EXH. RPB-6
DOCKETS UE-22___/UG-22___
2022 PSE GENERAL RATE CASE
WITNESS: RYAN P. BLOOD

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, Complainant, v. PUGET SOUND ENERGY, Respondent.	Docket UE-22____ Docket UG-22____

FIFTH EXHIBIT (NONCONFIDENTIAL) TO THE PREFILED DIRECT TESTIMONY OF

RYAN P. BLOOD

ON BEHALF OF PUGET SOUND ENERGY

JANUARY 31, 2022

Seepage Reduction Alternatives
Lower Baker Dam
Concrete, Washington

July 7, 2017

SHANNON & WILSON, INC.

GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

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21-1-22284-005

EXECUTIVE SUMMARY

This report presents alternatives to reduce seepage through the Lower Baker Dam (LBD) foundation and abutments. It provides descriptions of seepage reduction alternatives selected for further consideration, a preferred alternative, and alternatives considered but discounted.

The LBD is a 285-foot-high by 570-foot-long (crest length) concrete semi-gravity arch dam on the Baker River, about 1 mile upstream of Concrete, Washington. The dam was constructed in 1925 and impounds Lake Shannon. The dam has a history of seepage through the foundation and abutment bedrock. Leakage into the plunge pool from the downstream slope near the dam-foundation/abutment contact and through bedrock joints was measured at between 160 and 170 cubic feet per second in early April 2017 using down-looker leakage flow monitoring instrumentation.

Previous foundation grouting programs have been implemented at LBD in 1934, 1959, and 1982. These programs each used bitumen grout or a combination of bitumen grout, cementitious, and chemical grout. Seepage was reduced after each grouting program compared to the pre-grouting program seepage flow. Seepage increased to pre-grouting levels within a few decades after completing each grouting program.

Alternatives considered to reduce seepage included the following:

1. Low hydraulic conductivity blanket over the reservoir bottom upstream of the dam,
2. Cutoff wall,
3. Grout curtain,
4. Grouting debris and soil just above its contact with bedrock in the reservoir just upstream of the dam,
5. Injecting gravel and sand through the debris upstream of the reservoir to partially fill joints and fractures, and
6. Constructing a new dam downstream of the existing dam.

The recommended preferred approach is to both grout debris and soil above the bedrock (Alternative 4) and institute a foundation grouting program to construct a multiple-line grout curtain (Alternative 3). The primary differences between the proposed grouting program and prior LBD grouting programs is that the objective would be to construct a multi-line grout curtain that is wider, longer, and extends to a lower elevation than prior LBD seepage reduction grouting attempts.

The grout curtain would be constructed using a combination of low-mobility bitumen grout, low-mobility cementitious grout, and higher-mobility cementitious grout. Drilling for grouting would be advanced across the dam by drilling through the dam crest or through the downstream dam face. The grout curtain lines would continue off the dam into each abutment. Low-mobility grouting would be conducted first, along the downstream grout curtain line. Subsequent grouting along grout lines upstream of the low-mobility grout line would use higher-mobility cementitious grout. Supplemental grout holes would be added in each grout line and in areas where grout takes are high or grouting challenges encountered, as necessary, to achieve cutoff. Grouting debris upstream of the dam just above the bedrock contact would be implemented in conjunction with this alternative.

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SEEPAGE REDUCTION ALTERNATIVES
LOWER BAKER DAM
CONCRETE, WASHINGTON

1.0 INTRODUCTION, AUTHORIZATION, AND APPROACH

1.1 Introduction

The Lower Baker Dam (LBD) is a 285-foot-high by 570-foot-long (crest length) concrete semi-gravity arch dam on the Baker River, about 1 mile upstream of Concrete, Washington. The dam was constructed in 1925 and impounds Lake Shannon. The dam has a history of seepage through the foundation and abutment bedrock, with leakage first observed soon after impoundment of water behind LBD in 1925. Leakage into the plunge pool from the downstream slope near the dam-foundation/abutment contact and through bedrock joints was measured at between 160 and 170 cubic feet per second in early April 2017 using down-looker leakage flow monitoring instrumentation. Geologic and hydrogeologic interpretation of the foundation and abutment bedrock and seepage through it are discussed in Tetra Tech (2016).

This report presents alternatives to reduce seepage through the LBD foundation and abutments. The report is divided into four parts:

1. An introductory section presenting background on the purpose of implementing seepage reduction measures.
2. Descriptions of seepage reduction alternatives selected for further consideration.
3. A discussion of tradeoffs between the selected seepage reduction measures.
4. Discussion of the preferred alternative(s).
5. Appendix A presents seepage reduction alternatives considered but discounted as not practical or cost effective or presenting excessive environmental or construction challenges.

To reduce leakage, foundation and abutment grouting programs were conducted in 1934, 1959, and 1982. The last grouting program was completed in 1982. Seepage was reduced after each grouting program compared to the pre-grouting program seepage flow. Seepage increased to pre-grouting levels within a few decades after completing each grouting program (Tetra Tech, 2016).

1.2 Authorization

Puget Sound Energy (PSE) authorized Shannon & Wilson, Inc. (Shannon & Wilson) to conduct the seepage reduction study discussed in this report to identify measures that might be implemented to reduce seepage through the dam foundation and abutments and that would be longer-lasting than the previously performed foundation grouting programs. This authorization was provided under Change Order No. 3 to Statement of Work to PSE Outline Agreement No. 4600009716: Task 6 – Seepage Reduction Alternatives Analysis, signed by PSE February 28, 2017.

1.3 Approach to Developing Seepage Reduction Alternatives

We performed the following activities to develop the seepage reduction alternatives presented in this report:

- Met with PSE to discuss their objectives, schedule, and approach for this work.
- Reviewed selected LBD documents.
- Reviewed selected papers and references in the engineering literature on seepage cutoff walls, dam foundation grouting, and seepage reduction measures implemented at other dams.
- Conducted a brainstorming session with participants from Shannon & Wilson and Hatch, Ltd. (Hatch) to identify potential seepage reduction alternatives and discuss pros, cons, constructability, cost, and risks associated with implementing each alternative.
- Met with PSE representatives to discuss the seepage reduction alternatives identified during the March 21, 2017, brainstorming session and follow-up discussion with March 21, 2017, session participants.
- Further evaluated selected alternatives and prepared this report.

The seepage reduction alternatives identified were evaluated according to their effectiveness at reducing seepage, construction means and methods, and general costs as compared to the other alternatives considered. A list of pros, cons, risks, and environmental considerations was developed and used to evaluate the relative merits of each alternative.

2.0 SEEPAGE REDUCTION ALTERNATIVES

2.1 General

Shannon & Wilson and Hatch representatives conducted a brainstorming session at Shannon & Wilson's Seattle office on March 21, 2017. Potential seepage reduction alternatives identified at this meeting and through follow-up discussions with meeting participants are presented in the body of this report and Appendix A. We grouped LBD seepage reduction alternatives identified by the predominant seepage reduction method that would be employed.

- Alternative 1: Blanket the reservoir bottom and slopes using soil filters, low hydraulic conductivity soil blanket, and geomembranes
- Alternative 2: Cutoff wall
- Alternative 3: Grout curtain
- Alternative 4: Grout debris in reservoir upstream of dam
- Alternative 5: Use gravel and sand to partially plug the upstream entrance to joints where seepage flow is concentrated
- Alternative 6: Construct new dam downstream of the existing dam

We considered several permutations on Alternatives 1, 2, and 3.

Shannon & Wilson and PSE representatives met at Shannon & Wilson's Seattle office on April 12, 2017, to discuss the seepage reduction alternatives identified. At this meeting, seepage reduction alternatives warranting further assessment were selected. Alternatives selected for further consideration are discussed in the body of this report. Alternatives deemed not worth considering further are presented in Appendix A. Alternative permutations are identified by adding an alphabetic or alpha-numeric designation following the alternative number.

The following alternatives were selected as warranting further consideration.

- Alternative 1A: Blanket sinkholes upstream of dam
- Alternative 2D: Cutoff wall and grout curtain combination – upstream of dam
- Alternative 3A: Grout curtain – drilling from top of dam and from abutments
- Alternative 3D: Grout curtain – inclined drilling through dam from barge upstream of dam
- Alternative 3E: Grout curtain – drilling from downstream dam face
- Alternative 3F: Grout curtain – vertical drilling from barge upstream of dam

Alternative 4: Grout debris in reservoir upstream of dam

The pros, cons, risks, potential failure modes, relative cost, and construction schedule for each of the above alternatives are presented in this report. Alternatives identified as not warranting further consideration are described in Appendix A. Alternatives described in Appendix A were discarded based on perceived construction challenges, potential construction risks, challenging construction access, uncertainty in successful implementation, potential environmental impacts, and cost.

Alternatives that included a cutoff wall and/or a grout curtain are considered to have the highest potential to be successfully implemented to provide long-term, reliable seepage reduction. We considered four cutoff wall concepts. Alternative 2D, the combination cutoff wall-grout curtain system, was selected for further consideration to take advantage of potential benefits of cutoff wall construction across parts of the dam and to use less costly and easier-to-implement grouting techniques at great depths, on steep slopes, in difficult access areas, and into the abutments.

We considered seven grout curtain alternatives. We selected four grout curtain alternatives for further consideration: Alternatives 3A and 3D through 3F. Alternatives 3B, 3B-2, and 3C, which include grouting from constructed adits or shafts, were discarded because of perceived construction risks associated with groundwater flow into adits and shafts, construction access challenges, and potential to affect structural integrity of the dam.

Alternatives 1A and 4 were identified as measures that may improve success of cutoff wall and grout curtain construction if they are implemented prior to cutoff wall or grout curtain construction. Alternatives 1A and 4 may only temporarily or locally reduce seepage volume and velocity. Consequently, they are considered as unlikely to provide reliable long-term seepage reduction. Alternatives 1A and 4 are proposed to be used in combination with cutoff wall and grout curtain alternatives.

2.2 Alternative 1A: Blanket Forebay Depression Upstream of Dam

Alternative 1A consists of filling the throat of a location of observed concentrated flow of water into sediment on the reservoir bottom (sinkhole) in the forebay (Exhibit Alt 1A-1) and constructing a blanket over the forebay depressions (Exhibits Alt 1A-2 through Alt 1A-4). The objective of Alternative 1A is to reduce seepage and seepage velocities through bedrock joints and fractures in the dam foundation and increase potential for successful completion of cutoff wall or grout curtain construction.

Bathymetry collected in 2012 indicates depressions in the reservoir bottom of the forebay upstream of the dam (Tetra Tech, 2106). Underwater video collected using a remotely operated vehicle (ROV) documented concentrated flow from the reservoir into the soil and debris on the bottom of the reservoir. Dye tests conducted in 2015 confirmed direct and rapid hydraulic connection between flow into the sinkholes and flow emerging downstream of the dam. Only a couple of minutes passed between dye injection near the sinkhole entrances and dye emerging in water downstream of the dam (Tetra Tech, 2106).

High-volume and high-velocity flow through joints and fractures in the bedrock below the dam could interfere with successful construction of either a concrete cutoff wall or a grout curtain. Alternative 1A would consist of constructing a blanket over the forebay depression to reduce flow into the bedrock joints and fractures. The blanket would consist of a filter of cobbles, gravel, and sand and a cap over the filter consisting of silt, clay, or a geomembrane. The concept of constructing the blanket would be to reduce the flow from the reservoir into the bedrock joints and fractures. Implementing Alternative 1A may reduce seepage flow velocities sufficiently to improve chances for successful cutoff wall and grout curtain construction.

Alternative 1A would be conducted working from barges in the reservoir. One means to construct the filter for the blanket would be to sequentially drop cobbles, gravel, and sand through the water column to construct a filter. Silt or clay capping soil would be dropped through the water column to construct a soil blanket layer after the filter is constructed. Accurately and reliably constructing the filter by dropping the soil through nearly 200 feet of water would be difficult. Tremie pipes, hoppers, clamshells, and other systems that deliver the material to near the reservoir bottom before being released would improve construction effectiveness and reduce material quantities.

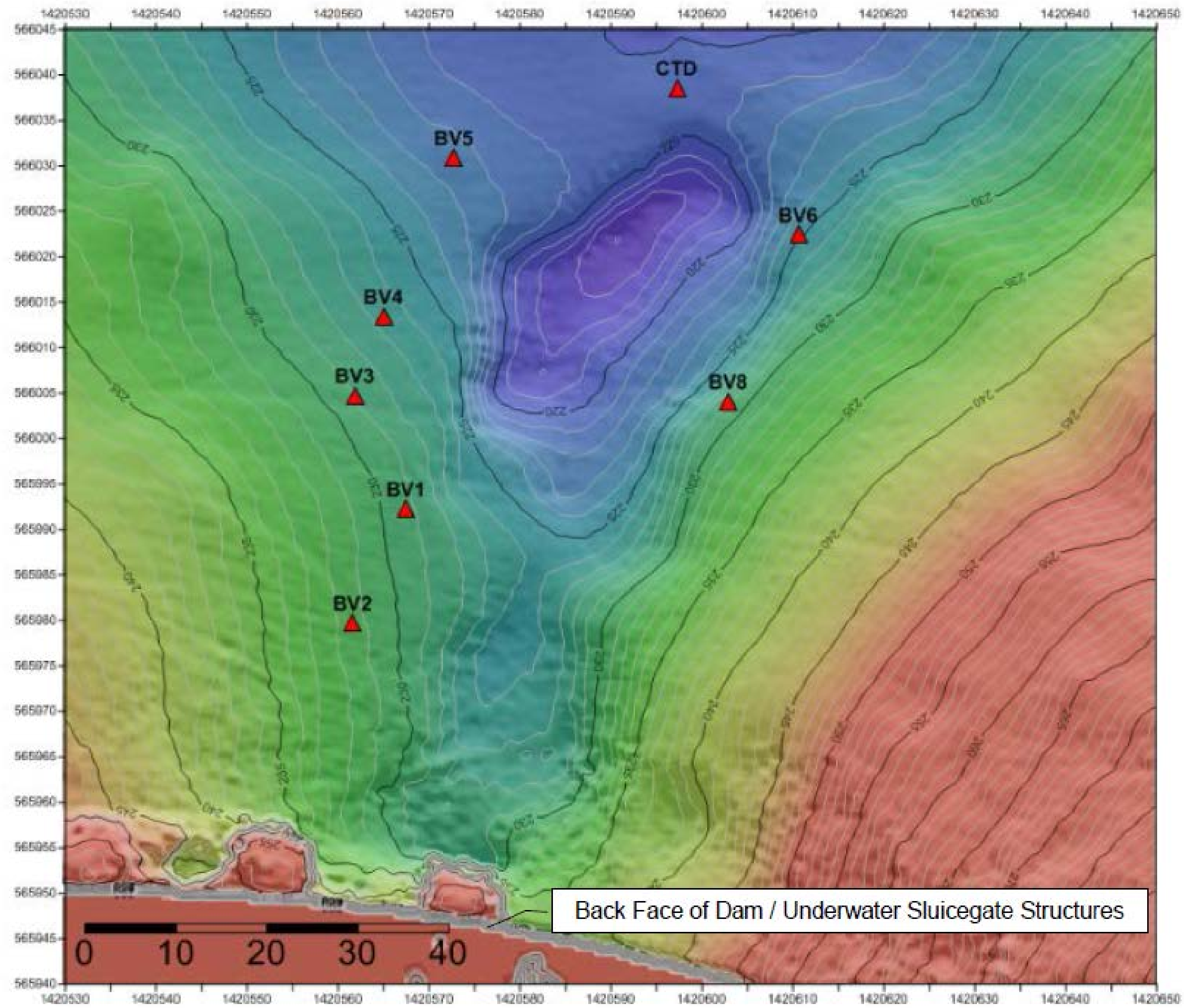

Figure 2-3. BlueView and ACDP Deployment Stations and CTD Cast Location

Exhibit Alt 1A-1: Bathymetric survey of depressions and sinkhole in reservoir bottom upstream of LBD (Tetra Tech, 2016)

As an alternative to a silt or clay blanket, a geomembrane could be placed over the filter to reduce flow-through into the sediment and debris in the reservoir bottom. Geomembrane placement would likely require the use of ROVs and divers.

The effectiveness of this alternative is uncertain, because flow into sediment beyond the limits of the blanket may be of such magnitude that placing a blanket over only a portion of the sediment in the forebay does not significantly reduce seepage flow and velocities through joints and fractures. Hydraulic modeling should be performed to evaluate the potential effectiveness of Alternative 1A before it is implemented.

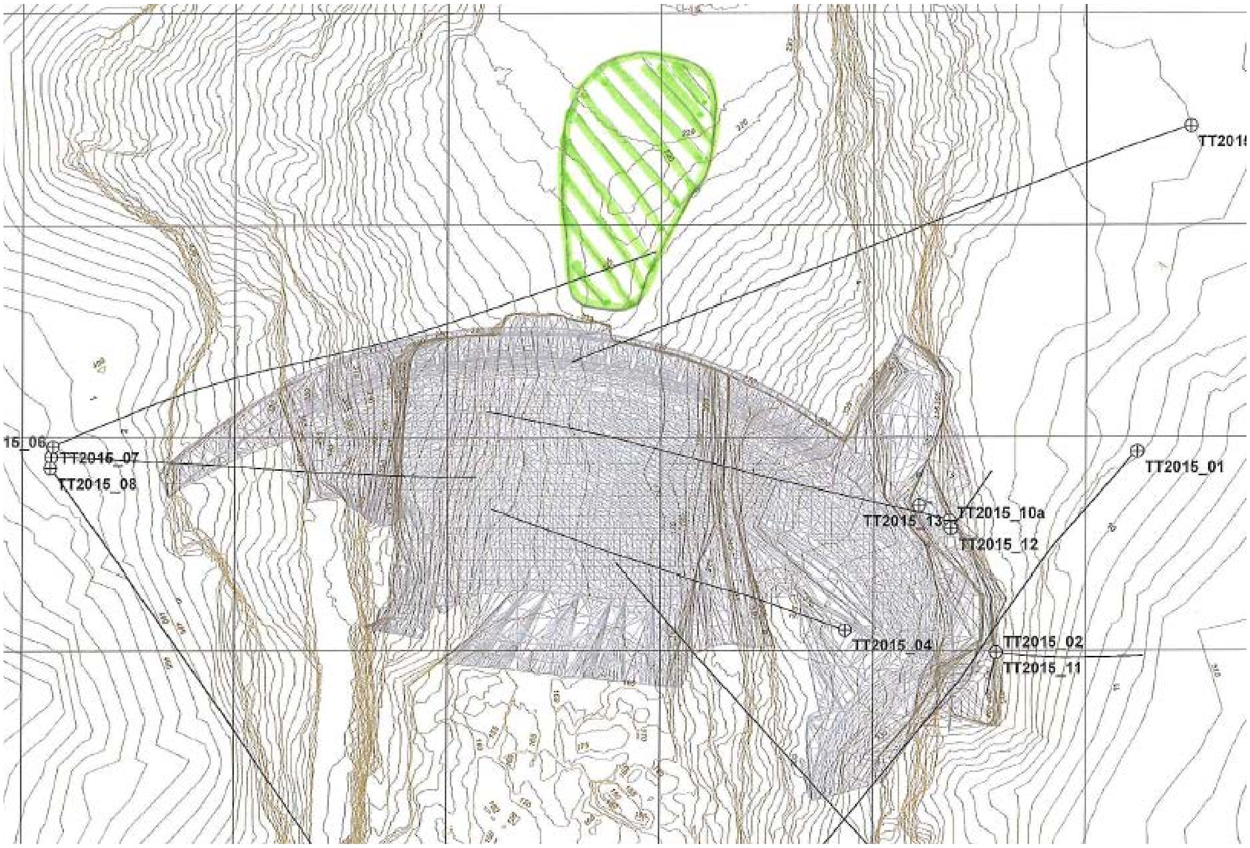

Exhibit Alt 1A-2: Blanket over forebay depressions, plan view

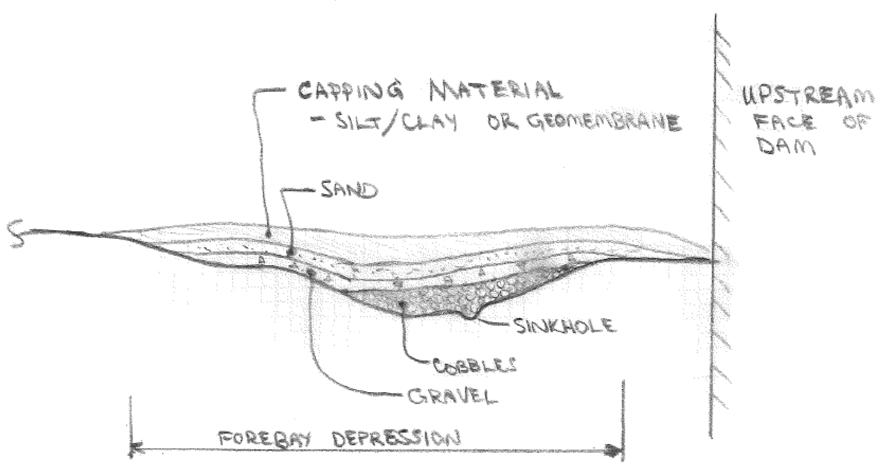

Exhibit Alt 1A-3: Blanket over forebay depression, detail

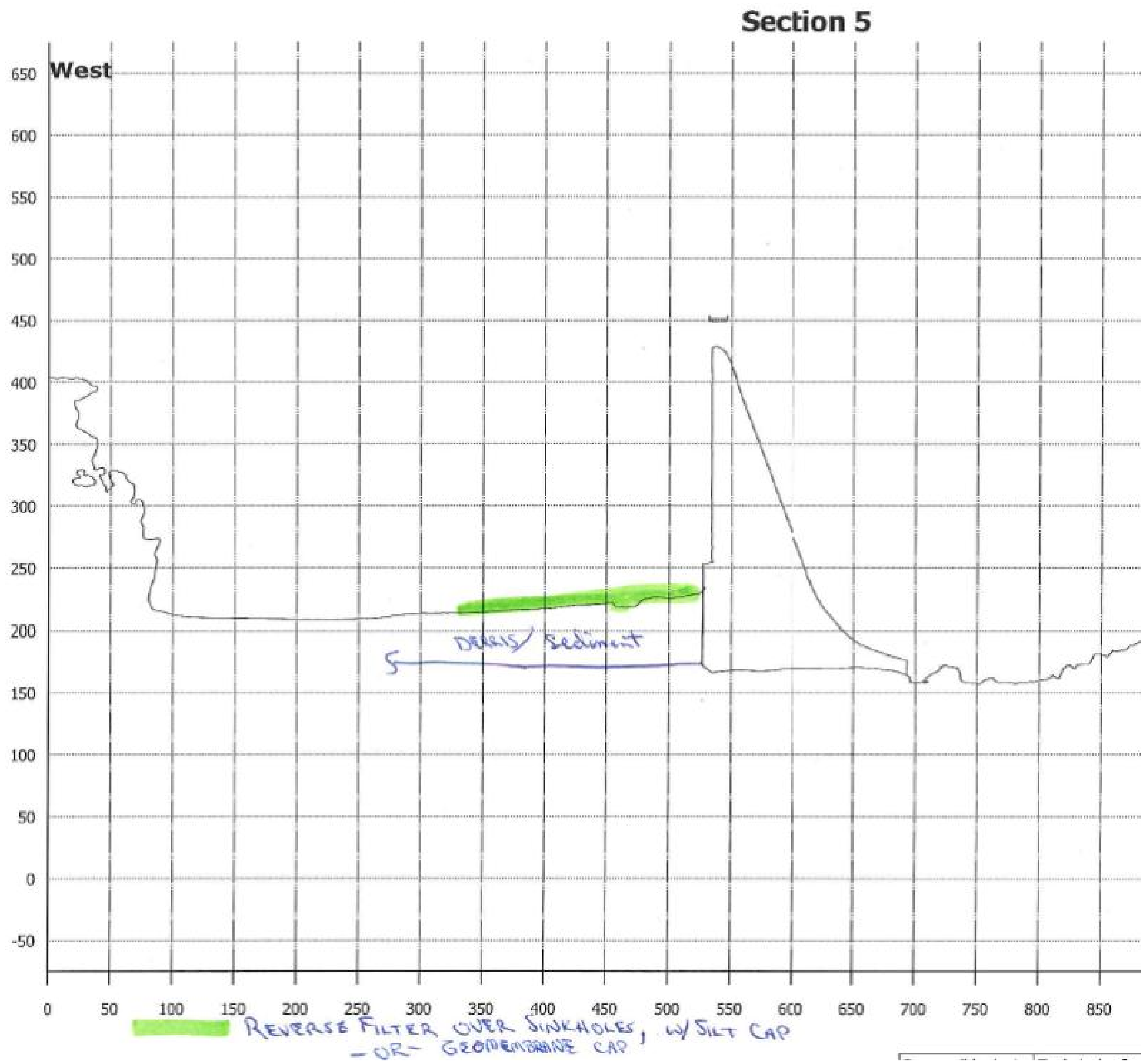

Exhibit Alt 1A-4: Blanket over forebay depressions, section perpendicular to dam

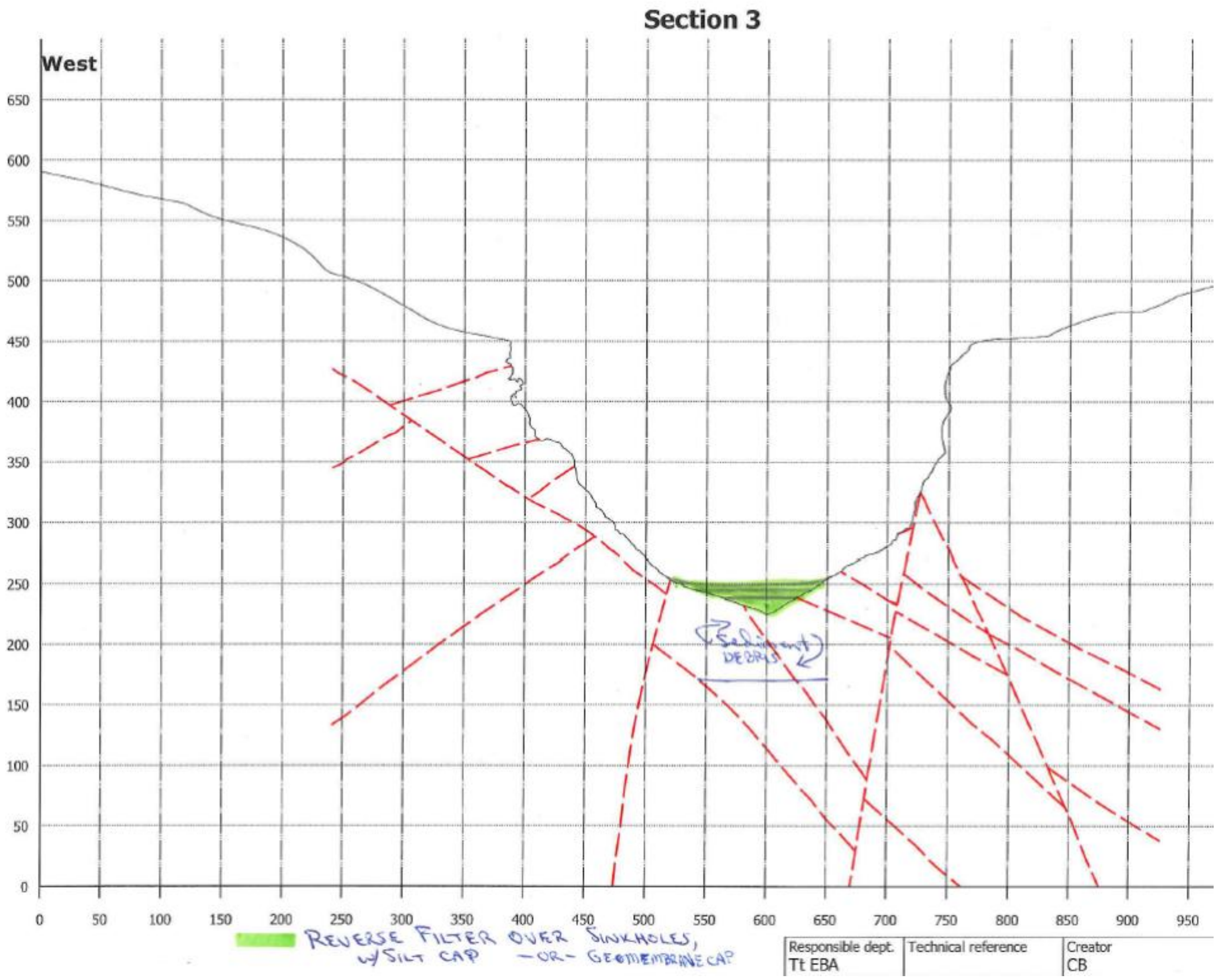

Exhibit Alt 1A-5: Blanket over forebay depressions, cross section

2.2.1.1 Pros

- Reduction of flow below the dam may result from blanket construction over the forebay depressions and where high-velocity flow into a sinkhole was documented in 2015. Reducing flow into sediment and debris in the forebay and sinkholes may reduce flow volume and velocity through fractures and joints below the dam.
- Reservoir elevation would not need to be lowered to facilitate fill placement, although lowering the reservoir may be beneficial.
- Placing a blanket over the forebay depression may reduce seepage volumes and flow velocities through fractures and joints to tolerable levels such that other seepage reduction measures are more easily constructed (e.g., cutoff wall and grouting).

- ROVs, instead of divers, could likely be used to perform the majority of inspections to check on material placement during filter and blanket construction.

2.2.1.2 Cons

- Power production may need to be stopped or reduced during construction activities to reduce potential for damage to the tunnel and turbines by turbid water.
- Dropping of soil through the nearly 200-foot water column results in uncontrolled material placement; the filter and soil blanket may not be continuous or uniform and may not be as effective as if the material were placed in a more controlled manner. Use of tremies, hoppers, clamshells, and other methods where the soil is lowered through the water column and delivered closer to its intended location would improve effectiveness and reduce material volume.
- Difficulty placing, seaming, and anchoring geomembrane below water.
- Divers may be required for portions of the work, e.g., confirming adequate extent of filter and soil cover, shaping of slopes and bottom, and assisting with geomembrane placement and anchoring. Diver visibility will be limited, likely to only a few feet.
- Placing a geomembrane over the filter soils and producing an adequate seal around the edges would likely be difficult in 200 plus feet of water.
- Placing the blanket over only a portion of the sediment in the forebay may not result in much reduction in seepage, because flow-through sediment beyond the limits of the blanket may be significant.

2.2.1.3 Risks and Potential Failure Modes

- Factors contributing to sinkhole and depression formation have not been definitively confirmed. Material loss into bedrock joints and fractures is believed to be the cause. The discharge point(s) for flow entering bedrock joints and fractures, and contributing to forebay depression development, have not been confirmed, e.g., it has not been confirmed that the majority of flow from the reservoir into the bedrock flows under the dam to discharge in the river immediately downstream of the dam.
- This effort may only result in a temporary seepage flow reduction, if a seepage flow reduction occurs, because seepage into debris and sediment on the reservoir bottom that is exposed adjacent to the blanket is likely.
- Internal erosion may occur within the approximately 50-foot-thick deposit of debris and sediment on the reservoir bottom, allowing formation of new preferential flow paths.
- Dropping of soil through the water column could result in some of this soil being pulled into the intake tunnel if the intake flow is not shut off during fill placement. This risk could be mitigated by using material placement methods that did not release

the material until it is close to its intended deposition location, e.g., tremies, hoppers, and clamshells that are lowered through the water column.

- Operating a barge and construction operation upstream of spillway gates and intake tunnel presents risk of damage to the LBD facility, e.g., should the barge break loose from its anchors.

2.2.1.4 Relative Cost

- Low to moderate, as compared to the other alternatives.

2.2.1.5 Constructability

- There are likely multiple marine contractors capable of delivering and placing soil through the water column to construct the soil filter and silt or geomembrane blanket.
- Access to the reservoir to launch barges and to transfer equipment, materials, and personnel to barges could be constructed a few hundred feet upstream of the left abutment adjacent to the fish pier.
- A crane operating from a barge and fitted with a grab or clamshell could be used to place filter material and silt capping material in a more controlled manner than would occur if the material is dropped through the entire water column.
- A crane operating from a barge and fitted with a grab or clamshell may need to be employed to rearrange and level materials if the material does not spread sufficiently when dropped.
- A significantly larger quantity of material will likely need to be purchased and placed than would be required if the work were constructed in a more controlled manner.
- ROVs could likely be used to reduce the level to which divers are used. ROVs could check the filter and blanket construction and be able to help place geomembrane.
- Low visibility is likely to interfere with ROV and diver abilities to assist with and assess construction.
- Cameras and scanning equipment could be lowered from a barge or boat to inspect placement.

2.2.1.6 Environmental Considerations and Permitting

- Dropping or placing of silt into the reservoir would increase water turbidity. Turbidity increase would be less affected when coarser materials that would be used to construct the filter (cobbles, gravel, sand) are dropped through the water column.
- Fish below the fill drop area in the lake may be directly impacted as the materials settle through the water column. Fish impacts may be limited, because the construction area is downstream of the floating surface collector fish screens.

- Use of a geomembrane cap instead of silt would reduce water turbidity during construction.
- Turbid, silt-laden water could spread laterally from the work area into the reservoir, thus affecting a larger area than the blanket footprint.
- Turbid, silt-laden water could flow into the intake tunnel, through the turbines, and discharge to the river downstream.
- Relative impact to water quality associated with soil placement in the reservoir might be reduced by performing soil placement during periods of high runoff when the background sediment load in the Baker and Skagit rivers is high.
- Based on past dye testing and observations, some sediment and turbid water could flow through the joints and fractures below the dam, to discharge in the river downstream, during the early stages of filter construction.
- Permitting from multiple state and federal agencies would be required.

2.2.1.7 Schedule

- Flexible construction schedule.
- Could be performed almost any time of year, allowing scheduling around fish windows.
- Potential to complete in less than six months.

2.3 Alternative 4: Grout Debris in Reservoir Upstream of Dam

Alternative 4 consists of grouting voids in debris and sediment that overlie the bedrock and cover the reservoir bottom upstream of the dam (Exhibit Alt 4-1), thus creating a grout blanket above the bedrock (Exhibits Alt 4-2 through Alt 4-4). Alternative 4 includes targeted filling and grouting of bedrock faults, joints, and fractures that have been identified as conduits for high seepage below the dam, such as those shown in Exhibit Alt 4-4. The objective of Alternative 4 is to reduce seepage through bedrock joints and fractures in the dam foundation and abutments so as to increase potential for successful completion of cutoff wall or grout curtain construction. Alternative 4 grouting would be performed in a few-feet-thick zone immediately above the bedrock to cap and plug fractures in the bedrock through which water flows from the reservoir into the bedrock. Alternative 4 would include targeted drilling into known faults, joints, and fractures to grout those features. Where very high flow occurs, this alternative includes drilling 4- to 8-inch-diameter holes and tremie-ing gravel and sand into the bedrock openings to reduce flow velocities prior to injecting grout.

Explorations, geologic interpretation, review of LBD construction photographs, and reservoir bathymetry suggest there is about 50 to 70 feet of debris and sediment overlying bedrock upstream of the dam. The debris consists of remains of a rock-filled timber crib cofferdam built for and abandoned after LBD construction, formwork timber associated with LBD construction, material excavated from the intake tunnel on the left abutment, and landslide debris from the slopes upstream of the right abutment (Tetra Tech, 2016). Where material excavated from the tunnel was dumped down the slope, it is likely that larger boulders and cobbles segregated and rolled to the bottom of the spoil slope. Thus, larger particles with larger voids between them may be present at the debris-bedrock contact than are present higher in the tunnel-excavation debris deposit. These larger voids may be conducive to grouting. Sediment likely consists of material deposited after dam construction.

Underwater video collected using an ROV in 2015 documented concentrated flow from the reservoir into the soil and debris on the bottom of the reservoir (Tetra Tech, 2106). Dye tests conducted in 2015 (Tetra Tech, 2016) confirmed direct and rapid hydraulic connection between flow into the sinkholes in the forebay and flow emerging downstream of the dam. Only a couple of minutes passed between dye injection near the sinkhole entrances and dye emerging in water downstream of the dam. Based on these observations, there are preferential, high-velocity flow paths through the debris, as well as through the bedrock.

Alternative 4 would be conducted using equipment working from barges in the reservoir. Pipe casing would be drilled through the debris to bedrock. Low-mobility cement grout with anti-washout agents or low-mobility bitumen grout flow could be used to fill larger voids, to reduce loss of grout through bedrock joints and fractures, and in areas where high-flow velocity is encountered. Grout consistency would likely need to be varied to penetrate voids in the debris, which is likely highly variable; potentially layered; and consisting of sand, gravel, cobbles, and boulders. If large voids are identified and where the drilling operations encounter an area with direct communication with a large bedrock joint or fracture, the hole could be re-drilled using a larger pipe (4- to 8-inch-diameter) and coarse gravel and sand fed through the pipe to attempt to plug or bridge voids with gravel prior to grouting.

2.3.1.1 Pros

- Constructing a grout blanket by grouting voids in debris above the bedrock would reduce flow volume and velocity through bedrock joints and fractures below the dam.
- The reservoir elevation would not necessarily need to be lowered to facilitate grouting.
- Constructing the grout blanket above the bedrock may reduce seepage volumes and flow velocities through bedrock joints and fractures such that other seepage reduction measures are not required.
- Constructing a grout blanket above the bedrock would likely reduce seepage volumes and flow velocities through bedrock joints and fractures such that a cutoff wall or grout curtain is more readily and more reliably constructed.
- Constructing a grout blanket at the bottom of the debris, just above the bedrock, would likely reduce the magnitude of seepage into the foundation more effectively than Alternative 1A, because the Alternative 4 grouting would occur just above the bedrock and near the bedrock joints and fractures, instead of 50 feet or more above these openings.
- Targeted drilling into and grouting of known bedrock faults, joints, and fractures that extend upstream of the dam would increase effectiveness of this alternative relative to only injecting grout into debris that overlays the bedrock.
- The Alternative 4 drilling and grouting program would better characterize the location of bedrock faults, joints, and fractures. This information could be used to improve the bedrock model and grout curtain construction.
- Monitoring grout takes when grouting the debris while simultaneously monitoring downstream seepage discharge may help to identify the general location where most seepage is entering the bedrock and thereby allow for cutoff wall or curtain grouting to target the area interpreted as contributing the most to the seepage.

- Injecting grout at the bottom of the debris to create a blanket upstream of the dam would have less risk to intake tunnel and turbine operations than Alternative 1A.
- Divers would likely not be needed for the work. ROV-assisted drill steel positioning may be beneficial.

2.3.1.2 Cons

- Uncertainty as to where open joints and fractures are in the bedrock below the debris and sediment in the reservoir bottom upstream of the dam.
- Uncertain penetration of grout into debris and uncertain lateral extent of the resulting grouted debris. Will need to be able to vary the stiffness, flowability, and mix of the grout used to grout the debris.
- Uncertainty as to where the grout flows within the debris and the continuity of the grout blanket.
- Low visibility is likely to interfere with ROV and diver abilities to assist with and assess construction. Limited grout penetration where debris contains sand and fine-grained soil.
- Potential for grout injected into debris to be washed through bedrock joints and fractures and into the river downstream of the dam.
- Work would be performed inside the reservoir, increasing the potential for drilling fluids, spoils, or cement to get in reservoir water.
- Drilling through timber within debris in the reservoir will present challenges.

2.3.1.3 Risks and Potential Failure Modes

- This effort may only result in a temporary seepage flow reduction, if relied on as the primary seepage reduction measure, because of progressive erosion of debris in areas that are not grouted or not well grouted, or through creation of a new primary seepage path through the debris and into bedrock joints and fractures upstream of the grout blanket.
- Incomplete blanket creation.
- Operation of a barge and construction operation upstream of spillway gates and intake tunnel presents risk of damage to the LBD facility, e.g., should the barge break loose of its anchors.
- Transport of grout material through joints and fractures and discharge of cementitious grout into water downstream of the dam.

Puget Sound Energy 2016 Lower Baker Dam Interpretive Report

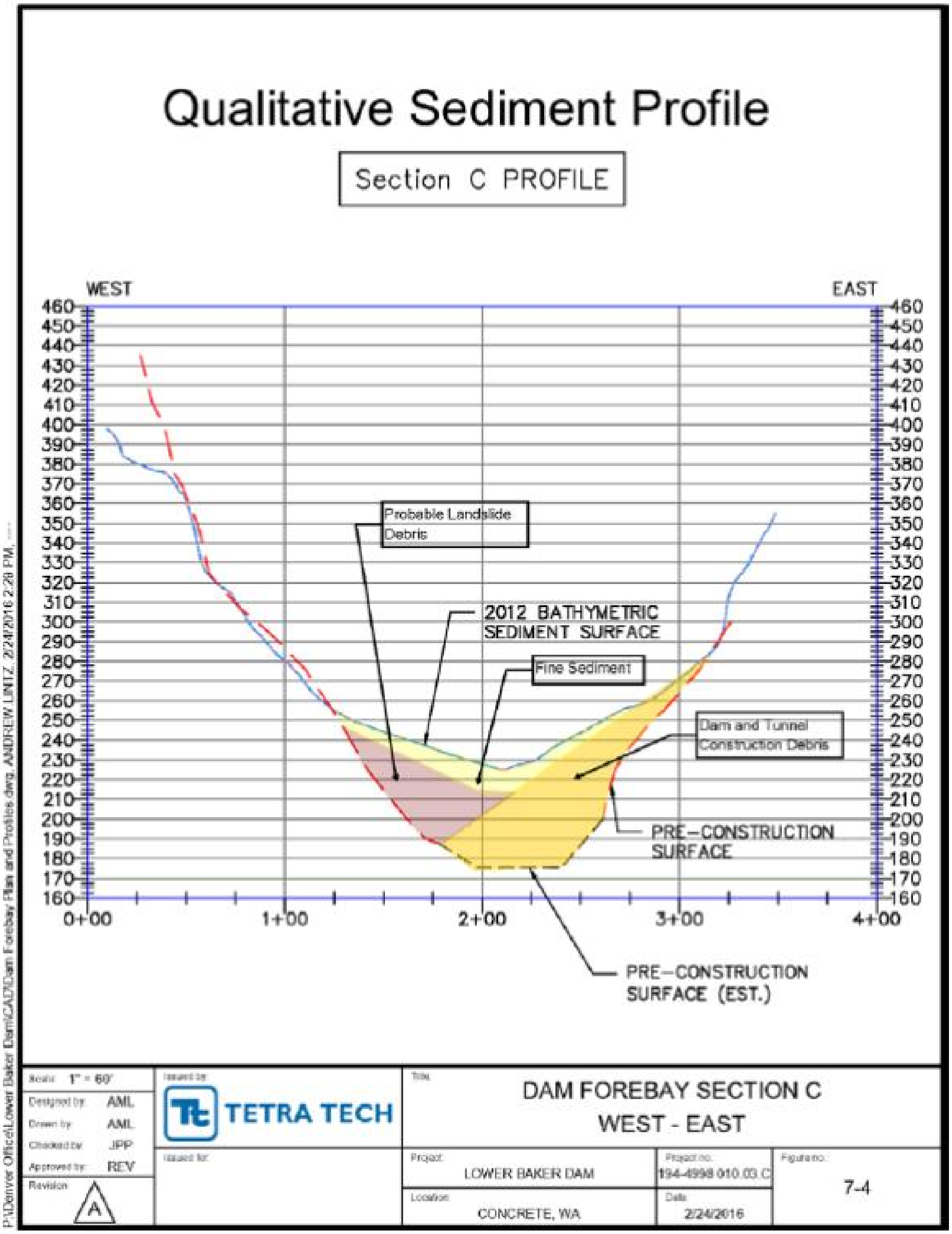

Figure 7-4: Dam Forebay Section C

Exhibit Alt 4-1: Debris and sediment upstream of LBD, cross section (Tetra Tech, 2016)

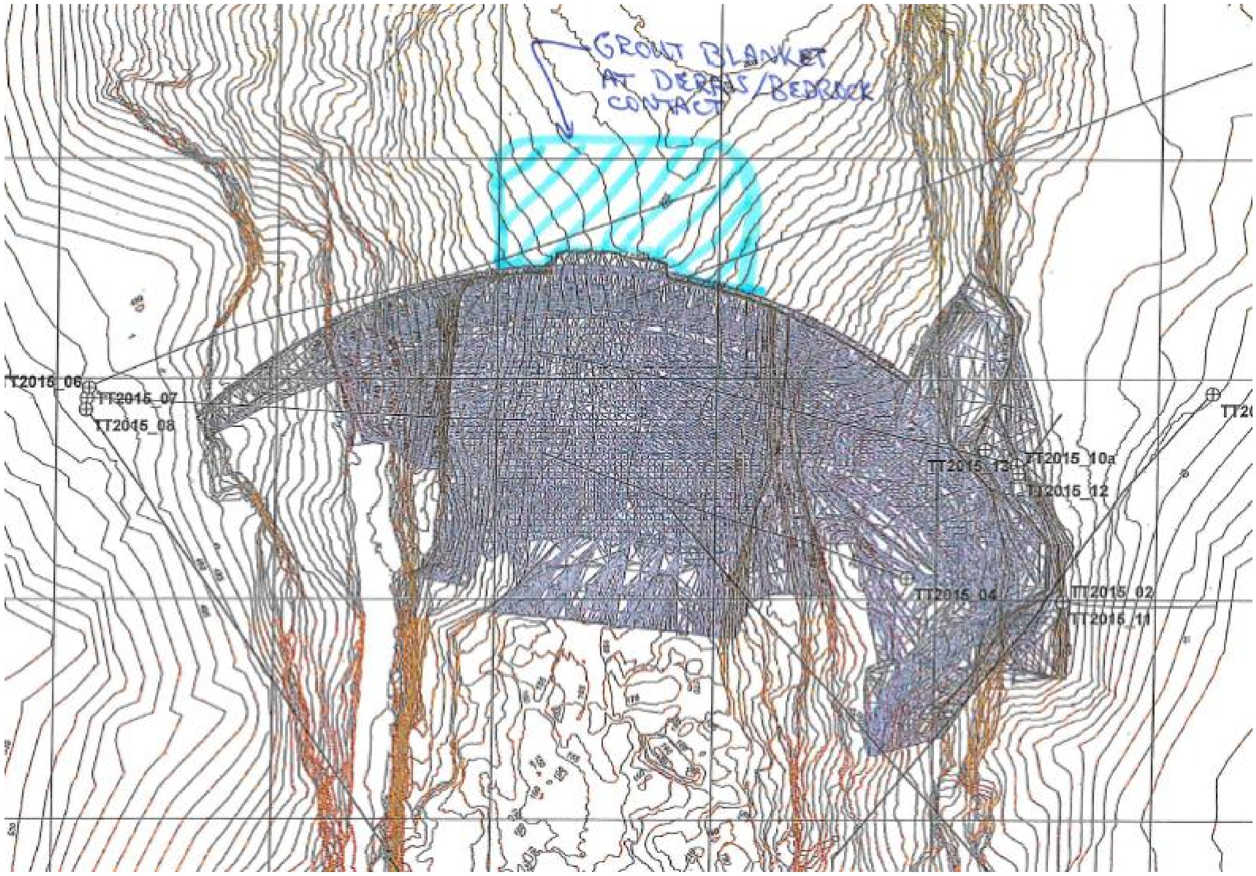

Exhibit Alt 4-2: Grout blanket in debris upstream of LBD, plan view

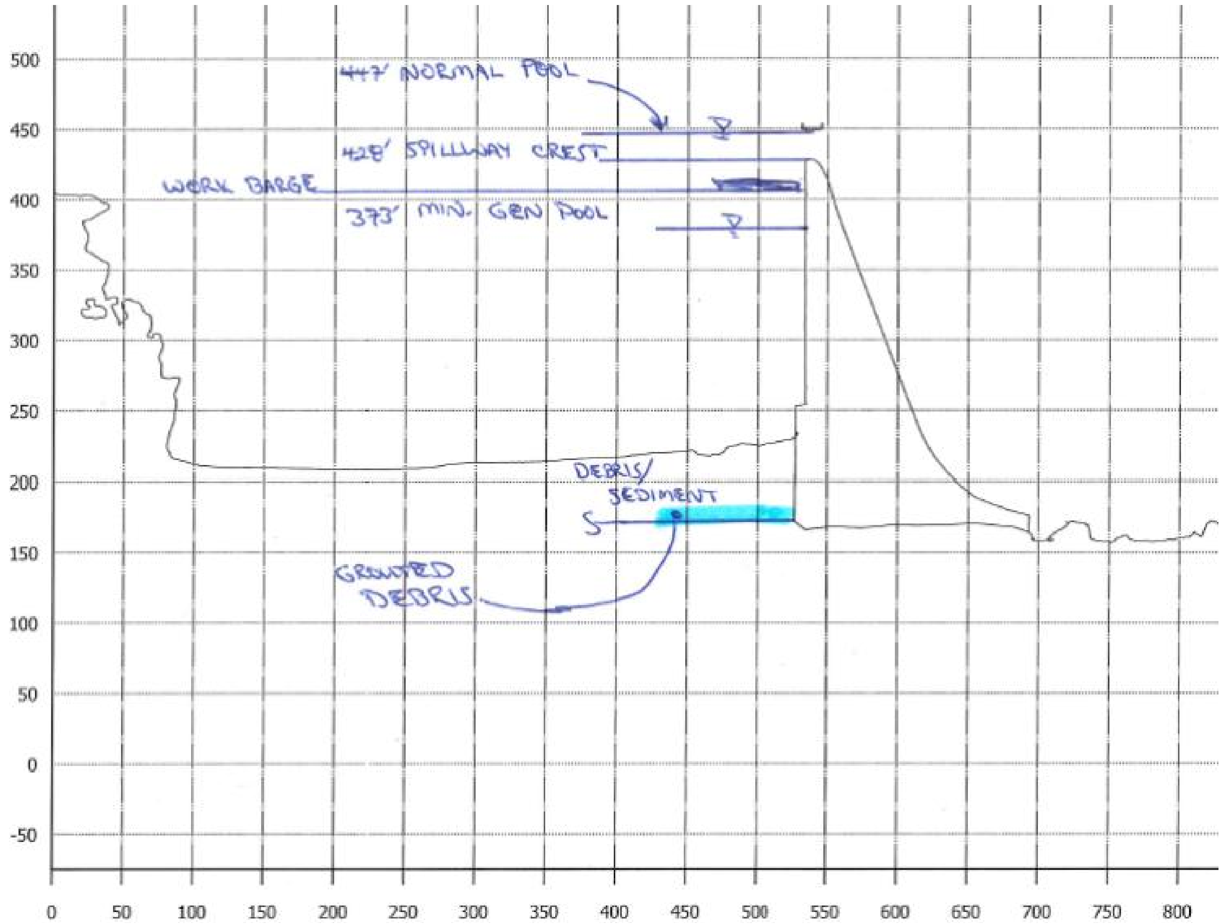

Exhibit Alt 4-3: Grout blanket in debris upstream of LBD, section perpendicular to dam

2.3.1.4 Relative Cost

- Moderate, as compared to the other alternatives.

2.3.1.5 Constructability

- Construction of the grout blanket at the bottom of 50 to 70 feet of debris in over 200 feet of water while working from barges will be challenging.
- Access to the reservoir to launch barges and to transfer equipment, materials, and personnel to barges could be constructed a few hundred feet upstream of the left abutment adjacent to the fish pier.

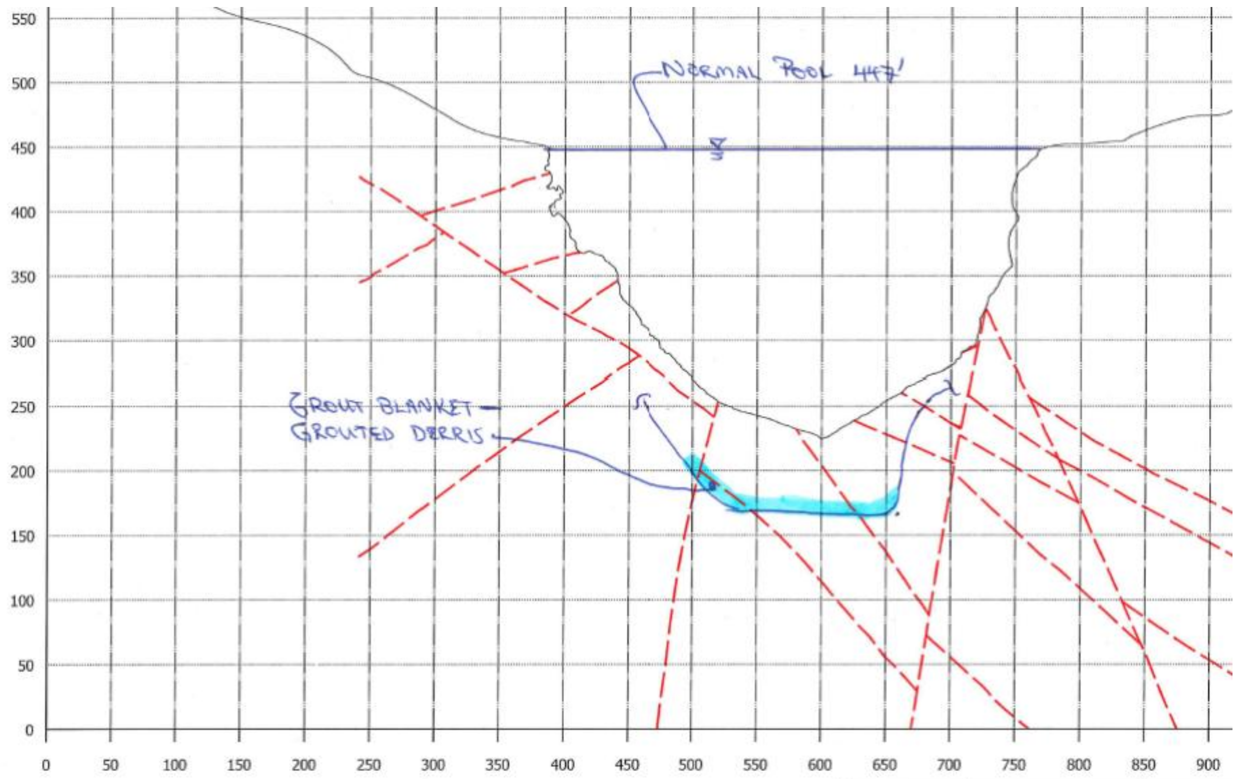

Exhibit Alt 4-4: Grout blanket in debris upstream of LBD, cross section

- Positioning the barge and drill bits to reliably and accurately drill and grout the debris will have challenges. ROVs and/or divers may be required.
- Low-mobility bitumen grout or low-mobility cementitious grout might be used for initial grouting of debris near areas where flow into bedrock joints and fractures is known to be concentrated, thereby decreasing potential for grout to wash through the joints and fractures. Using low-mobility grout might increase the potential for the joints and fractures to plug, slowing water flow into the joints and fractures, and allowing for higher-mobility cementitious grout to better penetrate voids in the debris to then be injected.
- Tremie injection of coarse gravel and sand into open faults, joints, and fractures in the bedrock through a casing drilled to bedrock could have some challenges if the gravel and sand is fed too fast down the tremie and the material bridges and plugs the pipe. If successfully injected and the openings are bridged, the potential for successful grouting on the reservoir side of the gravel/sand plug would increase.
- Drilling through the angular debris from the intake tunnel excavation may deflect or damage drill rods and bits. The potential to lose drill rods and bits is high.

2.3.1.6 Environmental Considerations and Permitting

- Drilling and flushing of drill holes may introduce sediment into the reservoir and locally increase turbidity.
- Performing grouting operations from barges within the reservoir presents the possibility of hoses breaking, spills, or grout returning to result in cement getting in the reservoir water.
- Injection of cement grout into the debris and above the bedrock contact presents a high likelihood of cement being washed from the grout through the joints and fractures in the foundation and for this cement to then discharge into the river downstream of the dam.
- Permitting from multiple state and federal agencies would be required.

2.3.1.7 Schedule

- Completed in less than 6 months.

2.4 Alternative 2: Cutoff Wall

2.4.1 Alternative 2D: Cutoff Wall and Grout Curtain Combination – Upstream of Dam

2.4.1.1 Description

Alternative 2D would use a combination of a cutoff wall and grout curtain to reduce seepage through the dam foundations and abutments (Exhibits Alt 2D-1 through Alt 2D-3). The cutoff wall would be constructed just upstream of the upstream face of the dam, across areas of known large voids and documented high seepage flow. The cutoff wall would extend down through sediment and debris and into foundation bedrock to the depth at which the rock joints are known to permit high-volume and high-velocity seepage. The vertical and lateral cutoff wall limits would roughly correspond to areas of previous foundation and abutment grouting. After completing the cutoff wall, construct a grout curtain to reduce flow through foundation and abutment rock below the bottom of the cutoff wall and farther into the abutments where seepage could otherwise occur below or around the cutoff wall. The grout curtain extension below the cutoff wall would include grout lines along the cutoff wall alignment and upstream of the cutoff wall alignment.

Cutoff wall construction and grout curtain construction below the bottom of the cutoff wall would be performed working from a barge in the reservoir. Casing might be installed in cutoff wall elements to allow grout curtain advancement through the cutoff wall without drilling through cutoff wall concrete. Above the reservoir elevation, where operating from a barge is not practical, grout curtain construction on the reservoir slopes and into the abutment would be performed using land-based equipment. The grout curtain would extend into the right and left abutments to a distance to be determined. Cutoff wall and abutment grout curtain work could occur simultaneously.

Alternative 2D has constructability and cost advantages over alternatives considered that consist only of a cutoff wall (e.g., Alternatives 2B and 2C). Grout curtain construction would be more constructible and less costly where:

- Construction equipment and personnel must work on steep slopes of the abutments above the reservoir pool elevation at which barge construction is effective,
- Ensuring cutoff wall overlap or cutoff wall completion at greater depth may be challenging, and
- Seepage velocities through cracks in abutments and at depths below the dam are low enough that grouting is more likely to be successful than it might be in the region

proposed under this alternative for cutoff wall construction, i.e., where large open joints and fractures and high seepage velocities occur.

The cutoff wall would consist of overlapping secant piles, overlapping concrete panels, or interlocking steel pipes. Challenges associated with alternative cutoff wall construction methods are discussed below. The grout curtain would consist of multiple rows of grout holes. Because the cutoff wall would block flow along seepage paths where high seepage rates occur, the grout program would consist of using higher-mobility grout along low-seepage flow joints and fractures.

After cutoff wall and grout curtain construction, construct a seepage blanket that extends from the cutoff wall to the dam face to reduce seepage through the reservoir bottom and abutments in the area between the cutoff wall and the upstream dam face. If the tops of the cutoff wall elements are at the top of bedrock, this seepage blanket could be constructed by injecting low- to higher-mobility grout into debris just above the bedrock contact. If the tops of the cutoff wall elements extend to or near the top of the debris and sediment, the blanket could be constructed by grouting voids in the debris between the cutoff wall elements and the dam for some portion of the debris depth.

Success completing cutoff wall and grout curtain construction may be improved if Alternative 4 and/or both Alternative 1A and 4 are completed prior to constructing the grout curtain and if implementing these alternatives results in decreased seepage flow velocities and volumes.

2.4.1.2 Pros

- This combination of cutoff wall and grout curtain construction may reduce costs that would otherwise incur to develop access and work platforms for cutoff wall construction on steep slopes and other areas above the reservoir elevation. Grout curtain construction should be less expensive to perform in these areas than cutoff wall construction.
- By using grout curtain technology to grout rock at greater depth, the depth of drilling for cutoff wall construction would be reduced compared to a full depth cutoff wall alternative, reducing uncertainty and challenges associated with cutoff wall construction at great depth.
- Access development to conduct grout curtain drilling and grouting into the abutments is not as substantial as would be required to construct cutoff walls into the abutments.

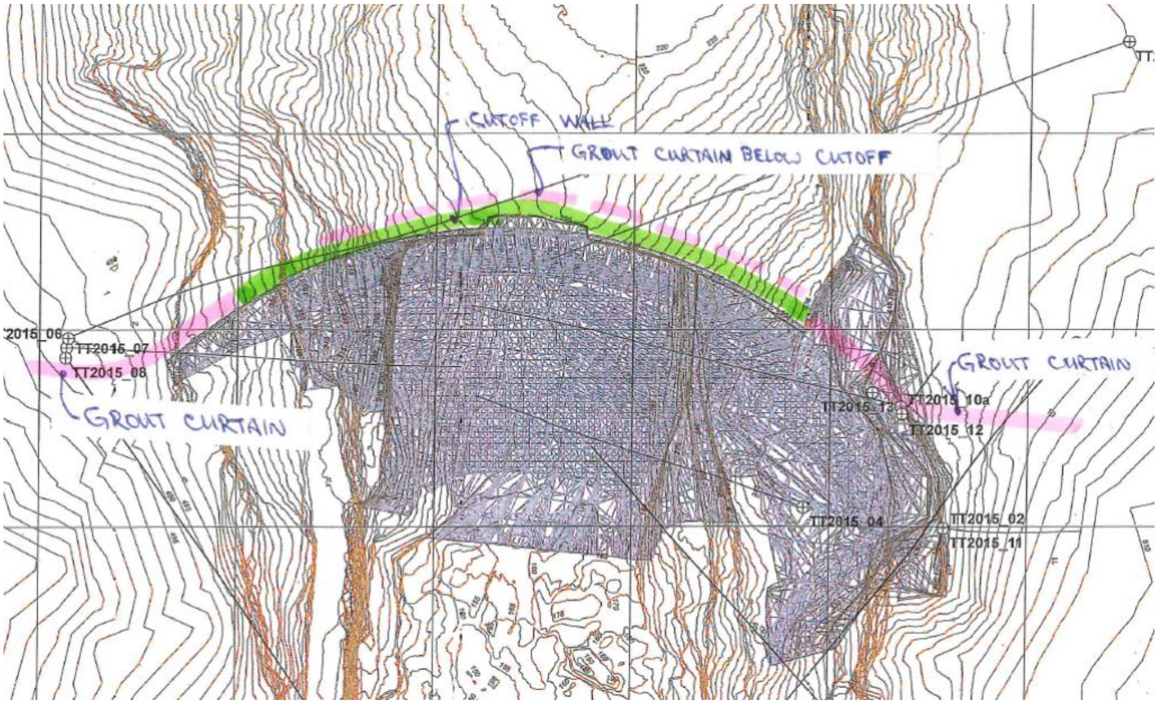

Exhibit Alt 2D-1: Cutoff wall and grout curtain upstream of dam, plan view

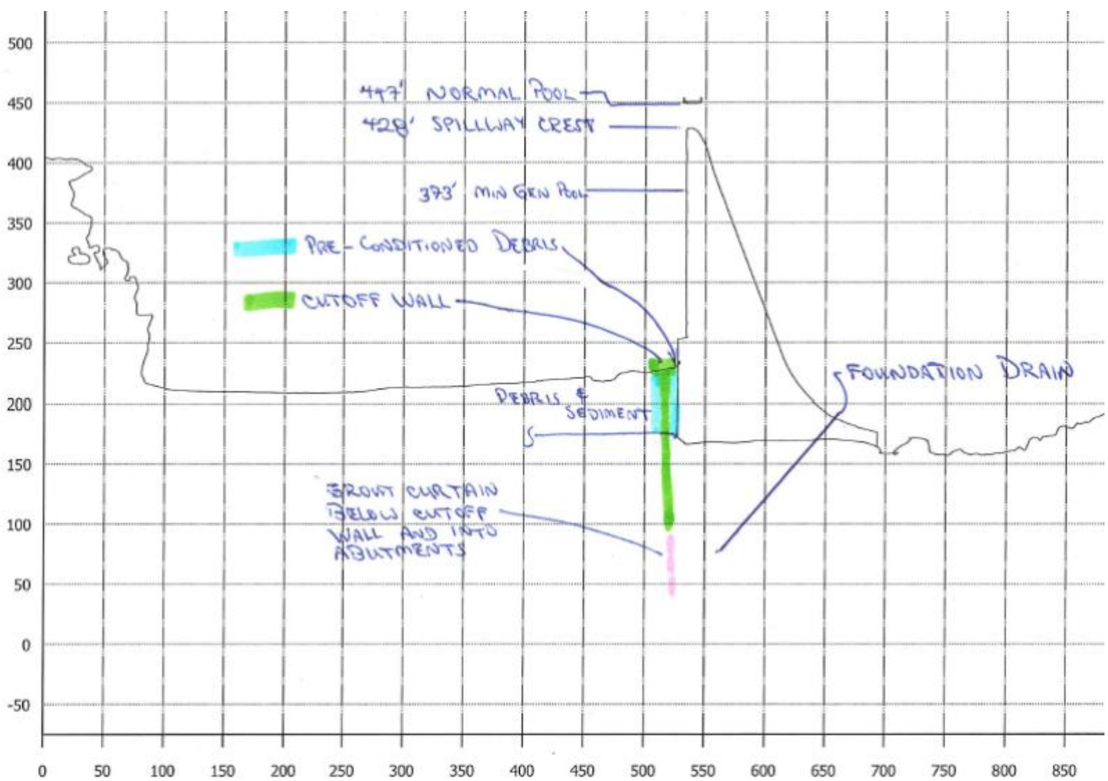

Exhibit Alt 2D-2: Cutoff wall and grout curtain upstream of dam, section perpendicular to dam

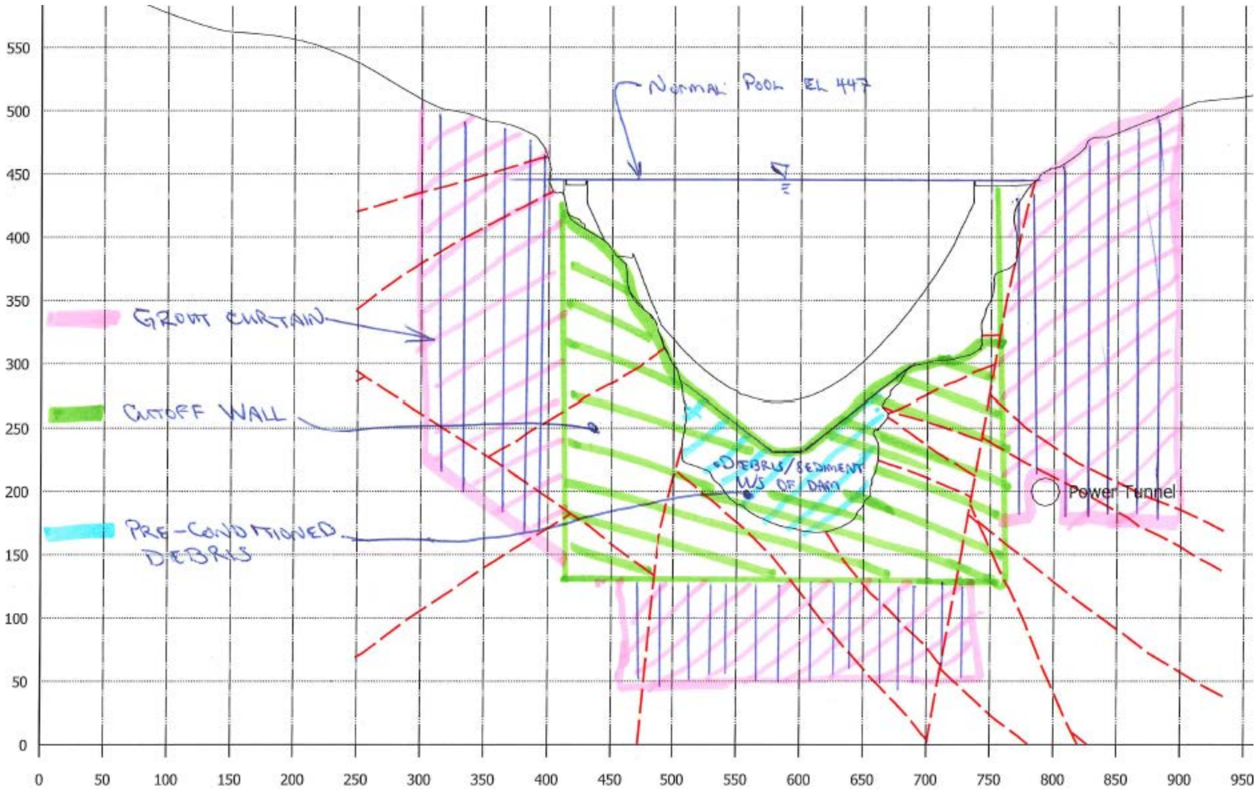

Exhibit Alt 2D-3: Cutoff wall and grout curtain upstream of dam, cross section (grout holes shown vertical–grout holes may be inclined and grout holes in adjacent grout curtain lines drilled at different orientations)

- Extending the grout line between the dam and intake tunnel reduces risks to intake operations associated with constructing a cutoff wall across the front of the intake.
- The cutoff wall is not constructed through the existing dam, thus eliminating risks to the existing dam that would accompany cutoff wall construction through the dam.
- The depth of drilling for cutoff wall construction is reduced compared to the alternative of drilling through the dam from the dam crest.
- Modifications to the spillway and dam crest are not required for cutoff wall or grout curtain construction.
- Access development and working on steep slopes is reduced to only those areas above reservoir water elevation.
- Work barges and equipment can be moved out of the way of the gates and spillway if it is necessary to spill water from the reservoir.

2.4.1.3 Cons

- Would need to perform work under water and through 200 feet of water.

- Work would be performed inside the reservoir, increasing the potential for drilling fluids, spoils, or cement to get in the water.
- Divers would likely be required to aid in constructing a "guide" for cutoff wall and grout curtain construction on the reservoir bottom and up the reservoir sides below the reservoir elevation.
- Divers, an ROV, or underwater camera capability may be required to assist in positioning the drill or cutting tool in the guide at the start of drilling for each cutoff wall element.
- Low visibility is likely to interfere with ROV and diver abilities to assist with and assess construction.
- Drilling through the debris and timber within the debris, and potential for concrete losses into the debris, will present challenges for cutoff wall construction. It may be beneficial to install temporary casing through the debris or necessary to pre-condition the debris to improve reliability of constructing the cutoff wall through it.
- Special equipment may need to be manufactured to construct the cutoff wall.
- Seepage will increase over time in the grout curtain section as water develops new pathways in ungrouted areas presently occupied by poor quality rock mass or erodible filling material. An effective grout program, with multiple grout curtain rows and good grout penetration into rock fractures and joints, would decrease erosion rates and delay opening of new seepage pathways.
- Lowering the reservoir during construction could be necessary, or beneficial, to reduce the depth of water that the work is performed in.
- Difficult access to work area, requiring construction of access, roadways, platforms, and equipment and materials transport systems on the abutment slopes above the reservoir elevation.
- Construction on steep slopes above the reservoir elevation.
- Inclined drilling or drilling and grouting from within the tunnel may be required to complete the grout curtain around the tunnel.

2.4.1.4 Risks and Potential Failure Modes

- Equipment operating immediately upstream of the spillway and near the tunnel inlet is dislodged and damages the dam.
- Hazards to divers working upstream of tunnel intake and to turbines if materials associated with underwater work are pulled into tunnel.
- Shaping of the reservoir bottom and sides to facilitate construction of cutoff wall guide and cutoff wall poses potential for materials to get pulled into the tunnel and impact turbines.

- Cutoff wall elements do not all overlap, resulting in incomplete cutoff.
- Increased seepage through grout curtain as new pathways develop.
- Obstructions are encountered in the debris upstream of the dam that prevent advancement of the cutoff wall elements or deflect them from the intended path.
- Grouting operations could plug, fill, or change flow through existing drains in the dam, which could result in higher uplift pressures below the dam.

2.4.1.5 Relative Cost

- High, as compared to the other alternatives.

2.4.1.6 Constructability

- Construction of a cutoff wall would likely be very challenging because of the water depth, thickness of debris and sediment, sloping bedrock surfaces below the debris and sediment, the large equipment required, the necessity to maintain element verticality and overlap of adjacent elements, and the necessity for all the work to be performed from barges.
- Access to the reservoir to launch barges and to transfer equipment, materials, and personnel to barges could be constructed a few hundred feet upstream of the left abutment adjacent to the fish pier.
- Relatively large barges may be required to support and provide a stable work platform for cutoff wall drilling equipment.
- Pre-conditioning of the debris and sediment along and around the cutoff wall alignment may be beneficial. Benefits include better ability to maintain cutoff wall element position and verticality, removing obstructions in the debris and sediment column prior to construction of the critical secant pile elements, and reducing potential for concrete loss into the debris during casing withdrawal and secant pile construction.
- Pre-conditioning of debris and sediment might consist of constructing a line of low-strength concrete shafts along the cutoff wall alignment. The shafts would extend from the top of sediment to the bedrock surface, or bonding debris and sediment by injecting grout.
- A guide beam will need to be positioned, constructed on, and anchored to the reservoir bottom, on top of the sediment and debris, to aid in positioning of the drill for each cutoff wall element. The guide beam could be constructed on top of pre-conditioned debris and sediment.
- The guide beam could be constructed of concrete or steel. Use of a steel or pre-cast concrete template, pre-manufactured prior to placement below the water surface, may

reduce underwater concrete volumes and underwater concrete work that would otherwise be needed to construct the guide beam.

- Positioning the barge and drill bits to reliably construct the cutoff wall and maintain cutoff wall element verticality will have challenges.
- Steel casing, extending through the water column, would likely be required to be installed and held in position around the drill equipment for each secant pile cutoff wall element. The steel casing could also be extended through reservoir debris and sediment to the top of bedrock. Installing, holding, and retrieving the more than 250 feet of casing that would be required near the central portion of the dam would be challenging.
- ROVs and/or divers may be required for initial positioning of steel casing and drill bits in the guide beam.
- Construction of a sound and continuous, concrete secant pile wall, where the top of the wall is nearly 200 feet below the water surface, should be expected to be very challenging and may be breaking new territory.
- If an interlocking steel pipe wall is constructed, the need to pre-condition the debris and sediment may be reduced and a casing pipe extending from the water surface to the guide beam may not be required.
- Construction of a grout cap on top of or adjacent to the cutoff wall would likely be required to grout the foundation bedrock below the bottom of the cutoff wall.
- The grout cap could be cast in place, include pre-cast elements, or be fabricated of steel. Short guide pipes integral to the grout cap would be used for positioning drill bits to drill grout holes.
- Divers and/or ROVs would likely be required to guide drill bits into the guide pipes in the grout cap.
- Low visibility is likely to interfere with ROV and diver abilities to assist with and assess construction.
- Maintaining alignment of grout holes drilled through the debris may be challenging and could result in holidays in the grout curtain.

2.4.1.7 Environmental Considerations and Permitting

- Drilling and flushing of drill holes may introduce sediment into the reservoir and locally increase turbidity.
- Drilling and flushing operations in proximity to bedrock joints and fractures through which seepage is flowing could carry sediment produced by the drilling into the joints and fractures, and result in turbid water discharging to the river downstream of the dam.

- Performing concreting and grouting operations from barges within the reservoir presents possibility for hoses breaking; spills; or concrete, grout, and cement getting in the reservoir water.
- If seepage velocities are not sufficiently reduced through implementation of Alternatives 4, and/or Alternatives 1A and 4, and concrete secant pile wall construction is used, the potential for cement to be washed out of the secant pile concrete and into joints and fractures in the foundation is high. Washed out cement would then discharge into the river downstream of the dam.
- The potential for cement to be washed through bedrock joints and fractures would be reduced if an interlocking steel pile wall is constructed. Grouting and sealing of the interlocking steel piles and joints between piles could result in cement and sealant being carried by seepage through bedrock joints and fractures. The cement and sealant could be carried by the seepage to discharge in the river downstream of the dam.
- There is potential for cement to be washed from joints and fractures into the river downstream of the dam during foundation grouting operations.
- Permitting from multiple state and federal agencies would be required.

2.4.1.8 Schedule

- Potentially require two to three years to complete.

2.4.1.9 Other Comments

- Install foundation drains into foundation rock downstream of cutoff and grout curtain if determined to be appropriate.

2.4.2 Cutoff Wall Construction Methods

2.4.2.1 Secant Pile Cutoff Wall

A secant pile wall consists of a line of overlapping concrete-filled piles constructed in drilled holes. The piles may range in diameter from about 12 inches to 6 feet or more. Adjacent piles are constructed such that they overlap, thereby creating a continuous cutoff wall. A guide/template is frequently constructed at the ground surface to aid in positioning drill equipment such that pile drilling starts in the appropriate location with appropriate overlap.

Controlling construction such that piles overlap for their full depth is a primary construction challenge. Drills may get off alignment or be deflected by soil, boulders, or rock joints, and because of differences in hardness of materials being drilled. Down-hole position measuring systems can be used to confirm the shaft alignment and overlap prior to casting concrete in each shaft. Techniques to maintain pile alignment or to re-drill portions of the pile that get too far off alignment to achieve the desired pile overlap are necessary.

Secant piles for dam foundation and abutment cutoffs do not typically include steel reinforcement. Reinforcement could be included in the piles if deemed advantageous.

At the LBD site, pre-conditioning of the debris and sediment would be required to reduce challenges with constructing a cutoff wall upstream of the dam through the sediment and debris. One pre-conditioning alternative might consist of pre-drilling a series of shafts along the cutoff wall alignment, through the sediment and debris, to the top of bedrock, and filling each drilled shaft with tremied concrete. As the casing that is advanced to drill each shaft is retracted, concrete/grout would fill the shaft and flow into the surrounding debris. This concrete/grout would create a weak concrete column and cement adjacent debris, potentially allowing greater alignment control when drilling the secant pile wall. A decision on whether or not to pre-condition the debris would be made based on the secant pile construction method.

2.4.2.2 Secant Pile Cutoff Wall – Traditional

Secant pile walls are most commonly constructed by independently drilling each pile. The drilled hole is backfilled with concrete. Achieving the desired pile overlap for the full pile depth requires careful initial positioning of drill equipment, selecting sufficiently stiff equipment and drill tools, and selecting pile diameter and pile overlap dimensions that account for the degree to which piles may get off the design alignment during drilling.

Top-down drilled secant piles that are 3 or more feet in diameter and constructed on land are frequently designed assuming the drill can be maintained within 1 percent of vertical for the depth of the pile. Some equipment is capable of reliably maintaining verticality within 0.5 percent of vertical for the depth of the pile. The verticality tolerance of the construction equipment and the depth to which the secant pile is to extend are used to select the pile diameter and overlap dimension at the top of the pile that is required to improve the chances that sufficient overlap of the piles will occur for the full pile depth. Deeper secant pile installations generally require larger diameter piles to improve potential for adequate pile overlap. One hundred feet below ground surface may be near the practical depth limit for secant pile walls constructed using traditional methods.

2.4.2.3 Secant Pile Cutoff Wall – Guide Bore

If a guide bore is used to help maintain pile alignment during drilling, secant pile walls can be constructed to greater depth and using smaller diameter piles than is achievable using traditional secant pile wall construction techniques. The guide bore technique consists of directionally drilling a small diameter (few inches) guide bore down the center of each secant pile location. Directional drilling tools allow for dynamic monitoring of bit location and orientation and allow for course corrections to keep the drill following near the intended pile centerline. After the guide bore is drilled and its alignment confirmed using a down-hole position measuring device, the secant pile is drilled using traditional drilling equipment. A drill extension rod, or guide rod, that extends below the secant pile drill bit tip is inserted into the guide bore to steer the drill and maintain alignment.

Prior to drilling the guide bore, the debris above the bedrock in the reservoir upstream of the dam may need to be pre-conditioned to create a more uniform material in which to drill through and to reduce potential for deflection of drill rods when drilling through the debris. Pre-conditioning could consist of constructing secant or tangent piles that extend through the debris to bedrock and then drilling the guide bore through these weak concrete piles.

Construction cost and schedule savings may be possible using a guide bore secant pile construction method when compared with other secant pile construction alternatives. Cost savings could result from better pile alignment control, by allowing smaller diameter secant piles to be constructed, the reduced potential for the secant pile to stray from its intended alignment, and as a result of faster secant pile drilling because the drilling alignment does not need to be checked as frequently.

2.4.2.4 Secant Pile Cutoff Wall – Guide Piles

Previously constructed secant piles can be used to guide construction of adjacent secant piles. This can be accomplished using specially manufactured and modified drill equipment. The process involves drilling and constructing an initial pile using the type of drill rig that would be used for traditional secant pile construction or using directional drilling to construct the first pile as described above for guide bore secant pile construction. Prior to backfilling the hole with concrete, a plastic casing pipe is installed and centered in the drill hole. The plastic casing extends from the bottom to top of the pile. The adjacent secant pile is drilled using a drill that has a guide rod attached to the side and extending below the tip of the secant pile drill. This guide rod is inserted in the casing pipe in the adjacent previously constructed pile so that the guide rod steers the drill. Adjacent piles overlap nearly the pile radius, with the drill bit cutting through the casing pipe as the drill advances.

The guide pile technique helps maintain pile alignment during drilling, allowing secant pile walls to be constructed to greater depth and using smaller diameter piles than is achievable using traditional secant pile wall construction techniques. The guide pile technique was reportedly successfully used to construct a secant pile cutoff wall for the Arapuni Dam in New Zealand (Amos and others, 2008). The Arapuni Dam installation consisted of overlapping 400-millimeter (mm)-diameter piles installed to a maximum depth of nearly 300 feet.

2.4.2.5 Hydromill Cutoff Wall

Hydromills have been used to construct cutoff walls in foundations and abutments of numerous existing dams. Hydromills consist of equipment-mounted rock-milling, rotary grinding tools capable of cutting rectangular (in plan view) panels into soil and rock. As the rock is milled, the cable-supported grinding tools are lowered into the ground. Dynamic sensors and multiple, independently controllable cutting wheels are used to maintain alignment of each panel as the cutter is advanced. After excavating each panel, the excavation is backfilled with concrete. Cutoff walls constructed with hydromills would be of uniform thickness from top to bottom and along their length, with thickness typically ranging from about 30 to 48 inches.

Adjacent panels are constructed to overlap and thus result in a continuous wall, similar to overlapping adjacent piles in a secant pile wall. Hydromill-constructed cutoff walls can extend to hundreds of feet deep because of the vertical alignment accuracy to which the panels can be excavated.

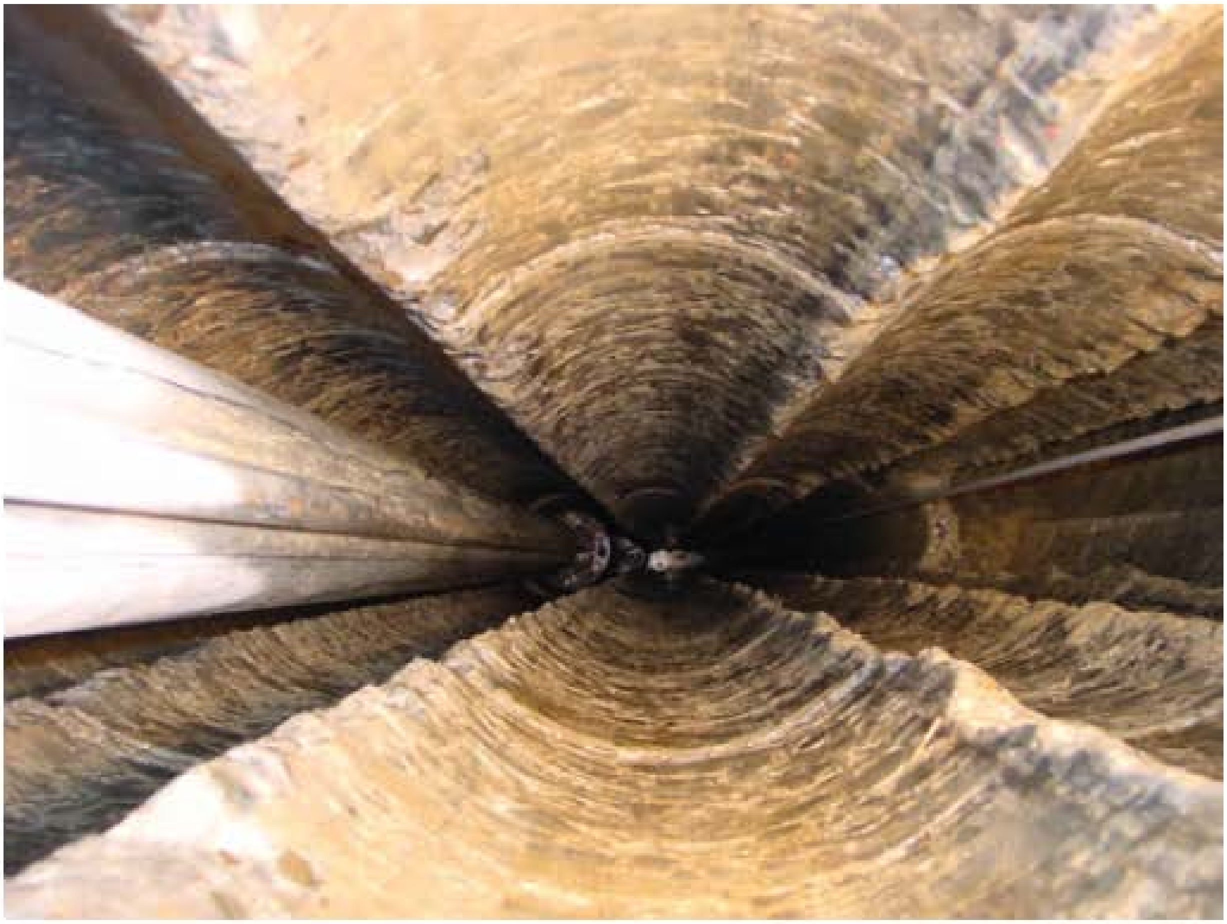

Exhibit Alt 2D-4: Downhole photograph of overlapping secant pile drill holes, Arapuni Dam (Amos and others, 2008)

Hydromill advancement rates may be slow in hard to very hard rock. Consequently, hydromill cutoff wall construction may not be the first-choice construction method for a cutoff wall for the LBD project.

2.4.2.6 RD Pile Wall

The RD® pile wall is a patented wall system consisting of a row of drilled steel pipe piles that are connected to each other with interlocks welded to the piles. Each steel pipe pile is installed using a down-the-hole (DTH) hammer using the centric drilling system and oversized ring bits. The RD pile wall drilling and pipe advancement system reportedly enables penetration of stone and boulder overburden as well as bedrock. By using interlock sealants and injection grouting, the RD pile wall can reportedly be constructed as near watertight. The RD pile wall is described in Uotinen and Jokiniemi (2012) and at SSAB (2017):

Because the RD pile wall system consists of steel pipe piles, an RD pile cutoff wall could potentially be constructed without pre-conditioning the debris and sediment above the bedrock. Because steel interlocks connect adjacent RD piles, the potential to successfully construct a contiguous cutoff wall is enhanced as installed piles are used to guide advancement of the adjacent pile and the interlocks maintain connectivity between adjacent piles. RD pile wall construction would advance outward from the middle of the dam so that previously installed RD piles would resist the tendency for the piles to deflect from their intended location when steeply dipping bedrock surfaces are encountered as the wall advances up the sides of the valley.

RD piles are typically from 220 to 610 mm in diameter. We are not certain that RD pile technology could successfully be applied to the depths and debris and bedrock conditions that occur at the LBD site. Pre-conditioning of sediment and debris above the bedrock by constructing a secant or tangent pile wall through the debris through which to drill the RD piles may be beneficial because obstructions that could interfere with RD pile installation would be removed. Further assessment of this alternative would be required.

Divers or ROVs would be required to cut off RD piles where they emerge from the top of the debris and sediment in the reservoir. Constructing a guide on the reservoir bottom, similar to a guide for secant pile construction, to facilitate proper initial placement and alignment of adjacent RD piles may be warranted.

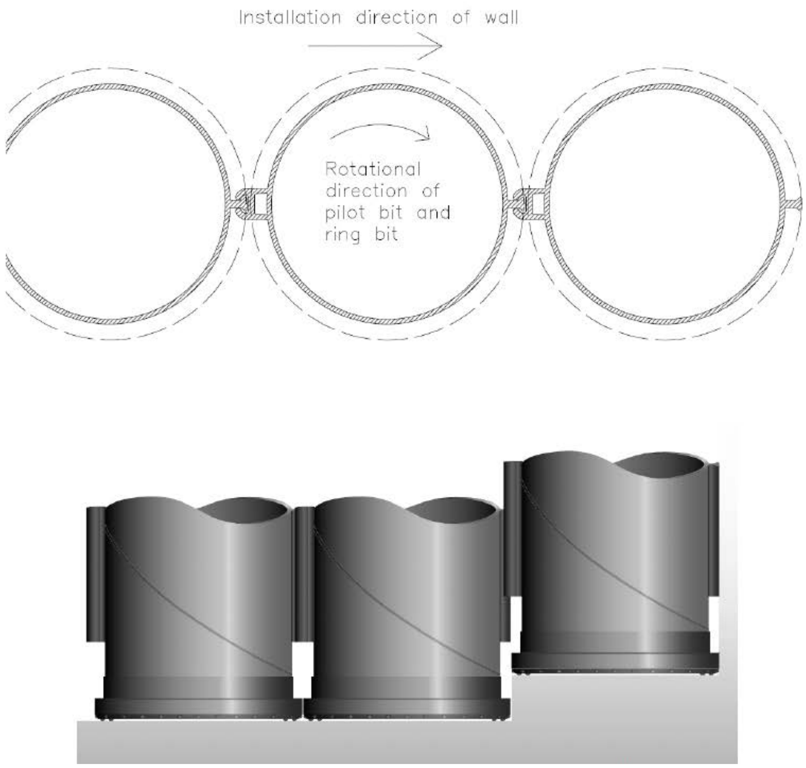

Exhibit Alt 2D-5: Principle of RD piles, interlock, and installation (Uotinen and Jokiniemi, 2012)

Exhibit Alt 2D-6: RD pile bit and downhole hammer (left) and view of top of piles after installation (right) (Uotinen and Jokiniemi, 2012)

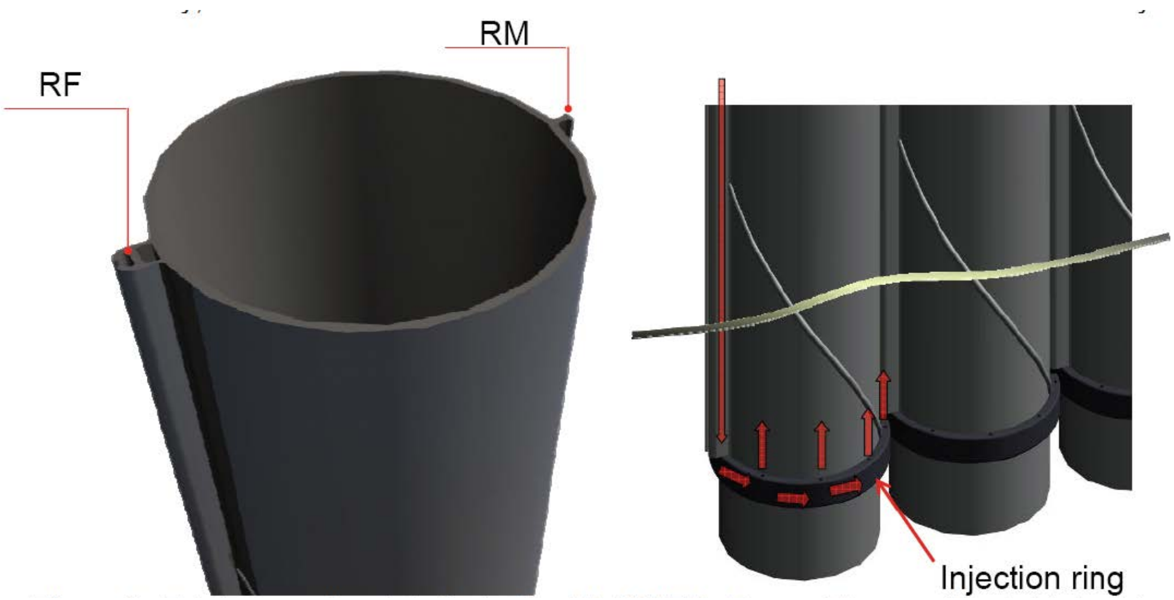

Exhibit Alt 2D-7: RD pile interlock details (left) and grout injection ring (right) (Uotinen and Jokiniemi, 2012)

2.5 Alternative 3 – Grout Curtain

2.5.1 Prior Lower Baker Dam (LBD) Seepage Reduction Grouting

Seepage and leakage through the LBD foundation and abutments has been documented since soon after dam completion in 1925. Programs to inject grout into joints and fractures in the foundation and abutment bedrock were completed in 1934, 1959, and 1982. The 1934 and 1959 grouting programs used bituminous grout or a combination of bituminous and cementitious grout. The 1982 grouting program used a two-component, water-reactive chemical grout and bituminous grout. Seepage was reduced after each grouting program. Seepage increased progressively over the years following each grout program. Seepage was measured at between 160 and 170 cubic feet per second in early April 2017 using down-looker leakage flow monitoring instrumentation.

The progressive increase in seepage that occurred following each grout program has been attributed to incomplete grouting of bedrock joints and fractures and subsequent erosion of limestone bedrock by water flowing past grouted zones through bedrock joints and fractures (Tetra Tech, 2016). Incomplete grouting of bedrock joints and fractures by past grouting programs may have resulted because of challenges grouting relatively wide openings through which high-velocity flow is occurring during the grouting. Cementitious grout, or cement within the grout, may have washed out prior to setting. Bituminous grout, which is stiffer and less prone to being washed out, is thicker and unable to penetrate narrow joints and fractures. Thus, bituminous grout is unlikely to provide a complete cutoff, because small fractures are not grouted. The previous LBD grouting programs did not attempt to construct grout curtains, but only to generally grout zones where high seepage occurred.

2.5.2 Grout Curtain Construction

As part of the current work to develop alternatives that would reduce seepage through the LBD foundation and abutments, Shannon & Wilson and Hatch re-assessed the potential to employ foundation grouting to mitigate LBD seepage. We identified the following factors as having likely contributed to the poor long-term performance of the LBD grouting programs: (a) grouting under high seepage velocity conditions, (b) incomplete grouting because bitumen grout did not likely fully penetrate and seal joints and fractures, (c) not systematically grouting a wide enough zone to achieve sufficient and reliable seepage cutoff, and (d) progressive erosion of foundation rock where seepage was occurring.

In our opinion, a longer-lasting and more successful seepage reduction program incorporating foundation grouting could be accomplished by constructing a grout curtain through areas where wide joints and fractures exist and where high seepage flows occur. A grout curtain consists of multiple rows of grout holes that are drilled and grouted to create a relatively wide (10 to 30 feet) zone in which the bedrock is systematically grouted. The grout curtain could consist of three to four rows of grout holes. The rows would be generally parallel to the dam axis across the width of the dam. The rows could extend perpendicular to the valley walls where the grout curtain extends into the abutments. Grout holes in each row would be inclined to intersect joints and fractures and decrease potential for ungrouted zones to remain after the grout program is complete.

A combination of low-mobility bitumen grout, low-mobility chemical grout, low-mobility cementitious grout, and higher-mobility chemical or cementitious grout could be used to improve chances for successful grout curtain construction. Low-mobility grout would be used first to grout the downstream-most row of grout holes. Low-mobility bitumen grout could be used for this first phase of the grouting in high-velocity zones, because it has a higher likelihood of successfully slowing seepage flow when subjected to high seepage velocities, as was demonstrated during the prior grouting programs. Low-mobility cementitious grout might be used where large voids are present, but seepage velocities are not sufficiently high to wash out the grout or cement from the grout.

After completing a row of grout holes using low-mobility grout, and thus reducing seepage velocities, multiple rows of grout holes could be sequentially drilled and grouted upstream of the low-mobility grouted line of holes. These upstream grout hole lines would be grouted with cementitious grout that is capable of penetrating and more fully sealing off bedrock joints and fractures than the bitumen grout is capable of. Two to three rows of grout holes upstream of the row of bitumen grouted holes would be grouted using cement grout. Grouting multiple rows and using higher-mobility cementitious grout for multiple curtain lines increases the probability of longer-lasting seepage reduction. The primary differences between the proposed grouting program and prior LBD grouting programs is that the objective would be to construct a multi-line grout curtain that would be wider, longer, and extend to lower elevation than areas grouted in prior LBD seepage reduction grouting attempts.

Where grout takes in some areas are high even after multiple grout lines are completed, additional holes would be installed at split spacing to concentrate the grouting effort in those areas. Supplemental grouting could be conducted along faults, fractures, and joints upstream and downstream of the grout curtain lines to reduce flows through these bedrock features.

In the abutment bedrock, west and east of the dam, and away from areas of known high seepage, the grout curtain might be reduced to two or three lines of grout holes. Similarly, at depth, below the areas of high seepage, if pre-grouting water pressure testing determines the bedrock to be relatively tight, fewer rows of grout holes or only a single row of grout holes might be drilled and grouted. Cement grout would be used in these areas.

Benefits of using foundation grouting to reduce LBD seepage include:

- Equipment for grouting operations can work on steep slopes and does not require as much access development as would be required for cutoff wall construction;
- Less spoil and waste are generated for each hole drilled;
- Lower cost to drill the relatively small-diameter holes (2 to 3 inches);
- No need for special equipment to be developed just for the LBD project, as may be required for a cutoff wall alternative; and
- Ability to readily add more grout holes at relatively low incremental cost in areas where additional grouting is deemed necessary.

2.5.3 Alternative 3A: Grout Curtain – Drilling from Dam Crest and from Abutments

2.5.3.1 Description

Construct a multi-row grout curtain in the dam foundation to seal seepage flow paths. Perform drilling from the dam crest and from the ground surface where the grouting operations extend into the abutments (Exhibits Alt 3A-1 through 3A-3). Use low-mobility grout on the first row of grout holes to decrease seepage flow and velocity. Use higher-mobility grout to grout a minimum of two additional rows for the grout curtain. Extend the grout curtain sufficiently far into the dam abutments to reduce potential for seepage to flow around the grout curtain. Additional grout holes or grout hole lines can be added as required.

Success completing the grout curtain may be improved if Alternative 4 and/or both Alternative 1A and 4 are completed prior to constructing the grout curtain and if implementing these alternatives results in decreased seepage flow velocities and volumes.

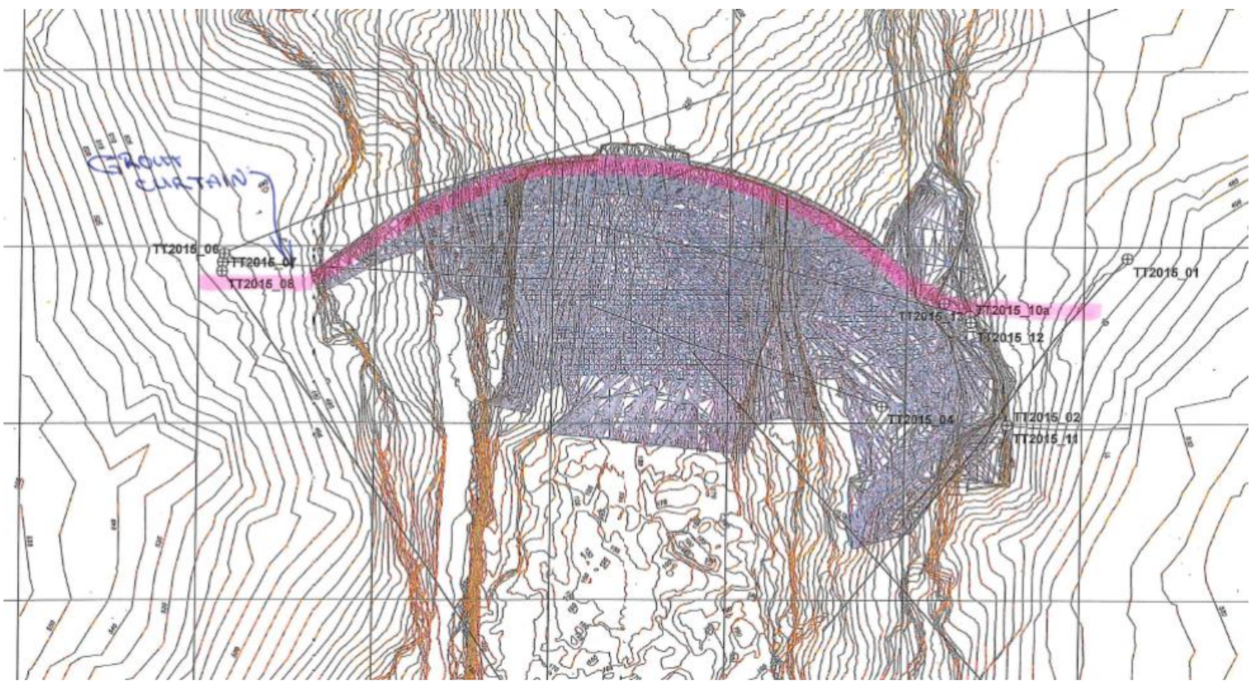

Exhibit Alt 3A-1: Grout curtain drilling through dam crest, plan view

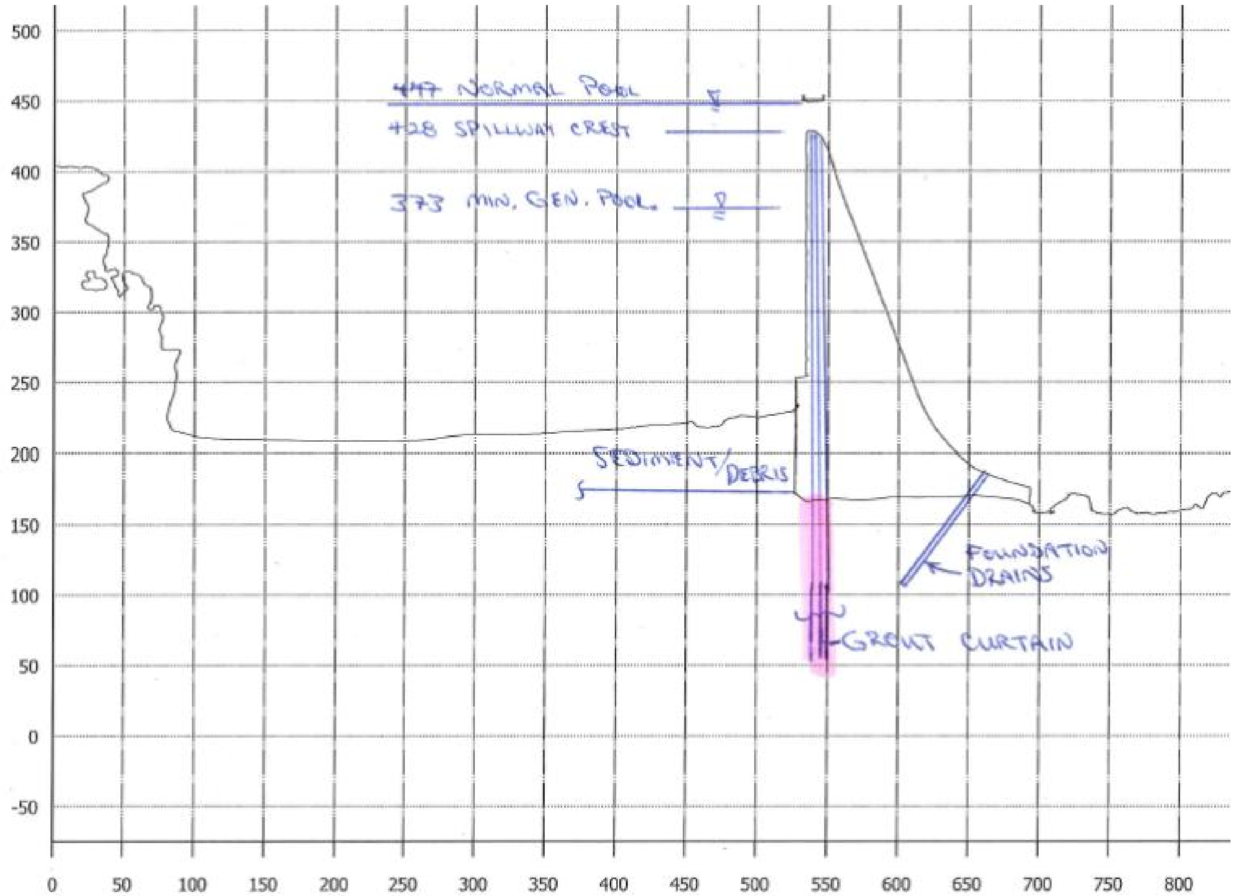

Exhibit Alt 3A-2: Grout curtain drilling through dam crest, section perpendicular to dam

2.5.3.2 Pros

- Past success using low-mobility grout to reduce seepage suggests a more extensive grout curtain program that better cuts of seepage and lasts longer than previous grout efforts can likely be successfully accomplished.
- Dam foundation and abutment grouting to the depths required for this project are common in the industry.
- Relatively small equipment can be used for the work (compared to equipment necessary to construct a cutoff wall).
- Less difficult access development to access locations where grouting would be conducted from than would be required to develop access for cutoff wall construction.
- Grout program can be readily modified as necessary by adding or removing grout holes or grout hole lines based on water pressure tests in holes drilled for grouting.

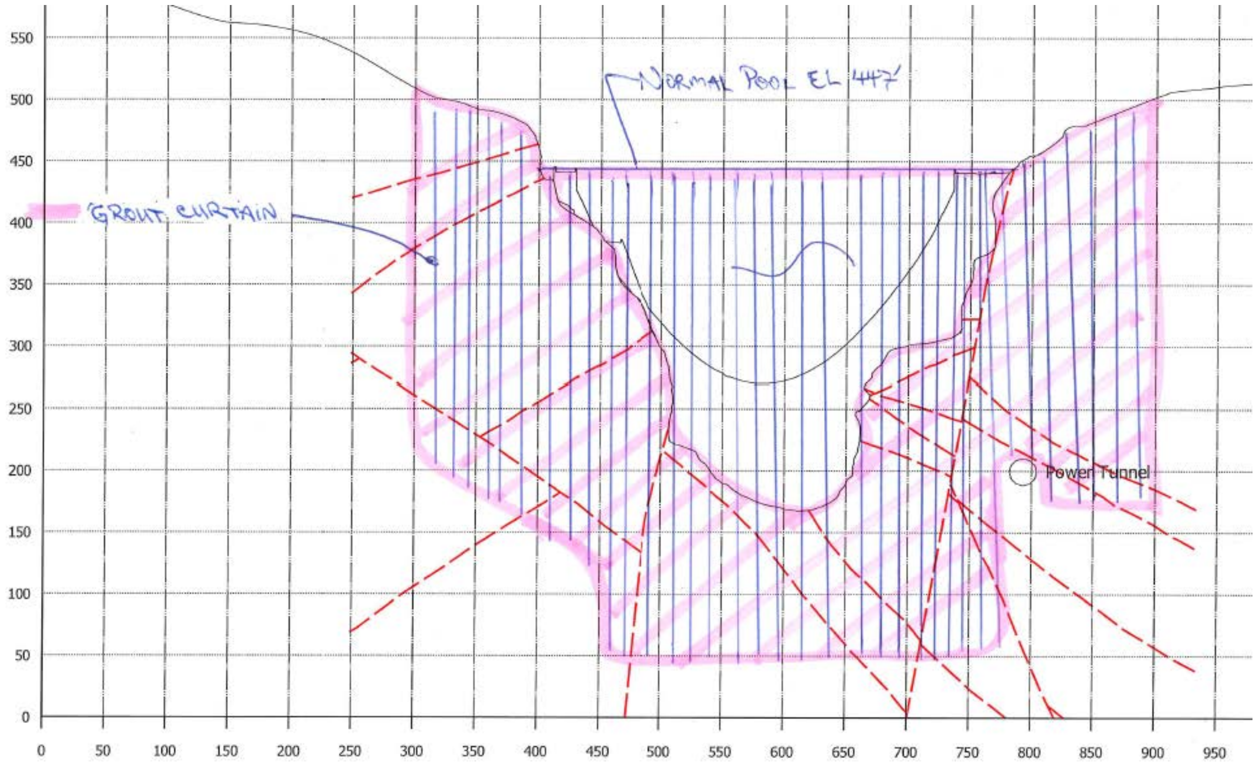

Exhibit Alt 3A-3: Grout curtain drilling through dam crest, cross section (grout holes shown vertical–grout holes may be inclined and grout holes in adjacent grout curtain lines drilled at different orientations)

- No work required in the reservoir or in the river downstream of the dam.
- No need to lower the reservoir elevation during grouting.
- Drilling for grouting and grouting can be performed on steep slopes using available equipment and methods.
- Grout curtain can extend below the tunnel elevation.
- Borehole televiewer surveys can be performed in planned or additional holes to assess grout curtain effectiveness.
- Grouting could be conducted year-round.

2.5.3.3 Cons

- Wide fractures in foundation have previously been challenging to grout, even with low-mobility grout.
- Past grouting efforts have not achieved long-term cutoff.
- High-velocity flow through the foundation may wash grout out of fractures, making complete grouting difficult.

- Accuracy drilling holes for parallel grout lines in the grout curtain may be a challenge. The challenge and difficulty of maintaining hole alignment accuracy increases with increasing drilling depth. Holes drilled to greater than 300 feet below the working surface would be required in some areas.
- Work across the top of the dam may interfere with spillway gate operations or require removal of gate operators (motor and lifter).
- A reduced number of gates may be available during high flow if gate operators are removed.
- It would be challenging to remove the screw gate operators; they are one-of-a-kind units and risk of damage could increase operational concerns.
- Inclined drilling or drilling and grouting from within the tunnel may be required to complete the grout curtain around the tunnel.
- May not be able to drill and work along dam crest during spills.
- Additional demobilization/remobilization cost associated with planned and unplanned spills.

2.5.3.4 Risks and Potential Failure Modes

- Fractures are too large and seepage velocities too high for grout to plug the fractures.
- Grout losses result in grout flowing into the river or reservoir, contaminating the water.
- Grout penetrates and plugs foundation drains that were constructed at the dam-foundation contact.
- Grout flows through gaps in the tunnel lining and into the tunnel.
- Grout pressures are not controlled adequately, resulting in displacement or movement of foundation or abutment rock blocks.
- Grout pressures are not controlled adequately, resulting in damage to the tunnel lining.
- Parallel grout lines cannot be successfully constructed because of difficulty maintaining hole alignment during drilling.
- Interference with ability to operate spillway.
- Grouting operations could plug, fill, or change flow through existing drains in the dam, which could result in higher uplift pressures below the dam.

2.5.3.5 Relative Cost

- Moderate to high, as compared to the other alternatives.

2.5.3.6 Constructability

- There is ready access to the top of the dam.
- The depth of drilling is significant and maintaining grout hole alignment may be challenging.
- The location and alignment of grout holes would be checked prior to grouting. Additional holes could be added if grout hole alignment is determined to be too far from the desired location.
- Short guide pipes to position drill bits would be installed into the top of the dam, a pre-fabricated structure with guide pipes mounted on the top of the dam, or guide pipes would be installed in a grout cap constructed across to top of the dam. A grout cap with guide pipes would be constructed on the ground surface beyond the dam limits.
- Spillway gates, motors, rail, and other equipment may need to be relocated during grouting operations.
- Rebar encountered during drilling through the dam could deflect the drill bit, adding to grout hole alignment control challenges.
- Grout hole layout needs to be evaluated to confirm there is sufficient room for drilling multiple grout lines. Work platforms may need to extend over the downstream dam face to create sufficient space between adjacent grout lines and so that the upstream grout line is sufficiently far from the upstream dam face.

2.5.3.7 Environmental Considerations and Permitting

- Fluid and sediment flushed from drill holes may be difficult to capture when working on top of the dam and in the spillways. Fluid and sediment not captured could spill into the reservoir or over the downstream face, where it could wash into the river.
- Drilling and flushing operations in proximity to bedrock joints and fractures through which seepage is flowing could carry sediment produced by the drilling into the joints and fractures, and result in turbid water discharging to the river downstream of the dam.
- There is potential for cement to be washed from joints and fractures into the river downstream of the dam during foundation grouting operations. This potential would be reduced by completing bitumen grouting of the downstream-most line of grout holes prior to cement grouting of additional grout lines.
- Permitting from multiple state and federal agencies would be required.

2.5.3.8 Schedule

- Drilling and grouting could occur almost any time of year.
- Grouting can likely be complete in one to two years.
- Drilling and grouting on the dam and immediately adjacent to the dam on the abutments can occur only when the spillway is not operating.
- New foundation drainage would need to be installed when the spillway is not operating.

2.5.3.9 Other Comments

- If the dam were to be constructed at the site today, a multi-row grout curtain would likely be selected as the foundation treatment and seepage control measure.
- Install foundation drains into foundation rock downstream of cutoff if determined to be appropriate.

2.5.4 Alternative 3D: Grout Curtain – Inclined Drilling through Dam from Barge Upstream of the Dam

2.5.4.1 Description

Construct a multi-row grout curtain to seal seepage flow paths. Operate from barges to drill grout holes into the dam and dam foundation below the reservoir pool elevation (Exhibits Alt 3D-1 through 3D-3). Grouting of higher elevation zones above the elevation that a barge could operate and grouting abutments beyond the dam limits could be completed by drilling vertical holes from the top of the dam and abutment ground surface. Drilling inclined holes through the dam, entering the dam just above the top of debris and sediment at the reservoir bottom, would improve positioning control for the grout holes and avoid challenges with maintaining grout hole location when compared with the alternative of drilling grout holes through the debris upstream of the dam.

Grouting using low-mobility grout followed by higher-mobility grout lines would be performed as is described for Alternative 3A. At the left abutment, the grout curtain alignment would go between the intake tunnel and the dam centerline. Extend the grout curtain sufficiently far enough into the dam abutments to reduce potential for seepage to flow around the grout curtain.

Success completing the grout curtain may be improved if Alternative 4 and/or both Alternative 1A and 4 are completed prior to constructing the grout curtain and if implementing these alternatives results in decreased seepage flow velocities and volumes. Equipment, methods, and planning for Alternative 3D grouting from a barge upstream of the dam would be similar to those required for Alternative 4 grouting of debris and sediment, allowing both Alternatives 3D and 4 to be jointly implemented.

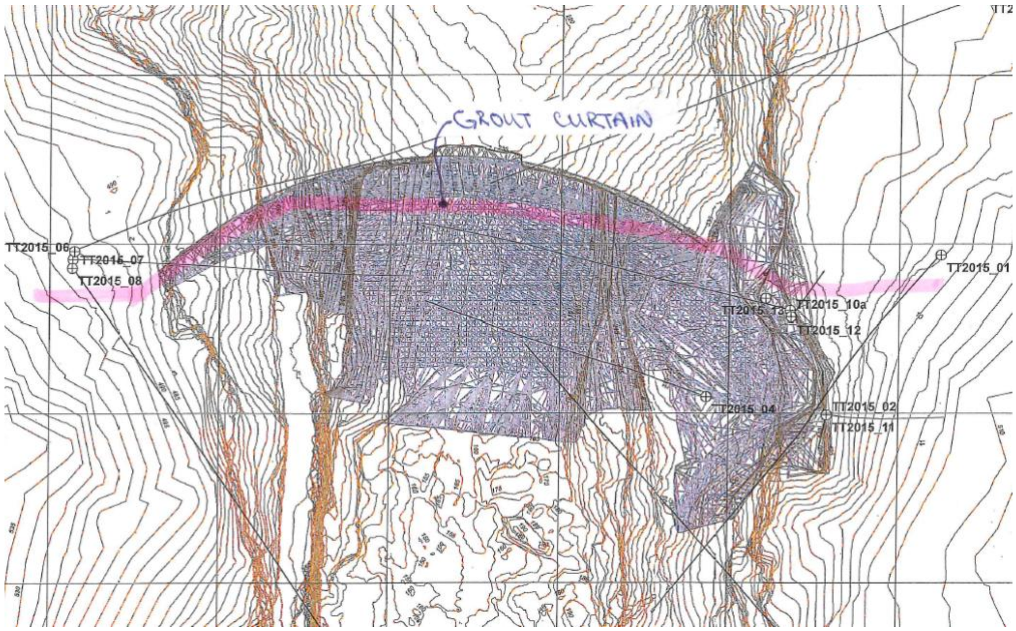

Exhibit Alt 3D-1: Grout curtain drilling from barge through upstream dam face, plan view

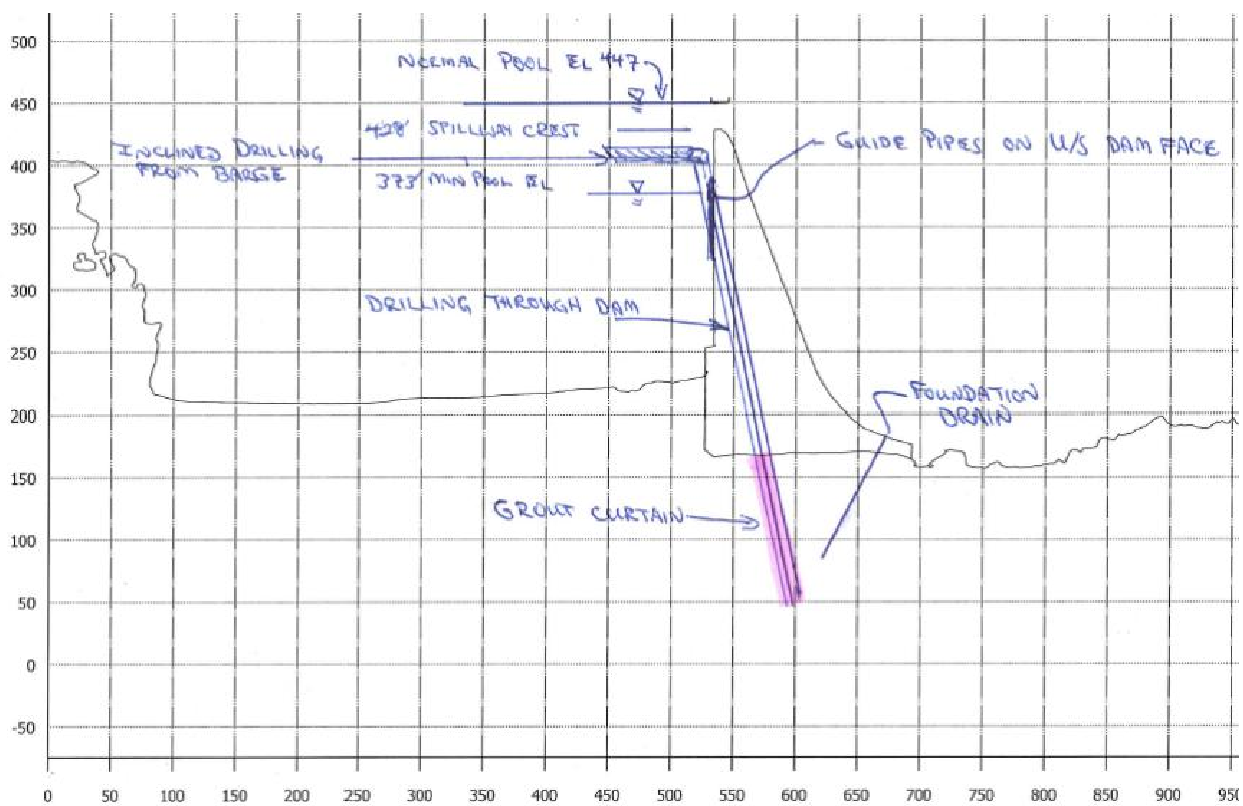

Exhibit Alt 3D-2: Grout curtain drilling from barge through upstream dam face, section perpendicular to dam

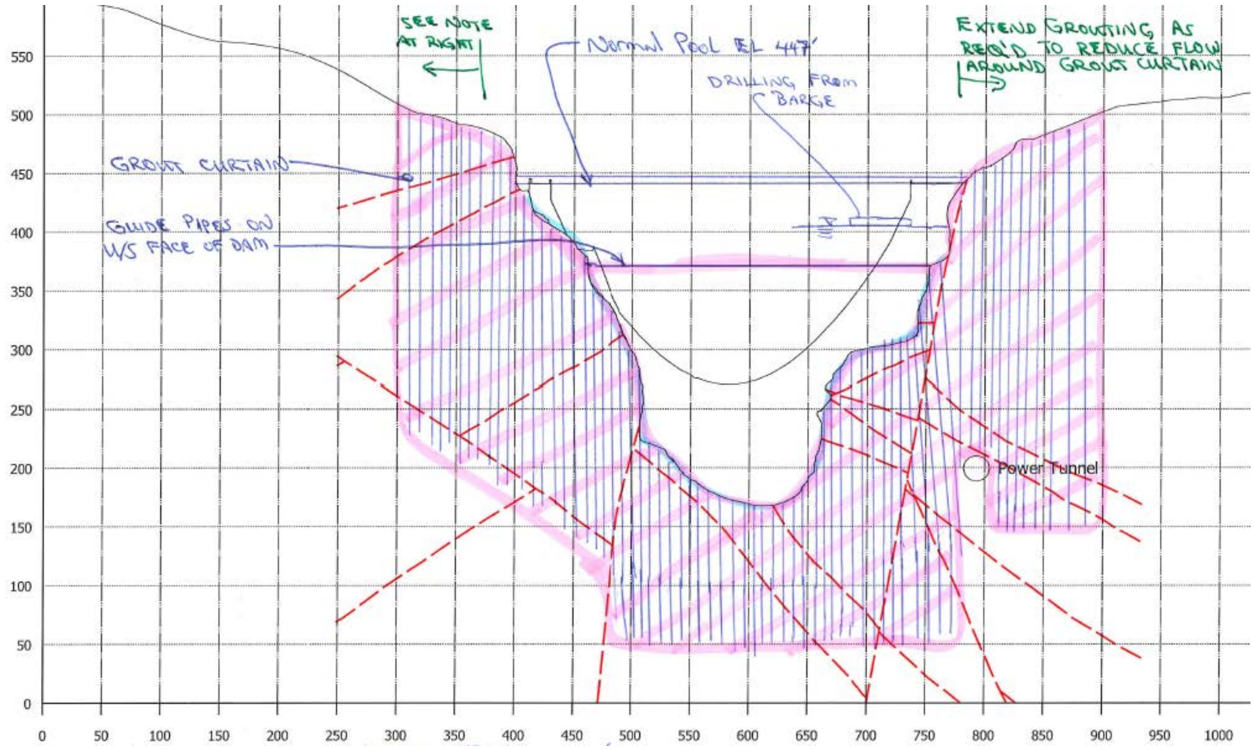

Exhibit Alt 3D-3: Grout curtain drilling from barge through upstream dam face, cross section (grout holes shown vertical–grout holes may be inclined and grout holes in adjacent grout curtain lines drilled at different orientations)

2.5.4.2 Pros

- Past success using low-mobility grout to reduce seepage suggests a more extensive grout curtain program that better cuts off seepage and lasts longer than previous grout efforts can likely be successfully accomplished.
- Dam foundation and abutment grouting to the depths required for this project are common in the industry.
- Relatively small equipment can be used for the work (compared to equipment necessary to construct a cutoff wall).
- Less difficult access development to access locations where grouting would be conducted from than would be required to develop access for cutoff wall construction.
- Grout program can be readily modified as necessary by adding or removing grout holes or grout hole lines based on water pressure tests in holes drilled for grouting.
- Drilling for grouting and grouting can be performed on steep slopes using available equipment and methods.
- Grout curtain can extend below the tunnel elevation.

- Slightly decreased drilling through the dam and decreased total length of drilling to get to locations to be grouted compared with Alternative 3A.
- Borehole televiewer surveys can be performed in planned or additional holes to assess grout curtain effectiveness.

2.5.4.3 Cons

- Wide fractures in foundation have previously been challenging to grout, even with low-mobility grout.
- Past grouting efforts have not achieved long-term cutoff.
- High-velocity flow through the foundation may wash grout out of fractures, making complete grouting difficult.
- Accuracy drilling holes for parallel grout lines in the grout curtain may be a challenge. The challenge and difficulty of maintaining hole alignment accuracy increases with increasing drilling depth and because drilling would be conducted from a barge and in the blind (top of hole below water elevation).
- Work within the reservoir would likely be performed from barges.
- Must perform work under water to depths of 50 to 100 feet.
- Work would be performed inside the reservoir, increasing the potential for drilling fluids, spoils, or cement to get in reservoir water.
- Divers would likely be required to aid in constructing a guide on the upstream face of the dam and a guide or grout cap up the reservoir sides.
- Divers, an ROV, or underwater camera capability may be required to assist in positioning the drill in the guide and grout curtain cap at the start of drilling for each grout hole.
- Low visibility is likely to interfere with ROV and diver abilities to assist with and assess construction.
- Lowering the reservoir during construction could be necessary, or beneficial, to reduce the depth of water that the work is performed in.
- Inclined drilling or drilling and grouting from within the tunnel may be required to complete the grout curtain around the tunnel.

2.5.4.4 Risks and Potential Failure Modes

- Fractures are too large and seepage velocities too high for grout to plug the fractures.
- Drilling and completion of grout curtain may subject heel of dam to increased uplift pressures.

- Grout losses result in grout flowing into the river or reservoir, contaminating the water.
- Grout penetrates and plugs foundation drains that were constructed at the dam-foundation contact.
- Grout flows through gaps in the tunnel lining and into the tunnel.
- Grout pressures are not controlled adequately, resulting in displacement or movement of foundation or abutment rock blocks.
- Grout pressures are not controlled adequately, resulting in damage to the tunnel lining.
- Parallel grout lines cannot be successfully constructed.
- Equipment operating immediately upstream of the spillway and tunnel inlet is dislodged and damages the dam.
- Hazards to divers working upstream of tunnel intake.
- Hazard to LBD operations if materials associated with underwater work are pulled into tunnel.
- Shaping of the reservoir bottom and sides to facilitate construction of grout curtain cap/guide poses potential for materials to get pulled into the tunnel and impact turbines.
- Working from a barge upstream of the dam may interfere with spillway gate operation.
- Divers may need to be employed to help position drill steel and to construct a grout curtain cap or guide on the reservoir bottom or upstream face of dam.
- Potential for grout materials to get into the reservoir and contaminate the water.
- Grouting operations could plug, fill, or change flow through existing drains in the dam, which could result in higher uplift pressures below the dam.

2.5.4.5 Relative Cost

- High, as compared to the other grouting alternatives.

2.5.4.6 Constructability

- Constructing a cutoff wall while drilling from barges may be challenging.
- Access to the reservoir to launch barges and to transfer equipment, materials, and personnel to barges could be constructed a few hundred feet upstream of the left abutment adjacent to the fish pier.

- The depth of drilling is significant and maintaining grout hole alignment may be challenging.
- The location and alignment of grout holes would be checked prior to grouting. Additional holes could be added if grout hole alignment is determined to be too far from the desired location.
- To position drill bits at each drilling location, short guide pipes would be installed into the upstream dam face, or a pre-fabricated guide plate would be mounted on the upstream dam face. A grout cap with guide pipes would be constructed on the ground surface beyond the dam limits.
- Divers and/or ROVs would likely be required to guide drill bits into the guide pipes.
- Rebar encountered during drilling through the dam could deflect the drill bit, adding to grout hole alignment control challenges.

2.5.4.7 Environmental Considerations and Permitting

- Drilling and flushing of drill holes may introduce sediment into the reservoir and locally increase turbidity.
- Drilling and flushing operations in proximity to bedrock joints and fractures through which seepage is flowing could carry sediment produced by the drilling into the joints and fractures, and result in turbid water discharging to the river downstream of the dam.
- Performing grouting operations from barges within the reservoir presents possibility for hoses breaking and spills and for grout and cement to get in the reservoir water.
- There is potential for cement to be washed from joints and fractures into the river downstream of the dam during foundation grouting operations.
- Permitting from multiple state and federal agencies would be required.

2.5.4.8 Schedule

- Grouting complete over one to three years.
- Work from barges within the reservoir could not occur during spill periods.
- Drilling and grouting upstream of the spillways and immediately adjacent to the dam on the abutments can occur only when the spillway is not operating.
- New foundation drainage may need to be installed when the spillway is not operating.

2.5.4.9 Other Comments

- See comments for Alternative 3A.

2.5.5 Alternative 3E: Grout Curtain Drilling from Downstream of Dam Crest – Drilling from Face of Dam

2.5.5.1 Description

Construct a multi-row grout curtain in the dam foundation to seal seepage flow paths. Perform drilling from multiple locations, including working from platforms anchored to the downstream dam face, working on the steep slopes on each abutment downstream of the dam centerline, and on the slopes extending into the abutments (Exhibits Alt 3D-1 through 3D-3). Use low-mobility grout on the first row of grout holes to decrease seepage flow and velocity. Use higher-mobility grout to grout a minimum of two additional rows for the grout curtain. Extend the grout curtain sufficiently far into the dam abutments to reduce potential for seepage to flow around the grout curtain. Additional grout holes or grout hole lines can be added as required.

Success completing the grout curtain may be improved if Alternative 4 and/or both Alternative 1A and 4 are completed prior to constructing the grout curtain and if implementing these alternatives results in decreased seepage flow velocities and volumes.

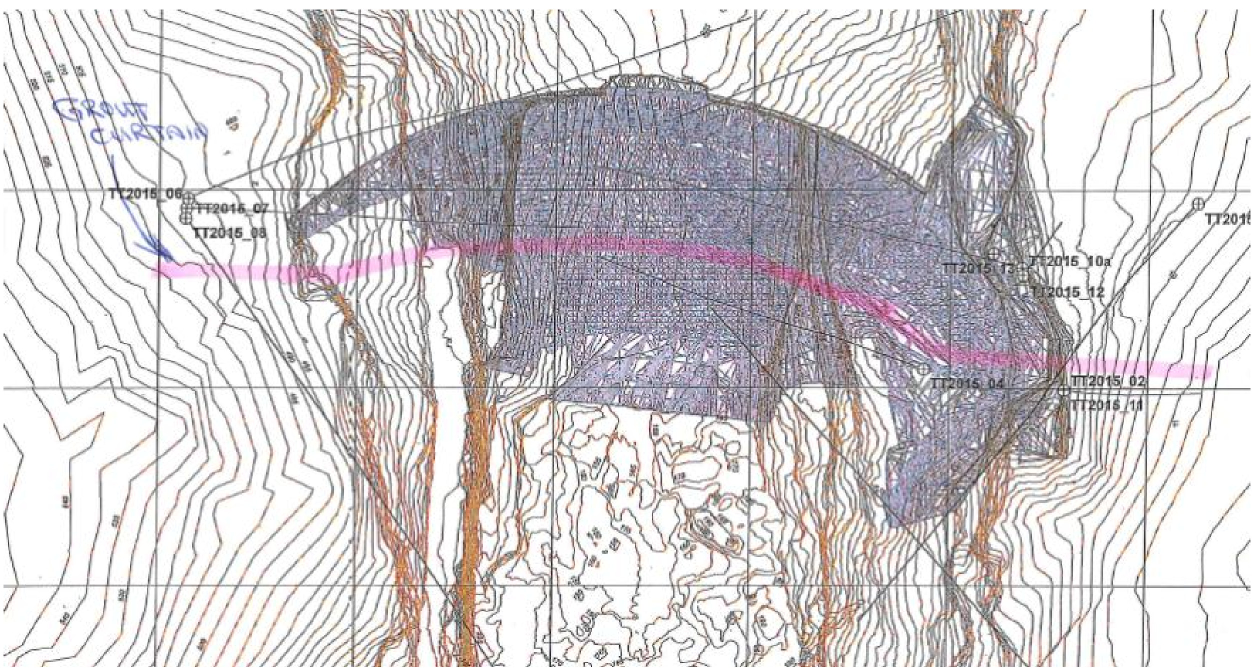

Exhibit 3E-1: Grout curtain drilling through dam from downstream dam face, plan view

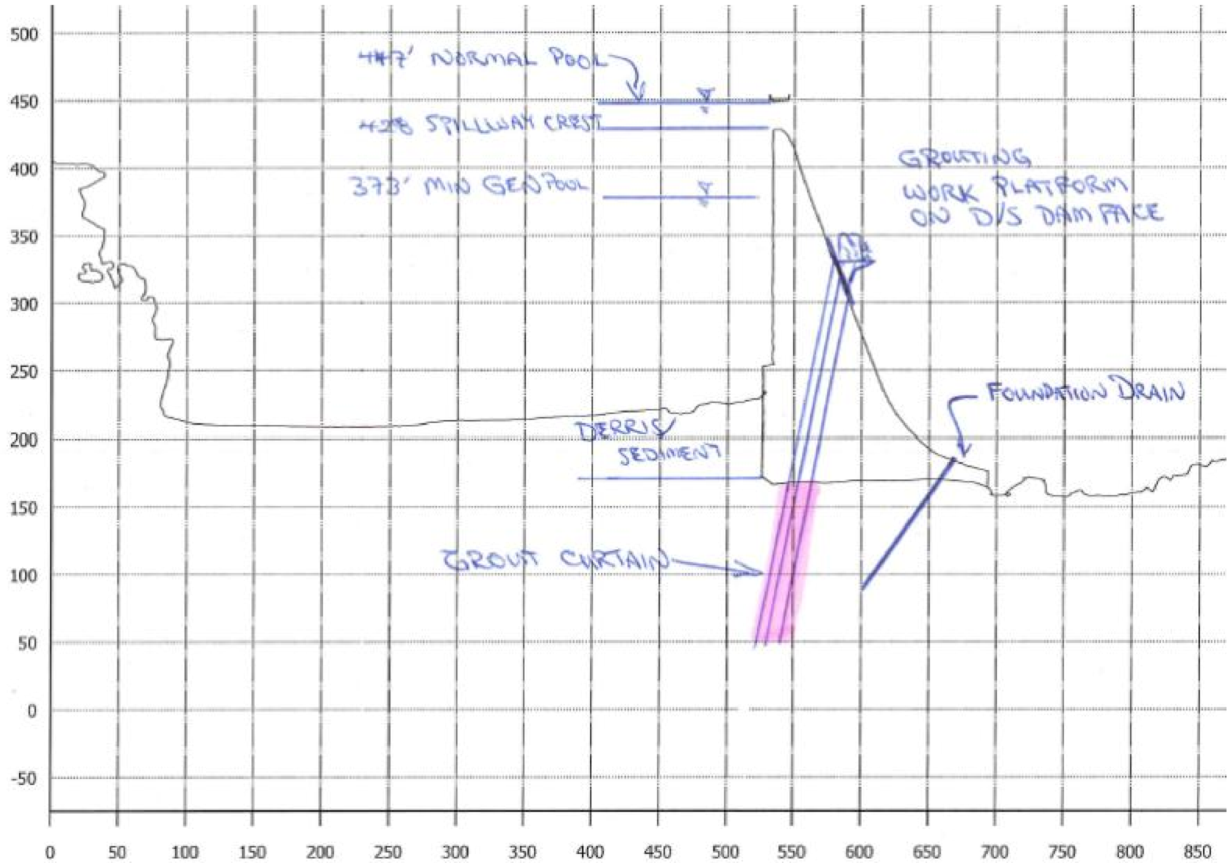

Exhibit 3E-2: Grout curtain drilling through dam from downstream dam face, section perpendicular to dam

2.5.5.2 Pros

- Past success using low-mobility grout to reduce seepage suggests a more extensive grout curtain program that better cuts off seepage and lasts longer than previous grout efforts can likely be successfully accomplished.
- Dam foundation and abutment grouting to the depths required for this project are common in the industry.
- Relatively small equipment can be used for the work (compared to equipment necessary to construct a cutoff wall).
- Grout program can be readily modified as necessary by adding or removing grout holes or grout hole lines based on water pressure tests in holes drilled for grouting.
- No work required in the reservoir or in the river downstream of the dam.
- No divers or underwater construction required.

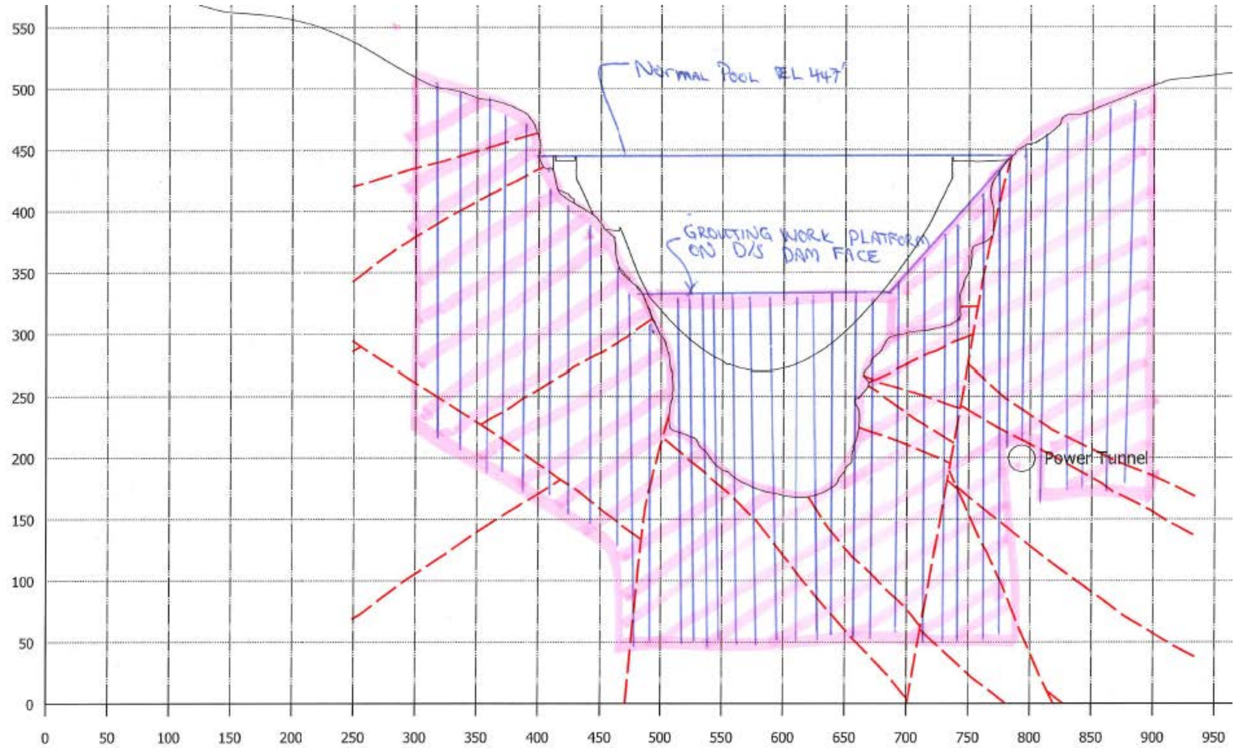

Exhibit 3E-3: Grout curtain drilling through dam from downstream dam face, cross section (grout holes shown vertical–grout holes may be inclined and grout holes in adjacent grout curtain lines drilled at different orientations)

- No need to lower the reservoir elevation during grouting, although lowering the reservoir may reduce backpressure and blowout at the drilling equipment.
- No modification to or working around the spillway and gates is required.
- Drilling for grouting and grouting can be performed on steep slopes using available equipment and methods.
- Reduced drilling depths compared with grout curtain Alternative 3A.
- Grout curtain can extend below tunnel elevation.
- Borehole televiewer surveys can be performed in planned or additional holes to assess grout curtain effectiveness.

2.5.5.3 Cons

- Wide fractures in foundation have previously been challenging to grout, even with low-mobility grout.
- Past grouting efforts have not achieved long-term cutoff.

- High-velocity flow through the foundation may wash grout out of fractures, making complete grouting difficult.
- Accuracy drilling holes for parallel grout lines in the grout curtain may be a challenge. The challenge and difficulty of maintaining hole alignment accuracy increases with increasing drilling depth. Deep inclined holes, to greater than 250 feet, are required in some areas.
- Drilling from the steep face of the dam presents access challenges and other considerations, because work would be performed below the spillway.
- Will need to use excess head blow-off preventers to overcome reservoir pressure when drilling from below reservoir elevation.
- Inclined drilling or drilling and grouting from within the tunnel may be required to complete the grout curtain around the tunnel.
- Cannot work downstream of dam during spills from spillway.
- Additional demobilization/remobilization costs associated with planned and unplanned spills.

2.5.5.4 Risks and Potential Failure Modes

- Fractures are too large and seepage velocities too high for grout to plug the fractures.
- Potential to develop a direct connection to the reservoir, resulting in flow from the grout holes.
- Grout losses result in grout flowing into the river or reservoir, contaminating the water.
- Grout penetrates and plugs foundation drains that were constructed at the dam-foundation contact.
- Grout flows through gaps in the tunnel lining and into the tunnel.
- Grout pressures are not controlled adequately, resulting in displacement or movement of foundation or abutment rock blocks.
- Grout pressures are not controlled adequately, resulting in damage to the tunnel lining.
- Parallel grout lines cannot be successfully constructed.
- Hazards associated with working below the spillway.
- Equipment and workers may need to be removed if spillways need to be operated.
- Multiple inclined holes through the dam would be required. Potential impacts of drilling multiple grout holes through the dam would need to be assessed.

- Grouting operations could plug, fill, or change flow through existing drains in the dam, which could result in higher uplift pressures below the dam.

2.5.5.5 Relative Cost

- Moderate to high, as compared to the other alternatives.

2.5.5.6 Constructability

- There is ready access to the top of the dam and access could be developed to work platforms mounted on the dam face and slopes downstream of the dam.
- The depth of drilling is significant and maintaining grout hole alignment may be challenging.
- The location and alignment of grout holes would be checked prior to grouting. Additional holes could be added if grout hole alignment is determined to be too far from the desired location.
- To position drill bits at each drilling location, short guide pipes would be installed into the dam face, or a pre-fabricated guide plate would be mounted on the dam face. A grout cap with guide pipes would be constructed on the ground surface beyond the dam limits.
- Rebar encountered during drilling through the dam could deflect the drill bit, adding to grout hole alignment control challenges.
- Grout holes could be inclined at flatter angles to intersect and grout major bedrock faults, fractures, and joints that extend upstream from the dam (i.e., below the sediment and debris in the reservoir).
- Grout hole layout needs to be evaluated to confirm there is sufficient room for drilling multiple grout lines.

2.5.5.7 Environmental Considerations and Permitting

- Fluid and sediment flushed from drill holes may be difficult to capture when working on the dam face. Fluid and sediment not captured could spill down the downstream face, where it could wash into the river.
- Drilling and flushing operations in proximity to bedrock joints and fractures through which seepage is flowing could carry sediment produced by the drilling into the joints and fractures, and result in turbid water discharging to the river downstream of the dam.
- There is potential for cement to be washed from joints and fractures into the river downstream of the dam during foundation grouting operations. This potential would be reduced by completing bitumen grouting of the downstream-most line of grout holes prior to cement grouting of additional grout lines.

- Permitting from multiple state and federal agencies would be required.

2.5.5.8 Schedule

- Grouting can likely be complete in less than two years.
- Drilling and grouting on the dam and immediately adjacent to the dam on the abutments can occur only when the spillway is not operating.
- New foundation drainage may need to be installed when the spillway is not operating.

2.5.5.9 Other Comments

- See comments for Alternative 3A.

2.5.6 Alternative 3F: Grout Curtain – Vertical Drilling from a Barge Upstream of the Dam

2.5.6.1 Description

Construct a multi-row grout curtain to seal seepage flow paths. Operate from barges to drill grout holes through the debris and sediment into bedrock upstream of the dam (Exhibits Alt 3F-1 through 3F-3). Grouting of higher elevation zones above the elevation that a barge could operate and grouting abutments beyond the dam limits could be completed by drilling holes from the top of the dam and abutment ground surface. Pre-condition the debris and sediment by drilling 2- to 4-foot-diameter shafts at each grout hole location or constructing a secant pile or tangent pile wall along the grout curtain lines. Pre-conditioning would include drilling from the reservoir bottom to the top of bedrock, removing debris that could deflect the grout drill rod, and backfilling the drilled hole with weak concrete. Or, prior to advancing drilling for grouting into the bedrock foundation, inject grout into the debris to fill voids within the debris, then re-drill through the grouted debris into the bedrock foundation. The purpose of pre-conditioning the debris is to reduce potential for grout pipes to be deflected when drilling through the debris upstream of the dam.

Grouting using low-mobility grout followed by higher-mobility grout lines would be performed as is described for Alternative 3A. At the left abutment, the grout curtain alignment would go between the intake tunnel and the dam centerline. Extend the grout curtain sufficiently far enough into the dam abutments to reduce potential for seepage to flow around the grout curtain.

Success completing the grout curtain may be improved if Alternative 4 and/or both Alternative 1A and 4 are completed prior to constructing the grout curtain and if implementing these alternatives results in decreased seepage flow velocities and volumes. Equipment, methods, and planning for Alternative 3F grouting from a barge upstream of the dam would be similar to those required for Alternative 4 grouting of debris and sediment, allowing both Alternatives 3F and 4 to be jointly implemented.

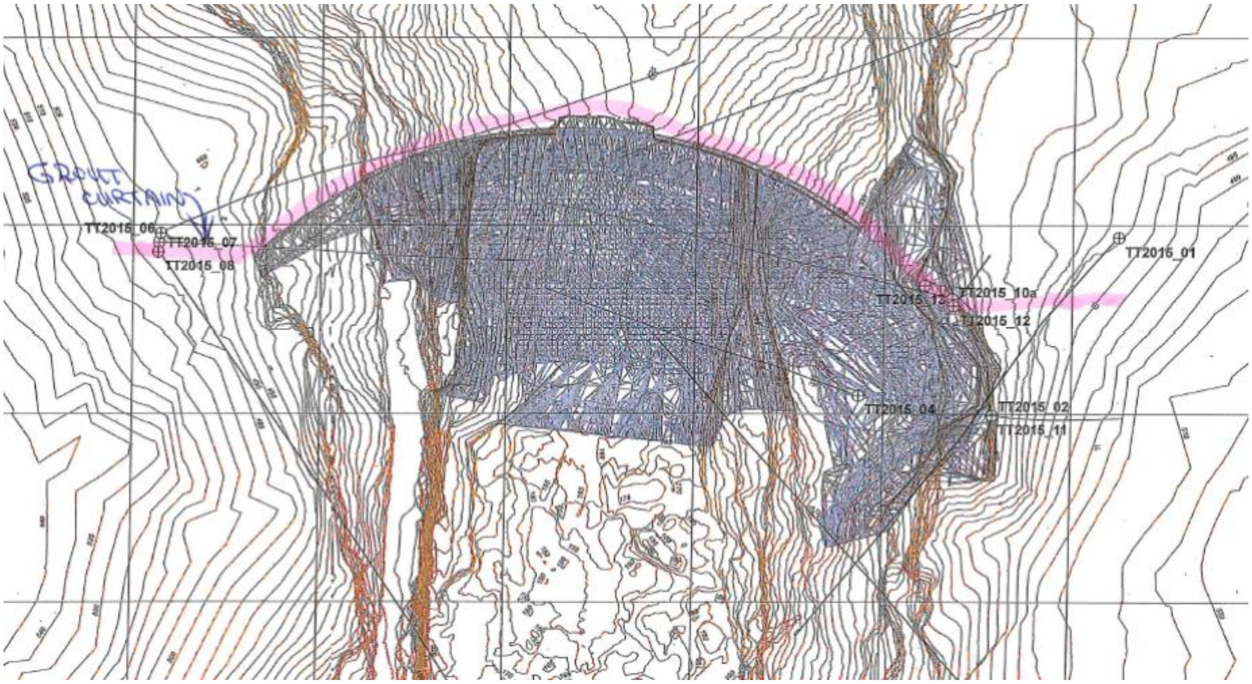

Exhibit Alt 3F-1: Grout curtain upstream of dam, drilling from barge upstream of dam, plan view

2.5.6.2 Pros

- Past success using low-mobility grout to reduce seepage suggests a more extensive grout curtain program that better cuts off seepage and lasts longer than previous grout efforts can likely be successfully accomplished.
- Dam foundation and abutment grouting to the depths required for this project are common in the industry.
- For grout holes drilled from land, relatively small equipment can be used for the work (compared to equipment necessary to construct a cutoff wall).
- Grout program can be readily modified as necessary by adding or removing grout holes or grout hole lines based on water pressure tests in holes drilled for grouting.
- Drilling for grouting and grouting can be performed on steep slopes using available equipment and methods.
- Grout curtain can extend below tunnel elevation.
- Eliminates drilling through the dam (Alternatives 3A and 3D) and decreases the total length of drilling to get to locations to be grouted compared with Alternative 3A.

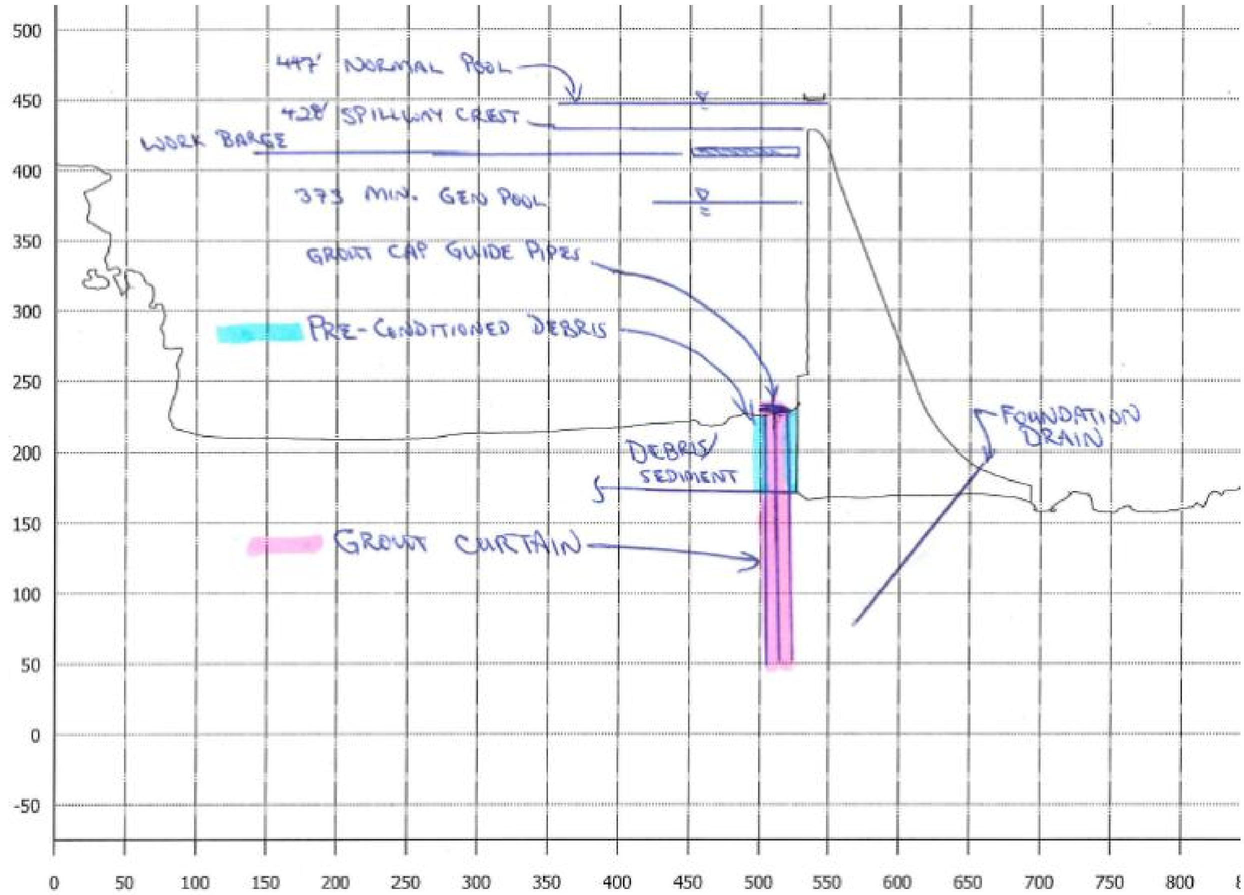

Exhibit Alt 3F-2: Grout curtain upstream of dam, drilling from barge upstream of dam, section perpendicular to dam

2.5.6.3 Cons

- Wide fractures in foundation have previously been challenging to grout, even with low-mobility grout.
- Past grouting efforts have not achieved long-term cutoff.
- High-velocity flow through the foundation may wash grout out of fractures, making complete grouting difficult.
- Accuracy drilling holes for parallel grout lines in the grout curtain may be a challenge. The challenge and difficulty of maintaining hole alignment accuracy increases with increasing drilling depth and because drilling would be conducted from a barge and in the blind (top of hole below water elevation).
- Work within the reservoir would likely be performed from barges.
- Must perform work under water and through up to 200 feet of water.

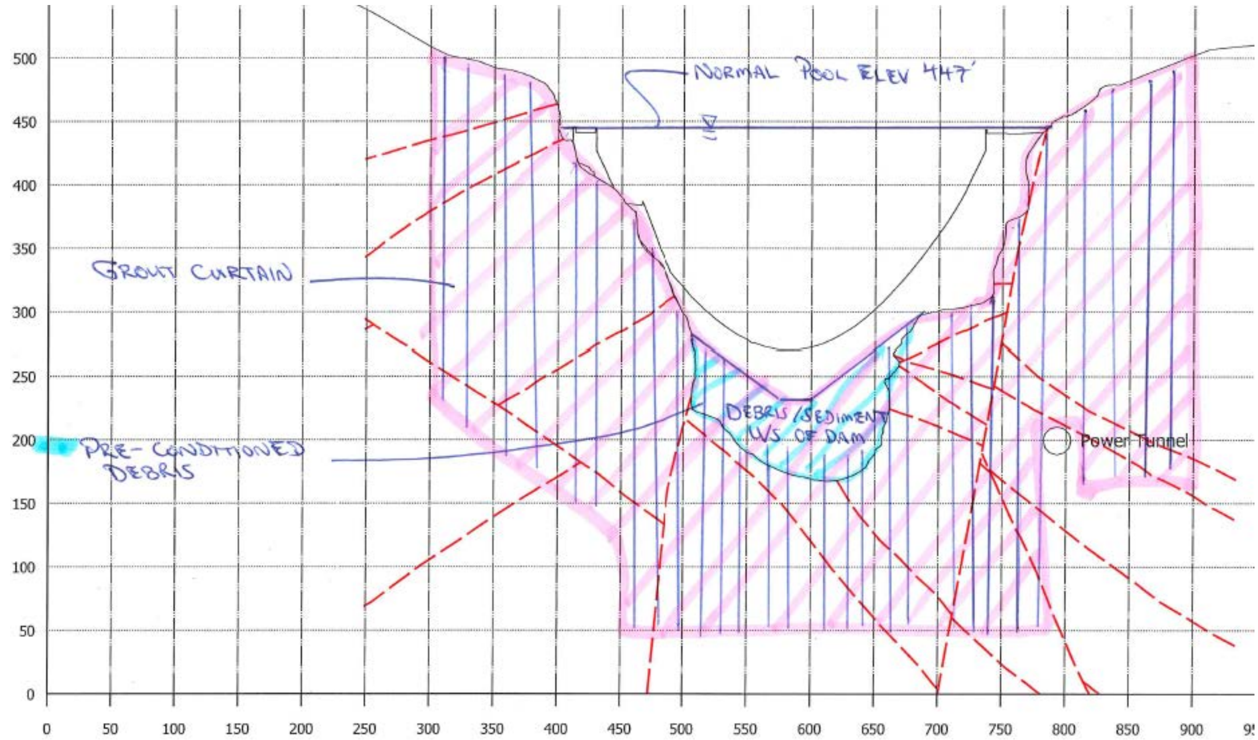

Exhibit Alt 3F-3: Grout curtain upstream of dam, drilling from barge upstream of dam, cross section (grout holes shown vertical–grout holes may be inclined and grout holes in adjacent grout curtain lines drilled at different orientations)

- Must drill through 50 to 70 feet of debris.
- Work would be performed inside the reservoir, increasing the potential for drilling fluids, spoils, or cement to get in reservoir water.
- Divers would likely be required to aid in installing pipe guides and constructing a grout curtain cap on the reservoir bottom and up the reservoir sides.
- The grout curtain cap on the reservoir bottom would not be anchored to or founded on bedrock, and, without pre-conditioning of the debris and sediment, would not facilitate use of higher grouting pressures that could be used if a grout cap were secured to bedrock.
- Divers, an ROV, or underwater camera capability may be required to assist in positioning the drill in the grout curtain cap at the start of drilling for each grout hole.
- Lowering the reservoir during construction could be necessary, or beneficial, to reduce the depth of water that the work is performed in.
- For holes drilled under water from a barge, it will be difficult to deploy a borehole televiewer to assess grout curtain effectiveness.

- Inclined drilling through the debris upstream of the dam would be challenging, even with pre-conditioning of the debris prior to grouting.
- Inclined drilling or drilling and grouting from within the tunnel may be required to complete the grout curtain around the tunnel.

2.5.6.4 Risks and Potential Failure Modes

- Fractures are too large and seepage velocities too high for grout to plug the fractures.
- Grout losses result in grout flowing into the river or reservoir, contaminating the water.
- Grout penetrates and plugs foundation drains that were constructed at the dam-foundation contact.
- Grout flows through gaps in the tunnel lining and into the tunnel.
- Grout pressures are not controlled adequately, resulting in displacement or movement of foundation or abutment rock blocks.
- Grout pressures are not controlled adequately, resulting in damage to the tunnel lining.
- Parallel grout lines cannot be successfully constructed.
- Equipment operating immediately upstream of the spillway and tunnel inlet could come dislodged.
- Hazards to divers working upstream of tunnel intake.
- Hazard to LBD operations if materials associated with underwater work are pulled into tunnel.
- Shaping of the reservoir bottom and sides to facilitate construction of grout curtain cap/guide poses potential for materials to get pulled into the tunnel and impact turbines.
- Working from a barge upstream of the dam may interfere with spillway gate operation.
- Potential for grout materials to get into the reservoir and contaminate the water.
- Grouting operations could plug, fill, or change flow through existing drains in the dam, which could result in higher uplift pressures below the dam.

2.5.6.5 Relative Cost

- High, as compared to the other grouting alternatives.

2.5.6.6 Constructability

- Access to the reservoir to launch barges and to transfer equipment, materials, and personnel to barges could be constructed a few hundred feet upstream of the left abutment adjacent to the fish pier.
- The depth of drilling is significant and maintaining grout hole alignment may be challenging.
- The location and alignment of grout holes would be checked prior to grouting. Additional holes could be added if grout hole alignment is determined to be too far from the desired location.
- Pre-conditioning of the debris and sediment prior to advancing the grout curtain into foundation bedrock could be beneficial. Benefits include better ability to maintain grout drill pipe position and verticality, removing obstructions in the debris and sediment column, and reduction in the potential for grout loss into the debris during grouting.
- To position drill bits at each drilling location, short guide pipes would be installed into the upstream dam face, or a pre-fabricated guide plate would be mounted on the upstream dam face. A grout cap with guide pipes would be constructed on the ground surface beyond the dam limits.
- Divers and/or ROVs would likely be required to guide drill bits into the guide pipes.

2.5.6.7 Environmental Considerations and Permitting

- Drilling and flushing of drill holes may introduce sediment into the reservoir and locally increase turbidity.
- Drilling and flushing operations in proximity to bedrock joints and fractures through which seepage is flowing could carry sediment produced by the drilling into the joints and fractures, and result in turbid water discharging to the river downstream of the dam.
- Performing grouting operations from barges within the reservoir presents possibility for hoses breaking and spills and for grout and cement to get in the reservoir water.
- There is potential for cement to be washed from joints and fractures into the river downstream of the dam during foundation grouting operations.
- Permitting from multiple state and federal agencies would be required.

2.5.6.8 Schedule

- Grouting complete in less than two years.

2.5.6.9 Other Comments

- See comments for Alternative 3A.

3.0 DISCUSSION

3.1 Alternative 1A: Blanket Forebay Depression Upstream of Dam

Alternative 1A, constructing a blanket over the forebay depression and known areas of concentrated flow from the reservoir (sinkholes), if successful, could reduce seepage velocities. The concept behind Alternative 1A is to reduce seepage velocities sufficiently that construction of cutoff wall or grout curtain seepage reduction measures could be more readily accomplished.

Alternative 1A seepage velocity reduction could be lasting, or temporary (weeks to months). Because the blanket envisioned for Alternative 1A would only cover a portion of the reservoir bottom, the potential for flow from the reservoir into the sediment and debris to occur beyond the limits of the Alternative 1A blanket is high. Because the reservoir bottom surface area and sediment and debris depth are large, the potential is high for large volumes of water to bypass the blanket, flow through the sediment and debris, and flow below the dam through existing joints and fractures at velocities near the existing velocities.

Numerical modeling of the potential impact of Alternative 1A construction on seepage should be conducted and a cost estimate produced before deciding if implementing Alternative 1A would provide sufficient benefit to warrant the cost.

3.2 Alternative 4: Grout Debris in Reservoir Upstream of Dam

Alternative 4, grouting debris just above the bedrock contact in the area upstream of the dam, if successful, could reduce seepage velocities and potentially significantly reduce seepage volumes. Alternative 4 includes injection of grout and gravel/sand into bedrock faults, joints, and fractures to decrease seepage velocity and bridge these bedrock structures prior to constructing the grout blanket above the bedrock. The concept behind Alternative 4 is to reduce seepage velocities sufficiently that construction of cutoff wall or grout curtain seepage reduction measures could be more readily accomplished.

It is unlikely that implementing Alternative 4 would provide complete cutoff of seepage because the debris in the forebay consists of random material that is likely difficult to thoroughly penetrate with grout, the locations of faults, joints, and fractures below the debris are not accurately mapped, and cannot be reliably targeted for blanketing with grout or injecting grout into, and the bedrock structures may extend upstream for significant distance allowing flow through them to bypass the blanket.

Alternative 4 seepage velocity reduction could be lasting, or temporary (months to years). Because the grout blanket envisioned for Alternative 4 would be directly in contact with or just above bedrock, the flow volume from the reservoir into bedrock and ungrouted debris below the grout blanket would be expected to be significantly less than could flow around an Alternative 1A blanket placed over the reservoir bottom, i.e., tens of feet above the bedrock surface. Information previously developed about approximate locations of bedrock faults, joints, and fractures, and grout takes documented during Alternative 4 implementation could be used to select locations for supplemental grouting during Alternative 4 construction.

There is the potential, although deemed remote, that implementing Alternative 4 would reduce seepage volumes and velocity sufficiently that cutoff wall or grout curtain construction are not required, could be postponed, or the scope of cutoff wall or grout curtain construction reduced. The long-term reliability of Alternative 4 grout blanket construction could only be assessed through completing it. Monitoring of seepage reduction that does occur during Alterative 4 implementation could help inform the cutoff wall and grout curtain construction programs because more information on the locations of bedrock joints and fractures could be obtained.

The cost to implement Alternative 4 and the potential benefit it could provide in reducing costs or improving performance of cutoff wall or grout curtain construction should be further assessed prior to deciding to move forward with Alternative 4 construction.

3.3 Alternative 2D: Cutoff Wall and Grout Curtain Combination – Upstream of Dam

Alternative 2D, constructing a cutoff wall upstream of the dam, in conjunction with constructing a grout curtain in the abutments, would, if it is able to be constructed, likely produce the desired seepage flow reduction. However, constructing the cutoff wall has many construction challenges and would likely be more expensive than some of the grout curtain alternatives.

Consequently, Alternative 2D was not selected as the preferred alternative.

3.4 Alternative 3: Grout Curtain

Alternative 3, constructing a grout curtain below the dam and extending from abutment to abutment, is thought likely to be effective to reduce seepage to acceptable or tolerable levels. Grouting would be performed using a combination of low-mobility grout, higher-mobility grout, and multiple grout hole lines. Four Alternative 3 permutations were advanced for further consideration.

Alternative 3D, inclined drilling through the dam from a barge upstream of the dam, and Alternative 3F, vertical curtain drilling from a barge upstream of the dam, are thought likely to have high risk of not achieving complete grout curtain construction, have significant construction challenges, and are likely more costly than either Alternative 3A or 3E. The need to work from a barge in the reservoir and below water, and for Alternative 3F, drilling through debris in the reservoir, are principle factors contributing to construction uncertainty, constructability issues, and high cost of these alternatives.

Alternative 3A, drilling from the dam crest and from abutments, and Alternative 3E, drilling from the dam face downstream of the dam crest, are thought to be constructible and likely to achieve the desired seepage reduction. Additional analyses, constructability review, assessment of potential impacts to LBD operations, and discussion with PSE are required before a decision as to which of these two alternatives to pursue is made. Combining Alternatives 3A and 3E, performing some of the drilling and grouting from the dam crest and some from platforms on the downstream dam face, may make sense to decrease impacts to dam operations, the spillway, and gates.

A decision as to whether to implement Alternative 1A and/or 4 prior to grout curtain construction must be made. The cost of implementing either Alternative 1A or 4 could be substantial and the benefits uncertain. If the curtain grouting methods are deemed likely to achieve necessary seepage reduction without implementing Alternatives 1A or 4, even if there is some increase in cost to implement the grout program, then the merit of completing Alternative 1A or 4 may be questionable.

4.0 PREFERRED ALTERNATIVE

The recommended approach is to institute a foundation grouting program. This program would consist of a combination of Alternative 4, or Alternative 1A and 4, followed by construction of a multiple-line grout curtain using either Alternative 3A (drilling from dam crest) or Alternative 3F (drilling from downstream dam face), or a combination of the two. The decision as to which of Alternative 3A or 3F is the preferred alternative, or how they are combined, would be made after further discussion with PSE and potential contractors and after developing and evaluating 3-D graphics of proposed work areas and grout zone. The grout curtain lines would continue off the dam into each abutment.

Grout program completion and success will likely be improved by first implementing Alternative 4 or both Alternatives 1A and 4. Alternative 1A consists of constructing a low hydraulic conductivity blanket of limited aerial extent in the reservoir. A scaled-down version of Alternative 1A that only installs a gravel filter to reducing flows into known sinkholes is recommended. Implementation of Alternative 4 would follow filter placement. Alternative 4 consists of injecting gravel and sand directly into open bedrock faults, joints, and fractures in the forebay just upstream of the dam; grouting these bedrock features on the upflow side of the gravel/sand plug that is created; and following this with grouting of debris and sediment just above the bedrock. Injection of gravel and sand should initially be targeted for injection into locations of known concentrated flow associated with observed flow into sinkholes on the reservoir bottom.

The goal of completing Alternative 1A and 4 is to reduce seepage velocities, and thereby improve potential for successful grout curtain completion. Cutting off or reducing flow into bedrock faults, joints, and fractures where seepage flow is known to be high will likely provide the most benefit for the least cost. Because neither Alternative 1A or Alternative 4 is expected to be sufficient to cut off seepage sufficiently to meet project goals, the decision to perform them or not should recognize that completing Alternatives 1A and/or 4 should not be expected to reduce the number of grout holes drilled or quantity of grout injected.

For grout curtain construction, low-mobility grouting would be conducted first and progress along the downstream grout curtain line. Subsequent grouting along grout lines upstream of the low-mobility grout line would use higher-mobility grout. Supplemental grout holes would be added in each grout line, and in areas where grout takes are high or grouting challenges encountered, as necessary to achieve cutoff. Three to five grout curtain lines may be required where joints and fractures have larger openings and are more frequent and where seepage velocities are highest. The number of grout curtain lines may decrease to one to three where rock fractures and joints are tighter at greater depth below the dam and with increasing distance into the abutments. Grout curtain construction could progress simultaneously in the abutments and across the dam foundation. Abutment grouting could commence simultaneous with implementation of Alternatives 1A and 4.

Dye testing conducted in 2015 confirmed multiple seepage pathways and hydraulic connection between identified bedrock structures. There is potential for many braided openings and flow pathways below the dam. Drains installed below the dam may have hydraulic communication with bedrock structures and be contributing to high seepage flow. To address uncertainty regarding bedrock and dam drains that contribute to seepage, where high grout takes occur, supplemental grout holes would be drilled to split-space the holes drilled along the grout curtain lines. Supplemental grout holes would be drilled between grout curtain lines and upstream and downstream of the grout curtain in areas of high grout take to fill voids and follow bedrock structures that could contribute to seepage.

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APPENDIX A

ALTERNATIVES CONSIDERED AND DISCOUNTED

APPENDIX A

ALTERNATIVES CONSIDERED AND DISCOUNTED

TABLE OF CONTENTS

EXHIBITS

ALTERNATIVE 1B

BLANKET RESERVOIR BOTTOM AND PARTWAY UP SLOPES UPSTREAM OF DAM

Description

Reduce flow of water through voids below the dam and debris and sediment in the reservoir bottom by reshaping existing debris and sediment in the reservoir upstream of the dam and constructing a blanket over the bottom and reshaped slopes (Exhibits A-Alt 1B-1 through A-Alt 1B-3).

Construct a filter of cobbles and gravel, overlain by gravel, overlain by sand. Cap the filter with a low hydraulic conductivity blanket consisting of a layer of silt and clay or a geomembrane.

- Reshape existing sediment; rock and soil construction debris that was placed in reservoir immediately upstream of the dam during dam construction (e.g., below tunnel entrance at left abutment); and landslide debris immediately upstream of dam on left abutment.
- Construct filter of mineral aggregate over reshaped reservoir slopes and over bottom of reservoir for the limits of the area to be addressed.
- Cap the filter with low hydraulic conductivity blanket consisting of silt and clay or a geomembrane.
- Where the geomembrane is placed, a nonwoven geotextile cushion would be placed below and possibly above the geotextile to reduce damage and puncturing of geomembrane.
- The geomembrane would be keyed into reservoir bottom or otherwise buried with soil to reduce water flow below the geomembrane along the dam edge, east and west slope edges, and upstream edge of the geomembrane.

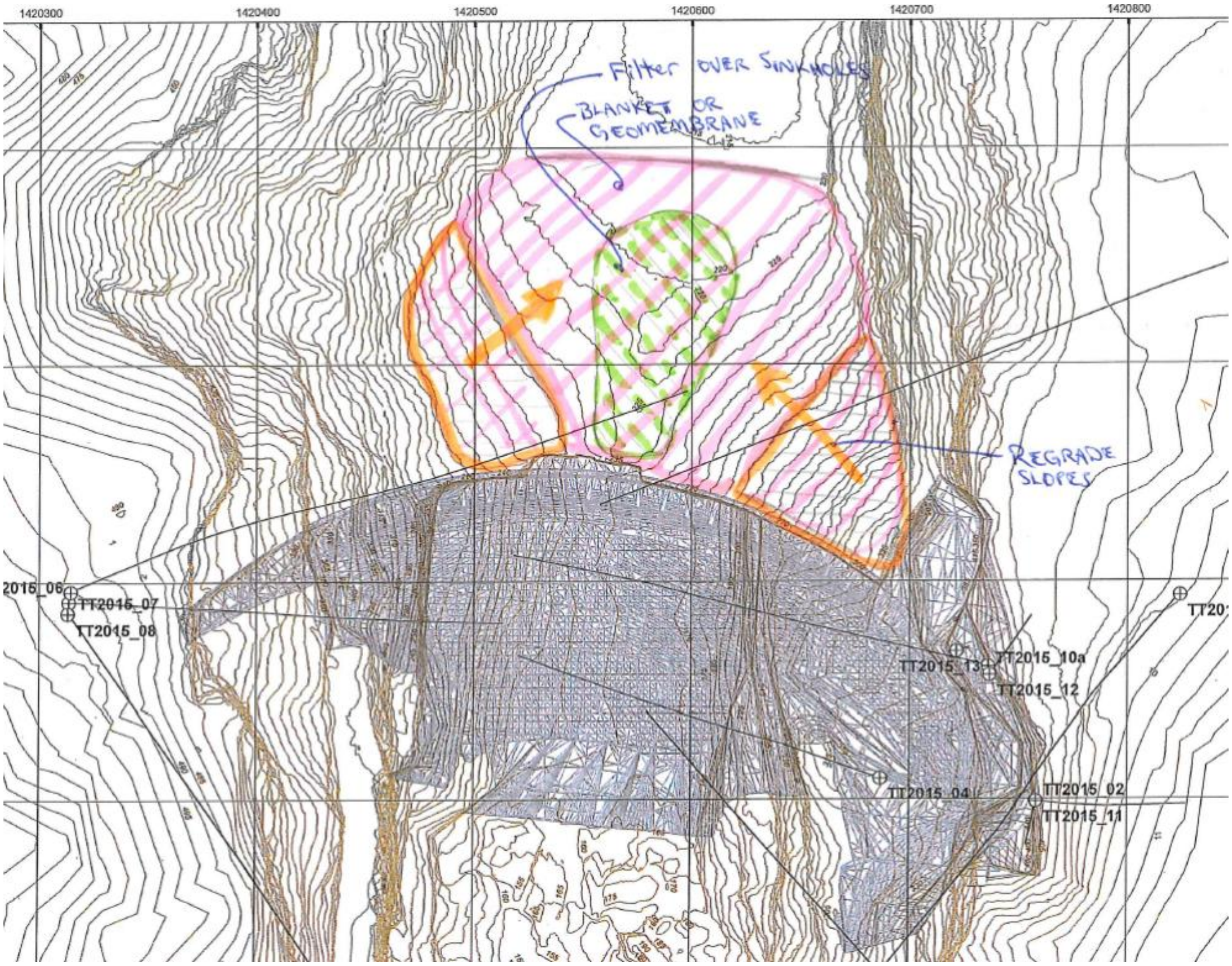

Exhibit A-Alt 1B-1: Filter over depressions and sinkholes, debris regrading, and blanket; plan view

Reasons for Discounting this Alternative

- Seepage below dam may be occurring at higher elevation than the top of the seepage blanket would extend.
- Sediment and debris on the reservoir bottom is thought to extend more than the about 200 feet upstream extent of the upstream limits of the blanket envisioned for this alternative. Thus, the blanket would not provide an upstream cutoff for seepage and seepage could get below the blanket.
- Cutoff wall or grouting would likely be required even after expending costs to construct Alternative 1B blanket over reservoir bottom.

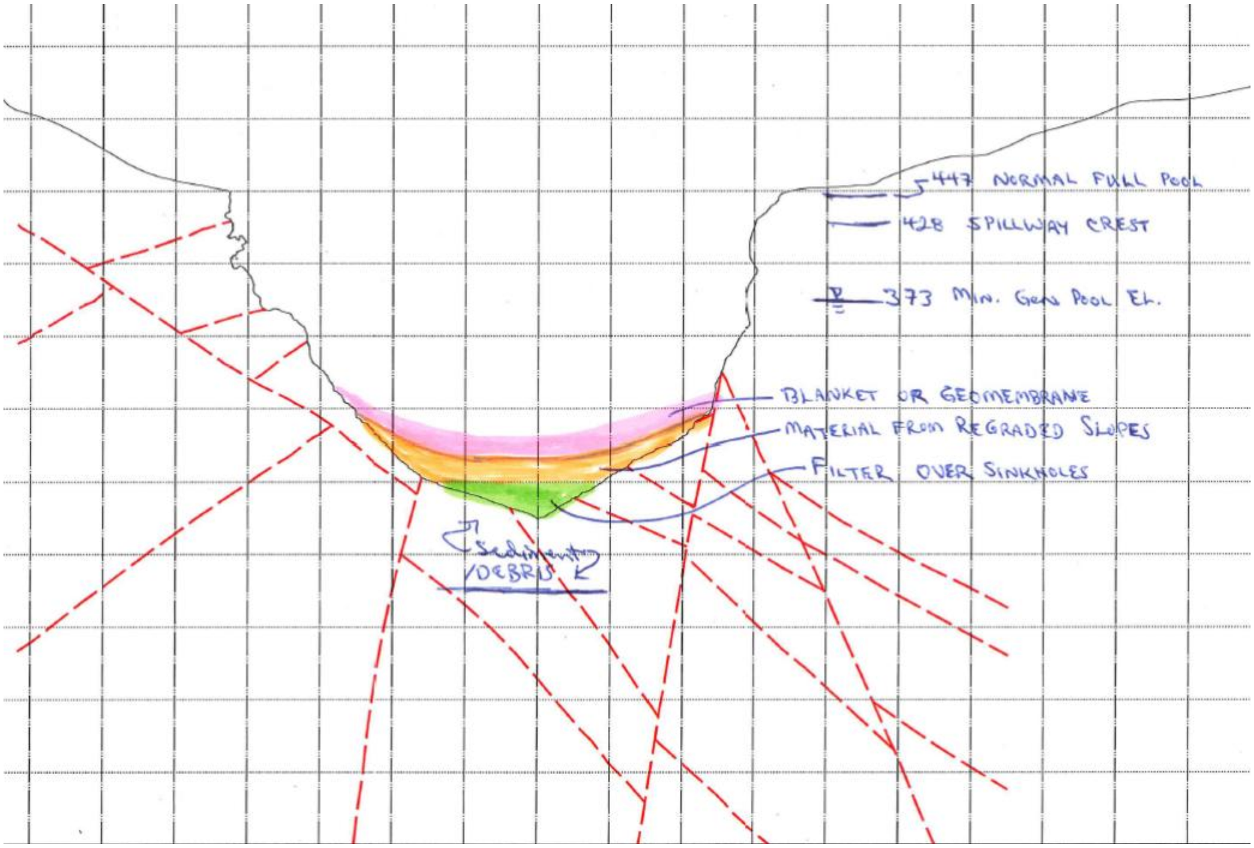

Exhibit A-Alt 1B-2: Filter over depressions and sinkholes, debris regrading, and blanket; cross section

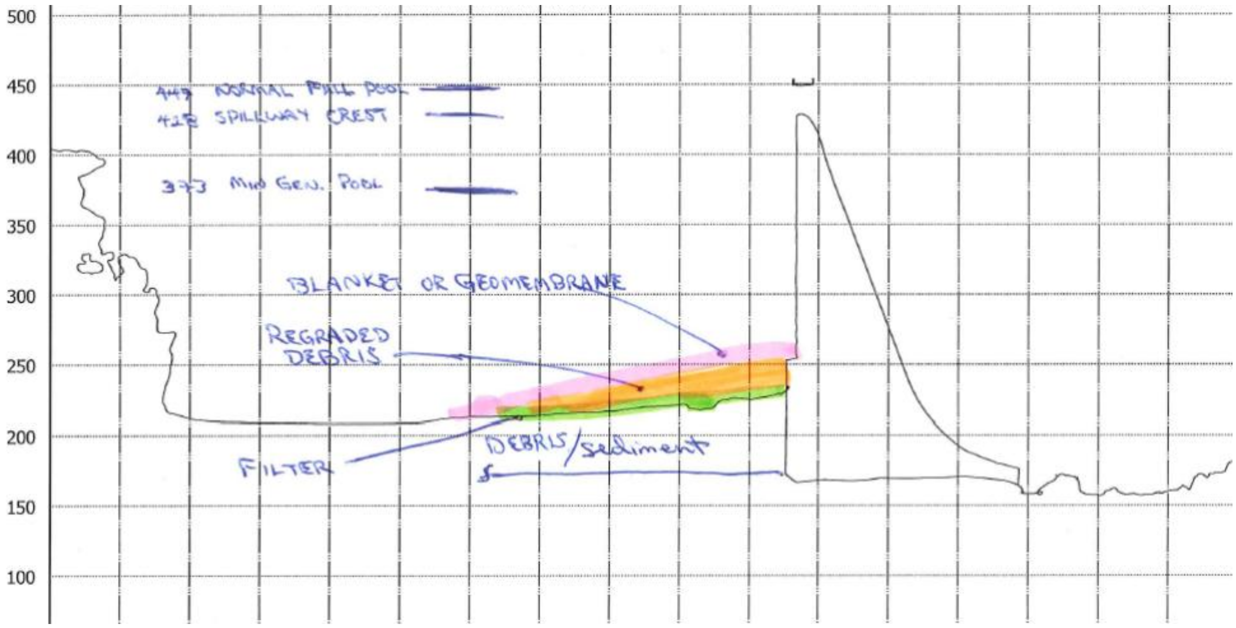

Exhibit A-Alt 1B-3: Filter over depressions and sinkholes, debris regrading, and blanket; section perpendicular to dam

ALTERNATIVE 1C

BLANKET RESERVOIR BOTTOM AND ATTACH GEOMEMBRANE TO HIGHER AND STEEPER PARTS OF RESERVOIR SLOPES UPSTREAM OF DAM

Description

Reduce flow of water through voids below the dam and debris and sediment in the reservoir bottom by reshaping existing debris and sediment in the reservoir upstream of the dam and constructing a blanket over the bottom and reshaped slopes (Exhibits A-Alt 1C-1 through A-Alt 1C-3).

Construct a filter of cobbles and gravel, overlain by gravel, overlain by sand. Cap the filter with a low hydraulic conductivity blanket consisting of a layer of silt and clay or a geomembrane.

Attach a geomembrane to the steep upper slopes of the reservoir sides upstream of the dam to reduce infiltration.

- Reshape existing sediment; rock and soil construction debris that was placed in reservoir immediately upstream of the dam during dam construction (e.g., below tunnel entrance at left abutment); and landslide debris immediately upstream of dam on left abutment.
- Remove sharp edges and uneven rock surfaces and slightly flatten the steep rock slopes on the higher elevation reservoir slopes upstream of the dam to reduce damage to and improve installation of a geomembrane on the rock slopes.
- Install rock bolts to reduce potential for a failure occurring behind the geomembrane or where rock slope failure could damage the geomembrane.
- Construct filter of mineral aggregate over reshaped reservoir slopes and over bottom of reservoir for the limits of the area to be addressed.
- Cap filter with low hydraulic conductivity blanket consisting of soil or geomembrane. Because a geomembrane would be placed on the steep rock slopes, for this alternative, it may make sense that a geomembrane also be used to cover the filter at lower elevations and across the reservoir bottom.
- Where the geomembrane is placed, a geotextile cushion would be placed below and possibly above the geomembrane to reduce damage and puncturing of geomembrane.
- Below the elevation where the reservoir sides are bedrock, the geomembrane would be keyed into reservoir bottom or otherwise buried with soil to reduce water flow below the geomembrane along the dam edge, east and west slope edges, and upstream edge of the geomembrane.

- A means to drain water from behind the geomembrane as water in reservoir is lowered.
- Above the elevation where the reservoir sides are bedrock, the upstream and dam ends of the geomembrane would be sealed and anchored to the bedrock and dam, respectively, to reduce flows from bypassing the geomembrane.

Reasons for Discounting this Alternative

- Shaping reservoir rock slopes and installing geomembrane extremely challenging.
- Uncertainty in effectiveness of geomembrane and high potential for geomembrane to be punctured or torn during installation or while in service.
- Sediment and debris on the reservoir bottom is thought to extend more than the about 200 feet upstream extent of the upstream limits of the blanket envisioned for this alternative. Thus, the blanket would not provide an upstream cutoff for seepage and seepage could get below the blanket.
- Cutoff wall or grouting would likely be required even after expending costs to construct Alternative 1C blanket over reservoir bottom and place geomembrane over reservoir sides.

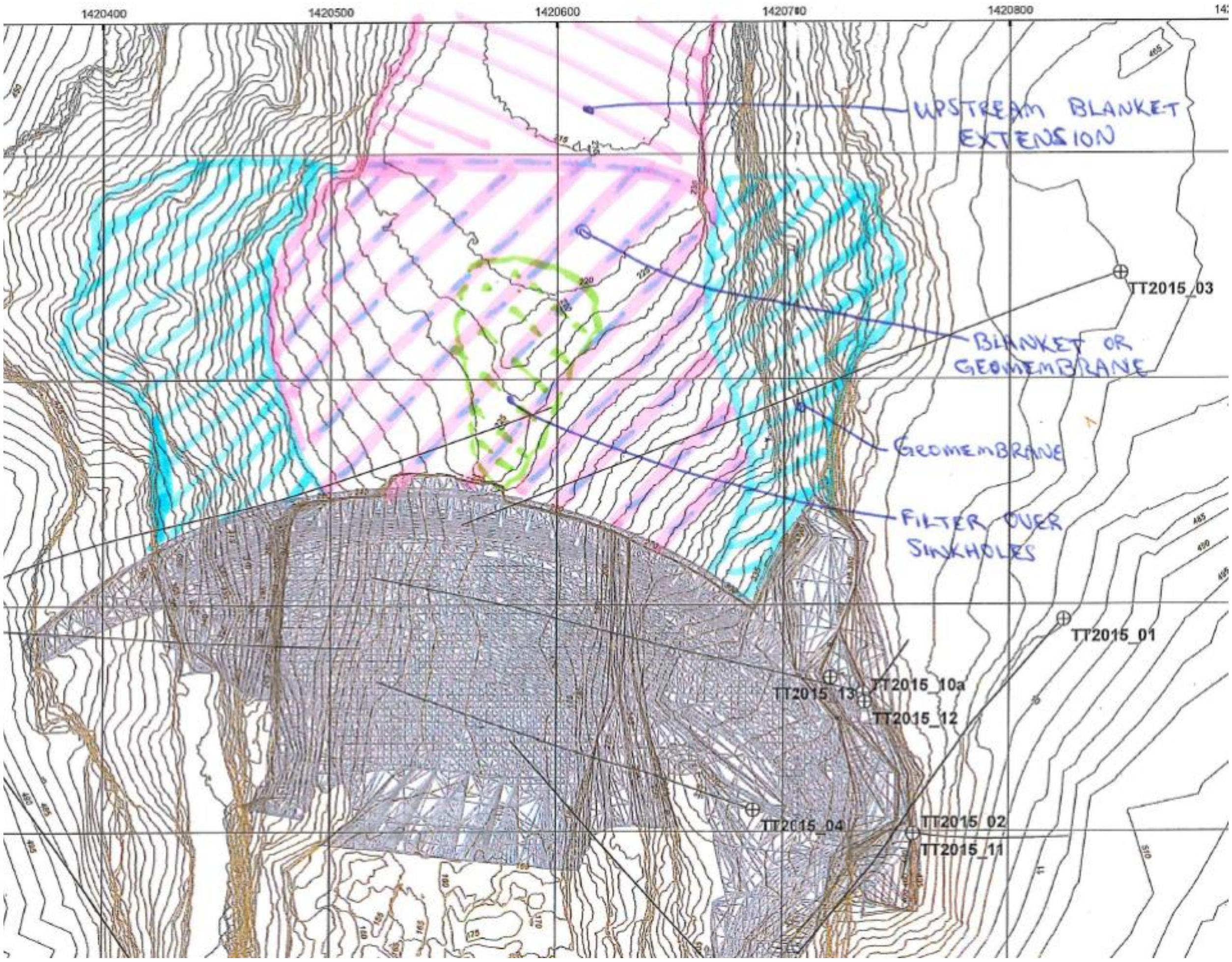

Exhibit A-Alt 1C-1: Filter over depressions and sinkholes, debris regrading, blanket, and geomembrane on slope; plan view

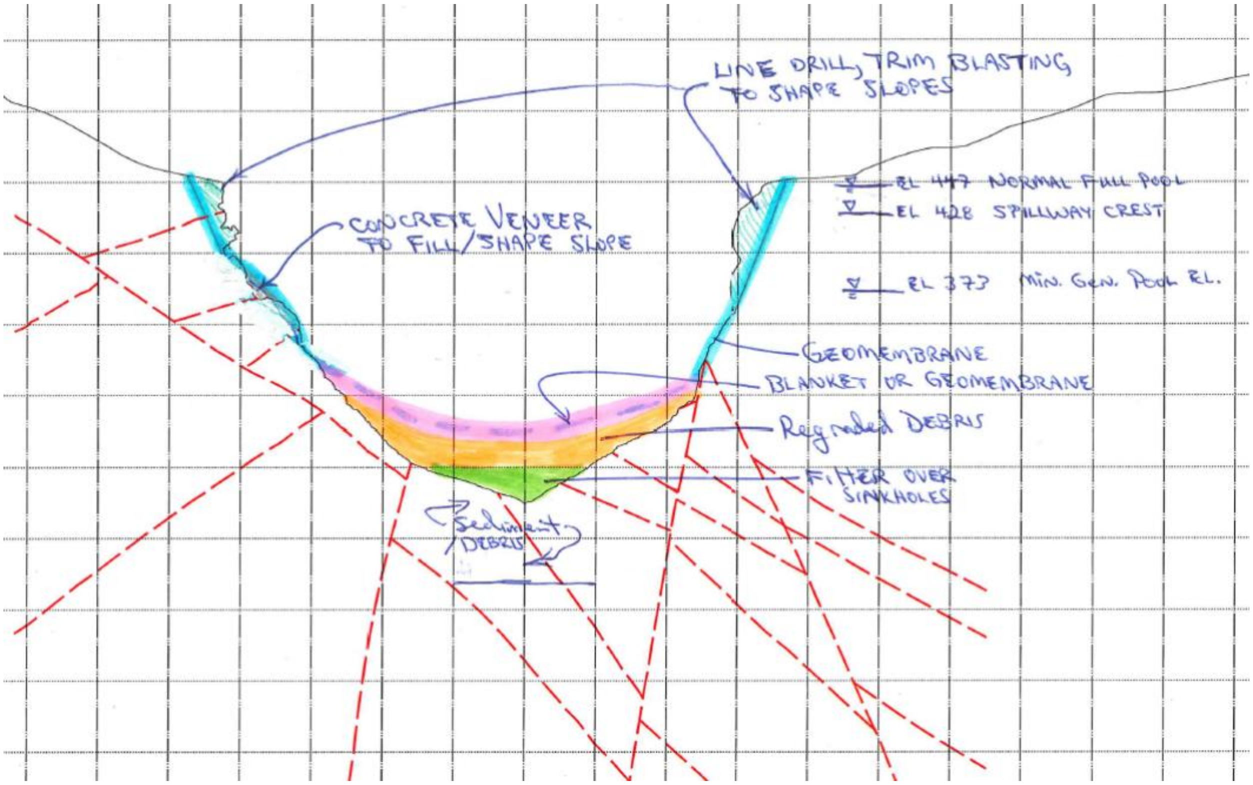

Exhibit A-Alt 1C-2: Filter over depressions and sinkholes, debris regrading, blanket, and geomembrane on slope; cross section

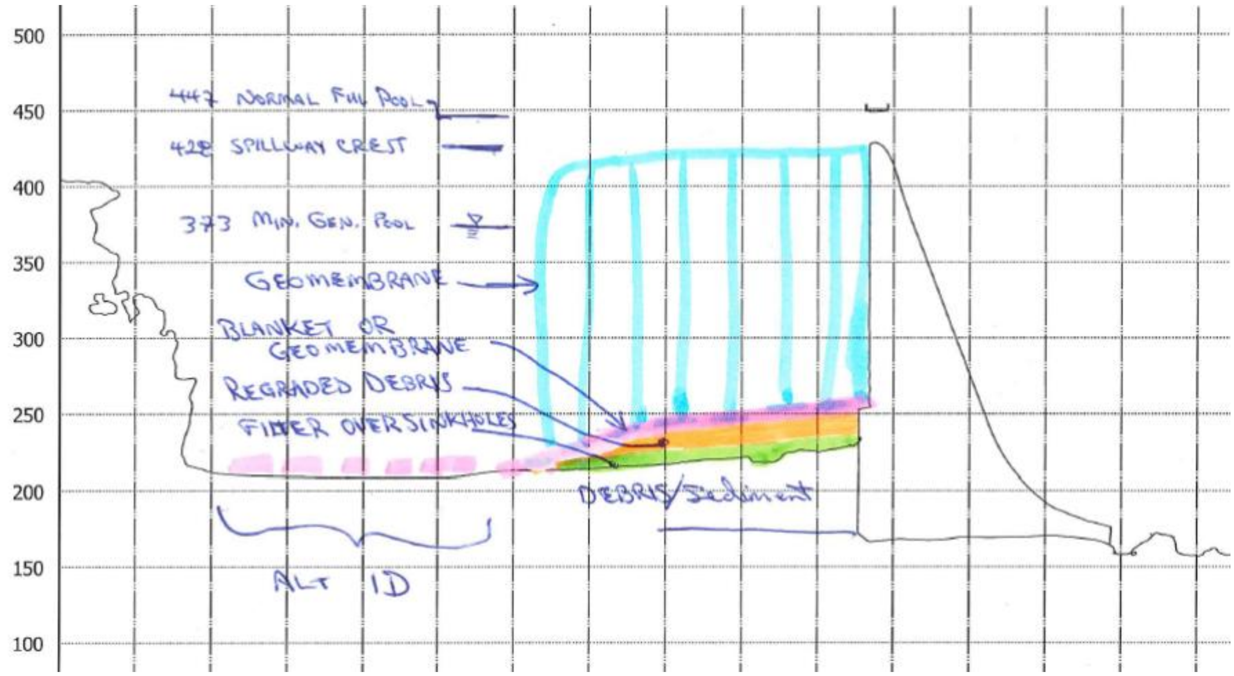

Exhibit A-Alt 1C-3: Filter over depressions and sinkholes, debris regrading, blanket, and geomembrane on slope; section perpendicular to dam

ALTERNATIVE 1D

BLANKET RESERVOIR BOTTOM FARTHER UPSTREAM OF BOTTOM BLANKET CONSTRUCTED IN EITHER ALTERNATIVES 1B OR 1C

Description

This alternative consists of extending the blanket along the reservoir bottom farther upstream than it is extended for Alternatives 1B and 1C, and would be completed after completing one of those alternatives. See Exhibits A-Alt 1C-1 and A-Alt 1C-3.

This alternative could be performed if, after completing Alternative 1B or 1C, substantial seepage reduction occurs and if dye testing or other evidence suggests that seepage from the reservoir bottom could be economically further reduced by extending the blanket farther upstream on the reservoir bottom.

Reasons for Discounting this Alternative

- See discussion for Alternatives 1B and 1C.
- Significant environmental impacts associated with wide-area blanket construction in reservoir.
- High cost and environmental impacts and uncertain performance.

ALTERNATIVE 2A

CUTOFF WALL – DOWNSTREAM OF DAM

Description

Install cutoff wall along/near downstream toe of dam (Exhibits A-Alt 2A-1 through A-Alt 2A-3). Cutoff would likely go through the apron if it crosses the dam toe. Keep cutoff wall alignment close to the groin of dam and abutments as the cutoff wall progresses into the abutments and the work moves up/down the valley walls. Prior to installing the cutoff wall, perform analyses to evaluate uplift resistance of dam and construct a buttress against downstream side of dam to increase uplift and sliding resistance to offset any reduction in stability that could result from increase in water pressure caused by installing cutoff wall. Use buttress construction to construct access and work platforms from which to drill and construct cutoff wall.

Assume Alternative 4 and possibly Alternative 1A are completed prior to constructing the cutoff wall. Extend cutoff beyond east and west top of dam contact with the abutments, to a distance to be determined.

The buttress constructed against the downstream face of the dam could be constructed of concrete, roller compacted concrete (RCC), or compacted soil/rock. Construction of the buttress would include installation of drainage systems below the buttress, downstream of the cutoff wall.

Reasons for Discounting Alternative

- Difficult access to portions of the work area, requiring construction of access, roadways, platforms, and equipment and materials transport systems.
- Inability to practically offset high heads and upward flow during cutoff wall drilling without lowering reservoir.
- Construction on steep slopes.
- Fill or concrete placement in a work area constructed in the river downstream of existing dam. Downstream cofferdam to isolate work area likely required.
- Excavation into river bottom and valley wall slopes required to prepare foundation and abutments where buttress will be constructed.
- Potential damage to buttress or cutoff wall construction if it is necessary to spill water over the dam during the buttress or cutoff wall construction period.
- Will increase uplift pressures below dam as cutoff blocks ability of water to flow through foundation rock. The decrease in dam stability relative to the current

condition that would accompany the increased water pressure would be compensated for prior to installing cutoff wall.

- Constructing an earth buttress downstream of existing dam may impose lateral earth pressures against the downstream face of the arch, resulting in unacceptable changes in the internal stresses of the existing dam. (Constructing the buttress of concrete or RCC would not impose similar high upstream-acting lateral loads against the downstream dam face.)
- High cost.

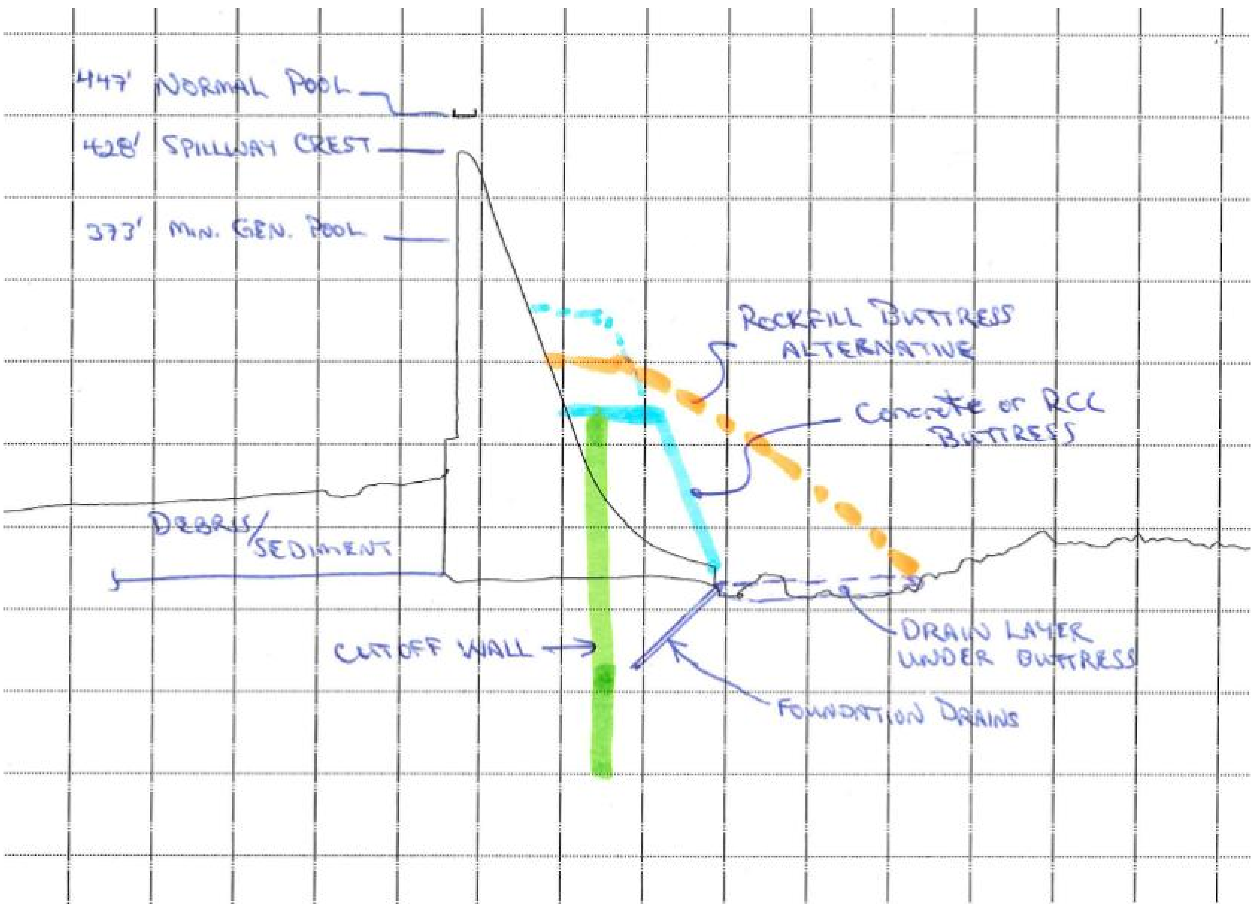

Exhibit A-Alt 2A-1: Cutoff wall downstream of dam; section perpendicular to dam.

ALTERNATIVE 2B

CUTOFF WALL – THROUGH DAM

Description

Install cutoff wall through the dam. The cutoff wall would be constructed from the dam crest and extend from the top of the dam to the necessary depth into the dam foundation (Exhibits A-Alt 2B-1 through A-Alt 2B-2). The cutoff wall would likely be constructed using small diameter secant piles. Prior to installing the cutoff wall, perform analyses to evaluate effects of cutoff wall construction on the internal and post-construction stress state in the dam. Design the cutoff wall construction method to mitigate potential adverse impacts of cutoff wall construction.

Assume Alternative 4 and possibly Alternative 1A are completed prior to constructing the cutoff wall.

Extend cutoff beyond east and west top of dam contact with the abutments, to a distance to be determined.

Reasons for Discounting Alternative

- Potential for cutoff wall construction to modify the stress state in the dam or weaken the dam.
- Modifications to dam crest and existing gates would be required to create work platform from which cutoff wall construction equipment could operate.
- Difficult access. Work platforms on top of dam and equipment and materials transport systems would need to be constructed to deliver materials to cutoff wall work locations.
- Cutoff wall drilling depth is maximized, increasing the challenges of maintaining overlap of adjacent cutoff wall elements and challenges with equipment achieving the design depth. High precision drilling is required.
- Construction on steep slopes on either side of the dam to extend the cutoff wall into abutments.
- Ability to operate spillway gates and spillway may be reduced during construction period.
- High cost.

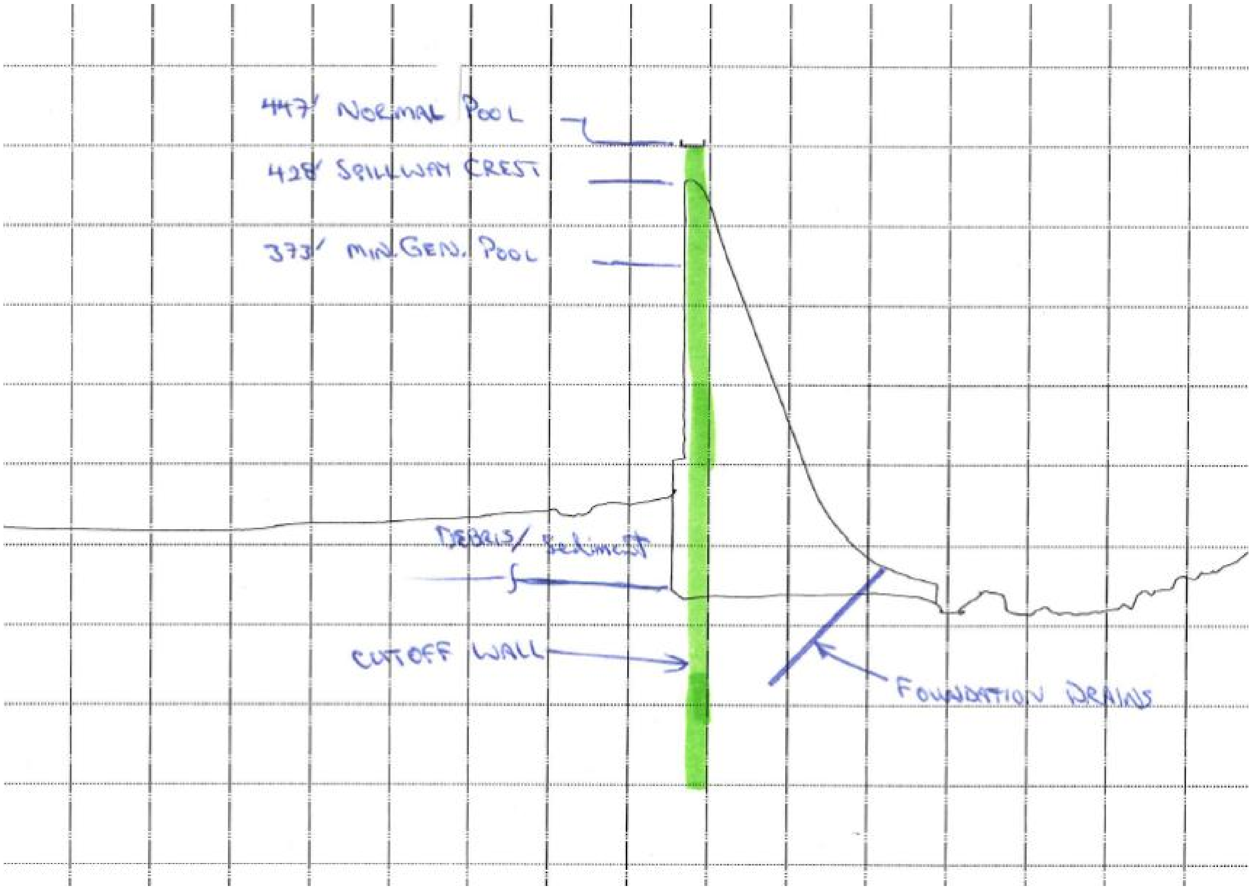

Exhibit A-Alt 2B-1: Cutoff wall through dam; section perpendicular to dam

ALTERNATIVE 2C

CUTOFF WALL - UPSTREAM OF DAM

Description

Install a cutoff wall just upstream of the upstream face of the dam. Significant portion of work would likely be performed operating from barges (Exhibits A-Alt 2C-1 through A-Alt 2C-3). Wrap cutoff wall around tunnel entrance to upstream side of tunnel entrance. Construct work platforms to construct cutoff wall up steep slopes above reservoir pool elevation, i.e., above elevation that drilling from barge allows. This alternative is similar to Alternative 2D, except Alternative 2C only uses a cutoff wall to address seepage.

Assume Alternative 4 and possibly Alternative 1A are completed prior to constructing the cutoff wall.

Extend the cutoff wall beyond the east and west top of dam contact with the abutments, to a distance to be determined. After cutoff wall construction, construct a seepage blanket that extends from the cutoff wall to the dam face to reduce seepage volumes infiltrating the reservoir bottom and abutments in the area between the cutoff wall and the upstream dam face.

Reasons for Discounting Alternative

- High cost relative to Alternative 2D, where grout curtain would be proposed to extend cutoff to greater depth below the dam and into the abutments.

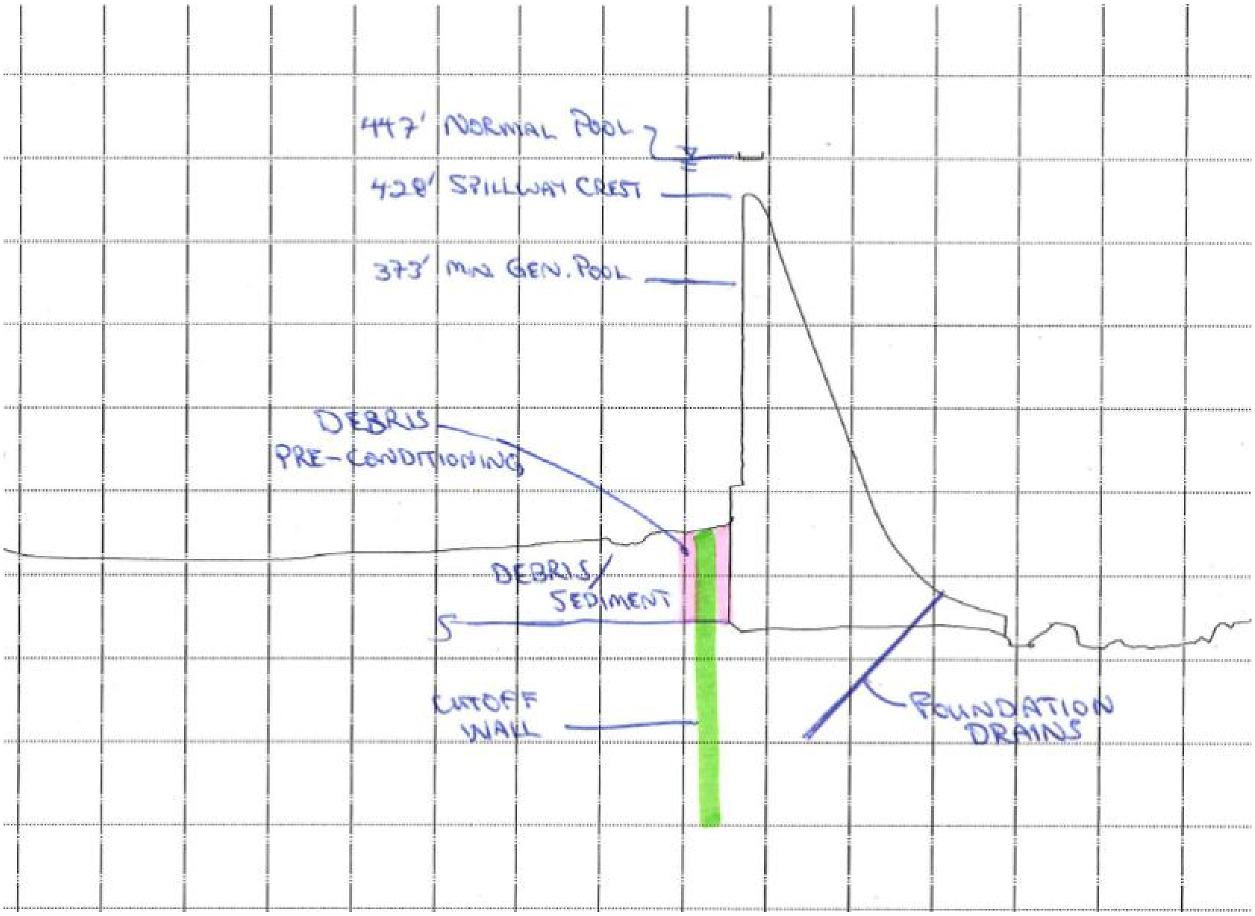

Exhibit A-Alt 2C-1: Cutoff wall upstream of dam; section perpendicular to dam

ALTERNATIVE 3B

GROUT CURTAIN – DRILLING FROM ADITS/GALLERIES

Description

Construct a multi-row grout curtain to seal seepage flow paths. Most drilling and grouting would be completed from adits drilled in the abutments and foundation (Exhibits A-Alt 3B-1 through A-Alt 3B-2). Grouting of higher elevation zones and into the abutments beyond the dam limits could be completed by drilling vertical holes from the top of the dam and abutment ground surface.

Grouting using low mobility grout followed by a minimum of two lines grouted with cementitious grout would be performed, as is described for Alternative 3A. Extend the grout curtain sufficiently far enough into the dam abutments to reduce potential for seepage to flow around the grout curtain.

Reasons for Discounting Alternative

- Local grouting programs may be required to advance and work in adits.
- Access development to adit portal locations for personnel and material delivery and to remove spoils may be challenging.
- Work downstream of dam in river or on sides of river to deliver material to and from adits may be challenging and increase potential for excavated material-, cement-, and equipment-related contaminants to enter the water relative to a ground-surface-based grouting program conducted from higher on the dam and abutments.
- Difficulty controlling groundwater seepage into adits to be used for grouting.
- Excavating adits in existing dam foundation and abutments could change the stress state in the dam and foundation/abutment, potentially impacting the dam.

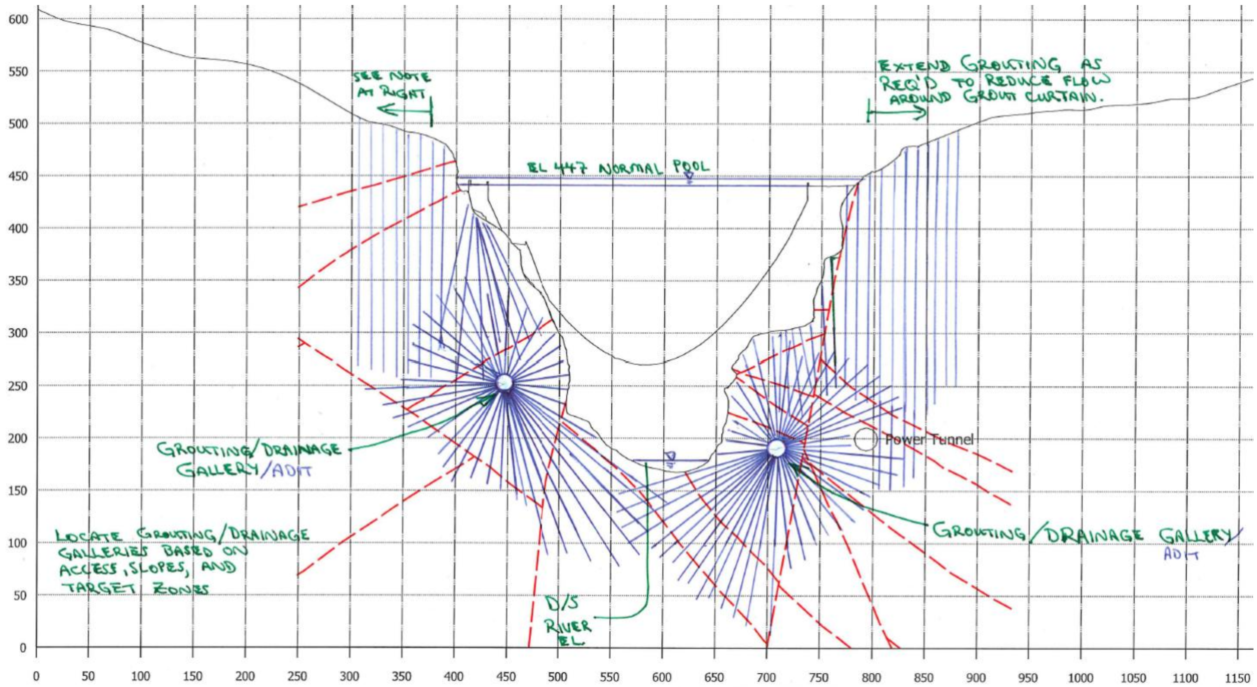

Exhibit A-Alt 3B-1: Grout curtain – drilling from adits; cross section (vertical and horizontal grout holes shown for convenience–grout hole orientations would vary and would be different on adjacent grout lines)

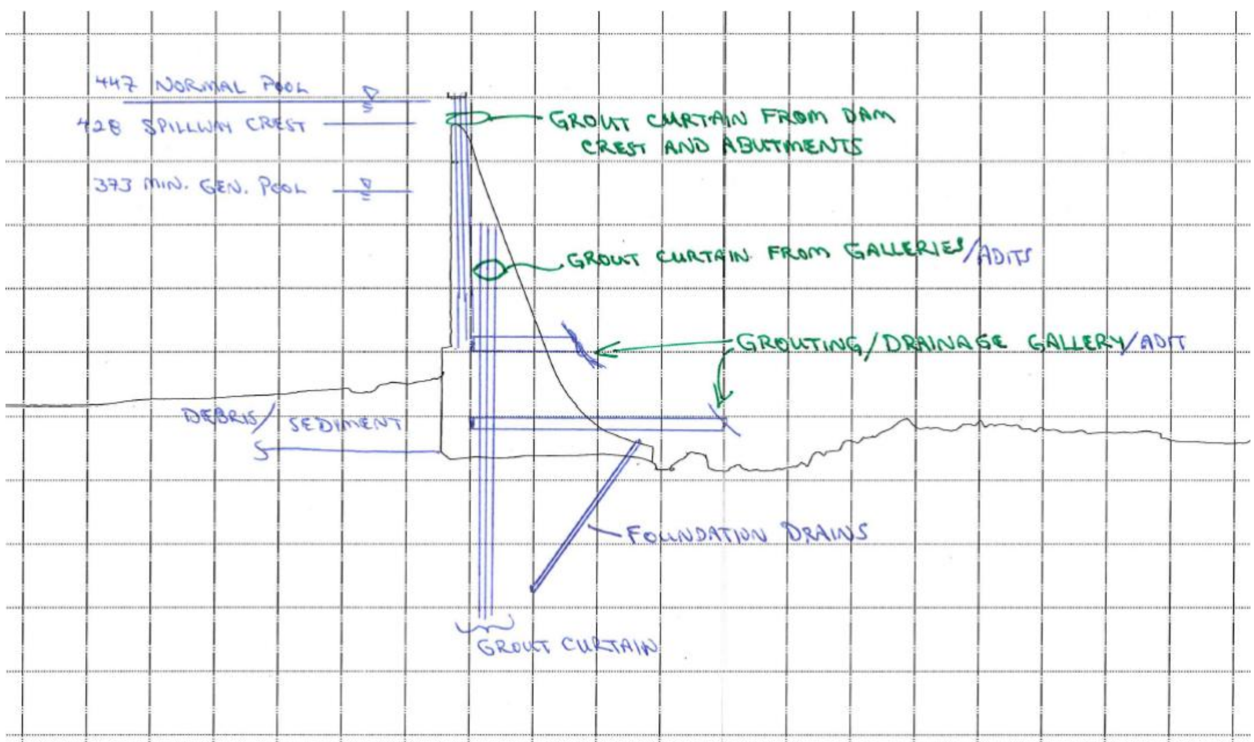

Exhibit A-Alt 3B-2: Grout curtain – drilling from adits; section perpendicular to dam

ALTERNATIVE 3B-2

GROUT CURTAIN – DRILLING FROM ADITS/GALLERIES IN ABANDONED DAM SLUICEWAYS

Description

Construct a multi-row grout curtain to seal seepage flow paths. Most drilling and grouting would be completed from adits excavated into the downstream face of the dam along the alignment of abandoned and backfilled sluiceways that were used during LBD initial construction foundation. The concept would appear similar to that shown in Exhibits A-Alt 3B-1 and A-Alt 3B-2, except the adits would be in the dam along the abandoned sluiceways. Grouting of higher elevation zones and into the abutments beyond the dam limits could be completed by drilling vertical holes from the top of the dam and abutment ground surface.

Grouting using low mobility grout followed by a minimum of two lines grouted with higher mobility grout would be performed, as is described for Alternative 3A. Extend the grout curtain sufficiently far enough into the dam abutments to reduce potential for seepage to flow around the grout curtain.

Reasons for Discounting Alternative

- Access development to adit portal locations for personnel and material delivery and to remove spoils may be challenging.
- Excavating into the dam along the former sluiceway alignments may reduce structural integrity of the dam, change the stress state in the dam and foundation/abutment, and potentially impact the dam.
- Access development to dam face and adit portal locations for personnel and material delivery and to remove spoils may be challenging.
- Work downstream of dam above the river may be challenging and increase potential for excavated material-, cement-, and equipment-related contaminants to enter the water relative to a ground-surface-based grouting program conducted from higher on the dam and abutments.

ALTERNATIVE 3C

GROUT CURTAIN – DRILLING FROM VERTICAL SHAFTS

Description

Construct a multi-row grout curtain to seal seepage flow paths. Most drilling and grouting would be completed from shafts drilled in the abutments and foundation (Exhibits A-Alt 3C-1 through A-Alt 3C-2). Grouting of higher elevation zones and into the abutments beyond the dam limits could be completed by drilling vertical holes from the top of the dam and abutment ground surface.

Grouting using low mobility grout followed by a minimum of two lines grouted with higher mobility grout would be performed, as is described for Alternative 3A. Extend the grout curtain sufficiently far enough into the dam abutments to reduce potential for seepage to flow around the grout curtain.

Reasons for Discounting Alternative

- Local grouting programs may be required to advance and work in the shafts.
- Access development to shaft locations for personnel and material delivery and to remove spoils may be challenging.
- Difficulty controlling groundwater seepage into shafts to be used for grouting.
- Excavating shafts in existing dam foundation and abutments could change the stress state in the dam and foundation/abutment, potentially impacting the dam.

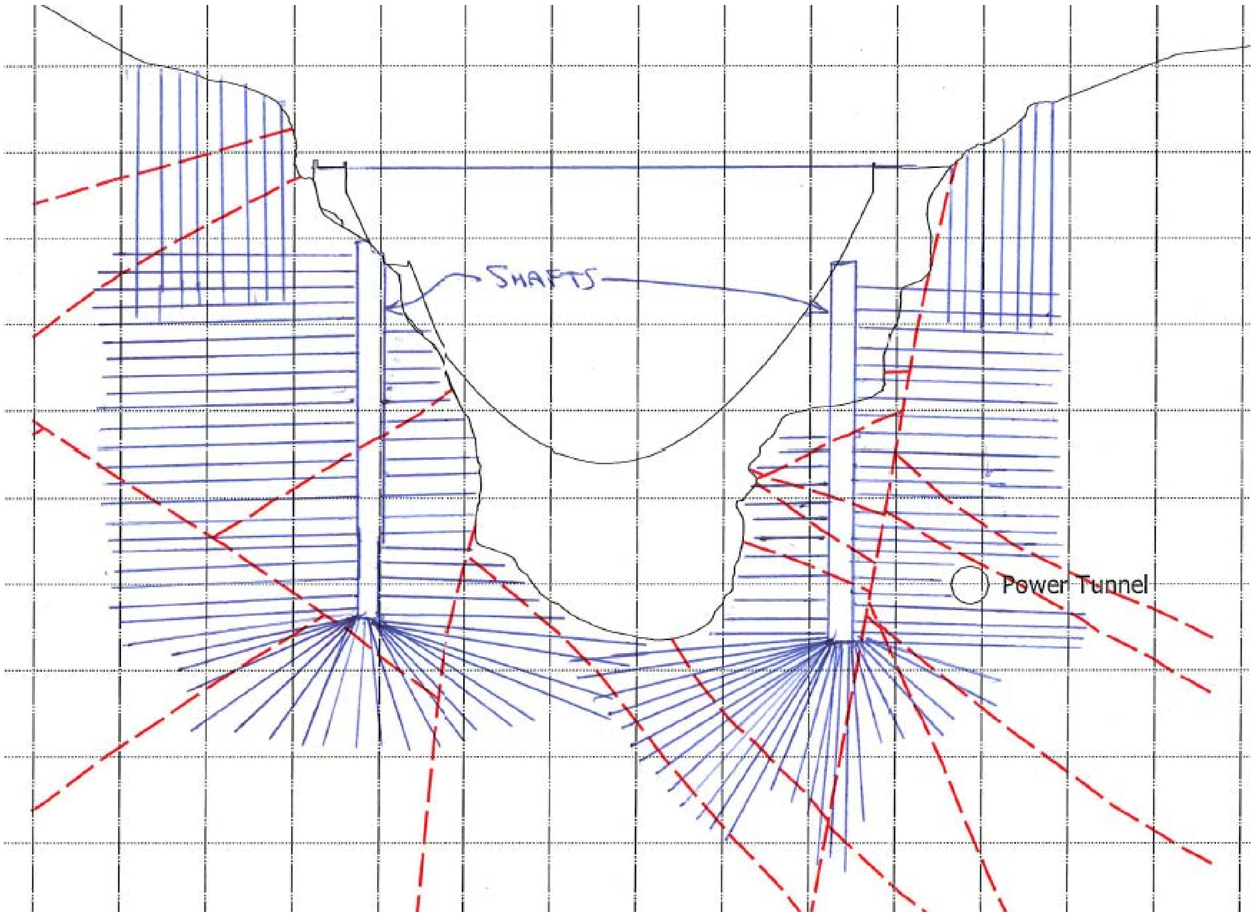

Exhibit A-Alt 3C-1: Grout curtain – drilling from shafts; cross section (vertical and horizontal grout holes shown for convenience–grout hole orientations would vary and would be different on adjacent grout lines.)

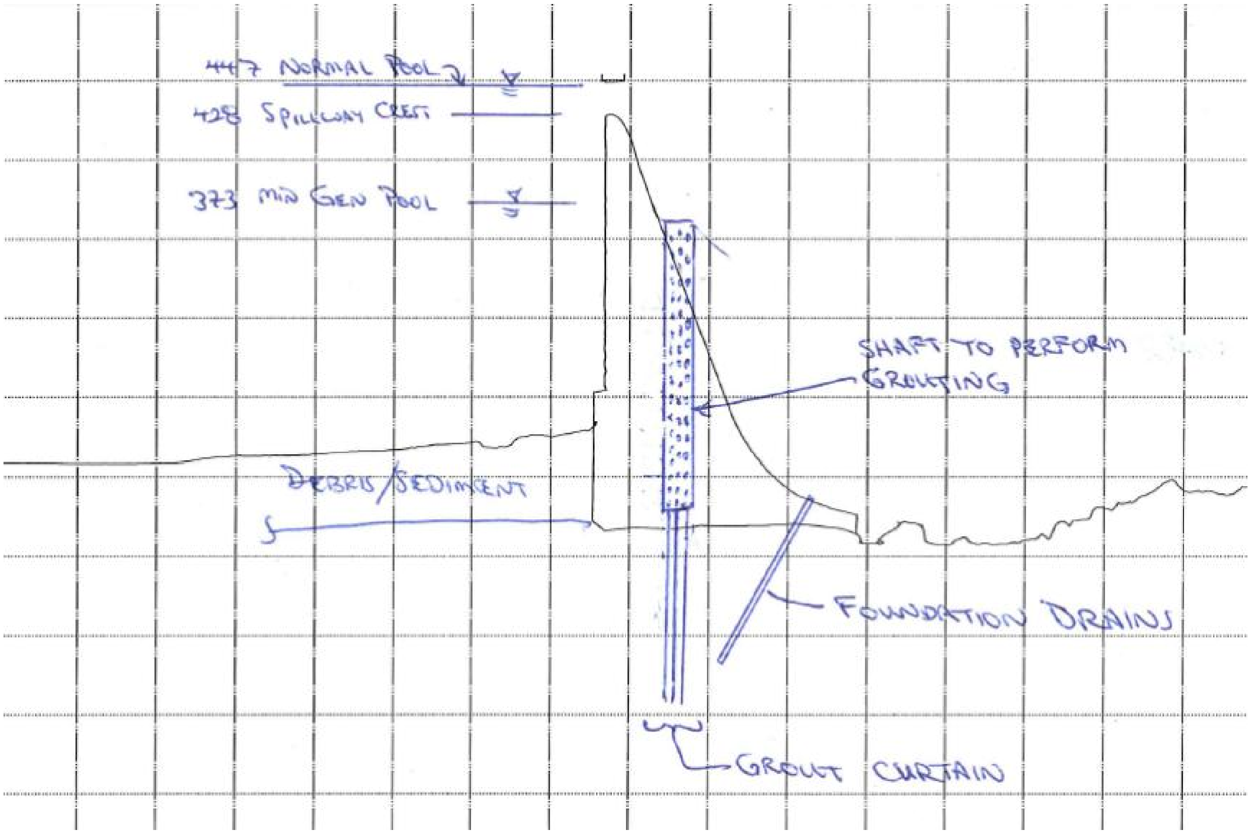

Exhibit A-Alt 3C-2: Grout curtain – drilling from shafts; section perpendicular to dam

ALTERNATIVE 5

PLUG UPSTREAM ENTRANCE TO JOINTS WHERE SEEPAGE MOST CONCENTRATED

Description

Plug or reduce flow through the two bottom-of-reservoir locations that dye testing shows concentrated flow and direct connection between reservoir and downstream seepage discharge has been demonstrated. Reduce flow through the joint system through which most of the flow entering at the sinkhole upstream of the dam by introducing progressively larger gravel into the flow that is going down into the sinkhole until the gravel bridges and plugs the entrance. Then introduce progressively smaller gravel, and then sand, into the flow until the sand is no longer pulled into the flow. Then introduce grout into the flow and grout over the surface of the sand to reduce flow through the sand.

Reasons for Discounting Alternative

- Cutoff wall or grout curtain program would likely be required in addition to implementing Alternative 5.
- Uncertainty of success:
  - After initial plugging of opening in rock joint set, the flow velocity toward the joints may slow such that gravel, sand, and grout is no longer pulled toward the joint opening, and thus the seepage may not be sufficiently cut off with this technique.
  - The gravels and sand would need to flow through more than 50 feet of debris to reach bedrock and the joint system.
  - Much is left to chance in this process for gravel, soil, and grout to make its way through the debris to the joint opening and to bridge and fill the opening.
- Once the main opening in the bedrock, which is interpreted to be relatively large, is plugged, seepage could continue through adjacent parts of the joint system that are connected to the now gravel-bridged larger opening. This flow could result in future erosion and widening of the joint.
- Would not address seepage where dye testing showed concentrated flow at other location on the reservoir bottom or the fault system high on the right abutment. An alternative mitigation method would be employed to seal this leakage area.
- May redirect flows in joint system, redirecting location of rock and joint erosion.

ALTERNATIVE 6

CONSTRUCT NEW DAM DOWNSTREAM OF EXISTING DAM

Description

Construct a new dam downstream of the existing dam.

Reasons for Discounting Alternative

- Very high cost.
- Challenges and delays associated with getting permits for the work.
- Decade(s) long process to permit, design, and construct.
- Implementing this alternative, while possible, is likely unnecessary because other less expensive alternatives to mitigate seepage under the existing dam are available. The design, permitting, and construction of a new dam would be both costly and a long, drawn-out process.