.19

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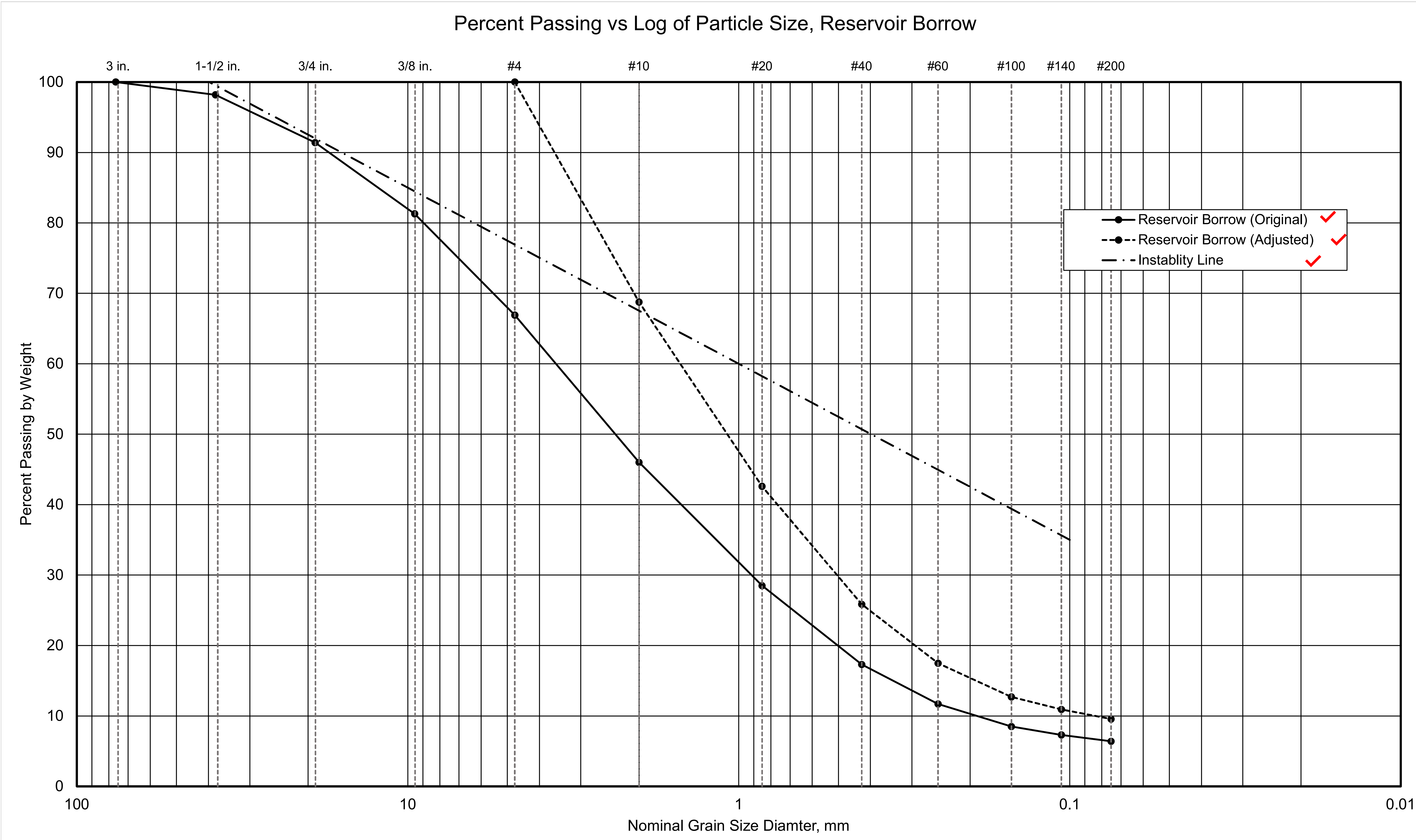
Reservoir Borrow Base Soil Gradation and Properties



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12/06/21 CLS
MLG 12/09/2021

Reservoir Borrow Filter Gradation Band "Filter Sand 2"

Filter Band Select Particle Sizes (NRCS)

NRCS Step	Particle Size	Percent Passing by Weight	Nominal Grain Size Diameter, mm
Step 5	Max D_{15}	15	13.72
Step 6	Min D_{15}	15	2.74
Step 7	Max D_{60}	60	68.59
	Min D_{60}	60	13.72
Step 8	Max D_{100}	100	50.00 76.2
	Min D_5	5 3	0.075
Step 9	Min D_{10}	10	2.29
	Max D_{90}	90	40.00

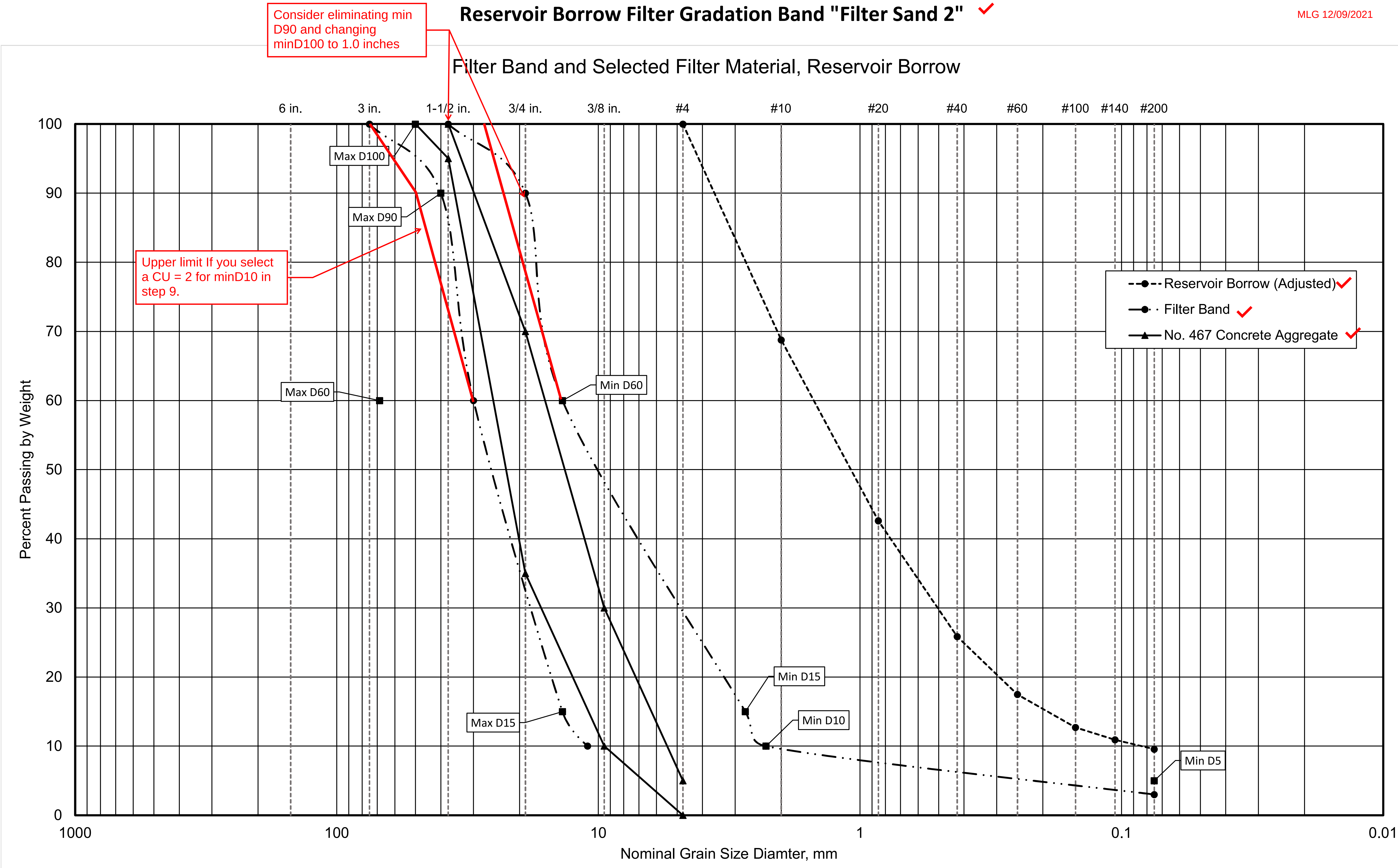
Proposed Filter Band

Percent Passing (%)	Minimum Particle Size (mm)	Maximum Particle Size (mm)
100	37.5	75
90	19	40
60	13.72	30.00
15	2.74	13.72
10	2.29	11
3	0.075	#N/A
0	#N/A	#N/A

adjusted

bandwidth of 5, CU of 2.6

Reservoir Borrow Filter Gradation Band "Filter Sand 2"



4 – Transition Material/Filter Gravel Compatible with Filter Sand 2

Transition material and filter gravel are anticipated to be required as shown on Figure 11 on page 31. The purpose of this section is to investigate the transition material and filter gravel that are compatible with Filter Sand 2, determined in Section 3.

Is a two stage filter compatibility analysis necessary for reservoir borrow material? Filter sand 2 already classifies as a gravel based on No. 467 concrete aggregate.

Step 1: Plot the gradation curves of the base soil material.

The gradation curve of the base soil material was assumed to be the same as the finer side of the filter band. The gradation curve is shown on page 27.

Step 2: Determine if the gradation curve should be regraded.

Base material has <15% fines, is not gap graded and is not broadly graded.

As shown on the gradation curve, the soil has about 30% passing the No. 4 sieve; however, the material does not require regrading because the coefficient of uniformity and curvature are within acceptable limits and the curve is generally steeper than the line of instability as shown on pages 26 and 27.

Step 3: Prepare adjusted re-graded gradation curve.

The gradation curve does not require adjustment in general accordance with NRCS Part 633.2605 (page 37).

Step 4: Determine the base soil category based on percent passing the No. 200 sieve.

By NRCS Table 26-1, the re-graded base soil category is category 4.

Step 5: Estimate the maximum 15-percent passing particle size for the filter.

By NRCS Table 26-2, for Base Soil Category 4:

$D_{15,max} <= 4*d_{85}$

By linear interpolation of adjusted gradation curve, d_{85} = 18.12 mm

$D_{15,max}$ = 72.48 mm

Step 6: Estimate the minimum 15-percent passing particle size for the filter.

By NRCS Part 633.2605 (page 37), the minimum D_{15} particle size is the greater of:

- 0.1 mm
- 1/5 the maximum D_{15} particle size

$D_{15,min} >= D_{15,max}/5$ = 14.496 mm

Step 7: Establish the minimum and maximum 60-percent passing particle sizes for the filter band.

Minimum D_{60} for the filter band:

By NRCS Part 633.2605 (page 37):

$D_{60,min} = D_{15,max} = 72.48$ mm ✓

Maximum D_{60} for the filter band:

$D_{60,max} = 5*D_{60,min} = 362.4$ mm ✓

Step 8: Determine the maximum particle size and percent passing the No. 200 sieve.

NRCS recommends a maximum particle size of 2 inches. This criterion could not be met due to the maximum and minimum D_{60} particle sizes of the filter band. ok

To limit the percent fines in the filter, the maximum percent passing the No. 200 sieve was assumed 3-percent, which is less than the 5 percent allowed by NRCS (NRCS, 2017). ok

Step 9: Estimate the maximum 90-percent passing size for the filter band.

Assuming a coefficient of uniformity of 6, the minimum D_{10} particle size is:

$D_{10,min} = D_{15,min}/1.2 = 12.08$ mm ✓

By Table 26-3, the maximum D_{90} particle size is 60 mm. ✓

Step 10/12: Estimate the filter band.

ok

The filter band is shown on page 29. The filter band was extrapolated to the 100 percent passing line by assuming the same particle size as the maximum and minimum D_{60} particle sizes. The filter band was extrapolated in this fashion because the minimum D_{60} particle size was greater than the maximum D_{90} and D_{100} particle sizes, as recommended by NRCS (2017). A vertical extrapolation reduces the potential for a broadly graded filter gravel zone. ✓

Step 11: Collector Pipe Perforation/Slot Sizing

Perforation/slot sizes were estimated using the finer side of the filter band. By NRCS (2017), the perforations or slots should be no larger than the smaller of:

- Half the D_{85} of the fine side of the filter
- The D_{50} size of the fine side of the filter

By linear interpolation of the fine side of the filter band, $D_{85} = 72.48$ mm ✓

		Project	21125	Page	
		Date	12/03/21	By	AJY
Client	Twin Lakes Reservoir and Canal Co.	Checked	12/06/21	By	CLS
Subject	Filter Diaphragm Filter Compatibility	Approved	MLG		12/09/2021

Perforation/Slot Size = $D_{85}/2$ = 36.2 mm

Consider using D85/2 and D50 of fine side of aggregate material that falls within filter band limits not values from lower limits of filter band.

By linear interpolation of the fine side of the filter band, D_{50} = 59.6 mm

Therefore, the perforations should be no larger than 36.2 mm.

Recommended transition material/filter gravel.

A possible filter ~~sand~~ material that partially plots within the filter band is No. 1 Concrete Aggregate as shown on page 29. The gradation of No. 1 Concrete Aggregate is provided in the table on page 47. The selection of filter ~~sand~~ material is anticipated to changed based on investigation of local available sand and aggregate as design progresses.

"Filter Sand 2" Finer Gradation Band Properties

Filter Sand 2 Finer Band Gradation

Sieve Size (mm)	Filter Sand 2
	Percent Passing by Weight (%)
37.500	100.0
19.000	90.0
13.720	60.0
2.744	15.0
2.290	10.0
0.075	3.0

Base Soil Select Particle Sizes

Base Soil d_{85}	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
85	18.120
Base Soil d_{15}	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
15	2.744
Base Soil d_{60}	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
60	13.720
Base Soil d_{10}	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
10	2.290
Base Soil d_{30}	
Percent Passing by Weight	Nominal Grain Size Diameter, mm
30	6.402

Coefficinet of Uniforminaty and Curvature

C_u	5.99
C_z	1.30

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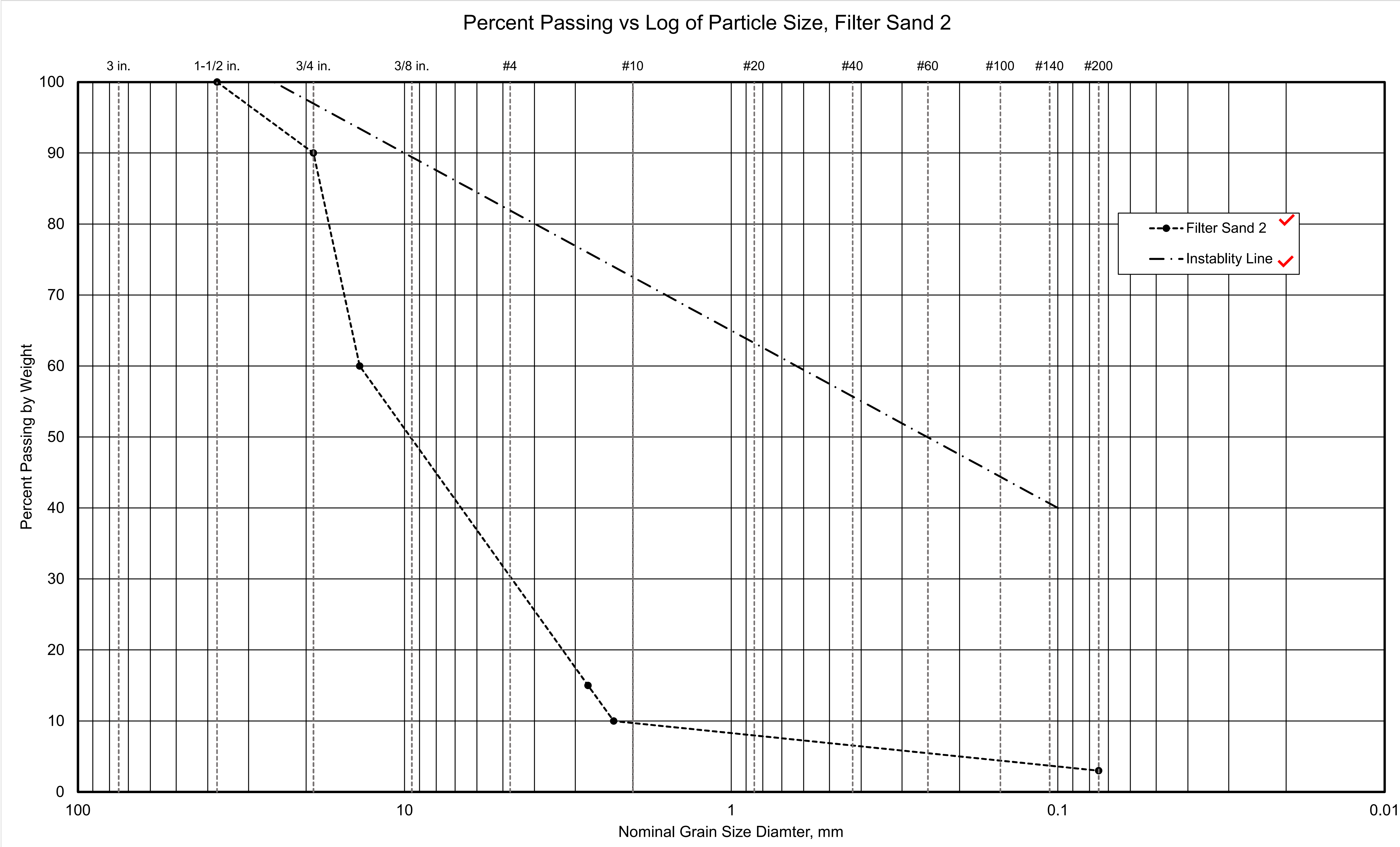
"Filter Sand 2" Finer Gradation Band Properties



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12/06/21 CLS
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"Filter Sand 2" Gradation Band

Filter Band Select Particle Sizes (NRCS)

NRCS Step	Particle Size	Percent Passing by Weight	Nominal Grain Size Diameter, mm
Step 5	Max D_{15}	15	72.480
Step 6	Min D_{15}	15	14.496
Step 7	Max D_{60}	60	362.40
	Min D_{60}	60	72.480
Step 8	Max D_{100}	100	~~50.00~~
	Min D_5	5 3	0.075
Step 9	Min D_{10}	10	12.080
	Max D_{90}	90	60.00

Proposed Filter Band

Percent Passing (%)	Minimum Particle Size (mm)	Maximum Particle Size (mm)
100	72.48	362.40
90	#N/A	#N/A
60	72.48	362.40
15	14.50	72.48
10	12.08	60.40
3	0.075	#N/A
0	#N/A	#N/A

adjusted

12/06/21 CLS
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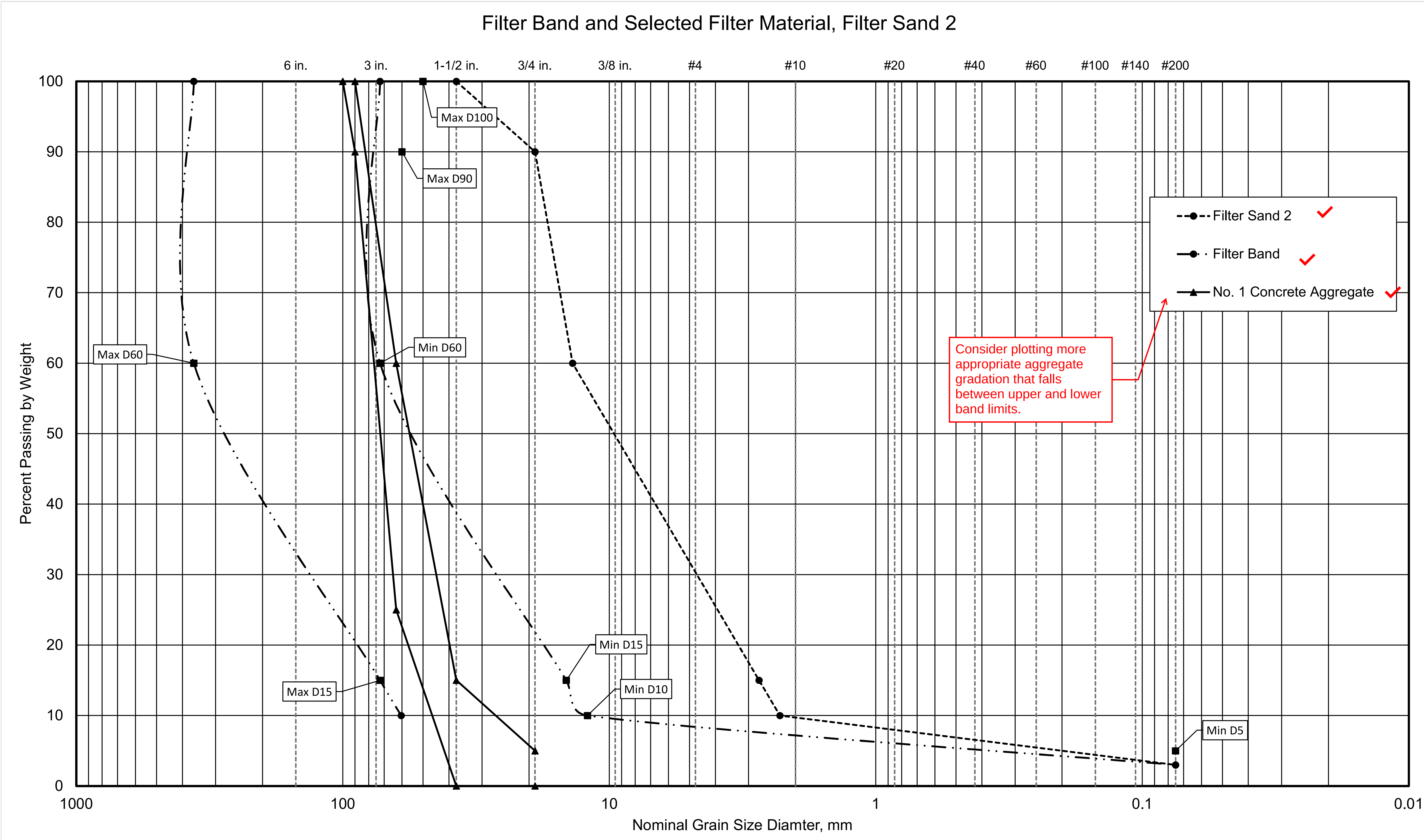
"Filter Sand 2" Gradation Band



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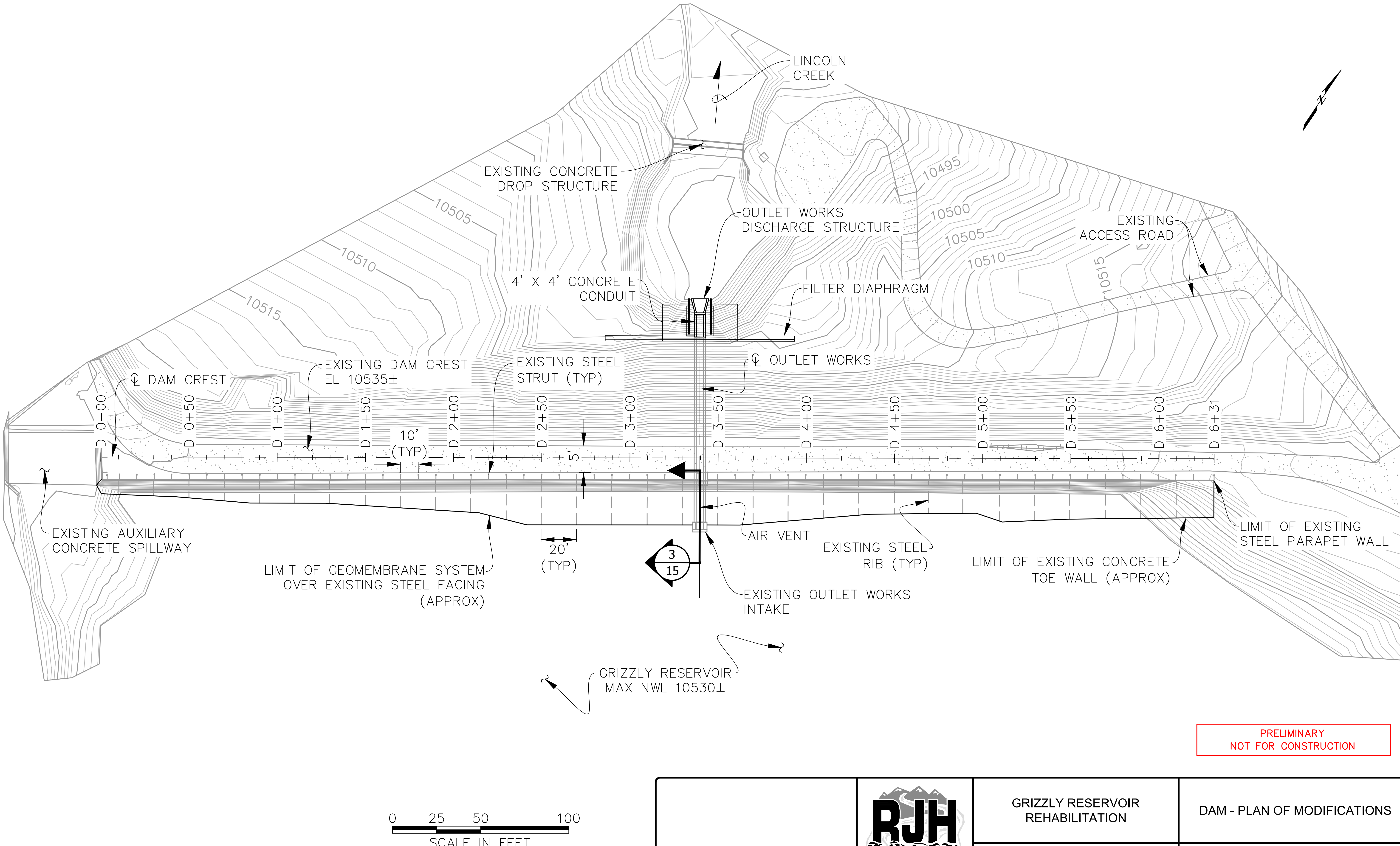

PRELIMINARY
NOT FOR CONSTRUCTION

RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - PLAN OF MODIFICATIONS	
	PROJECT NO. 21125	November 2021	Figure 9

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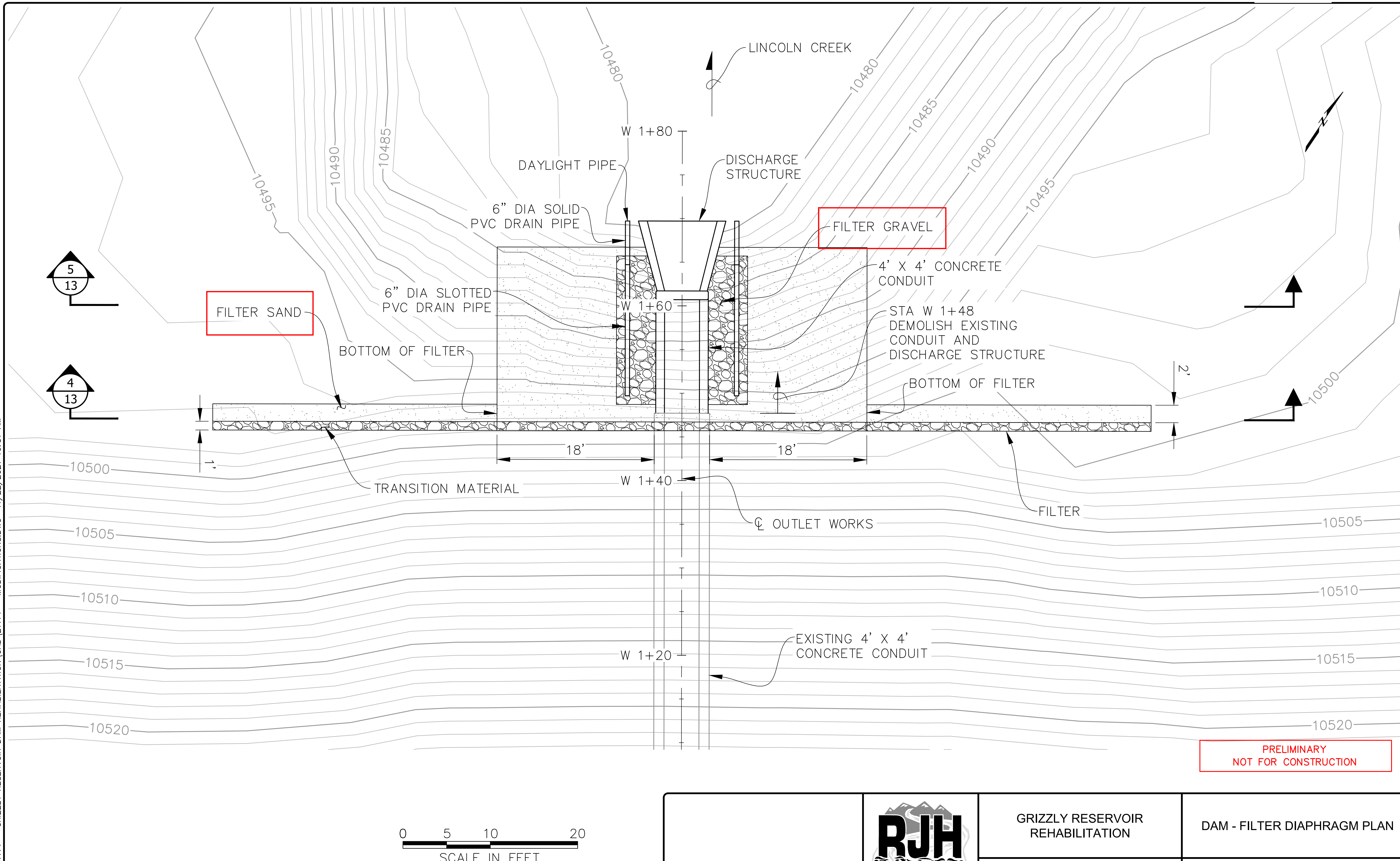

PRELIMINARY
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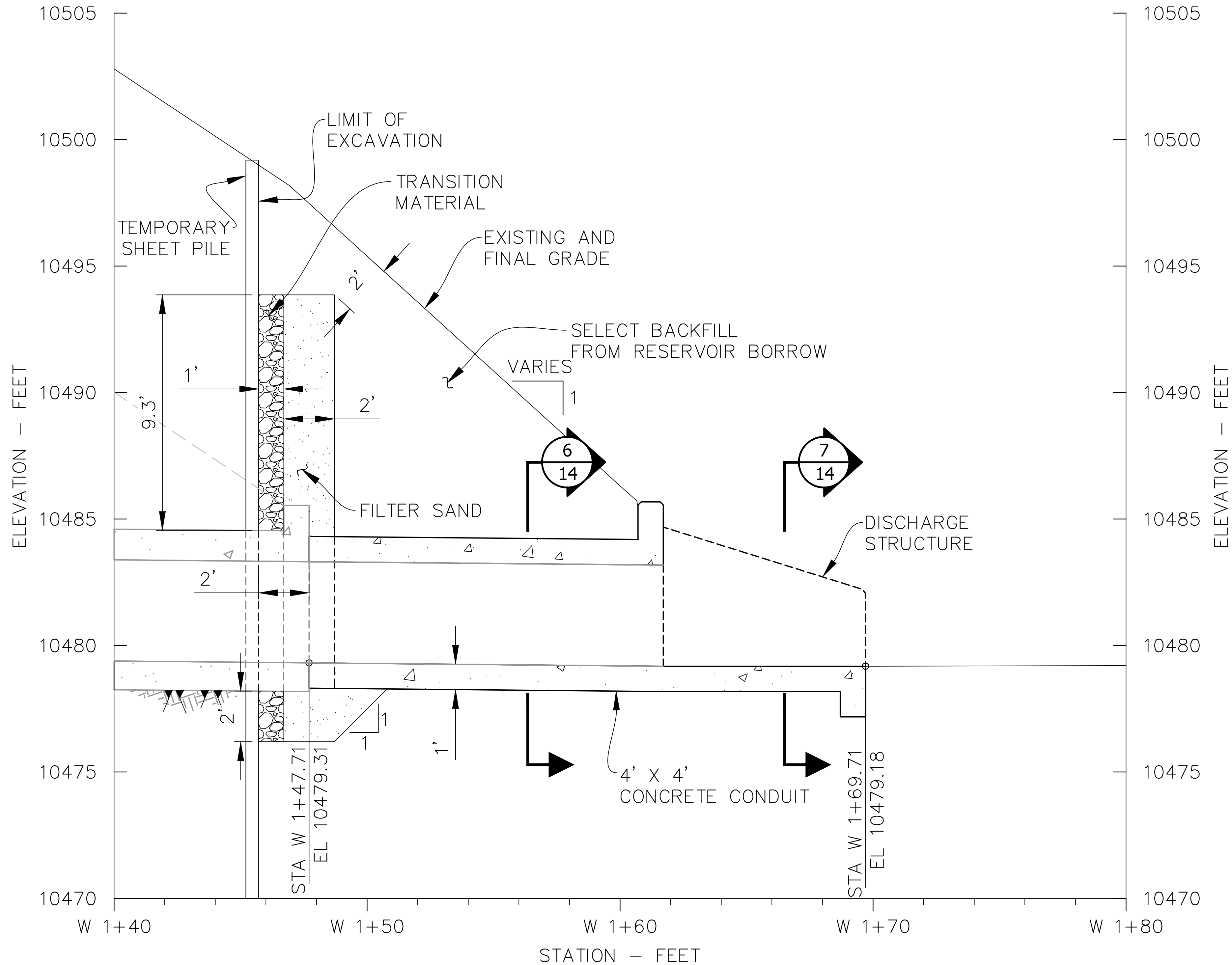
RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - FILTER DIAPHRAGM PLAN	
	PROJECT NO. 21125	November 2021	**Figure 11**



PRELIMINARY
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RJH CONSULTANTS, INC.	GRIZZLY RESERVOIR REHABILITATION	DAM - FILTER DIAPHRAGM PROFILE	
	PROJECT NO. 21125	November 2021	Figure 12

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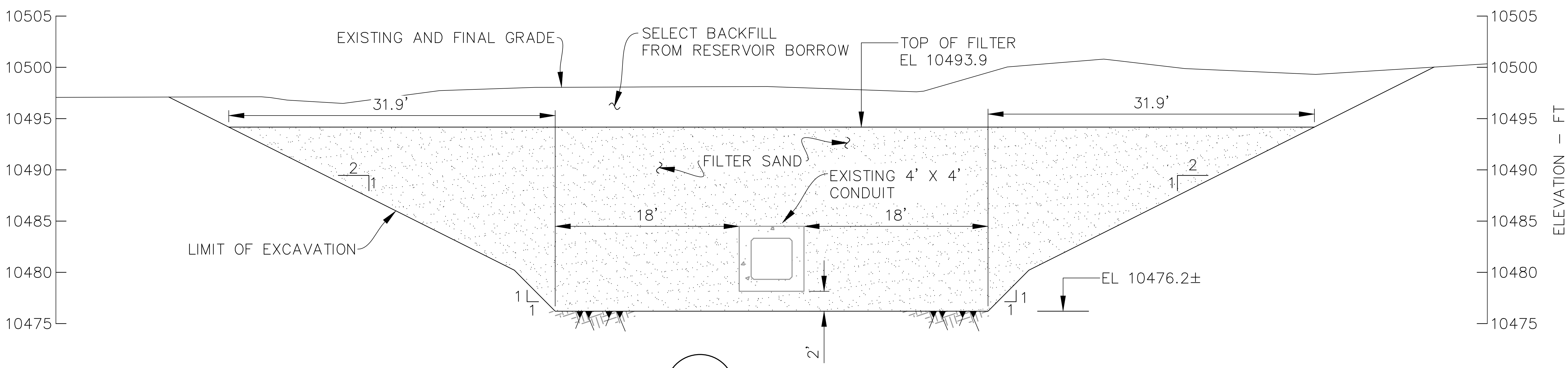
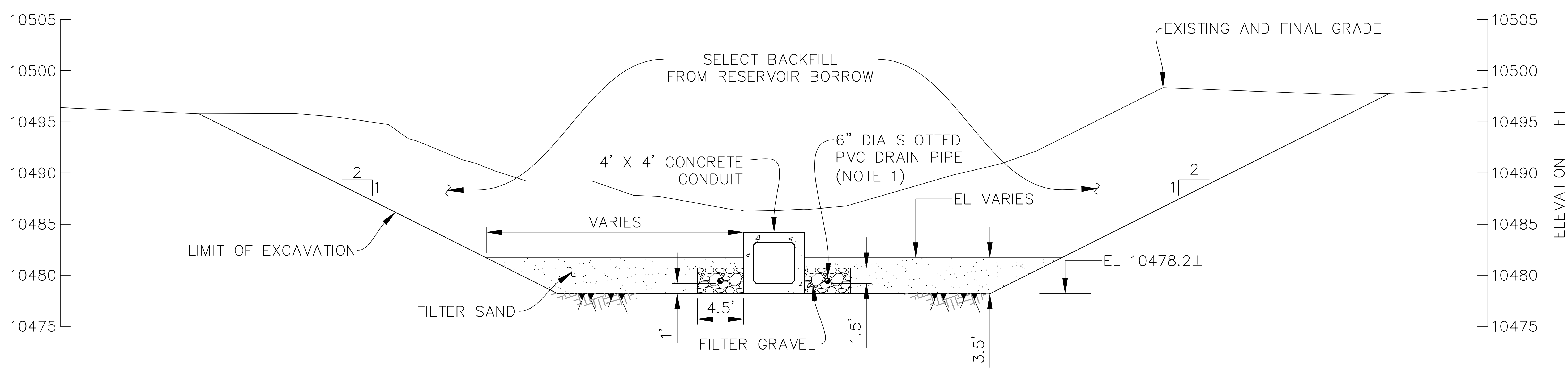


SECTION 4/11
W 1+47

0 5 10 20
SCALE IN FEET



SECTION 5/11
W 1+60

0 5 10 20
SCALE IN FEET

PRELIMINARY
NOT FOR CONSTRUCTION

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GRIZZLY RESERVOIR REHABILITATION	DAM - FILTER DIAPHRAGM SECTIONS	
PROJECT NO. 21125	November 2021	**Figure 13**

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United States
Department of
Agriculture

Part 633 Soils Engineering
National Engineering Handbook

Chapter 26 Gradation Design of Sand and Gravel Filters

(210-633-H, 1st Ed., Amend. 61, Aug 2017)

Drain—A designed pervious zone, layer, or other feature used to reduce seepage pressures and carry water.

Filter—Sand or sand and gravel having a gradation designed to prevent movement of soil particles from a base soil by flowing water. Guidance on design using geotextiles and other nonsoil filter materials is not included.

Fines—That portion of a soil finer than a No. 200 (0.075 mm) U.S. Standard sieve as explained in table 26–1.

Soil category—One of four types of base soil material based on the percentage finer than the No. 200 (0.075 mm) U.S. Standard sieve as explained in table 26–1.

633.2605 Procedures for determining filter gradation limits

Appendix 26A provides more detailed and expanded information of this chapter on the step-by-step procedures. Determine filter gradation limits using these steps (refer to fig. 26–1 for illustration):

Step 1 Plot the gradation curves (grain-size distribution) of the base soil materials. Determine if the base soils have dispersive clay content (appendix 26A, A–1 provides further explanation).

Step 2 Determine if the base soils have particles larger than the No. 4 sieve. At the same time, determine if the base soils are gap-graded and potentially subject to internal instability (see app. 26A, A–2 for further explanation).

(a) If the base soil has no gravel particles and is not gap-graded, proceed to step 4.

(b) If a base soil contains any particles larger than the No. 4 (4.75 mm) sieve, the soil should be regraded on the No. 4 sieve; proceed to step 3, with the following exceptions.

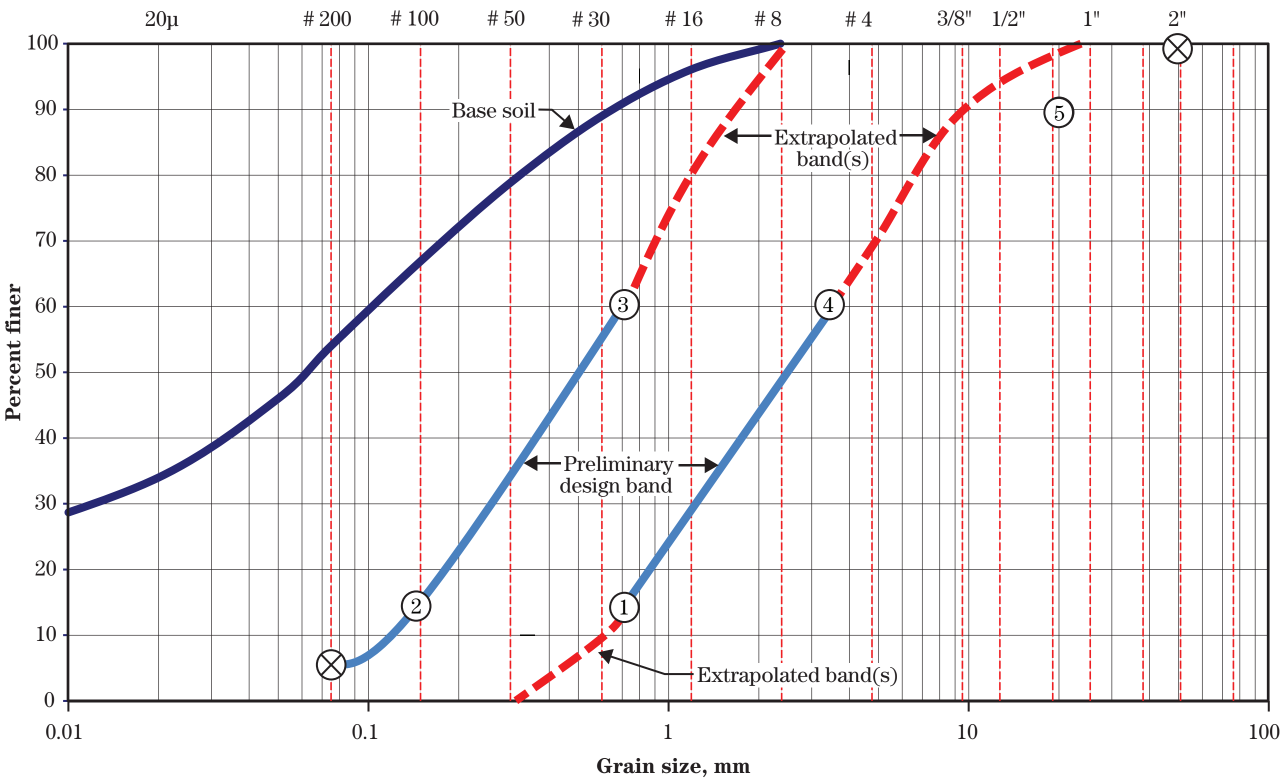
(1) Sands and gravels with less than 15 percent passing the No. 200 (0.075 mm) sieve that are not gap-graded and not broadly graded do not require regrading; proceed to step 4.

(2) Gap-graded soils should be regraded at the point of inflection where the curve inflects. Regrading procedures are similar to those in step 3, but rather than regrading on the No. 4 sieve, the regrading is done on

Table 26–1 Base soil categories

Base soil category	Percent finer than No. 200 sieve (0.075 mm) (after regrading where applicable)	Base soil description
1	> 85	Fine silt and clays
2	40–85	Sands, silts, clays, and silty sands
3	15–39	Silty and clayey sands and gravels
4	< 15	Sands and gravels

Figure 26–1 Illustration of step-by-step procedure



the sieve closest to the upper size where the gradation curve inflects.

Step 3 Prepare adjusted gradation curves for base soils with particles larger than the No. 4 (4.75 mm) sieve, or on a smaller sieve if the soil has unstable portions in its gradation curve. Soils with less than 15 percent fines do not ordinarily require regrading (app. 26A, 26A–2).

(a) Obtain a correction factor by dividing 100 by the percent passing the No. 4 (4.75 mm) sieve size (regraded or smaller sieve if applicable).

(b) Multiply the percentage passing each sieve size of the base soil smaller than No. 4 (4.75 mm) sieve (or smaller sieve, if applicable) by the correction factor from step 3(a).

(c) Plot these adjusted percentages to obtain a new gradation curve.

(d) Use the adjusted curve to determine the percentage passing the No. 200 (0.075 mm) sieve to use in step 4.

Step 4 Place the base soil in a category based on the percent passing the No. 200 (0.075 mm) sieve from the regraded gradation curve data in accordance with table 26–1.

Step 5 To satisfy filtration requirements, determine the maximum allowable D_{15} size for the filter in accordance with table 26–2. The table uses the d_{85} of the base soil after the sample is regraded. (See fig. 26–1 point 1 and app. 26A, 26A–5 for further clarification of soils with dispersive fines.)

Step 6 Establish the minimum D_{15} of the filter as the greater of:

- 0.1 mm
- a fifth of the maximum D_{15} size established in step 5
- In some cases, this minimum D_{15} size may be too fine for adequate permeability, and the preliminary design band may need to be narrowed at this step by shifting the minimum D_{15} to be slightly coarser.

See figure 26–1, point 2 and appendix 26A, 26A–5 for a further description.

Step 7 Establish the minimum and maximum D_{60} sizes for the design filter band. This rationale is based on a maximum acceptable coefficient of uniformity (CU) value of 6 and a band width of 5. The minimum D_{60} size is equal to the maximum D_{15} size established in step 7. The maximum D_{60}

Table 26–2 Filtering criteria

Base soil category	Filtering—maximum D_{15}
1	The maximum D_{15} should be $\leq 9 \times d_{85}$ of the base soil, but not less than 0.2 mm, unless the soils are dispersive. Dispersive soils in category 1 require a filter with a maximum D_{15} that is $\leq$ 6.5 times the d_{85} of the base soil size, but not less than 0.2 mm.
2	The maximum D_{15} should be $\leq$ 0.7 mm unless soil is dispersive, in which case the maximum D_{15} should be < 0.5 mm.
3	The maximum D_{15} should be: $\leq \left(\frac{40-A}{40-15}\right)\left[\left(4\times d_{85}\right)-0.7\text{ mm}^*\right]+0.7\text{ mm}^*$ A = percent passing No. 200 sieve after regrading (when $4 \times d_{85}$ is less than 0.7 mm*, use 0.7 mm*).
4	The maximum D_{15} should be $\leq 4 \times d_{85}$ of base soil after regrading.

* If fines are dispersive, use 0.5 mm rather than 0.7 mm.

size is then five times the minimum D_{60} size. See figure 26–1, points 3 and 4.

To prevent gap graded filters
Both sides of the design filter band will have a CU defined as coefficient of uniformity = $D_{60} \div D_{10}$, equal to or less than 6. Initial design filter bands by this step will have CU values of 6. For final design, filter bands may be adjusted to a steeper configuration, with CU values less than 6, if needed. This is acceptable as long as other filter and permeability criteria are satisfied. Filters should not be designed with a CU value less than 2, as this would be a very poorly graded filter that could be subject to bulking, difficult to obtain, and difficult to compact. Initial bands are often steepened to accommodate the use of a standard commercially available gradation. Appendix 26A, 26A–12 has extensive additional descriptions of this step in the design of filters.

Step 8 The maximum particle size allowed is 2 inches and the maximum percentage passing the No. 200 sieve is 5 percent. Refer to appendix 26A, 26A–8 for additional guidance.

Step 9 To ensure that the filter cannot easily segregate during construction, the filter must not be overly broad in gradation. The relationship between the maximum D_{90} and the minimum D_{10} of the filter is important. Calculate a preliminary minimum D_{10} size by dividing the minimum D_{15} size by 1.2. (This factor of 1.2 is based on the assumption that the slope of the line connecting D_{15} and D_{10} should be on a coefficient of uniformity of about 6.) Determine the maximum D_{90}. The coarse side of the design band must be finer than the maximum $D_{90.}$ (See point 5 on fig. 26–1. See app. 26A, 26A–9 for the description.)

Step 10 Connect the minimum $D_{5,}$ D_{15}, and D_{60} sizes with a smooth curve to begin forming the fine side of the design band. Then, extrapolate the curve upwards smoothly, with a slightly convex shape to the D_{100} size. Connect the coarse control points, which are the maximum D_{15} and D_{60} control points, with a smooth curve. Extrapolate the curve upwards to an even D_{100} size that is equal to or smaller than the established maximum D_{100} size from step 8. Extrapolate the curve downwards from the maximum D_{15} size to the zero percent passing axis, intercepting the axis at a sieve size that will be used in writing specifications. Ensure that the curve is finer than the maximum D_{90} size established in step 9. For purposes of writing specifications, select appropriate sieves and corresponding percent finer values that best reconstruct the design band and tabulate the values. See appendix 26A, 26A–10 for an illustration.

Step 11 The D_{50} of the surrounding filter must be larger than the perforation diameters or slot widths in a collector pipe installed in the filter. Perforations or slots should not be smaller than a quarter inch unless the pipe is surrounded with a gravel filter or a well-screen-type pipe is used with a slot size smaller than the criterion specified. See appendix 26A, 26A–11 for more detail.

Criteria for filters used adjacent to perforated collector pipe
Perforations or slots in pipes placed in the designed filter zone should be no larger than the smaller of the following:

- Half the d_{85} of the fine side of the filter
- The D_{50} size of the fine side of the filter

Step 12 The design band obtained in these steps is satisfactory to meet all the established filter and permeability requirements for a filter. However, in some cases, adjustments to the preliminary design band are made to accommodate standard readily available gradations. Appendix 26A, 26A–12 has additional information on adjusting the preliminary design band obtained in these steps to accommodate standard readily available gradations.

Table 26–3 Segregation criteria

Base soil category	If D_{10} is: (mm)	Then, maximum D_{90} is: (mm)
ALL categories	< 0.5	20
	0.5-1.0	25
	1.0-2.0	30
	2.0-5.0	40
	5.0-10	50
	> 10	60

Appendix 26B has numerous examples showing the application of these design procedures to a variety of base soils types.

633.2606 References

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12/06/21 CLS

MLG 12/09/2021

Appendix 26A Supplemental Information

Introduction

The procedures section in this document was intentionally kept as basic as possible for brevity and clarity of the design process. The basic steps may have some exceptions and some additional description is warranted to explain some of the steps in more detail. The purpose of this appendix is to provide those supplemental descriptions. This allows a simpler step-by-step process to be separated in the body of the document, with the auxiliary explanations provided in this appendix.

The following paragraphs are numbered according to the step in the procedure that is being explained more fully. Section A–1 explains step 1 in the design procedure.

A–1 Defining the base soil

The step-by-step filter design procedure assumes that a single gradation of base soil has been predetermined and a filter design is prepared for that gradation. More often, a number of gradations are generally obtained for any given zone for which a filter is being designed, rather than just a single gradation. Plotting several samples that represent the zone in which a filter is being designed on the same gradation sheet is a good visual tool that helps to determine the uniformity of the soils and whether the data includes anomalous gradations that may need special attention. Use enough samples to define the range of grain sizes for the base soil or soils.

For base soils with more than 15 percent passing the No. 200 sieve, adequate tests should be performed to establish whether the clay fines are dispersive in character. The crumb test and double hydrometer usually define this property adequately, but in some cases, pinhole and chemical tests may also be required. Generally, soils with a crumb dispersion rating of 2 or less and a double hydrometer percentage of dispersive clay less than 30 can be assumed to not contain sufficient dispersive clay to be problematic. 210-NEH, Part 633, Chapter 13, "Dispersive Clays," contains useful advice for sampling and testing for dispersive clays.

A–2 Additional considerations on regrading the base soil

Regrading samples with gravel particles on the No. 4 sieve is a standard practice that should always be followed. Very broadly graded gravelly soils and some gap-graded soils may be inherently unstable, with the finer particles being capable of moving internally within a matrix of larger particles. In some cases, very broadly graded and gap-graded soils should be regraded on a sieve finer than the No. 4 sieve. Additional information follows in the bulleted items.

An exception to the requirement for regrading gravelly soils on the No. 4 sieve is base soils that have less than 15 percent fines. These soils do not require regrading on the No. 4 sieve unless they are very broadly graded soils. See the following bullet for additional requirements for regrading broadly graded soils. The filter design process contains a thorough description of the mathematical process for regrading samples.

- **Regrading broadly graded soils**
  Sherard (1979) described a unique type of problem that can occur with very broadly graded soils. These soil types may be susceptible to a process where fines in the soil can move within the matrix, and sinkholes can occur in embankments as a result of this movement. He studied soils susceptible to this phenomenon and determined a range of gradations of soils that experienced this problem. The red lines in figure 26A–1 reproduce the range of gradations Sherard found susceptible to the problem. Other authors have also described the problem of internal instability in broadly graded soils, and various methods have been presented for analyzing the nature of soils that should be considered susceptible. Chapuis (1992) analyzed the various methods for assessing internal stability, and distilled the guidance to a rule-of-thumb basis, which is shown with the blue lines in figure 26A–1. The blue lines repre-sent a slope of 25 percent on the grain size plot. Chapuis demonstrated in his article that soils with portions of their gradation curve that are flatter than about 20 to 25 percent are susceptible to the problem of internal instability. Design example 26B–2 in appendix B incorporates this concept and demonstrates a broadly graded soil that should be regraded on a sieve other than the No. 4 sieve.

An overly broad gradation is considered to be one where the gradation curve on a semi-log plot has a slope (defined as the percent finer divided by the change in log of particle size), of flatter than 20 to 25 percent (a change of 20–25% passing over a log cycle of particle sizes). Gradation curves of base soils should be plotted on a graph that includes this defining line as shown in the examples in appendix B.

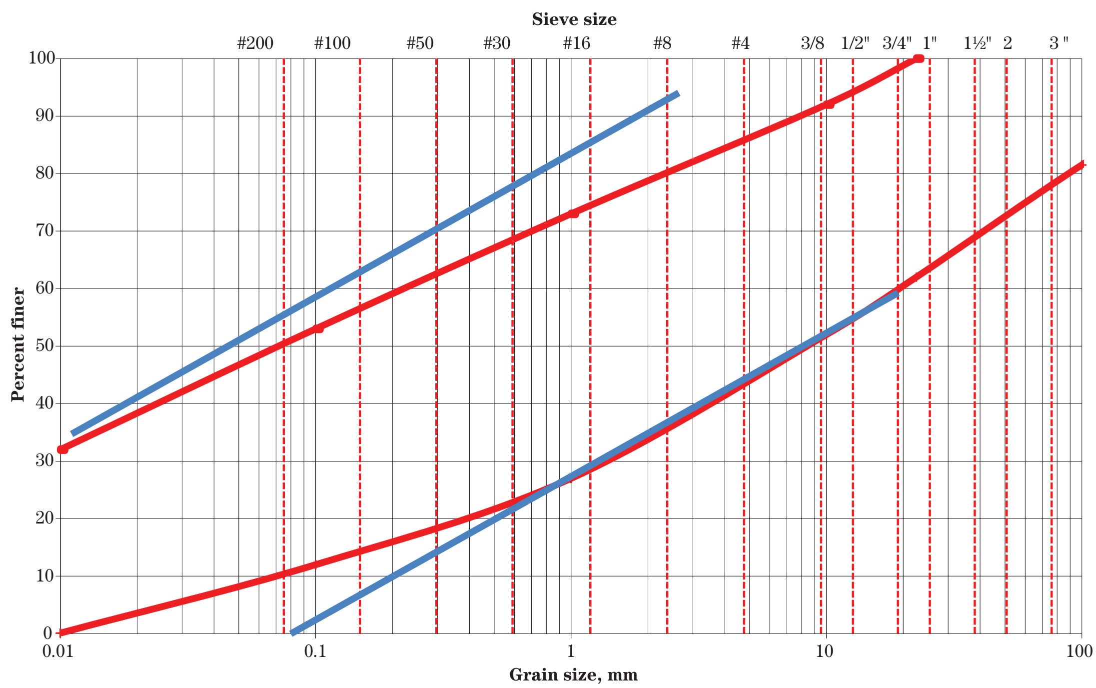
- **Gap–graded soils**
  A potential problem with gap-graded soils is similar to that with very broadly graded soils. Finer particles may be moved by seepage forces internally within the soil matrix, leaving voids. To avoid this problem, filter design should protect finer fraction of the sample against movement, rather than the entire sample. Gap-graded base soils display a flat segment and an associated inflection in the gradation plot. Figure 26A–2 shows an example of a gap-graded soil. Filter designs that do not consider the nature of these soils may result in a filter that is too coarse to protect against movement of the finer particles in the sample. Example 26–10 in appendix B shows a filter design for a gap-graded soil.

  Regrading procedures are similar to those in step 3, but rather than regrading on the No. 4 sieve, the regrading is done on the sieve closest to the upper size where the gradation curve inflects. For the example soil shown in figure 26A–2, the regrading should be done on about the No. 16 sieve.

A–5 *Modified criterion for dispersive clays*

Foster and Fell (2001) recommended that filters protecting soils with dispersive clay fines should have a slightly more conservative filter criterion than for non-dispersive soils. This is a worthwhile modification of previous criteria and was incorporated into the recommended procedure for category-1, 2, and 3 soils. Category-4 soils have so few fines (less than 15%) that the dispersive character of the fines do not require special consideration. Several design examples in appendix B show how dispersive characteristics affect the design of several different categories of base soils.

Figure 26A–1 Range of gradations of soils susceptible to internal instability



For base soils with more than 15 percent fines, adequate tests should be performed to establish whether the clay fines are dispersive in character. The crumb test and double hydrometer usually define this property adequately, but in some cases, pinhole and chemical tests may also be required. Generally, soils with a crumb dispersion rating of 1 or 2 and a double hydrometer percentage value less than 30 can be assumed to be nondispersive. Conversely, soils with a crumb test reading of 3 to 4 and a double hydrometer reading of 60 or more should be considered dispersive. 210-NEH, Part 633, Chapter 13, "Dispersive Clays," contains useful advice for sampling and testing for dispersive clays.

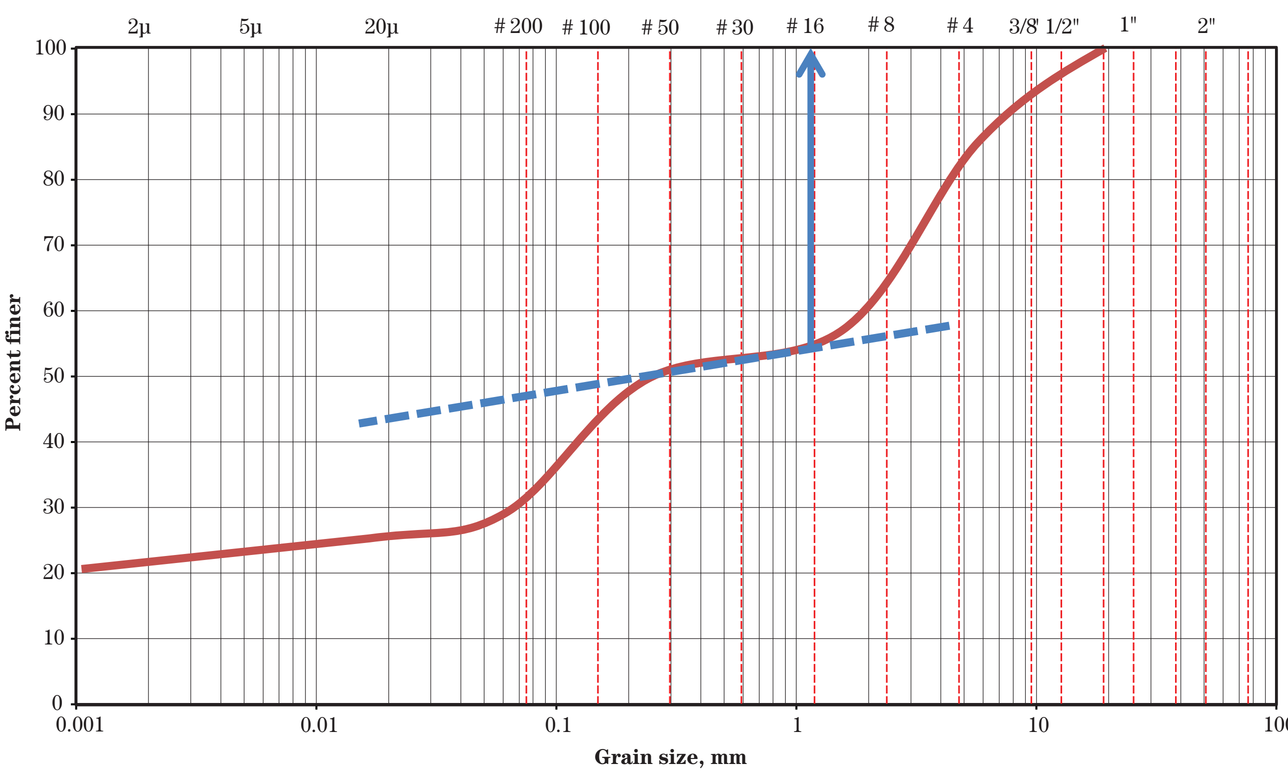
A–6 Additional information on permeability criterion

The design procedure provides a filter that protects against both intergranular seepage forces (backward erosion piping) and internal erosion of a crack in the base soil. The filter procedures establishes a minimum D_{15} size as equal to a fifth of the maximum D_{15} size required for filtering. This minimum D_{15} size usually results in a filter that is permeable enough to provide good drainage of the base soil. To evaluate permeability further; however, a designer may also want to compare the minimum D_{15} size obtained in the proce-dure to the maximum d_{15} size of the base soil before regrading the base soil.

Permeability is directly proportional to the square of the effective grain size (all other factors being equal). If a filter's minimum D_{15} size is at least 4 to 5 times the d_{15} of the base soil, then the filter will have a perme-ability about 16 to 25 times that of the base soil. In some very broadly graded base soils, this requirement may be difficult to meet. For those cases, the maximum D_{15} size established to meet filter criterion and the minimum D_{15} to meet permeability criterion may result in an overly narrow filter band design.

In cases where the minimum and maximum D_{15} sizes obtained in previous steps, makes sides of the filter too close together to be practical for specifications,

Figure 26A–2 Example of gap-graded soil gradation curve



the necessity of meeting filter criterion should out weigh the permeability requirement. If widening the preliminary filter band is necessary, it is the minimum D_{15} size that should be moved, and not the maximum D_{15} size. In other words, filtering should always outweigh permeability in decisions regarding filter band design.

A–8 Supplemental considerations on maximum and minimum particle sizes

The filter design process allows filters to have a maximum of 5-percent fines. A designer may feel that a more restrictive requirement is needed in some cases. Designs requiring a maximum of 3-percent fines on filter materials delivered to the site and allowing then 5-percent fines in the placed filter zone are common. This allows the possibility of some breakdown of the filters during placement and compaction. Provisions for placement and compaction of filters are outside the scope of this document.

The maximum particle size in step 8 for all filters is 2 inches. However, for finer filters with small D_{10} sizes, the maximum particle size will essentially be controlled by the maximum D_{90} size. For instance, for filters that have a D_{10} size of less than 0.5 millimeter, the maximum allowable D_{90} size is 20 millimeters. With this restriction, the maximum particle size is essentially limited to about 25 millimeters or 1 inch.

The minus No. 40 (.425 mm) material for all filters must be nonplastic as determined in accordance with ASTM D4318. A supplemental test to qualify filters may be considered, the sand equivalent test (SEV). Sand for concrete is sometimes required to have a SEV value of 70 or higher.

A–9 Maximum D_{90} information

For the design of many fine filters, when the coarse side of the design band is extrapolated upwards with a slightly convex shape, the coarse D_{90} size of the design band and the maximum particle size that results will be considerably finer than is allowed by the criterion. For those cases, the criterion allowing a larger maximum D_{90} and maximum particle size criterion should be ignored and the design specifications should be based simply on the design band obtained in previous steps. Figure 26B–2 shows a filter design where this occurs. Examples 26B–1 through 26B–4 and several others in appendix B also illustrate designs where the band is considerably finer than the maximum D_{90} and D_{100} size criterion allow. Example 26B–8 shows one case where the maximum D_{90} size restricts the design significantly.

A–10 Completing the preliminary design band

Step 10 in the filter design process describes how the initial control points plotted on a grain-size distribution graph are used to establish a filter design band. The process of extrapolating upwards and downwards from the established points is described narratively. Figure 26–1 illustrates step A–10 graphically.

A–11 Filter criterion for perforated and slotted pipe

The criterion in the body of this document addresses the compatibility of filters surrounding perforated or slotted collector pipes. The criterion usually applies to designs with a two-stage filter, where a fine filter is

Figure 26A–3 Double filter surrounding collector pipe

used next to the base soils in the foundation or embankment and a coarse filter is used surrounding the collector pipe. See figure 26A–3.

If a designer wishes to use a single finely graded filter surrounding a collector pipe, more stringent criteria are recommended. For this condition, two restrictions are recommended.

- First, slots should be used rather than perforations.
- Secondly, the slots in the pipe should be smaller than half of the d_{85} of the surrounding filter.

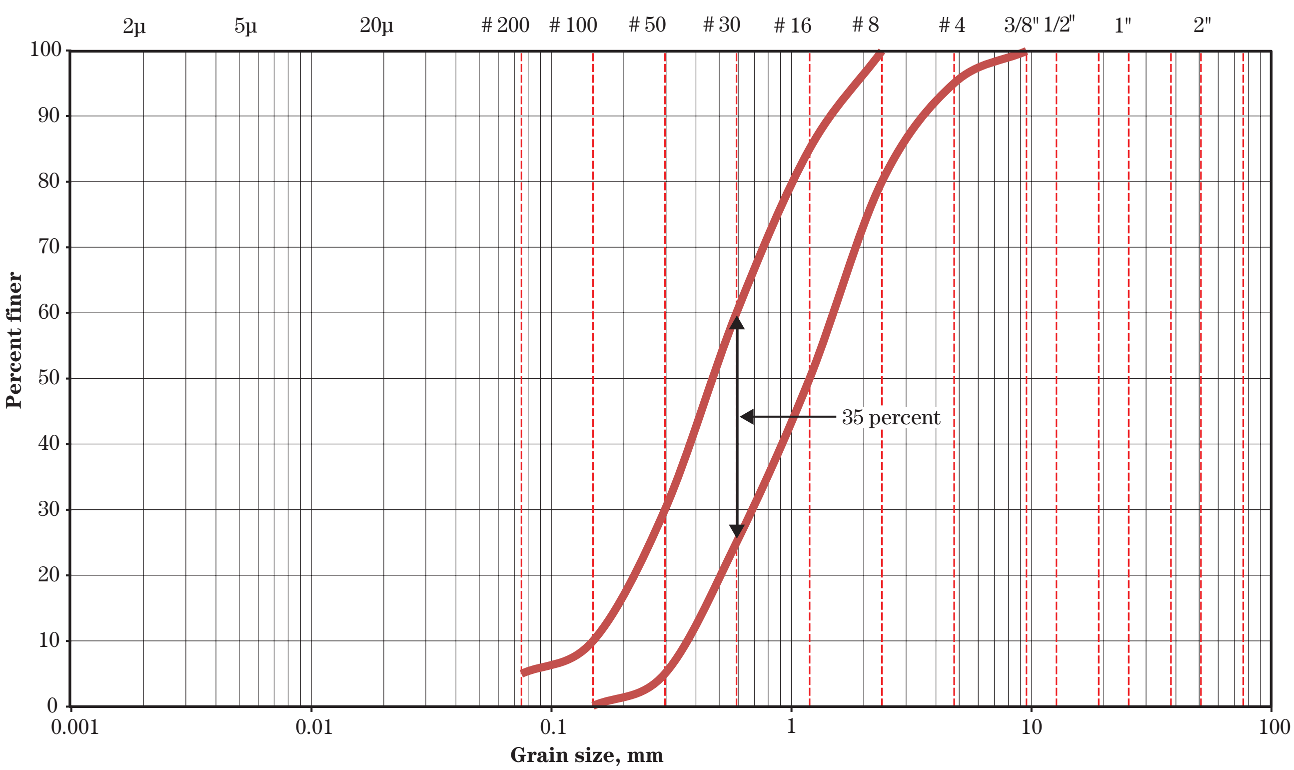
There is some research that indicates less plugging of the slots if the slot size is a fourth of the d_{85} of the surrounding filter.

A–12 Adjustments to preliminary design band

Step 7 of the procedure provides for a filter band design that is as well graded as considered advisable one with a CU (coefficient of uniformity $CU=D_{60}/D_{10}$) value of 6 for the preliminary design. More broadly graded filters would be susceptible to segregation and seldom should a filter have a flatter slope than allowed by this procedure.

However, in some cases, a more uniformly graded (more steeply graded curve) filter may be desired. Examples are cases where a standard commercial gradation is available that does not plot within the initial design band, but could fit if the design curve were adjusted to a steeper configuration. Other cases where adjustments may be is desirable are those where onsite filters are available that are more uniformly graded than the preliminary filter design.

Figure 26A–4 Illustration of 35-percent passing guideline



In these cases, the filter limits that define the preliminary design band can be steepened to accommodate the more uniformly graded material. The filter band can be steepened, but not to the point where the CU is less than 2. In making the limits steeper, only the upper portion of the filter band above the D_{15} limits can be moved. The limits set for the D_{15} must remain as designed in step 5 to meet the filtering and permeability criteria. Several design examples in appendix B illustrate how adjustments can be made to the preliminary design band.

The requirements for coefficient of uniformity apply only to the coarse and fine limits of the design filter band individually. It is possible that an individual, acceptable filter whose gradation plots are completely within the specified limits could have a CU greater than 6 and still be acceptable. The design steps of this procedure will prevent use of gap-graded filters. It is not necessary to closely examine the coefficient of uniformity of a particular filter, as long as it plots within the design filter band.

Another requirement used by some engineers is to limit the maximum percentage change in percent passing for a given sieve to about 35 percent. This seems to be based on the shape of a commonly used material for fine filters, ASTM C33 fine concrete aggregate. As shown in the figure 26A–4, the percent finer range for sieves in the mid-range of the gradation of the sand is about 35 percent.

This requirement may be intended to prevent gap-graded filters, but a separate requirement prohibiting the use of gap-graded filters could also provide the same protection. This step-by-step procedure, which employs an initial CU value of 6 and a band width of 5, results in a maximum vertical change in percent passing for a given sieve of about 40 to 50 percent. This provides a wider band and results in considerable flexibility for suppliers to meet the specification. Using an overly restrictive specification range for filters may result in more difficulty meeting the specification and a higher cost for the increased precision in manufacturing the filter.

Designation: C33/C33M – 13

Standard Specification for Concrete Aggregates[1]

This standard is issued under the fixed designation C33/C33M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification defines the requirements for grading and quality of fine and coarse aggregate (other than lightweight or heavyweight aggregate) for use in concrete.[2]

1.2 This specification is for use by a contractor, concrete supplier, or other purchaser as part of the purchase document describing the material to be furnished.

NOTE 1—This specification is regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, it may be either more or less restrictive than needed. For example, where aesthetics are important, more restrictive limits may be considered regarding impurities that would stain the concrete surface. The specifier should ascertain that aggregates specified are or can be made available in the area of the work, with regard to grading, physical, or chemical properties, or combination thereof.

1.3 This specification is also for use in project specifications to define the quality of aggregate, the nominal maximum size of the aggregate, and other specific grading requirements. Those responsible for selecting the proportions for the concrete mixture shall have the responsibility of determining the proportions of fine and coarse aggregate and the addition of blending aggregate sizes if required or approved.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C29/C29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate
C40 Test Method for Organic Impurities in Fine Aggregates for Concrete
C87 Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
C88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
C117 Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
C123 Test Method for Lightweight Particles in Aggregate
C125 Terminology Relating to Concrete and Concrete Aggregates
C131 Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
C142 Test Method for Clay Lumps and Friable Particles in Aggregates
C150 Specification for Portland Cement
C227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
C289 Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
C294 Descriptive Nomenclature for Constituents of Concrete Aggregates
C295 Guide for Petrographic Examination of Aggregates for Concrete
C311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C330 Specification for Lightweight Aggregates for Structural Concrete
C331 Specification for Lightweight Aggregates for Concrete Masonry Units

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Jan. 1, 2013. Published February 2013. Originally approved in 1921. Last previous edition approved in 2011 as C33/C33M–11A. DOI: 10.1520/C0033_C0033M-13.

[2] For lightweight aggregates, see Specifications C330, C331, and C332; for heavyweight aggregates see Specification C637 and Descriptive Nomenclature C638.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

TABLE 3 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Mass Percent													
		100 mm (4 in.)	90 mm (3½ in.)	75 mm (3 in.)	63 mm (2½ in.)	50 mm (2 in.)	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No.50)
1	90 to 37.5 mm (3½ to 1½ in.)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...	...
2	63 to 37.5 mm (2½ to 1½ in.)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...	...
3	50 to 25.0 mm (2 to 1 in.)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
357	50 to 4.75 mm (2 in. to No. 4)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...	...
4	37.5 to 19.0 mm (1½ to ¾ in.)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...	...
467	37.5 to 4.75 mm (1½ in. to No. 4)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...	...
5	25.0 to 12.5 mm (1 to ½ in.)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...	...
56	25.0 to 9.5 mm (1 to ⅜ in.)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...	...
57	25.0 to 4.75 mm (1 in. to No. 4)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...	...
6	19.0 to 9.5 mm (¾ to ⅜ in.)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...	...
67	19.0 to 4.75 mm (¾ in. to No. 4)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...	...
7	12.5 to 4.75 mm (½ in. to No. 4)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...	...
8	9.5 to 2.36 mm (⅜ in. to No. 8)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5	...
89	9.5 to 1.18 mm (⅜ in. to No. 16)	...	...	...	...	...	...	...	...	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5
9[A]	4.75 to 1.18 mm (No. 4 to No. 16)	...	...	...	...	...	...	...	...	...	100	85 to 100	10 to 40	0 to 10	0 to 5

[A] Size number 9 aggregate is defined in Terminology C125 as a fine aggregate. It is included as a coarse aggregate when it is combined with a size number 8 material to create a size number 89, which is a coarse aggregate as defined by Terminology C125.

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Filters for Embankment Dams

Best Practices for Design and Construction

October 2011

FEMA

5 Filter Design Procedure

5.1 Background

The base soil is the core (designed water barrier) material whose integrity must remain uncompromised during the dam's life cycle. The filter soil acts as the protective device or "fail-safe" mechanism to ensure proper functioning of the core material. The filter soil particles are coarser-grained than the base soil particles, to achieve the purposes discussed in greater detail elsewhere in this manual.

This chapter presents a step-by-step procedure for selecting the proper gradation band of a filter or drainage material whose purpose is to protect a base soil material. The procedure applies to zones used in embankment dams, foundation seepage collection zones such as toe drains, or any other application where seepage occurs and particle movement is to be prevented. This procedure can be used in both single- and multi-stage filter applications. For multistage applications, the procedure is repeated for each zone boundary progressing from the finest to the coarsest grained soils.

Filter gradation limits achieved by this procedure will be a balance between permeability requirements on the finer-grained particle distribution side and particle retention requirements on the coarser-grained particle distribution side. The window of fine-to-coarse limits allows for flexibility in selection of the optimum filter gradation band required to achieve the intended goal of the filter.

The procedure is primarily based on research performed at the Natural Resource Conservation Service (NRCS) in the 1980s (Sherard 1984). That research also influenced procedures used by NRCS, U.S. Army Corps of Engineers (USACE), and Bureau of Reclamation (Reclamation). While most design criteria are based on historical research by Sherard and others, there are some differences between the procedures of each of these U.S. Government agencies. These are elaborated on in {Link_015}. Additional research performed in the past decade by Foster and Fell (2001) and others has contributed to the awareness of dispersive clay base soils and how they should be filtered. The procedure included in this chapter is a compilation of the information from these sources.

5.1.1 Selection of base soil gradation

The first step in the filter design procedure is to determine the representative gradation of the soil being protected. Historically, design guidance has indicated a single gradation with little explanation of how that gradation is obtained. USACE {Link_016} and Reclamation {Link_017} provide narrative assessments on base soil selection, and detailed considerations are addressed in Attachment A. The information presented in Attachment A is intended to elucidate which factors should be considered when evaluating base soil data and choosing a representative gradation. The information should be used as a guide rather than strict procedural requirements for base soil selection.

Base soil selection is complicated by soil variability as it is represented in gradation tests. Variability will be less for embankment fill since there is blending and mixing of the source material as it is excavated from the borrow area and placed in the dam. On the other hand, foundation material will have a greater degree of variability and present a greater challenge in base soil selection. Foundation soils also present a challenge in that the selection of accurate base soil gradations is only as good as the understanding of the geology. If the lithology of the subsurface deposits is poorly understood, this can lead to incorrectly grouping multiple soil gradations, resulting in a too coarse or too fine a filter for a given geologic unit. Probably the most difficult geologic conditions to quantify are undifferentiated units. These are soil deposits that usually have limited areal extent and do not warrant mapping them as unique soil layers. This may result in a broad range of soil types for consideration during base soil candidate selection.

Consideration should also be given to sampling errors, classification errors, and so-called outliers. Invariably, when numerous samples are collected and obtained in earth materials, there will be one or two samples that do not appear to match all others, even when the sampled layer is thought to be homogenous. This variation can come from variability of the materials themselves or from collection or laboratory (testing) errors. When an outlier is on the finer side of the candidate gradations, a problem can arise if it is used as the representative base soil gradation since it will result in a too-fine filter being designed.

Since foundation soils typically have greater variability than earthfill materials, as described above, the base soil selection procedure is different for these two classes. As would be expected, the more variable class has a longer list of characteristics that needs to be evaluated (see Figure A-15), and the less variable material is simpler (see Figure A-14).

5.1.2 Dispersive clay base soil considerations

For base soils with more than 15% fines, adequate tests should be performed to establish whether the clay fines are dispersive in character. The crumb test (ASTM D 6572) and double hydrometer test (ASTM D 4221) usually define this property adequately, but in some cases, pinhole, ASTM D 4647, and chemical tests may also be required. The NRCS reference, “Chapter 13, Part 633 of the National Engineering Manual, Dispersive Clays,” contains useful advice for sampling and testing for dispersive clays as does the Reclamation reference, “R-91-09, Characteristics and Problems of Dispersive Clay Soils.”

As the name implies, dispersive clay minerals tend to “come apart” when immersed in fresh water, as opposed to flocculation (come together), which is seen in all other types of clays. This dispersion tends to make the nominal particle sizes effectively smaller than what is measured in non-dispersive samples. Since the effective particle sizes are smaller, the retention rules based on a D15 size are not entirely representative. A different set of retention criteria are used, as described later in this chapter.

5.1.3 Base soil computational re-grading

Computationally re-grading the base soil (i.e., calculating on paper instead of field sorting) at the beginning of the filter design procedure is a critical step that must be followed, when applicable, in order to obtain a correctly designed filter. The concept of computational re-grading was developed by Sherard to correct for broadly graded soils. Broadly graded base soils can be internally unstable (i.e., inadequate particle retention), and re-grading corrects for this phenomena. Permitting the inclusion of gravel (> sieve No. 4 size) within a base soil gradation will lead to a large D85B size and subsequently a large D15F size. Since gravel particles do not have any particle retention capability in broadly graded or gap-graded soils, the resulting filter gradation will be too coarse to provide particle retention of the finer fraction of the base soil (i.e., the filter will not meet particle retention criteria for the base soil). The exception to this rule is that soils with less than 15% fines do not require re-grading.

The procedure for base soil computational re-grading is illustrated in Figure 5-1, with the steps listed below:

Sieve Size	Original Percent Passing	Adjustment	Final Percent Passing
3"	100.0		(Re-graded gradation):
1 1/2"	85.7		
3/4"	74.6		
3/8"	65.9		
#4	57.9	(57.9 / 57.9) x 100	100.0
#8	54.6	(54.6 / 57.9) x 100	94.3
#16	49.0	(49.0 / 57.9) x 100	84.6
#30	42.6	(42.6 / 57.9) x 100	73.6
#50	32.2	(32.2 / 57.9) x 100	55.6
#100	19.8	(19.8 / 57.9) x 100	34.2
#200	13.0	(13.0 / 57.9) x 100	22.5
1 min	9.9	(9.9 / 57.9) x 100	17.1
4 min	5.4	(5.4 / 57.9) x 100	9.3
19 min	2.9	(2.9 / 57.9) x 100	5.0
60 min	1.6	(1.6 / 57.9) x 100	2.8

Figure 5-1. Example showing computational re-grading to the No. 4 sieve size.

1. Obtain a correction factor (or adjustment ratio) by dividing 100 by the percent passing the No. 4 (4.75-mm) sieve size of the base soil.
2. Multiply the percentage passing each sieve size of the original base soil by the correction factor (or adjustment ratio).
3. Plot these adjusted percentages to obtain the computationally re-graded gradation curve.
4. Use the re-graded curve plot to determine the percentage passing the No. 200 (0.075-mm) sieve to use in step 4 below.

The problem of not re-grading the base soil gradation is illustrated graphically in Figures 5-2 and 5-3. Figure 5-2 shows a base soil that has not been re-graded (i.e., original base gradation curve is shown). Sizing a filter for this material results in a filter consisting primarily of coarse gravel, as

12/06/21 CLS
MLG 12/09/2021

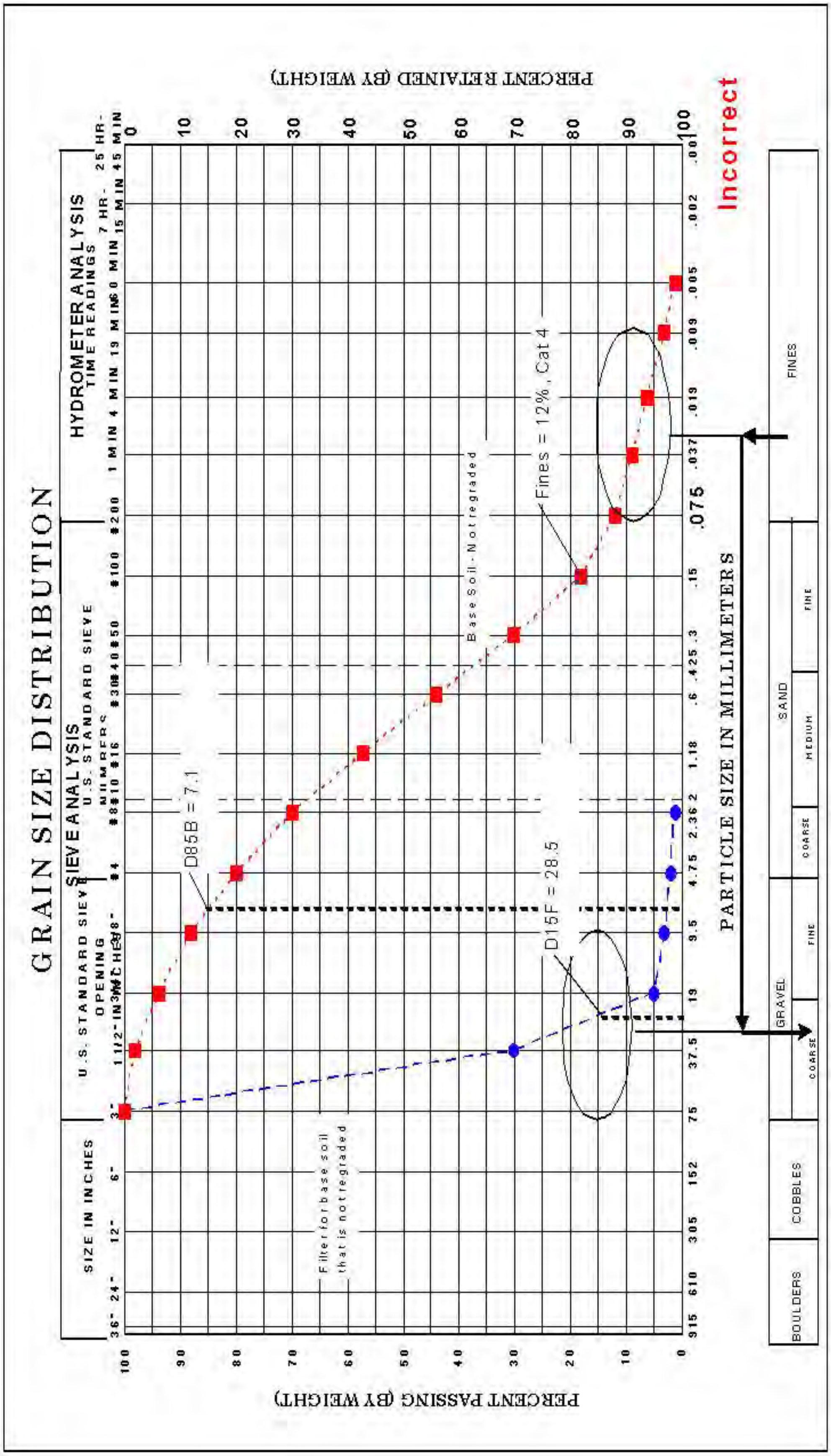


Figure 5-2. Illustration of an incorrectly designed filter gradation (blue line) because the base soil gradation (red line) was not computationally re-graded to the No. 4 sieve size.

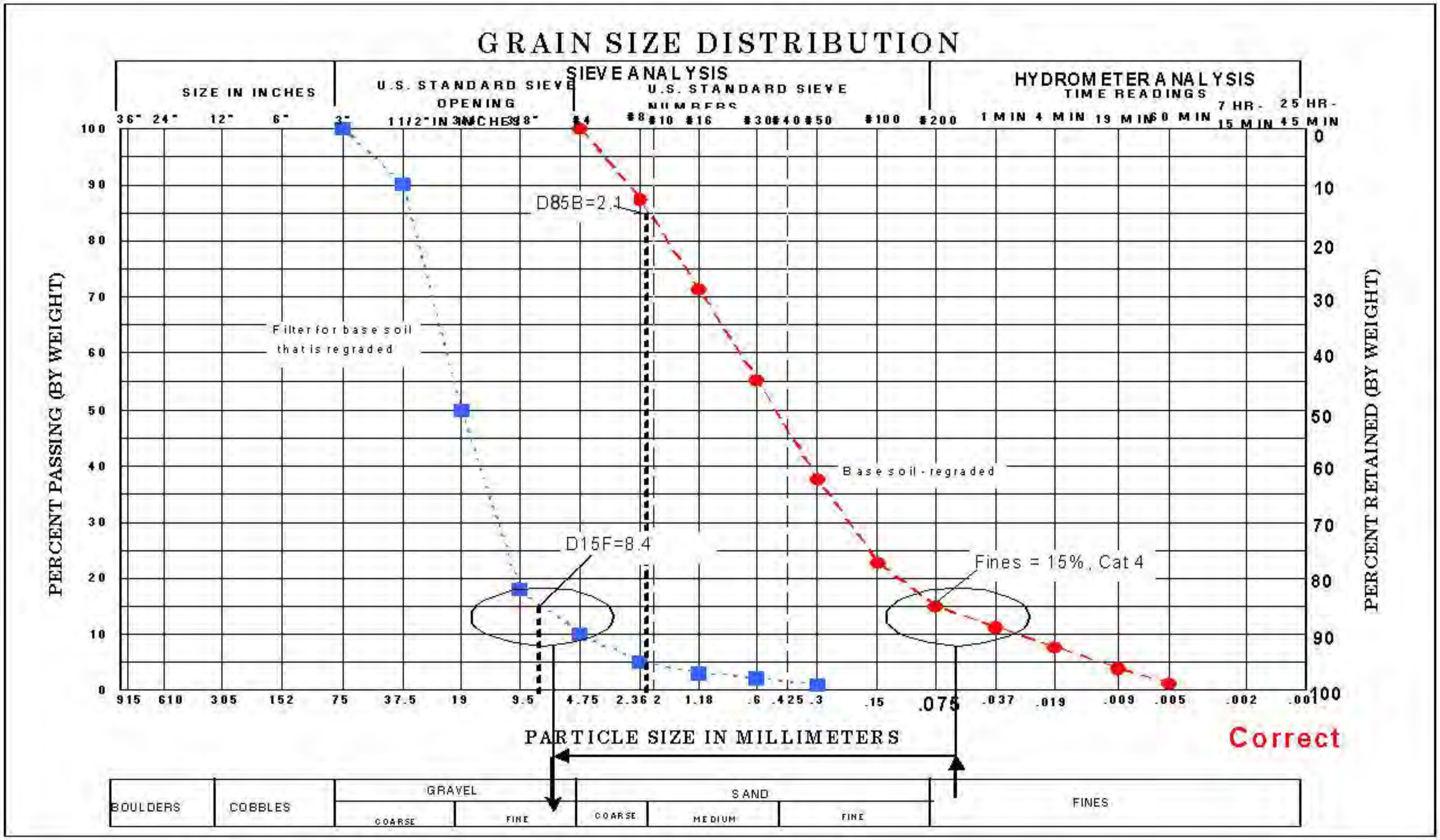


Figure 5-3. Illustration of the original base soil material as shown in Figure 5-2 after computational re-grading (red line). Re-grading results in a correctly sized (slightly finer-grained) filter (blue line).

shown on the figure. This design results in the silt and fine sand of the base material eroding through the voids in the coarse gravel filter.

Figure 5-3 shows the same base soil computationally re-graded beginning with the No. 4 sieve size. The filter design based on the re-graded soil is a fine gravel with 10% sand. This design will not permit movement of the silt and fine sand of the base soil through the sand and fine gravel filter.

5.2 Filter design procedure

The following section provides a step-by-step procedure based on Sherard's research, guidance of Federal agencies, and other studies in the last decade. More detailed discussions are found in Attachments D, G, and {Link_027}.

Step 1: Plot the gradation curve(s) (grain-size distribution) of the base soil material(s). Determine if the base soils have dispersive clay content and note it for later use in the procedure.

Step 2: Determine if the base soil(s) have particles larger than the No. 4 sieve (i.e., gravel sizes). Also, determine if the base soil(s) are gap-graded, thus potentially subject to internal instability (reduced particle retention capability).

(a) If the base soil has no gravel particles, proceed to Step 4.

(b) If a base soil contains any particles larger than the No. 4 sieve, the soil should be computationally re-graded on the No. 4 sieve (go to Step 3), with the following exception: sands and gravels with less than 15% fines that are not gap-graded and not broadly graded do not require re-grading (proceed to Step 4).

A flowchart illustrating the Step 2 process is shown in Figure 5-4.

If the base soil is gap-graded (i.e., missing medium grain sizes), the coarse grains may not deter the migration of the finer grains. The filter should be designed to protect the finer grains rather than the total range of particle sizes. USACE EM 1110-2-2300 (30 July 2004) illustrates how a gap-graded base soil may be re-graded on the No. 30 sieve (identical in fashion to the above procedure for re-grading on the No. 4 sieve), and the filter

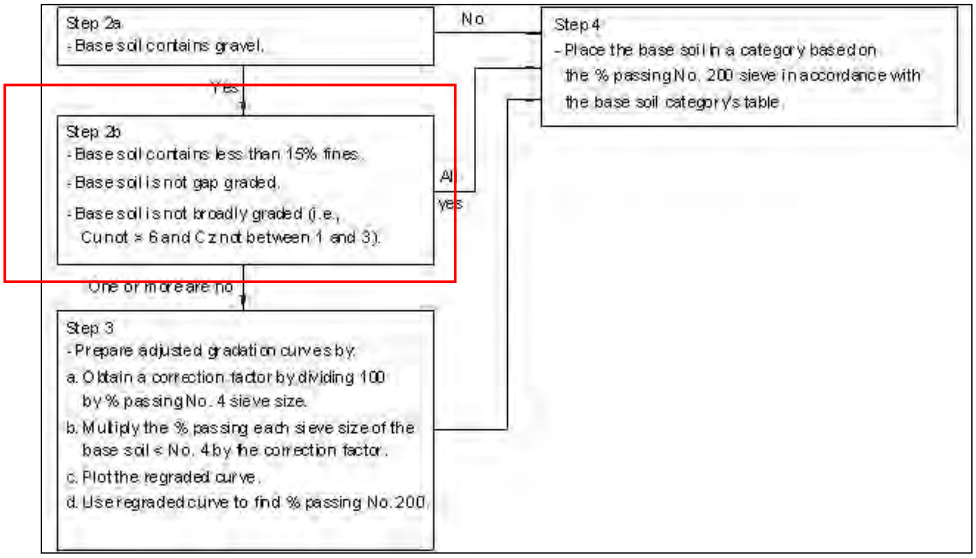


Figure 5-4. Flowchart of the Step 2 process.

design is based on the re-graded curve. The resultant filter design should be checked with filter testing to verify its performance.

Step 3: Prepare adjusted re-graded gradation curves (i.e., re-graded) for base soils that have particles larger than the No. 4 (4.75-millimeter [mm]) sieve.

Refer to either previous Section 5.1.3 or the above illustration for the re-grading procedure.

Step 4: Determine base soil category based on percent passing the No. 200 (0.075-mm) sieve in accordance with the following table.

Table 5-1. Base soil categories.

Base Soil Category	Percent Finer Than No. 200 Sieve (0.075-mm) (after re-grading where applicable)	Base Soil Description
1	> 85	Fine silt and clays
2	40 – 85	Sands, silts, clays, and silty and sands
3	15 – 39	Silty and clayey sands and gravels
4	< 15	Sands and gravels
Note: Table 5-1 is the same for USACE, Reclamation, and NRCS guidance (Table 2, USBR Design Standards No. 13(5); Table B-1, EM 1110-2-2300; Table D-1, EM 1110-2-1901; and NRCS Table 26-1)		

Step 5: To satisfy particle retention (internal stability) requirements, calculate the maximum allowable $D_{15}F$ size in accordance with the following table. Selection is based on the $D_{85}B$ of the re-graded (if applicable) base soil. Plot the result (maximum allowable $D_{15}F$ size) as a single point on a preliminary design plot (illustrated in Section 5.3).

Table 5-2. Filtering criteria.

Base Soil Category	Filtering – Maximum $D_{15}F$
1	The maximum $D_{15}F$ should be $\leq 9 \times D_{85}B$, but not less than 0.2 mm, unless the soils are dispersive. Dispersive soils require a maximum $D_{15}F$ that is $\leq 6.5 \times D_{85}B$ size, but not less than 0.2 mm.
2	The maximum $D_{15}F$ should be $\leq$ 0.7 mm unless soil is dispersive, in which case the maximum $D_{15}F$ should be < 0.5 mm.
3	For nondispersive soils, the maximum $D_{15}F$ should be $\leq \left[\frac{40-A}{25}\right]\left[(4 \times D_{85}B) - 0.7mm^*\right] + 0.7mm^*$ where: A =% passing No. 200 sieve after any re-grading. When $4 \times D_{85}B$ is less than 0.7 mm*, use 0.7 mm* * - For dispersive soils, use 0.5 mm instead of 0.7 mm.
4	The maximum $D_{15}F$ should be $\leq 4 \times D_{85}B$ of base soil after re-grading
Note: Table 5-2 has essentially the same criteria as seen in USACE, Reclamation, and NRCS guidance (Table 2, USBR Design Standards No. 13(5); Table B-2, EM 1110-2-2300; Table D-2, EM 1110-2-1901; and NRCS Table 26-2). NRCS adds dispersive soil criteria, and USACE adds wave/surge criteria.	

Step 6: To satisfy permeability requirements, determine the minimum allowable $D_{15}F$:

Minimum $D_{15}F \geq 5 \times$ maximum $D_{15}B$ (Reclamation)
Minimum $D_{15}F \geq 3$ to $5 \times$ maximum $D_{15}B$ (USACE)
Minimum $D_{15}F \geq 4$ to $5 \times$ maximum $D_{15}B$ (NRCS)
Minimum $D_{15}F$ is computed prior to any re-grading, if any, and should not be smaller than 0.1 mm.

Plot the result (minimum allowable $D_{15}F$ size) as a single point on the preliminary design plot (illustrated in Section 5.3).

Step 7: Limit the width of the filter band and prevent gap-graded filter design. After plotting the maximum and minimum $D_{15}F$ sizes on the preliminary design gradation plot, check that their ratio is less than or equal to 5 (i.e., maximum $D_{15}F < 5 \times$ minimum $D_{15}F$). In addition, check the D_{10} and D_{60} size limits to ensure coefficient of uniformity (C_u) between 2 and 6.

Plot the results as points on the preliminary design plot (illustrated in Section 5.3).

Additional discussion on preventing gap-graded filters is presented here {Link_019}.

Step 8: To limit the amount of fines and oversized material, determine the minimum D_5F and maximum $D_{100}F$ according to the following table:

Table 5-3. Maximum and minimum particle size criteria.

Base Soil Category	Maximum $D_{100}F$	Minimum D_5F
ALL categories	≤ 2 in. (51 mm)	0.075 mm (No. 200 sieve)

USACE sets maximum size at 3 in. (75 mm), maximum 5% fines passing the No. 200 sieve, and PI equal to zero.

Step 9: To limit segregation potential, determine maximum $D_{90}F$ from the following table:

Table 5-4. Segregation criteria.

Base Soil Category	If Minimum DF is: (mm)	Then, Maximum $D_{90}F$ is: (mm)
ALL categories	< 0.5	20
	0.5–1.0	25
	1.0–2.0	30
	2.0–5.0	40
	5.0–10	50
	10 - 50	60

Additional discussion of segregation is presented here {Link_019}.

Step 10: Determine the filter gradation band within the control points.

Select a gradation band within the control points (limits). Two methods are presented based on the practice of NRCS and Reclamation.

The NRCS method is:

To prevent use of gap-graded filters, the width of the filter band is adjusted such that the ratio of the maximum diameter at any passing less than 60% is 5 or less. To check this at the $D_{15}F$, divide the maximum $D_{15}F$ by 5, and use the coarsest of the new point. At the D_{60} limits (Step 7 above), the band width can be laterally adjusted to meet the Step 7 requirements. The adjustable band width may be set to accommodate commercially available gradations or other materials available at or near the project site.

The Reclamation method considers the purpose of the filter and provides guidance for those cases. This method, along with examples, is presented in Attachment G.

5.2.1 Drainpipe perforations

If the envelope filter will be used adjacent to a perforated pipe, then:

> *The maximum pipe perforation dimension should be no larger than the finer side of the $D_{50}E$ where $D_{50}E$ is taken from the gradation of the envelope (drain) material that surrounds the drainpipe.*

5.3 Design examples

5.3.1 General example

For the purpose of illustrating the procedures listed above for a single-stage filter design, a hypothetical re-graded base soil curve is shown in Figure 5-5. Steps 1 through 3 are not repeated since the base soil is already computationally re-graded. The purpose herein is not to select the optimum filter to protect this particular base soil, but to illustrate the steps required to accomplish the filter design process.

MLG 12/09/2021 12/06/21 CLS

ADVANCED TERRA TESTING
833 PARFET ST UNIT A
LAKEWOOD, CO
303-232-8308 www.terratesting.com

Monday, October 18, 2021

Project Number: 2679-164

Company: RJH Consultants

Address:

City:

State:

RE: Soil Testing
Grizzly Reservoir Dam
21125

Dear Austin Yahn,

With this letter you will find a report on Soil samples assigned on 9/24/2021.

Testing was performed in accordance with standardized test methods, accepted industry practices as well as specific instructions received from you, our client. Advanced Terra Testing accepts no responsibility and makes no claims to the use or purpose of the material being tested. Furthermore, the results herein are based solely on the material received and tested. Please note that all material will be disposed of after thirty days unless other arrangements are made.

We respectfully request that sample reports be considered proprietary information and are not to be reproduced, except in full and only with prior written approval of Advanced Terra Testing. We are pleased to have been given the opportunity to perform high quality laboratory testing for your project. We sincerely hope the results herein provide you with all the information required. If you have questions or need anything further, please reach out and we will be happy to assist you.

Respectfully,

William Rausch, PE - Technical Manager

12/06/21 CLS
MLG 12/09/2021

Grain Size Analysis
ASTM D 6913

ADVANCED TERRA TESTING

CLIENT	RJH Consultants	BORING NO.	reservoir sediment sample
JOB NO.	2679-164	DEPTH	
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	--
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	09/28/21		
TECHNICIAN	LG		

Hygroscopic Moisture of Fines

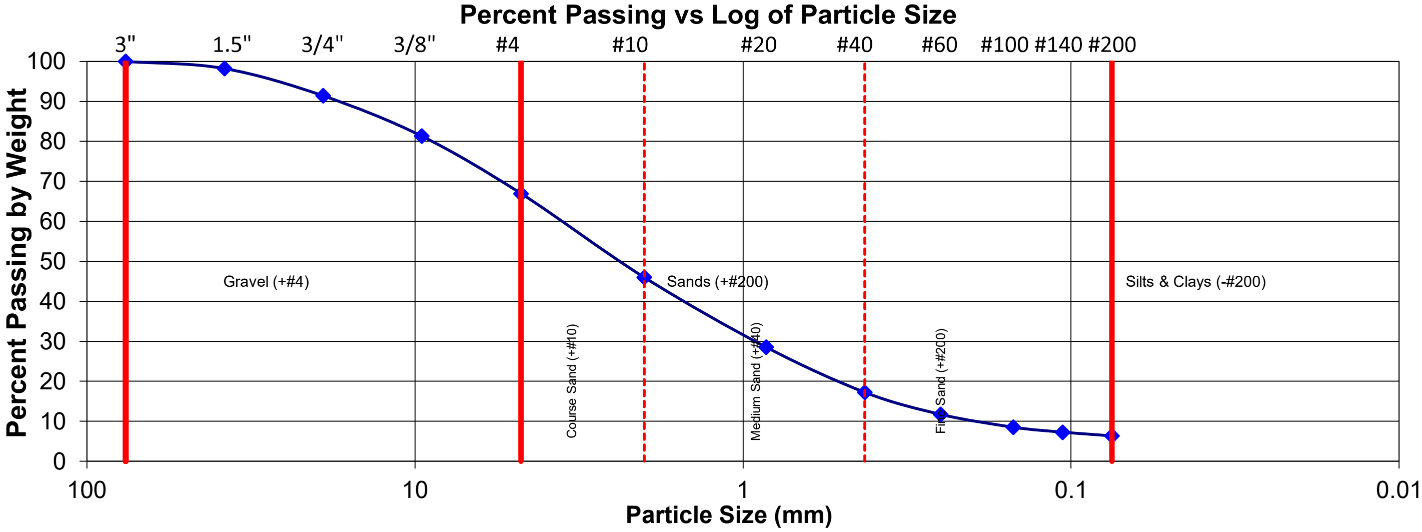
Mass Wet Pan and Soil (g): 1118.24
Mass Dry Pan and Soil (g): 1103.69
Mass of Pan (g): 264.75
Moisture (%): **1.7**

Sample Data

Total Wet Mass of Sample (g): 18583.3
Total Dry Mass of Sample (g): 18324.8
Split Fraction: 3/8"
Mass of Sub-Sample Fraction (g): 853.49

Sieve Number	Sieve Size (mm)	Mass of Pan and Soil (g)	Mass of Pan (g)	Mass of Individual Retained Soil (g)	Correction Factor	Percent Passing by Weight (%)
3"	76.2	0.0	--	--	--	**--**
1.5"	38.1	330.1	--	330.1	1.00	**98.2**
3/4"	19.05	1249.4	--	1249.4	1.00	**91.4**
3/8"	9.53	1842.6	--	1842.6	1.00	**81.3**
#4	4.75	148.4	--	148.4	0.81	**66.9**
#10	2.00	216.1	--	216.1	0.81	**46.0**
#20	0.850	180.1	--	180.1	0.81	**28.5**
#40	0.425	116.3	--	116.3	0.81	**17.3**
#60	0.250	57.1	--	57.1	0.81	**11.7**
#100	0.150	33.0	--	33.0	0.81	**8.5**
#140	0.106	13.2	--	13.2	0.81	**7.3**
#200	0.075	9.1	--	9.1	0.81	**6.4**

Percent Passing vs Log of Particle Size



USCS Classification ASTM D 2487

Atterberg Classification: NP
Coefficient of Curvature - C_c: 1.19
Group Symbol: SP-SM
Coefficient of Uniformity - C_u: 19.59
USCS Classification: Poorly Graded Sand With Silt And Gravel

Data entry by:	LOG	Date:	09/30/21
Checked by:	LG	Date:	10/04/21
File name:	2679164__Grain Size Analysis ASTM D6913_0.xlsm		

12/06/21 CLS

MLG 12/09/2021

ADVANCED TERRA TESTING

Grain Size Analysis with Hydrometer
ASTM D 6913 And D 7928

CLIENT	RJH Consultants	BORING NO.	TP-103
JOB NO.	2679-164	DEPTH	1.0-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-1
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	10/11/21		
TECHNICIAN	BDF		

Hygroscopic Moisture of Fines

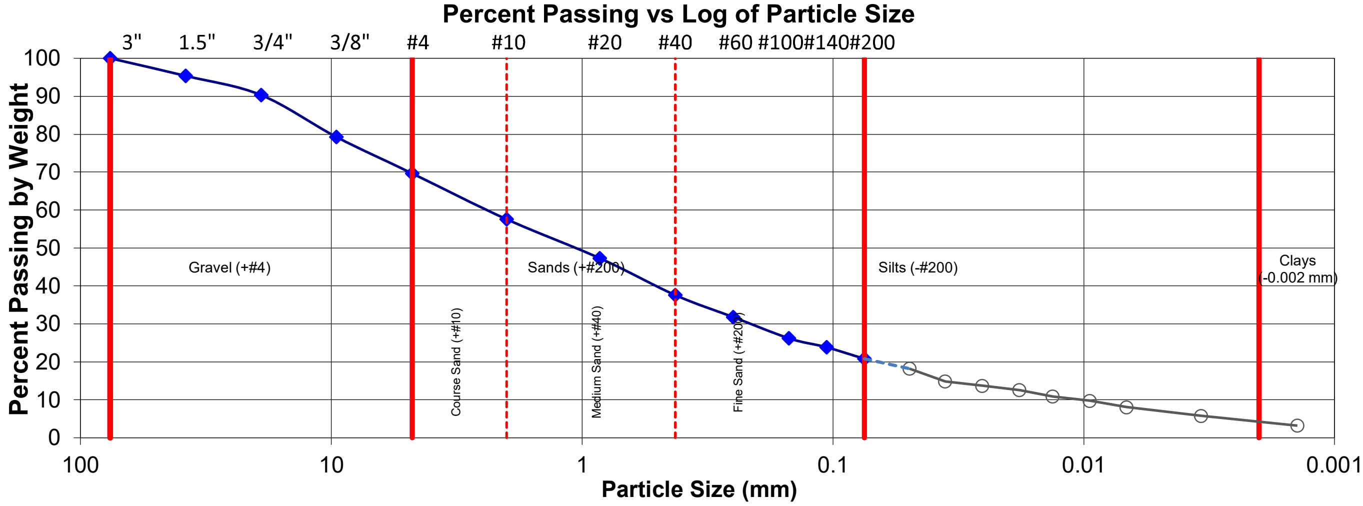
Mass Wet Pan and Soil (g): 118.02
Mass Dry Pan and Soil (g): 116.14
Mass of Pan (g): 6.81
Moisture (%): **1.7**

Sample Data

Total Wet Mass of Sample (g): 8778.1
Total Dry Mass of Sample (g): 8692.5
Split Fraction: #10 3/8"
Mass of Sub-Sample Fraction (g): 51.83 1063.20

Sieve Number	Sieve Size (mm)	Mass of Pan and Soil (g)	Mass of Pan (g)	Mass of Individual Retained Soil (g)	Correction Factor	Percent Passing by Weight (%)
3"	76.2	0.0	--	--	--	**100.0**
1.5"	38.1	403.2	--	403.2	1.00	**95.4**
3/4"	19.05	437.5	--	437.5	1.00	**90.3**
3/8"	9.53	964.3	--	964.3	1.00	**79.2**
#4	4.75	127.0	--	127.0	0.79	**69.7**
#10	2.00	159.8	--	159.82	0.792	**57.6**
#20	0.850	9.1	--	9.08	0.575	**47.3**
#40	0.425	8.6	--	8.63	0.575	**37.6**
#60	0.250	5.1	--	5.09	0.575	**31.8**
#100	0.150	5.0	--	4.95	0.575	**26.3**
#140	0.106	2.1	--	2.09	0.575	**23.9**
#200	0.075	2.7	--	2.73	0.575	**20.8**

Percent Passing vs Log of Particle Size



USCS Classification ASTM D 2487

Atterberg Classification: NP
Group Symbol: SM
USCS Classification: Silty Sand With Gravel

Coefficient of Curvature - C_c: --
Coefficient of Uniformity - C_u: --

Data entry by:	KMS	Date:	10/13/21
Checked by:	JJA	Date:	10/14/21
File name:	2679164__Grain Size with Hydrometer ASTM D6913 D7928_0.xlsm	Page 1 of 2	

12/06/21 CLS

MLG 12/09/2021

ADVANCED TERRA TESTING

Grain Size Analysis with Hydrometer
ASTM D 6913 And D 7928

CLIENT	RJH Consultants	BORING NO.	TP-103
JOB NO.	2679-164	DEPTH	1.0-3.0'
PROJECT	Grizzly Reservoir Dam	SAMPLE NO.	Bu-1
PROJECT NO.	21125	DATE SAMPLED	09/15/21
LOCATION	--	DESCRIPTION	--
DATE TESTED	10/11/21		
TECHNICIAN	BDF		

Hydrometer and Flask Parameters

Hydrometer ID:	0805	Flask ID:	1192
Average Mass Offset (g/L):	9.87	Flask Volume (cm^3):	1002.7
Hydrometer Bulb Volume (cm^3):	56.50	Flask Surface Area (cm^2):	27.82
Meniscus Correction (g/L):	1.00	Assumed Specific Gravity	2.65
H_b (cm):	24.5	Hydrometer Type:	152H
H_{cb} (cm):	6.8		
H_s (cm):	8.2	Percent Finer by Mass at 2 μm:	**4.0**

Hydrometer Data

Elapsed Time (minutes)	Hydrometer Reading (g/L)	Offset Reading (g/L)	Temperature (°C)	Effective Depth (cm)	Maximum Particle Diameter in Suspension (mm)	Percent Finer by Mass (%)
1	22.00	5.89	21.6	13.23	0.050	**18.2**
2	19.00	5.89	21.6	13.72	0.036	**14.8**
4	18.00	5.89	21.6	13.89	0.025	**13.7**
8	17.00	5.89	21.6	14.05	0.018	**12.6**
15	15.50	5.89	21.6	14.30	0.013	**10.9**
30	14.50	5.89	21.6	14.46	0.009	**9.7**
60	13.00	5.89	21.6	14.71	0.007	**8.1**
240	11.00	5.89	21.6	15.04	0.003	**5.8**
1440	9.00	6.17	20.8	15.37	0.001	**3.2**

NOTES:

File name: 2679164__Grain Size with Hydrometer ASTM D6913 D7928_0.xlsm

APPENDIX H

GEOSYNTHETIC SYSTEM

April 29, 2021

Michael L. Graber, PE
RJH Consultants, Inc.
Water Planning and Design
9800 Mt. Pyramid Ct., Suite 330
Englewood, CO 80112
mgraber@rjh-consultants.com

Dear Michael:

We are pleased to provide this quote for Grizzly Dam. This quote is contingent on having a site visit.


Alpe Gera Dam – (Italy 1994) – Left photo shows the 570 foot tall dam with a rusting steel facing on lower part of dam and the failed epoxy coating on the upper face. Right photo shows the 295 feet tall lower steel facing covered by an 80 mil (2 mm) thick Sibelon® PVC geocomposite. A swing stage can be seen part-way down the face on the right side of the right picture demonstrating the magnitude of the structure. The Carpi system is still operating after more than 25 years of service.

1.0 PRICING ASSUMPTIONS

The present proposal for Grizzly Dam is based on the following assumptions:

- The entire upstream face is lined.
- Work at Grizzly Dam is based on 2021 material and labour rates.
- The reservoir would be drawn down, and installation would occur in the dry.
- Unlimited access to the upstream dam face during construction working around public access.
- Water diversion and dewatering to be handled by Twin Lakes Colorado Canal Company.
- Laydown area at Grizzly Dam is in a nearby and convenient location.
- Geomembrane tensioning profiles will be welded to the existing upstream steel facing.
- The lower submersible seal will be affixed to existing concrete plinth on all sides
- The upper submersible seal will be attached to the steel face.
- Repairs to steel facing or concrete plinth, etc. will be charged on a T&M basis.
- Cathodic protection will be removed by Twin Lakes Colorado Canal Company
- Upstream steel plates are designed to hold the full hydrostatic head of the reservoir.

1.1 TYPE OF SOLUTION

The solution for Grizzly Dam is based on Carpi's work on similar dams representing more than 17 million sq. feet of installations on dams stretching back ~50 years. Our 175+ dam geomembrane installations now have more than 2,440 years of service. Additionally, we have more than 30 dam installations in United States with a total more than 300 years of service life.

The installation over the entire upstream face of Grizzly Dam consists of:

1. Watertight perimeter (stainless steel 80 x 8 mm batten) seal onto the concrete plinth and steel crest
2. Tri-planar geonet along lower perimeter seal for drainage collection (~2 feet wide)
3. Drainage plates (2) with a drilled hole through face to allow discharge of water into the body
4. Due to 2 feet of projected ice on reservoir, geotextile will be cut and fitted around each steel rivet and epoxied to the face.
5. 2000 gram/sq. meter (~57 ounce/yd) sacrificial geotextile over the whole face
6. Tensioning profiles (stainless steel with carbon steel tabs) welded vertically to hold geomembrane to dam every ~ 5.7 meters (~19 feet) - ~ 40 rows of vertical profiles
7. Steel studs welded directly to the dam face at the groins in area of projected ice accumulation.
8. Geocomposite (Sibelon® PVC geomembrane 3.0 mm with geotextile 500 gram/ square meter) in 2.1-meter widths – same geocomposite as used at Upper Blue and Big Toot in Colorado under more severe conditions.
9. Steel studs welded directly to the dam face with steel batten strip for top seal.
10. Tested details for sealing at the steel face contraction joints

Upper Blue dam (Colorado 2007) and Big Tooth (Colorado 2009) - shown on left is Upper Blue with geocomposite over entire face with snow and ice in Spring. This dam is at an elevation at ~ 11,700 feet, exceeding that of Grizzly by 1,000+ feet. On the right is Big Tooth during construction where the primary purpose of the geomembrane system was to cover the failed upstream liner of shotcrete which was flaking off.

1.2 QUANTITIES (Entire surface of Grizzly Dam)

Geomembrane System covering the entire upstream face **Total ~50,000 square feet**

1.3 SUPPLY TIME

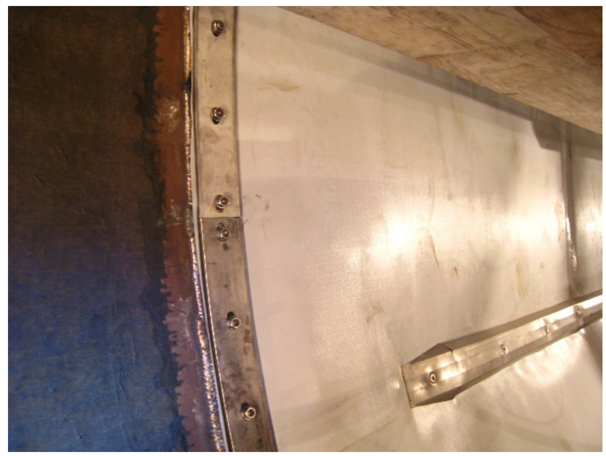
Time for supply and delivery of material to be installed on site is ~ 4-5 months from date of order.

1.4 INCLUDED IN THE FIXED PRICE PROPOSAL (TABLE A) BY CARPI

1. Final detailed design of the geosynthetic system
2. Design documentation will consist of at least:
   - 3 drawings and
   - 10 pages of text
3. Materials, fabrication, and installation of PVC geocomposite system
4. Supply of all the materials needed for the execution of the works as described in the present proposal (geomembrane SIBELON CNT4400 [liner material], geotextile, galvanized carbon steel plating welded to stainless steel tensioning profiles and stainless-steel submersible perimeter anchorage installed on concrete plinth, including all connecting devices). Shipments of material will include a certificate from the manufacturer stating lot or roll numbers, date of manufacture and guarantee that the materials conform the requirement of the specifications.
5. Materials and fabrication of stainless-steel batten strips for perimeter seal and stainless-steel tensioning profile attachment system with carbon steel tabs for welding to the face
6. Welding of stainless-steel profiles with carbon steel tabs to carbons steel face of dam
7. Drilling of 2 holes through steel face for drainage discharge
8. Thick geotextile covering the entire face as a sacrificial layer and as layered protection for steel rivets
9. Geonet drainage layer - ~ 2 feet wide at the groin.
10. Shipment of materials to staging area at Grizzly Dam
11. Mobilization of crew to site
12. All labor needed for the installation of the waterproofing system. The labor rates include all salary, social charges, insurance, fringe benefits, holidays, traveling expenses, etc.
13. All tools needed for the installation of the waterproofing system.
14. Mobilization / Demobilization of material and equipment
15. Supply and operation of suspended platforms including deploying from water and working from the water.
16. Supply and operation of hoisting equipment for all activities regarding installation of membrane.
17. Royalties on patents
18. Internal Quality Control on installation
19. Food and lodging of all personnel nearby (Aspen) to work site.
20. Cost for office trailer.
21. Cost of sanitary facilities onsite
22. Contingency for bad weather days if work is scheduled in summer/fall season
23. Characterization of geomembrane by an independent test laboratory
24. Supply of electricity and power distribution at site assuming the use of generators.
25. Relevant quality control certificates and internal quality control
26. Custom duties (as of proposal date) on imported materials
27. Local Colorado sales taxes at 4.65%
28. Written warranty of 2 years for material and installation.
29. Final report (update of drawings, i.e. Record Drawings and design specification)
30. Costs for bonds
31. Standard Contractor Insurance
    - General Aggregate Limit - $5,000,0000
    - Workers Compensation - Statutory limits
    - Pollution - $1,000,000
    - Each occurrence limit - $1,000,000

1.5 NOT INCLUDED IN THE FIXED PRICE PROPOSAL BY CARPI

1. Activities for work if reservoir levels cannot be maintained within agreed upon limits.
2. Work does not include site preparation or civil works (i.e. dewatering reservoir, dredging, cofferdams, grading for deployment of equipment, sediment removal, etc.)
3. Insurance above standard insurance requirements for contractors
4. Work does not include cost of concrete or steel surface preparation.
5. Boat(s) to support installation are not included. The reservoir is assumed to be completely dewatered.
6. Security at site.
7. Liquidated damage charges
8. Warranty beyond 2 years.
9. Costs for scaffolding – Primary access will be by swingstage, but some scaffolding may be needed at groins.



Belden hydraulic tunnel (California 2008) – Similar to Grizzly, one of the terminating submersible seals for Belden tunnel waterproofing system was to be placed on a carbon steel surface. The stainless-steel flat profiles making up the submersible seal were welded onto this steel surface circularly around the pressure tunnel. The picture on the left shows the flat profile for perimeter seal after welding to the carbon steel. Note, the flat profiles had anchor studs welded onto them as part of the liner anchorage. The picture on the right shows a completed perimeter seal installation as well as a tensioning profile prior to welding of coverstrip.

2.0 PRICES

The prices for the waterproofing system of the upstream face of Grizzly Dam in Colorado are preliminary and would be adjusted based on more detailed information and additional discussion.

Unit Prices will be calculated for a total quantity as specified above +/- 5 %.
Installation based on continuous uninterrupted operations. We intend to work 6 days a week.

Lago Nero dam (Italy, 1980) - The pictures show the concrete gravity dam before and after rehabilitation with the CARPI system. The dam is located very high in the Alps with severe weather and has been operating for more than 40 years with the CARPI system.

El Vado Dam (New Mexico 2018) – On the left is the test panel installation showing stainless steel tensioning profiles welded with tabs prior to the geomembrane installation. The right picture shows the completed installation. This is what the face of Grizzly will look like after we finish.

2.1 EXTRA WORK

For all materials or subcontracts on a time and material basis, a CARPI USA fee of 15% will be added.
For extra work related to surface preparation or other tasks, all CARPI workers will be charged at a rate of $105/hour which includes hand tools, lodging, food, overtime allowance and overhead.


Lago Verde dam (Italy 1970) - Carpi's first installation on a dam with 38,000 ft² of geomembrane to connect steel facing elements to concrete plinth. On right, the installation is still in place today, more than 50 years later. This installation mirrors Grizzly Dam regarding the tricky detail of connecting a steel face to a concrete plinth.

3.0 PAYMENTS

Saddlebag Dam (California 2011) and Midtbotnvatn (Norway 2004) – On the left is the Carpi system over the Saddlebag wood faced rockfill dam at over 10,000 foot elevation in the California Sierra Nevada Mountains demonstrating our system's ability to adapt to differing subgrades. On the right is the Carpi system on Midtbotnvatn dam at a latitude of 59.5 degrees. The gentlemen is standing on more than 15 feet of snow/ice demonstrating how ice can slide down an abutment – a detail we have accounted for in our design for Grizzly dam.

4.0 CONCLUDING REMARKS

We look forward to working with RJH on the rehabilitation of Grizzly Dam.

Warmest regards.

John A. Wilkes, P.E.
President, CARPI USA