US Army Corps of Engineers®
Portland District

Final Report

Silver Creek Dam Potential Failure Modes Analysis (PFMA)

11 APRIL 2011

EXECUTIVE SUMMARY

E.1 Introduction

Silver Creek Dam is located on Silver Creek, approximately 2 miles southeast of Silverton, Oregon. The drainage area for the dam is approximately 46 square miles and extends southeast of the project and includes Silver Falls State Park. The dam was designed by CH2Mhill and constructed between May 1973 and November 1974 for the City of Silverton, Oregon. Due to the history of seepage and proximity of the dam to residents of Silverton downstream of the dam, the City has decided to construct an automated data collection and early warning system in order to try to improve its ability to monitor the condition of the dam and to provide warning to residents if unsafe conditions develop at the dam.

The City of Silverton and the Portland District US Army Corps of Engineers (USACE) have agreed to partner on the design and installation of the data collection and warning system as part of the Continuing Authorities Program (CAP). As part of this project, USACE recommended that a potential failure modes analysis (PFMA) be conducted for the dam. The purpose of the PFMA was to identify potential modes of failure for the dam in order to evaluate what measures may be taken to reduce either a) the likelihood that failure of the dam will occur and/or b) the consequences if the dam should fail. The results of the PFMA will be used to focus the scope of work for the design of the monitoring and early warning system.

E.2 Results of PFMA

The PFMA team, consisting of engineers from USACE and City Operations Personnel identified 36 potential failure modes. Of these, 16 were preliminarily identified as being credible and significant. After evaluating these 16 failure modes further, some of the failure modes were found to be similar and were combined and some were considered credible but not significant. After further evaluation, 4 failure modes were considered credible and significant. The credible and significant failure modes were identified as: Spillway Slab Jacking, Downstream Sill and Stilling Basin Scour, Upstream Sill Scour and Overtopping. Seepage was considered, however it was judged to be less of a concern than the four significant failure modes identified.

E.3 Major Findings and Understandings

During the PFMA session the following Major Findings and Understandings were identified:

1) The Dam appears to be well maintained and project operations staff is maintaining the project to the best of their abilities.
2) A variety of documents were available for review for the PFMA. A list of the documents is included as Appendix A. In general, there was a lack of construction photos associated with original construction (one aerial photo was available from original construction).
3) General access to the right side of the project is by car. Access to the right abutment of the project site (including the right spillway training wall and fish ladder) can be gained on foot. Access to the embankment, low level outlet and left abutment of the dam requires a boat.

4) Under normal operations, pool rises to spillway crest (El. 424 feet) for about nine months of every year. Pool of record is about El. 430 feet (6 feet over the crest) .
5) Downstream flooding occurs every year at Silver Gardens Retirement Home, requiring sand bagging every year. This will continue unless structural measures are taken to prevent flooding.
6) There is no stream gauging upstream of the dam or forecast data available at the project. As a result, the City is unable to predict flooding in advance from rainfall.
7) There are no weirs to measure seepage present at this project. The city currently manually measures seepage with a bucket and stopwatch periodically. This method results in inconsistent data and no plotting of seepage data has occurred to date.
8) There is no seepage collection/measuring present on the left abutment. Because of the historical seepage concerns, seepage was extensively discussed. For this PFMA, general seepage was broken down into seepage leading to a specific failure mechanism (i.e. increased seepage causes an increase in uplift pressure beneath the spillway slabs, leading to failure of spillway slabs, which allows erosion of the underlying foundation materials, leading to breach of the dam).
9) Outlet capacity and reliability are keys to safe project operations. The project cannot dewater quickly if needed for an emergency (except in summer). In addition, there are reliability concerns based on operation history.
10) Inspectors/City Staff cannot view or inspect the left side of the Dam (embankment, spillway and abutment) without a boat. This results in infrequent and inadequate inspection.
11) City staff cannot intervene to stop dam failure without the use of a helicopter or boat/barge. Placing material at the dam, such as rock or other materials to prevent or stop dam failure is difficult.
12) The current Emergency Action Plan (EAP) does not allow for full contact with the population. The call list for the current emergency public notifications system (Everbridge Call System) is not complete. According to City Operations Staff, the suppliers of the old notification system (Code Red) will not release the full list to the City. The Everbridge system will automatically call all landlines in Silverton. However, City residents won't be contacted on cellular phones unless they have signed up for the Everbridge call system (even if they signed up originally for the old Red Code system).
13) The Project Operations plan needs trigger thresholds for inspection (when to go to 24-hour surveillance, etc.) and warning. Critical elevations need to be established for this project in order to ensure adequate inspection and early warning.
14) Known foundation features will continue to seep (basalt interflow zone @ 398, landslide talus on right abutment). However, these areas are not prone to piping and dam failure.
15) Visible signs of distress are present at the dam (the spillway training walls are tilted, stilling basin scour is apparent at the site, new and/or increased seepage has been identified in recent years).
16) The City reports that seepage has increased in recent years (left and right side of outlet works, new pipe installed in Feb 2010), but there is no way for the City to quantify or measure to verify if seepage is increasing due to a lack of a weir or other measurement system that could be used to quantify this seepage.
17) The City inspects the dam twice per year and the State inspects the dam approximately once per year. Inspection requires boat access so frequent inspection is difficult.

18) Stilling basin scour is evident and has been previously reported in post construction inspections. There is no record of scour inspection or monitoring by the City. Original recommended operations and maintenance document indicates that the stilling basin is prone to scour and should be frequently inspected. The inspections will require diverting water from the low level outlet and fish ladder and pumping from the stilling basin during periods of no flow through the spillway; or use of an ROV.
19) Power at the project is City supplied and is only currently available on the right side of the Dam. No backup power, such as an emergency generator, is available at the site. Some method of alternative power, such as a solar panel, may be needed for any proposed monitoring system.
20) Some of the piezometers are currently non-functional and some of the piezometer standpipes are small in diameter. Small diameter piezometers may prove difficult to automate. If new piezometers are required, access to the embankment will have to be gained by boat or helicopter.
21) Operations personnel have no means of verifying the low level outlet gate position (42-in. or 18-in outlet) – operations cannot see the outlet from the control stand located on the left bank.
22) Outlet operation during high flows (open or closed) is not defined in the operations manual. The outlet may not be structurally sound at high pools when the gate is open due to the potential for cavitation. In addition, the air intake for the outlet may be inundated in high flow events which will result in surge flow.
23) Low spots are present at the right abutment. This means overtopping may occur at lower elevations.
24) No current hydraulic modeling/routing has been performed in order to define thresholds (100 yr flood, PFM, etc.), pools and tailwaters. If modeling data was available, the ability to set meaningful thresholds for an early warning system would be improved.
25) While the top of the embankment is designed at elevation 440, the clay core within the embankment only extends up to Elev. 435; the filter extends up to Elev. 430. Increased seepage above the clay core should be anticipated with pool levels greater than El. 435. In addition, the lack of a clay core extending to the top of the dam may result in overtopping occurring at elevations below elevation 440 (i.e. overtopping may begin before the pool reaches the top of the dam due to wave/wind erosion of the embankment). The potential for overtopping to begin at a lower elevation should be considered when defining trigger points for an early warning system.
26) The City was not able to produce current survey data for true height of embankment crest, the tops of walls or abutments. Settlement of the embankment or other low spots may result in overtopping at lower elevations than anticipated. Knowing the location of low spots is important for determining locations of stocking emergency materials and to focus flood fighting efforts.
27) Based on the results of analysis performed to date by Cornforth Consultants, the embankment and abutments are expected to be adequately stable under seismic conditions and liquefaction susceptibility is low.
28) No seismic analysis of the concrete spillway or spillway wall has been performed. It is anticipated that loss of the wall may lead to failure of the embankment. (Walls designed for 0.05g, current MCE from USGS = 0. 4g).
29) There appears to be a gap in the core trench on the right abutment below the training wall. The presence of a gap at this location may result in seepage at pools above Elev. 430.

30) Intervention materials (sand bags, rip rap) are not currently stockpiled on the site.
31) There are residence locations within very short travel times downstream of the dam. Warning time would not be possible for some failure modes.
32) Loss of pool in summer months will eliminate the downstream water supply and force the City to go to water conservation.
33) A log boom was installed at the end of construction at the upper end of the pool but is no longer present. Build up of reservoir rim debris could clog the spillway during high flow events.
34) Large vegetation debris is expected to continue to collect downstream of the spillway below the stilling basin, reducing channel capacity. If this material continues to collect over many years, it may create a downstream hazard during a subsequent large flood event as occurred in recent flooding events on the Sandy River resulting in downstream damage to bridges and property.
35) Project staff was unaware of the presence of 4 foot filter drain that runs from the filter zone to the left of the outlet pipe and ends downstream immediately to the left of the outlet structure (this may or may not exist since as-built drawings do not show it but it is discussed in CH2MHill correspondence). If it exists, this drain may contribute to seepage exiting near the low level outlet structure at the toe of the dam.
36) There are no records of conduit inspection/ROV inside the outlet pipe.
37) Zone 1 materials on the upstream shell of the embankment consist of well graded silty, sandy gravel and should act as a flow limiter/piping restriction (fill developed voids) should it initiate.
38) The low level conduit passes through the dam at the base of the embankment. It is founded on bedrock where it passes beneath the impervious core. The conduit is square and has seepage collars on 10 foot centers. Impervious back fill around the conduit was placed in 4 inch lifts and compacted with hand tampers.

E.4 Conclusions

1) Failure modes related to seepage through the right abutment landslide material are considered credible but not as significant as the 4 credible and significant failure modes identified in this report. It was judged that even under high pool conditions, such as Elev. 440 (PMF conditions), the relative increase in hydraulic gradient compared to what the project has experienced is not enough to initiate piping in the generally pervious, angular, basalt fragments that comprise the landslide deposit. However, it is important to continue monitoring seepage to detect any increases that may indicate a potential developing issue of concern.
2) With respect to the significant and credible failure modes, an automated early warning system would be most effective at reducing risk associated with the overtopping failure mode.
3) For overtopping failure modes, it is anticipated that, if properly designed and maintained, an automated early warning system may be able to provide early warning to decision makers in time to reduce the risk associated with overtopping failure modes.
4) Initiation and progression of the failure modes associated with erosion of the spillway foundation would be difficult to monitor with an automated monitoring system and therefore difficult to

provide advanced warning of failure by an early warning system. Monitoring horizontal drain data and data from a new piezometer installed to the left of the left spillway wall and downstream of the embankment filter zone could be used to monitor development of the failure mode associated with upstream sill scour and increased seepage through the right abutment. However, visual monitoring for spillway slab offsets and stilling basin and upstream sill erosion are more direct ways to identify whether these failure modes are initiating.

5) For failure modes associated with spillway foundation erosion, it is anticipated that the time from initiation to uncontrolled release of the pool could be months if the failure occurred under normal pool conditions but days (possibly hours) under high flood (such as a 100 year event). **During high flows, unless initiation is observed directly by City staff, minimal warning will be provided to the downstream population for spillway failure initiated failure modes regardless of whether a warning system is installed**.
6) If properly designed and maintained, the automated data collection function of the proposed early warning system will provide a benefit of increased consistency and quality of data (including piezometer and drain data) collected by the system. All data should be stored for future reference. This data helps to assess the condition of the dam and improves understanding for how the dam responds under various pool and seasonal conditions.
7) The automated data collection function could also be used to provide confirmation of flows through the low level outlet and frequent updates on the elevation of Silver Creek Dam downstream of the dam to improve coordination of flood response activities associated with hydrologic events that are not related to dam failure.

E.5 Recommendations Regarding the Early Warning System

1) The automated early warning system should include a reservoir level measurement and rain gage. Multiple level thresholds for reservoir level and rain data should be defined as part of the design of the early warning system. At a minimum, the thresholds should consider the elevations of the top of the core (El. 435) and the low spot to the right of the right abutment wall (approx. El. 438). In addition, due to the gap in the core trench on the right abutment below the training wall, the City should anticipate the possibility of increased seepage with pools above Elev. 430 and monitor this location. The system should provide notification of the exceedance of the thresholds to appropriate decision-making personnel at the City. In addition, it should collect and store data for future reference and analysis.
2) The City should design and install weir collection boxes to measure the flow rate of known seeps and drain flows, especially flows associated with the toe drains. Changes in these flow rates may indicate changing conditions at the dam.
3) In the event that drain flows show sustained increases in flow, consider installation of a new piezometer to the left of the left spillway wall for the purposes of monitoring piezometric pressure within the landslide deposit that provides the foundation for the spillway. The water level in this

piezometer could be monitored with an automated data collection system with thresholds assigned to provide notification.

4) The reliability of the existing piezometers should be evaluated as part of the design of the warning system.
5) For the purposes of historical data collection, the automated warning system should be designed to collect data from the piezometers and weirs to improve the consistency of data collection and review.
6) The automated system should support storage of historical data for the purposes of reviewing historical trends and providing reports when needed. Time history plots of data should be reviewed at least monthly by the City and more frequently if visual observations indicate potential developing issues of concern.
7) For the purposes of improving flood response by the City, the automated warning system should be designed to collect data for water level at downstream locations as determined by the City. Multiple level thresholds can be developed to provide an assessment of level of urgency.
8) The City's Emergency Action Plan should be updated to incorporate the early warning system and to address notification of all citizens impacted by flooding.

E.6 Additional Recommendations to Improve Dam Safety and Reliability

1) Perform a survey of the dam along the crest of the dam from left abutment to right abutment in order to determine the presence of low points on the dam. If there are low spots, they should be raised to the design elevation.
2) Perform survey of spillway and abutment walls for vertical and horizontal deflection in order to establish a baseline for comparison with future surveys. Additional surveys should be completed at least every 5 years. If surveys indicate movement, the results of the surveys should be reviewed by a structural engineer for evaluation.
3) Inspect and survey the stilling basin for scour during period when spilling is not occurring (summer low pool inspection) in order to establish a baseline for comparison with future surveys. Inspect the stilling basin for increased scour after large flow events. Perform the inspections and surveys at least every 5 years.
4) Inspect the spillway for vertical offsets between slabs during period when spilling is not occurring (summer low pool inspection). The most critical offset is the downstream slab uplifted relative to the upstream slab; this creates localized high pressures that may penetrate down along the slab joint and create high uplift pressure. If downstream vertical offsets are present, grind the downstream slab down to remove offsets. Recommend visual inspections are completed at least once per year.
5) Visually inspect upstream impervious blanket for holes for its full length upstream (not just the upstream sill) when possible. Visually inspect sillfor erosion at least once per year or after large spill events.
6) Inspect the integrity of the low level outlet pipe using a Remotely Operated Vehicle (ROV).

7) Evaluate and implement options for increasing the reliability of the low level outlet hydraulic system and for confirmation of gate opening size. To this end, the warning system should include collection of data on the flow through the low level outlet to improve the ability to confirm gate opening size.
8) The City's new public notification system (Everbridge) will call all City of Silverton telephone landlines but does not include the entire contact list from the provider of the old public notification system (Code Red). Recommend evaluating ways to update the Everbridge system contact list for all cellular phone users to the extent possible.
9) Perform hydraulic modeling to determine the frequency and magnitude and routing of storm events (determine relationships between flood frequency, peak flow and downstream water elevations). The results of the modeling would help the City with decisions regarding balancing downstream flooding impacts with dam safety risks and to improve the City's ability to warn the population. Once the results of the modeling are complete, it may be appropriate to modify the operations plan for the project.
10) The City should consider making structural improvements to prevent flooding of residents at low elevation locations (such as Silver Gardens Retirement Home).
11) The increased woody debris building up downstream of the stilling basin creates a potential for downstream damage during future storm events. During large events, this material may become dislodged and cause damage to bridges and property. The City should consider removing this material every 5 years.

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1.0 INTRODUCTION

Silver Creek Dam is located on Silver Creek, approximately 2 miles southeast of Silverton, Oregon. Silver Creek is tributary to Pudding River approximately 6 miles below the project. The dam was designed by CH2MHill and was constructed between May 1973 and November 1974. The dam was constructed to store water for municipal water supply and recreation. Due to the history of seepage and proximity of the dam to residents of Silverton downstream of the dam, the City of Silverton has decided to construct an automated data collection and early warning system in order to try to improve its ability to monitor the condition of the dam and to provide warning to residents if unsafe conditions develop at the dam.

The City of Silverton and the Portland District US Army Corps of Engineers (USACE) have agreed to partner on the design and installation of the data collection and warning system as part of the Continuing Authorities Program (CAP). As part of this project, USACE recommended that a potential failure modes analysis (PFMA) be conducted for the dam. The purpose of the PFMA was to identify potential modes of failure for the dam in order to evaluate what measures may be taken to reduce either a) the likelihood that failure of the dam will occur and/or b) the consequences, if the dam should fail. Failure is defined in USACE Engineering Regulation (ER) 1110-2-1156 – Safety of Dams – Policies and Procedures and by the PFMA team as sudden, rapid and uncontrolled release of impounded water. A failure mode is a detailed description of a possible chain of events from initiation through failure. Risk is defined as the probability of a load (such as a pool level or earthquake) multiplied by the probability of failure (given the load), multiplied by the consequences of the failure. As a result, the PFMA provides a means for identifying risk at the project. The results of the PFMA provide a sense of what possible modes of failure an automated early warning system might be effective at reducing risk but also for those that the system may not be able to effectively reduce risk. The PFMA also provides valuable information that can be used to determine what data should be collected from the automated data collection and early warning system. Information learned from the PFMA can also inform the City of critical aspects or areas on the project that require special attention.

2.0 BACKGROUND

The dam was constructed between May 1973 and November 1974. Upon first filling, seepage was observed on the right side of the earth embankment. Figure 1 is a site plan for the dam. The reservoir was lowered shortly thereafter and a series of horizontal drains were installed into foundation materials below the right side of the earth embankment. In addition, a buttress filter layer berm was placed on much of the right side of the embankment to intercept seepage not captured by the drains.

In June 1981, USACE and the Oregon Water Resources Department completed a Phase 1 Inspection Report. It identified the Silver Creek Dam as a high hazard dam because of the potential loss of life risk and the level of potential property damage immediately downstream of the dam. The inspection evaluated abutment and foundation conditions, embankment stability, hydraulic and hydrologic

Figure 1. Site Plan

conditions, and structural/mechanical features. The inspection found the dam to be in satisfactory condition for continued operation.

In March 1993, a magnitude 5.6 earthquake (Scotts Mills) occurred with an epicenter approximately 10 miles east of the City of Silverton. The magnitude of the earthquake and its location near the dam caused increased focus on seismic safety in the region. In July 1999, the City contracted to Cornforth Consultants to perform an assessment of the stability of the dam under steady-state, rapid drawdown and seismic conditions. The analysis indicated that the dam demonstrated adequate factors of safety for each of the conditions considered.

At the request of the City of Silverton, a dam break analysis was performed by Philip Williams and Associates in January 2000. The analysis was performed to provide information to be incorporated into an Emergency Action Plan (EAP) for the project. The analysis concluded that full breach of Silver Creek Dam would be catastrophic to the City and that elapsed time from dam failure to the passage of the flood wave is less than one hour. It was recommended in this report that the City installs an early warning system at the dam.

In 2002, Squier Associates performed a preliminary design report for an early warning system. The design report included recommendations for an early warning system based on 3 failure mechanisms: seepage failure under normal operating conditions, seismic deformations and instability and overtopping failures resulting from flooding.

USACE regulations (ER 1110-2-1156) now require that a PFMA process be performed for all major dam modifications or evaluation of interim risk reduction measures. In 2010, USACE decided that a PFMA was necessary to evaluate the applicability of an early warning system to reduce risk at Silver Creek Dam.

3.0 PFMA PROCESS

The first step in the process was to identify the team members that would participate in the PFMA. In general, PFMA teams include a facilitator, co-facilitator and technical experts. The makeup of the technical experts on a PFMA team depends upon the nature of the project. Projects that have a high degree of complexity may require team members from each of Structural, Geotechnical, Mechanical and Electrical Engineering and Hydraulics and Hydrology disciplines in addition to members familiar with operational aspects of the dam. For Silver Creek Dam, it was decided that the complexity of the project with regard to electrical and mechanical equipment was such that team members representing the other disciplines and the City’s operational team member have sufficient knowledge in this area to address issues in these disciplines.

Once the team was identified, each of the team members reviewed background information on the project. Project information was gathered by the City of Silverton and was transmitted to USACE prior to the start of the PFMA, which was performed as a focused workshop, between 10 and 14 January, 2011. Each of the team members reviewed the background information prior to the PFMA workshop, so that each member had familiarity with the project by the time of the workshop. On day 1, the team continued to review background information as a group and summarized initial major findings and understandings (see Section 4.0). On the second day, the team conducted a site visit to the project so that the team could become more familiar with site conditions. The remainder of the week was spent identifying, describing and evaluating potential failure modes for the project. The team identified the major features of the project and based on the team's experience and training for performing PFMAs identified possible failure modes. With this list of potential failure modes, the team developed a preliminary rating as to how significant each potential mode was. By convention, USACE assigns each mode one of the following categories:

a) Credible: a physically plausible failure mode.
b) Significant (or Credible and Significant): these failure modes are a subset of credible failure modes. The probability of failure and associated consequences approach closely or exceed a tolerable risk limit guideline.
c) Non-credible: not a physically plausible failure mode.

Appendix B includes the detailed notes that were taken during the workshop.

4.0 MAJOR FINDINGS AND UNDERSTANDINGS

This section includes a list of the major findings and understandings about the project that were identified from review of the background information, the site visit and during the PFMA workshop:

1) The Dam appears to be well maintained and project operations staff is maintaining the project to the best of their abilities.
2) A variety of documents were available for review for the PFMA. A list of the documents is included as Appendix A. In general, there was a lack of construction photos associated with original construction (one aerial photo was available from original construction).
3) General access to the right side of the project is by car. Access to the right abutment of the project site (including the right spillway training wall and fish ladder) can be gained on foot. Access to the embankment, low level outlet and left abutment of the dam requires a boat.
4) Under normal operations, pool rises to spillway crest (El. 424 feet) for about nine months of every year. Pool of record is about El. 430 feet (6 feet over the crest) .
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37) Zone 1 materials on the upstream shell of the embankment consist of well graded silty, sandy gravel and should act as a flow limiter/piping restriction (fill developed voids) should it initiate.
38) The low level conduit passes through the dam at the base of the embankment. It is founded on bedrock where it passes beneath the impervious core. The conduit is square and has seepage collars on 10 foot centers. Impervious back fill around the conduit was placed in 4 inch lifts and compacted with hand tampers.

5.0 CREDIBLE AND SIGNIFICANT FAILURE MODES

During the PFMA, the team identified 36 potential failure modes (PFMs). Of these, 16 were preliminarily identified as possibly being credible and significant. After evaluating these 16 failure modes further, some of the identified failure modes were found to be similar and combined and some were considered credible but not significant. In the end, 4 failure modes were considered credible and significant. In this section, each of these significant failure modes are described, along with possible actions or measures that can be taken to reduce risk associated with the failure mode. The PFMA notes (Appendix B) includes more detailed information regarding the evaluation of each failure mode.

5.1 Spillway Slab Jacking (PFM C in Appendix B)

5.1.1 Description

Spillway flow impacts on vertical offset in spillway slabs which result from uplift pressure or slab settlement (either under long term static conditions or seismically induced). The most critical offset is the downstream slab uplifted relative to the upstream slab, which creates localized high pressures that may penetrate down along the slab joint and create high uplift pressure. Landslide foundation materials are exposed initiating erosion. Exposed talus/landslide is highly erodible and scour will progress. Continued loss of foundation material results in additional slab failures upstream and additional foundation exposure and erosion. Erosion progresses to the upmost slab eroding down to basalt resulting in uncontrolled release. Figure 2 is a sketch of this failure mode.

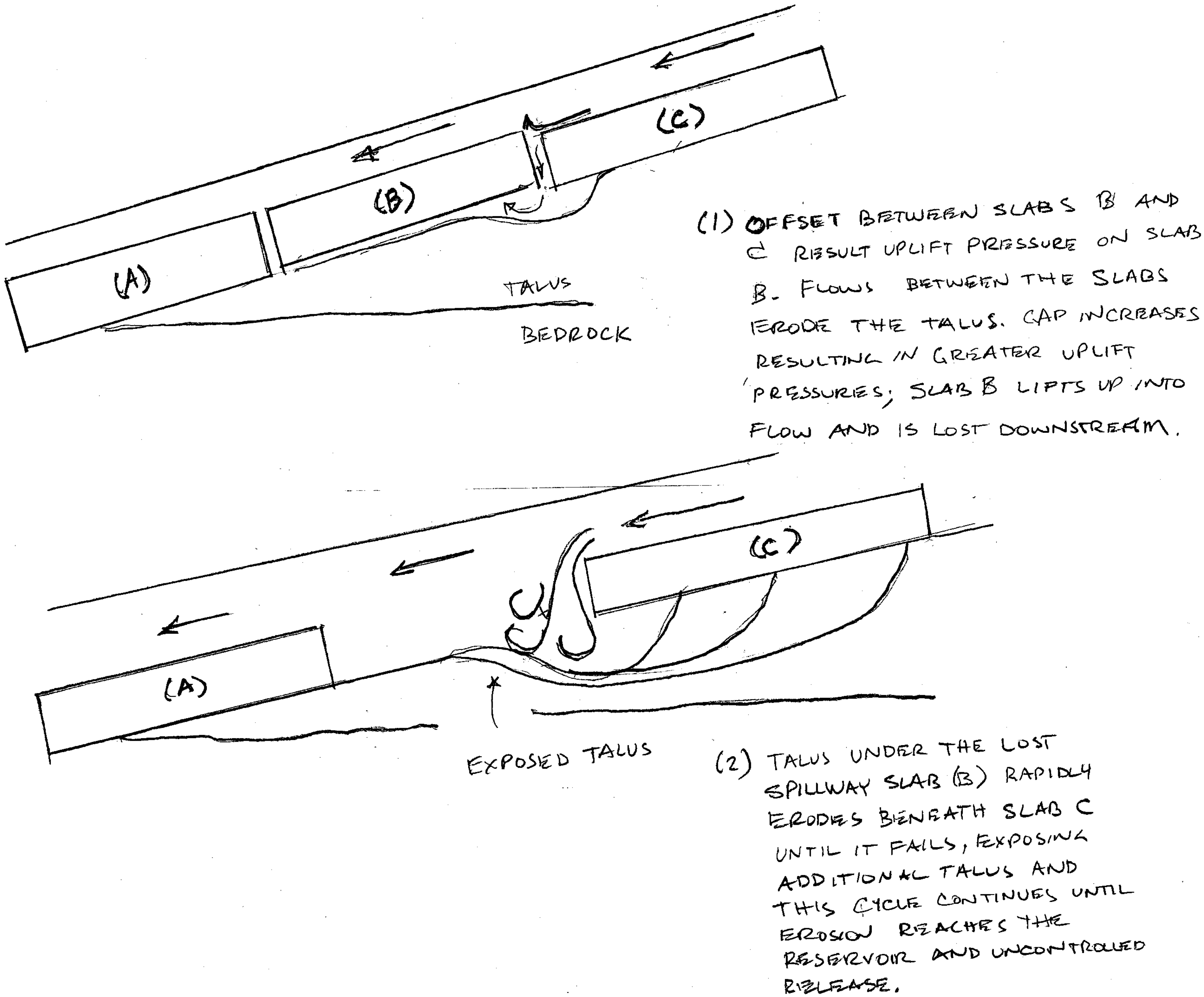


Figure 2. Spillway Slab Jacking Failure Mode

5.1.2 Factors that Increase the Likelihood of this PFM

- Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs).
- Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes).
- Visual observation during the site visit showed turbulence/flow disturbance on the left side of the spillway at the toe.
- Spillway flows occur approximately 9 months out of the year.
- Pool was very calm immediately downstream of end of spillway then turbulent downstream of calm area (possible deep pool).
- No data/inspection except visual flow disturbances documented during site visit.
- Drains are not inspected or cleaned.

5.1.3 Risk Reduction Measures

- At times of non-spilling, inspect for offsets between spillway blocks.
- Grind slabs flush at joints.
- Anchor the slabs.
- Fill voids/scour holes with concrete (holes around and under).

5.1.4 Warning Time

- Warning opportunity time (time from ability to detect failure mechanism to initiation of the mechanism) is 0 or negative. It can be seen after a slab has failed (maybe).
- Breach formation time (time from initiation of breach to loss of dam): for normal pools – months, and for high flows greater than 100 yrs – days, maybe hours.

5.2 Downstream Sill and Stilling Basin Scour (PFM D and PFM E in Appendix B)

5.2.1 Description

Spillway flow initiates erosion of the basalt and spillway stilling basin concrete. Erosion continues, undermining the spillway concrete and foundation. Failure/undermining of the spillway foundation at the toe results in loss of spillway slab support. Loss of slab support permits slab failure, exposing the talus/landslide foundation. Exposed talus is highly erodible and scour will progress. Continued loss of foundation material results in failure of additional slabs upstream and additional foundation exposure and erosion. Erosion progresses to the upmost slab, resulting in all spillway slabs having been displaced and eroding down to basalt resulting in uncontrolled release. Figure 3 is a sketch of this failure mode.

5.2.2 Factors that Increase the Likelihood of this PFM

- Spillway was extended due to poor foundation conditions (talus)

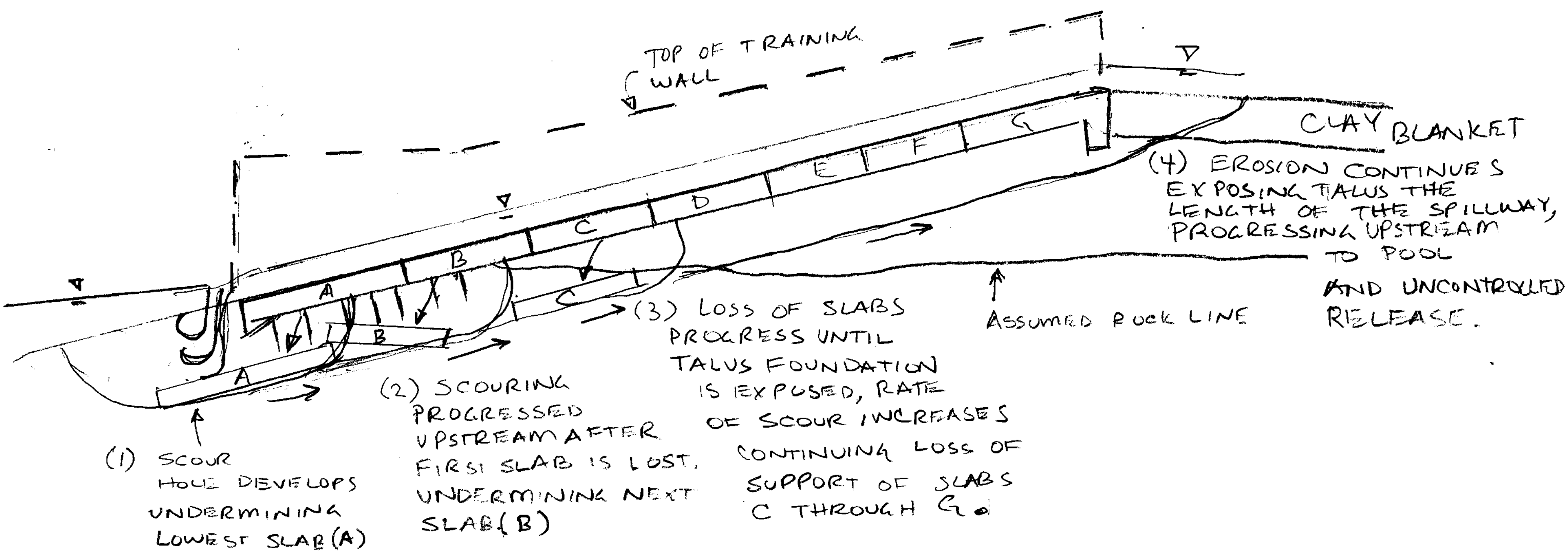


Figure 3. Spillway Downstream Sill and Stilling Basin Scour Failure Mode

- Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes).
- Oct. 1975 inspection mentions scour at the sill.
- Visual observation during the site visit showed turbulence/flow disturbance on the left side of the spillway at the toe.
- Foundation bedrock was described as poor to fair quality.
- Original inspection manual indicated concern about erosion of the stilling basin and recommends frequent inspections and monitoring for erosion. (Maximum historical pool of Elev. 430 corresponds to flow of approximately 5,000 cfs).
- Spillway flows occur approximately 9 months out of the year.
- Pool was very calm immediately downstream of end of spillway then turbulent downstream of calm area (possible deep pool). This may be indicative of a possible deep pool created by scour.

5.2.3 Risk Reduction Measures

- Visually monitor for scour and survey the downstream sill and stilling basin.
- Armor stilling basin.
- Anchor the spillway slabs.
- Fill voids/scour holes with concrete (holes around and under).

5.2.4 Warning Time

- Warning opportunity time is 0 or negative. It can be seen after a slab has failed (maybe).
- Breach formation time for normal pools – months; and for high flows greater than 100 yrs – days, maybe hours.

5.3 Scour of upstream spillway sill (PFM F in Appendix B).

5.3.1 Description

Scour present on the upstream sill of the spillway permits additional flow under the spillway. The resulting flow overtaxes the spillway drain system creating full uplift on the spillway and slabs. Increased uplift and cycles of loading displace spillway slabs (by offset, settlement, anchorage failure, etc.) resulting in exposed highly erodible talus/landslide foundation. Erosion progresses through continued loss of slab support and scour. Scour progresses upstream to full pool resulting in uncontrolled release down to bedrock (approximately El. 375). Figure 4 is a sketch of this failure mode.

5.3.2 Factors that Increase the Likelihood of this PFM

- Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes).
- Spillway flows occur approximately 9 months out of the year.
- Upstream impervious blanket has historically eroded and been repaired with pit run rock which does not provide the same seepage cutoff that the original blanket would provide.

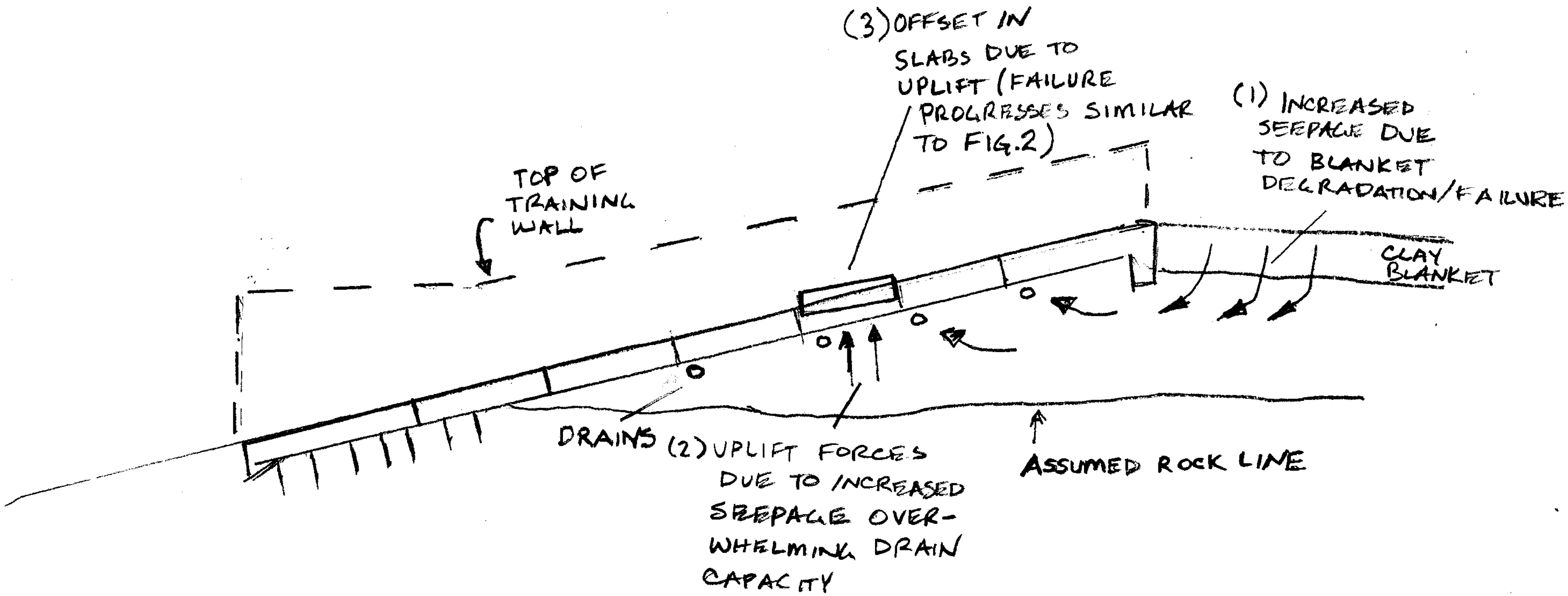


Figure 4. Upstream Spillway Sill Scour Failure Mode.

- Each repair cycle indicates removal of impervious blanket, resulting in reduced scour but increased flow beneath the spillway.

5.3.3 Risk Reduction Measures

- Ensure spillway drains are effective.
- Ensure upstream clay blanket remains impervious.
- Anchor slabs if needed.
- Add piezometer adjacent to the spillway as an indicator of hydraulic pressure under the spillway slabs. Calculate acceptable uplift pressure threshold at which slabs become dislodged and monitor for these pressures.

5.3.4 Warning Time

- Warning opportunity time is 0 or negative. It can be seen after a slab has failed (maybe).
- Breach formation time for normal pools – months, and for high flows greater than 100 yrs – days, maybe hours.

5.4 Overtopping (PFM J, K and N in Appendix B).

5.4.1 Description

Pool rises above the El. 435 (top of the clay core), wave action initiates erosion of sandy/gravel in the embankment upstream shell and crest. Material sloughing upstream and downstream decreases the crest width/seepage path leading to overtopping and continued overtopping leads to down-cutting of the embankment. Breach occurs, down-cutting to the valley floor leading to uncontrolled release and downstream consequences.

5.4.2 Factors that Increase the Likelihood of this PFM

- Core only designed to El. 435.
- Historical debris blockage could raise the pool.
- Insufficient free board
- Project cannot pass the PMF (according to PMF estimated in 1981 USACE Report)
- Flashy pool (i.e. pool rises quickly with rain events due to a small drainage basin).
- Actual crest elevation varies and is unknown due to a lack of survey data. True crest of dam could be lower resulting in more frequent overtopping at a lower than predicted level.
- Low spot occurs at right abutment at El. 438 would permit overtopping at lower elevations than PMF or rest of project.
- Insufficient draw down capacity
- Landslide prone areas in the basin (surge)

5.4.3 Risk Reduction Measures

- Raise low spots
- Armor the upstream face

- Armor the downstream face

5.4.4 Warning Time

- Warning opportunity time is hours but could be increased with an early/flood warning system..
- Breach formation time is approximately 2 hours.

5.5 Right Abutment Seepage

Seepage through the right abutment landslide deposit is considered an important issue but failure modes associated with this condition were not considered as critical as the significant failure modes identified above. The reservoir has generally filled up to the spillway crest (El 424 ft) each year. When observed, seepage has been clear with no evidence of piping initiating. Also, infrequent observations at higher pools above spillway (pool of record is 430 feet), does not provide any evidence of turbidity/cloudy seepage to suggest that piping may have initiated or occurred. There is no reason to believe that going from pool of record of El 430 to a 100-year pool of El 431 (one additional foot higher or 2 percent increase in depth of water down to the base of the embankment) would change the hydraulic gradient sufficiently to initiate piping. A PMF event would raise pool 10 feet above pool of record (20 percent higher). A 20 percent increase seepage gradient was thought not to be sufficient to initiate piping of the pervious landslide debris. However, it is important to continue monitoring seepage to detect any increases that may indicate a potential developing issue of concern.

6.0 APPLICABILITY OF AN EARLY WARNING SYSTEM TO SIGNIFICANT FAILURE MODES

The term 'early warning system' can be interpreted to encompass a variety of systems that could potentially be beneficial for reducing risk at this project. In a very simple form, an early warning system could simply be a 'flood warning system' that utilizes rainfall and/or reservoir water level data to provide notification of elevating pool conditions. In this simple form, the system would be pretty basic and have only that function. In more advanced form, the system could monitor data from a variety of instruments, compare that data to predetermined algorithms or thresholds based on several different failure modes and provide notification when certain conditions are met. This type of system might be referred to as an 'early dam failure warning system.' For the purposes of this report, it is assumed that the City desires to install a system consistent with the latter description.

For failure modes that have parameters that are directly related to the initiation and further development of those failure modes that can be monitored through automation, it is possible that a system could be designed to provide early detection and notification of these modes of failure. The effectiveness of this system would be rated based on the degree to which the initiation and development of the most significant failure modes (i.e. those that have the highest likelihood of causing significant downstream consequences) can be detected by the automated system in sufficient time to both notify decision makers and to allow time for intervention and/or evacuation. Clearly, then, the effectiveness of the system at a given project will depend upon the nature of the most significant failure modes at that project.

The significant failure modes for Silver Creek Dam, based on the PFMA workshop, were summarized in Section 5 above. Of the significant potential failure modes identified, an early dam failure warning system would be most effective at providing warning for the overtopping failure mode described in Section 5.4. The system could utilize criteria such as reservoir level or the rate of rise of the pool level (or combination of the two) to provide early detection of overtopping concerns. The system could provide notification at various thresholds to indicate how significant the conditions are. An important elevation for overtopping concerns is Elev. 435, the top of the impervious core section of the dam. The core section is the low permeability zone within the dam that provides the ability of the dam to impound water. Increased seepage through the embankment fill above the impervious core zone would be expected to occur for pool levels above El. 435 since the pool is above the top of the core. In addition, wave action at these high pool levels may erode the crest of the dam resulting in potential overtopping at elevations less than the current crest of the dam. Section 7 includes additional considerations and recommendations regarding overtopping.

The other credible and significant failure modes are related to rapid erosion of the foundation material beneath the spillway due to the loss of spillway slabs (see Sections 5.1 through 5.3). The most effective means of detecting a developing condition for these failure modes is to regularly inspect for offsets between adjacent slab joints and for scour in the stilling basin and on the upstream sill. The most critical offset is the downstream slab uplifted relative the upstream slab which creates localized high pressures that may penetrate down along the slab joint and create high uplift pressure beneath the slab. For the upstream sill scour failure mode, described in Section 5.3, it is anticipated that progression of this failure mode would result in increased seepage in the horizontal drains installed within the landslide deposit. A sustained, gradual increase in seepage during spilling that is not related to rainfall would be expected to occur. The early warning system should include automated collection of drain data from the drains (either individually or some drains can be combined). This will require construction of weirs to collect the flow. The City could also consider installing a new shallow piezometer to monitor development of this failure mode. The piezometer could be installed to the left of the left spillway wall downstream of the filter zone to a depth of approximately 10 feet below the base of the spillway with a pressure sensor for automated monitoring. Increased uplift pressure beneath the spillway should result in increased piezometric level in this piezometer due to hydraulic connectivity of landslide material beneath the spillway and that screened by the piezometer. While the weirs and piezometer might provide indication of progression of this failure mode, visual inspection of the upstream sill and clay blanket is a more direct and effective means for detecting if erosion is occurring. Also, it is important to note that the automated system would probably not be able to provide early detection and warning for the slab jacking (Section 5.1) and stilling basin and downstream sill scour failure modes (Section 5.2).

In addition to the benefits described above, an automated warning system that includes data collection from the existing piezometers and new drainage collection weirs near the toe of the dam would provide benefit in terms of increasing the frequency of measurements from these instruments. Although the existing piezometers were not tied to significant failure modes, they are tied to credible failure modes that the team identified. Traditionally, such measurements have been taken manually once per year at the project, although there have been gaps of time where several years have gone by without taking measurements. Piezometric water levels and drain flow rates are important indicators of dam performance. These instruments should be monitored consistently at least once per month (with automation, higher frequency is easily obtained) to understand seasonal fluctuations and long term trends. With proper maintenance, the automated system will consistently collect the data, improving the understanding of the behavior of the dam and reducing effort to review the historical data.

Adustments to the low level outlet gates are made using manual controls located at the crest of the dam adjacent to the right spillway training wall. Currently, operations cannot verify the low level outlet gate position when adjustments are made. The outlet is not visible from this location in order to confirm that the actual gate adjustments were made. The warning system should collect data for flow out of the low level outlet so that confirmation of gate adjustments can be obtained.

An automated warning system could also be used to notify City staff when important threshold water levels downstream of the dam are reached. Although this notification may not be tied to failure of the dam, it may be useful for the City to know when downstream water levels reach certain elevations to help coordinate flood response. The system could monitor downstream water levels at various locations and could be programmed to provide notification at multiple elevations to indicate how severe downstream flooding conditions are becoming.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

A list of major findings and understandings from the PFMA workshop is provided in Section 4. This section provides conclusions specifically related to the proposed early warning system.

1) The PFMA workshop resulted in the identification of 4 significant and credible potential failure modes. Three of the 4 modes were related to erosion of the spillway foundation due to either slab jacking, erosion of the stilling basin or erosion of the upstream sill of the spillway. The fourth mode is overtopping of the dam.
2) Failure modes related to seepage through the right abutment landslide material are considered credible but not as significant as the 4 modes identified above. It was judged that even under high pool conditions, such as Elev. 440 (PMF conditions), the relative increase in hydraulic gradient compared to what the project has experienced is not enough to initiate piping in the generally pervious, angular, basalt fragments that comprise the landslide deposit. However, it is important to continue monitoring seepage to detect any increases that may indicate a potential developing issue of concern.
3) With respect to the significant and credible failure modes, an automated early warning system would be most effective at reducing risk associated with the overtopping failure mode.

4) For overtopping failure modes, it is anticipated that, if properly designed and maintained, an automated early warning system may be able to provide early warning to decision makers in time to reduce the risk associated with overtopping failure modes.
5) Initiation and progression of the failure modes associated with erosion of the spillway foundation would be difficult to monitor with an automated monitoring system and therefore difficult to provide advanced warning of failure by an early warning system. Monitoring horizontal drain data and data from a new piezometer installed to the left of the left spillway wall and downstream of the embankment filter zone could be used to monitor development of the failure mode associated with upstream sill scour and increased seepage through the right abutment. However, visual monitoring for spillway slab offsets and stilling basin and upstream sill erosion are more direct ways to identify whether these failure modes are initiating.
6) For failure modes associated with spillway foundation erosion, it is anticipated that the time from initiation to uncontrolled release of the pool could be months if the failure occurred under normal pool conditions but days (possibly hours) under high flood (such as a 100 year event). **During high flows, unless initiation is observed directly by City staff, minimal warning will be provided to the downstream population for spillway failure initiated failure modes regardless of whether a warning system is installed**.
7) If properly designed and maintained, the automated data collection function of the proposed early warning system will provide a benefit of increased consistency and quality of data (including piezometer and drain data) collected by the system. This data helps to assess the condition of the dam and improves understanding for how the dam responds under various pool and seasonal conditions.
8) The automated data collection function could also be used to provide confirmation of flows through the low level outlet and frequent updates on the elevation of Silver Creek Dam downstream of the dam to improve coordination of flood response activities associated with hydrologic events that are not related to dam failure.

7.2 Recommendations

7.2.1 Automated Data Collection and Early Warning System Recommendations

1) The automated early warning system should include a reservoir level measurement and rain gage. Multiple level thresholds for reservoir level and rain data should be defined as part of the design of the early warning system. At a minimum, the thresholds should consider the elevations of the top of the core (El. 435) and the low spot to the right of the right abutment wall (approx. El. 438). In addition, due to the gap in the core trench on the right abutment below the training wall, the City should anticipate the possibility of increased seepage with pools above Elev. 430 and monitor this location. The system should provide notification of the exceedance of the thresholds to appropriate decision-making personnel at the City. In addition, it should collect and store data for future reference and analysis.

2) The City should design and install weir collection boxes to measure the flow rate of known seeps and drain flows, especially flows associated with the toe drains. Changes in these flow rates may indicate changing conditions at the dam.
3) In the event that drain flows show sustained increases in flow, consider installation of a new piezometer to the left of the left spillway wall for the purposes of monitoring piezometric pressure within the landslide deposit that provides the foundation for the spillway. The water level in this piezometer could be monitored with an automated data collection system with thresholds assigned to provide notification.
4) The reliability of the existing piezometers should be evaluated as part of the design of the warning system.
5) For the purposes of historical data collection, the automated warning system should be designed to collect data from the piezometers and weirs to improve the consistency of data collection and review.
6) The automated system should support storage of historical data for the purposes of reviewing historical trends and providing reports when needed. Time history plots of data should be reviewed at least monthly by the City and more frequently if visual observations indicate potential developing issues of concern.
7) For the purposes of improving flood response by the City, the automated warning system should be designed to collect data for water level at downstream locations as determined by the City. Multiple level thresholds can be developed to provide an assessment of level of urgency.
8) The City's Emergency Action Plan should be updated to incorporate the early warning system and to address notification of all citizens impacted by flooding.

7.2.2 Additional Recommendations to Improve Dam Safety and Reliability

1) Perform a survey of the dam along the crest of the dam from left abutment to right abutment in order to determine the presence of low points on the dam. If there are low spots, they should be raised to the design elevation.
2) Perform survey of spillway and abutment walls for vertical and horizontal deflection in order to establish a baseline for comparison with future surveys. Additional surveys should be completed at least every 5 years. If surveys indicate movement, the results of the surveys should be reviewed by a structural engineer for evaluation.
3) Inspect and survey the stilling basin for scour during period when spilling is not occurring (summer low pool inspection) in order to establish a baseline for comparison with future surveys. Inspect the stilling basin for increased scour after large flow events. Perform the inspections and surveys at least every 5 years.
4) Inspect the spillway for vertical offsets between slabs during period when spilling is not occurring (summer low pool inspection). The most critical offset is the downstream slab uplifted relative to the upstream slab; this creates localized high pressures that may penetrate down along the slab joint and create high uplift pressure. If downstream vertical offsets are present, grind the

downstream slab down to remove offsets. Recommend visual inspections are completed at least once per year.

5) Visually inspect upstream impervious blanket for holes for its full length upstream (not just the upstream sill) when possible. Visually inspect sillfor erosion at least once per year or after large spill events.
6) Inspect the integrity of the low level outlet pipe using a Remotely Operated Vehicle (ROV).
7) Evaluate and implement options for increasing the reliability of the low level outlet hydraulic system and for confirmation of gate opening size. To this end, the warning system should include collection of data on the flow through the low level outlet to improve the ability to confirm gate opening size.
8) The City's new public notification system (Everbridge) will call all City of Silverton telephone landlines but does not include the entire contact list from the provider of the old public notification system (Code Red). Recommend evaluating ways to update the Everbridge system contact list for all cellular phone users to the extent possible.
9) Perform hydraulic modeling to determine the frequency and magnitude and routing of storm events (determine relationships between flood frequency, peak flow and downstream water elevations). The results of the modeling would help the City with decisions regarding balancing downstream flooding impacts with dam safety risks and to improve the City's ability to warn the population. Once the results of the modeling are complete, it may be appropriate to modify the operations plan for the project.
10) The City should consider making structural improvements to prevent flooding of residents at low elevation locations (such as Silver Gardens Retirement Home).
11) The increased woody debris building up downstream of the stilling basin creates a potential for downstream damage during future storm events. During large events, this material may become dislodged and cause damage to bridges and property. The City should consider removing this material every 5 years.

SILVER CREEK DAM

POTENTIAL FAILURE MODES ANALYSIS (PFMA) REPORT

APPENDIX A

REFERENCES

Historical Documents

- Design Memoranda/Analysis
    - Design Letter to State Engineer, CH2M, 28 March 1973, (FILE 241 – D4, towards back)
    - Project Information letter to Silverton Mayor, CH2MHill, 10 April 1973, (FILE 241 – D4, towards back) – this includes info on the outlets, suggested O&M, fish facilities.
    - "Detailed Project Report – Section 205 Silver Creek Dam Early Warning System," Corps of Engineers, August 2004.
    - "Silver Creek Dam, Section 205 Preliminary Assessment, Corps of Engineers, Draft Material, 8 July 2003.
    - "Silver Creek Dam Break Analysis, Final Report," Philip Williams & Associates, Ltd., January 18, 2000. (Have entire project file).
    - "Silver Creek Dam Early Warning System Preliminary Design Report," Squier Associates, April 2002.
- Construction Control Data
    - "Final Construction Report, Silver Creek Dam," CH2MHill, 13 January 1975. (red file)
- Trip Reports and Field Inspection Reports
    - Inspection trip report, CH2MHill, 26 August 1975. (FILE 241 – D4)
    - Set of 16 Oregon Water Resource Department Inspection Reports between 1981 and 2010.
- "As-Built" Drawings
- Specifications
    - Project plans and specifications, March 1973.
- Construction Photographs
    - Aerial photo during construction (File #319).
- Geotechnical/Geological/Geophysical Investigations
    - "An Engineering Report on Subsurface Exploration and Preliminary Design Analysis for the Construction of a Dam on Silver Creek," CH2M, May 1966. (This investigation appears to be at a location downstream of the actual dam site).
    - "Subsurface Investigation of a Dam Site on Silver Creek," CH2MHill, April 1973. (Includes geologic mapping, boring logs and soil and rock descriptions at the current dam site (B) and at a proposed dam site downstream of the current location – location A).
- Boring Logs (included in above reports)

"Living" Documents

- Operation and Maintenance (O&M) Manual
    - "Suggested Inspection, Operation and Maintenance of Silver Creek Dam," no date, signed 'skw'.
- Emergency Action Plan (EAP)

- Water Control Manual (WCM)
    - "Suggested Inspection, Operation and Maintenance of Silver Creek Dam," no date, signed 'skw'.
    - ISO9000 7.11 Dam operating procedures, includes water demands and inspection checklist

Periodic Inspection and Continuing Evaluation

- Periodic Inspections
    - “Silver Creek Dam, Phase 1 Inspection Report,” National Dam Safety Program, Oregon Water Resources Department, June 1981.
- Intermediate Inspections
    - Annual Inspection – series of State Dam Safety inspections
    - Incidents
        - Dam seepage memo, City of Silverton, Feb 2010. Previously undetected seepage was encountered near downstream outlet structure, a seepage monitoring point was constructed, photos are included.
- Instrumentation Data
    - “Silver Creek Dam Piezometer Installation – Contractor – CH2MHill,” 1-19-78, File #319. (File contains specs and design details for ‘new’ piezometers – appears to be for piezos P3 through P10, includes some manual plots and tables of piezo and drain data for first couple years following construction).
    - Spreadsheets and tables of piezo and drain data for 1975 through 2007.

Evaluation and Modification Reports

- Seismic Safety Evaluation
    - “Seismic Stability Analysis, Silver Creek Dam,” Cornforth Consultants, 21 July 1999.
- Dam Modification Reports
    - Description and construction photos of intake repair performed in 1993 – pool was lowered - and description and photos of additional repairs in 2002.
    - File folder with correspondence and some sketches of repair work performed as a result of 1996 flood.
    - Plans and Specifications for Concrete Repairs project, July 9, 2009.
- Operation and Maintenance (O&M) Program
    - “Suggested Inspection, Operation and Maintenance of Silver Creek Dam,” no date, signed ‘skw’.

Other Documents

- Flood Insurance Study, U.S. Department of Housing and Urban Development, Federal Insurance Administration, September 1978 (includes flood profiles downstream for 10 year, 50 year, 100 year and 500 year floods).
- Series of untitled plans that appear to be inundation maps.
- Current rating curve (No. 9) for Silver Creek at downstream gaging station.

- Rating curve and flow data for conditions prior to dam.
- Set of plan drawings associated with getting permits for the dam.

SILVER CREEK DAM

POTENTIAL FAILURE MODES ANALYSIS (PFMA) REPORT

APPENDIX B

PFMA NOTES

PHYSICAL DATA

- Top of Dam: 440 (439.4)
- Top of Spillway Crest: 423.67 on north end curb with 424 to South.
- Outlet invert: 376.8
- Top of Core: 435.0
- Fish Ladder Pipe Invert: 421.0
- Top of Filter: 430
- Crest width = 20ft
- Base max = 340ft
- Elev. Of Base of Dam is approx. 370ft
- Max height approx. 70 ft.
- Embankment 490ft long, spillway 160ft long
- Outlet exit invert: 371.0 (from 376.8)
- Filter zone is 4 ft wide
- Core minimum 20 feet wide
- Core trench is 24ft wide to Elev 370

GEOTECH

- Core – 4-in minus sandy, clayey silt (ML) – low plasticity
- Zone 1 – upstream and downstream silty, sandy gravel (alluvium from river bottom-reservoir borrow)
- Zone 2 – downstream silty rock fragments
- Structural backfill – 3-in. minus rock
- Drainage berm – 3-in. minus crushed rock
- Filter zone – well graded, 4ft wide, 3-in. minus, less than 4% fines
- North (Right) Abutment – represented by B-13
    - Silt Deposit (Landslide) on top
    - Top 25ft extremely permeable (fractured, loose, open, 4-in. angular, leaked on first filling at spillway)
    - Silty talus on top of fractured basalt
    - Bedrock is at Elev. 375 (80 ft down)
- South (Left) Abutment – represented by B-12 and B-16 (250ft downstream)
    - Plastic silt, has clay to elev. 410
    - Sits on fractured basalt
    - B-16 shows boulders and gravels downstream
- Bedrock/Foundation Rock
    - North – landslide, porous
    - Spillway – same as north abutment
    - South – interflow zone at Elev. 398 (2 basalt flows)
- Liquefaction Potential – low (maybe some small isolated zones)

- Core trench – material was compacted in the wet (had to dewater during compaction)
- OBE = 0.0875g
- MCE = 0.4g

HYDRAULICS AND HYDROLOGY

Pools

Normal pool – 424 to 424.5

Winter Oct – Apr 424 to 427

August and September < 424

May to July – 424

Aug Sep < 424

Oct to Apr > 424

50% Pool is 424

Max pool is 427

Peak Pool Ever is 430

10yr = 429, 100yr = 431, 200yr = 432, 800yr>440, PMF>440

What is tailwater?? ********Data gap********

Flows

Normal Q in river: 50 cfs @El 424 (leakage through fish ladder)

Max pool: 200 cfs @El 424 (leakage through fish ladder and spillway)

100yr 5050 cfs @El. 431, tailwater is about El. 231.

PMF – 22,682 cfs inflow, 22650 release

Flood stage/bankfull: El. 228.2, 4 miles downstream

Gage station @ Web Street takes continuous readings and sends an auto email alert when tailwater is within 4 ft of El. 228.2

Who gets email – Andy gets it, when it's raining Police do a check of this.

Currently no flow predictions at this project – look for rain.

The gage is at the low spot, this area could be built up with a wall.

Next low spot is around El. 235

Sand bagging is done at Silver Gardens Family Care (El. 227)

High school is at same elevation.

First Street @ C Street at El. 234.1

Travel time to out of bank for piping failure from breach analysis is 52 min.

Overtopping – 21 minutes to leave bank@ James Street

Flow in town for 21 hours minimum (overtopping)

Treatment Plant is much further downstream but at Elev. 204. No loss of at this site (property damage).

Pool 429 is approx. equal to bankfull at tailwater of 227.

Every year if they build a 3' tall sand bag berm there is no other flooding.

*Conclusion – 232 is flood tailwater of concern.

OPERATIONS

42-in. gate never used, cycled once per year. Last time operated (Winter 2009) had to replace hydraulic cylinder in the control box. It took 1 week to have this repaired. This is the only way to dewater. In the winter this will not draw down the lake. In the Summer, it takes about 1 day to draw down the lake.

18-in. gate is a regulating line, adjusted for Q.

INTERVENTION

******OP ISSUE*****Access – only access to embankment side is by boat (or helicopter). Therefore, there is no ability to place emergency materials. Therefore, can't stop a pipe or breach.

No intervention currently possible.

Currently it takes 20 to 30 minutes for a crew person to get to the site; it takes 10 minutes to get there from the City center

Response – Andy calls key person with cell phone or radio to activate EOC – City manager (1), Police chief (2), Police captain (3) and Fire Department (4). Andy would provide a recommendation on action to take.

If bad enough, a code red is given: automated call goes out to people on a Code Red list. The City pays a company that maintains the red code list; the City has a new system (Everbridge Call System) but Code Red company won't provide the City with its list. The Everbridge system will automatically call all landlines in Silverton. However, City residents won't be contacted on cellular phones unless they signed up for the Everbridge call system (even if they signed up originally for the old Code Red system).

Evacuation routes are in the EAP but there has been no population education on evacuation (no public meetings).

PERFORMANCE HISTORY

First filling in 1974, seepage was observed on Nov. 7, 1974 , when the pool was at 401.5, next day water was seen flowing out the pipe (4-in toe drain). Downstream wet areas broadened at the right abutment through the landslide deposit materials; city crews installed 3 horizontal surface drains. Seepage was believed to be occurring upstream of the clay blanket but a clay layer forced flow into the filter and embankment.

Nov. 21, 1974 to Nov. 29, 1974, 11 horizontal drains were installed to monitor seepage rates and a downstream berm was installed. Ability to solve the problem was adversely impacted by not being able to get access upstream of the dam.

August, 1975 - Seepage was observed between Stations 3+00 and 3+60 just above the filter and buttress layer; it was recommended to add additional filter rock. Deterioration of clay blanket was also observed to the right of the spillway entrance channel. Weekly observation of blanket was recommended. Fill erosion hole at upstream end of spillway. Place gravel filter material on downstream face of dam. Filter and drainage blanket was recommended and apparently installed. It also appears that a 12 to 15ft deep, approx. 3 foot wide cutoff trench was installed upstream of the right end of the embankment.

No piezometer data between 1975 and 1979.

Piezometer #2 dropped off from 1975 to 1982. This piezometer is just to the left of the spillway where the cutoff trench was installed.

Drain data is not taken frequently enough to understand what the flows are responding to.

Seepage observed at right hand side 100 ft downstream of stilling pool.

June 1981 Inspection

Pool level was 424.4; normal pool.

No uncontrolled seepage observed; seepage only observed in the horizontal drains.

Phreatic surface has been established; primarily controlled by seepage through right abutment talus.

Conclusion – safe dam, blanket and core trench working.

Recommendation to read drains.

1993 Scotts Mills Earthquake

Earthquake was larger than OBE (operating base earthquake)

Source was 8 miles from project.

Mw = 5.6

No damage.

1993 Inlet Structure Repair

2002 Inlet Gate Repair

Mostly maintenance work, new hydraulic lines located in a concrete trench.

Between 1981 and Feb. 2010 no evidence of seepage related distress. Known seepage quantities have been measured approximately annually; seepage has occurred where you would anticipate it. No evidence of turbid seepage. No signs of slope movement.

Upstream and Downstream Flow Issues

1. Low spots for flooding (Silver Gardens) – *****OPS ISSUE*****close proximity, awareness
2. Flashy reservoir
3. Landslides upstream of pool in drainage basin causes upstream dam and surge (little or no warning) – contributes to overtopping failure modes.

BRAINSTORMING POTENTIAL FAILURE MODES

Step 1 – Identify features, locations and issues of the project for PFMs based on background information and site history review and the site visit.

Step 2 – Of the features identified in step 1, identify which of these have PFMs of concern associated with them.

Step 3 – Double-check that all standard Geotech initiation mechanisms have been accounted for.

Step 4 – Rank PFMs that we are most concerned with providing warnings for. Try to address most significant.

Definition – Documentation refers to the area left of the spillway as the right abutment. We consider this area as embankment. The abutment (on rock/slide) is to the right of the spillway.

Identification of potential failure modes based on brainstorming.

Spillway

1. Spillway slab jacking (drain concerns) – normal flow conditions, erodible material
2. Spillway sill downstream scour on left side – normal flow conditions, erodible foundation and concrete irregularity at the location
3. Spillway basin scour – normal flow conditions, no survey data, previous scour (is it on rock/seam?)
4. Spillway upstream sill scour – normal flow conditions, happened before, clay blanket may not be fully present, can lead to uplift of spillway slab
5. Spillway right upstream wall joint –
6. Spillway right downstream training wall offset/stability – normal flow, wall falls, erosion and headcutting
7. Spillway left downstream training wall offset/stability
8. Spillway tailwater/channel capacity-PMF conditions
9. Spillway foundation seepage/stability/settlement (potential for differential settlement due to different foundation upstream and downstream) – combine with PFMs 1,2,5 and 6
10. Debris blockage – PMF conditions, have bumper but no log boom; consider placing boom upstream of clay blanket.

Right Abutment

1. Surface runoff erosion – normal flow conditions, no exit for water on right abutment,
2. Abutment seepage, Integrity of upstream clay blanket, low hydraulic gradient

3. Inadequate training of water on right abutment (upstream of spillway) – PMF flow conditions, abutment scour.
4. Low spot adjacent to right abutment wall (ground appears to be around 438 (438.5). Scour at high pools. Shallow embedment of wall, lose wall, this could lead to release at pool level at El. 430*****OPS ISSUE*******
5. Landslide presence and creep movement.
6. Seismic stability/liquefaction – Cornforth report
7. Seepage at right wall, no core, going through landslide deposit with rock fragments, low head, low gradient.

<u>Fish Ladder</u>

1. Spillway drain on the right hand side of the ladder. Drain is a preferential seepage pathway alongside the drain through the granular backfill around the pipe; settlement has been observed. Normal flow conditions, slow head cut, lots of warning time.
2. Wall stability – differential movement between adjacent blocks observed. Flow in ladder is low.
3. Ball milling within the fish ladder chambers (cobbles and boulders observed). Low Q and velocity of flow.******OP ISSUE******
4. Operability of fish ladder gates. Ladder only, no life safety consequences.*****OP ISSUE*****

<u>Outlets/Conduit/Controls</u>

1. Reliability of hydraulic lines and controls, including submerged hydraulic cylinder on the gate. Happened before where the gate breaks, Normal flow, 1 in 20 chance of failure, no drawdown capabilities, stuck open, drain pool, lose drinking water capability, *******OP ISSUE********
2. Seepage on both sides of the outlet, around seepage collars. Normal flow conditions *********must address********
3. Conduit integrity – earthquake loading at joints, internal erosion; founded on bedrock, reinforced, cast-in place, seepage collars******OP ISSUE*****
4. Hydraulic capacity of the outlets, 200 cfs is max discharge (operation at PMF – could create problems if operating during PMF. Contributing factor to other PFMs (not a PFM on its own)*****OP ISSUE*****
5. Inability to know what the gate position is. Contributing factor to other PFMs (not a PFM on its own)********OP ISSUE********
6. Misoperation of outlet valve – PMF conditions – does not add consequences to overtopping in PMF *****OP ISSUE*****(not a separate PFM)
7. Seismic induced failure of the intake tower – failure of the intake does not result in overtopping or release greater than downstream channel capacity.

Embankment

1. Stability – static and EQ, 1981 report and 1999 Cornforth report, high freeboard (not likely to lose due to deformation)
2. Foundation seepage and piping – seem at 398, expect seepage but not piping due to bedrock foundation, no evidence of instability
3. Core stability/overtopping - height of core about 5 feet below crest, analyzed in stability, tested for 40 years.
4. Filter zone size, capacity, stability in EQ; designed filter, historically performed
5. Overtopping (core less than crest)-Lack of consistent survey on vertical settlement – potential low spots.
6. Embankment seepage and piping (11 drains that flow, 3 drains/berm/'75 trench/blanket/2 working piezometers) - burrowing animals, trees and vegetation******OPS ISSUE*****

Left Abutment

1. Seepage and piping, stability of interflow zone at Elev. 398 ; stable, shouldn't fail due to seepage and stability, has plastic fines (same material as core).
2. Silt foundation – seepage and piping, piping at Elev. 398 seam causes internal erosion of silt, creates a pipe in silt and uncontrolled release

Review Geotechnical of Initiation Mechanisms

Of the 28 IMs for seepage and piping, the following IMs were deemed applicable to this structure (the others do not apply).

IM1 – cross valley differential settlement – credible, not significant based on good performance (no evidence) and most likely to be contributing to seepage and piping failure mechanism which is covered elsewhere, uniform abutment slope – outlet #2.

IM14 – core foundation/abutment contact at right abutment – poor compaction results in possible seepage and piping along conduit Outlet #2 PFM (covered elsewhere).

IM17 – seepage adjacent to conduit – covered under outlet #2 PFM

IM18 –features allowing seepage into a non-pressurized conduit – not significant because more likely to seep along conduits

IM19 – seepage adjacent to spillway or abutment wall – all ready covered under spillway PFMs 5, 6, 7

IM20 – seepage due to crack or gap adjacent to spillway or abutment wall – all ready covered in spillway PFMs 5,6,7

IM22 –backward erosion and piping through a cohesionless foundation – not credible, have core trench that cuts it off

IM27 –scour along the contact in bedrock

Note=: The PFMs were given a preliminary rating regarding credibility and significance. The following abbreviations were used: C&S = credible and significant, C=credible, not significant and NC=not credible. The results of the evaluations are listed below for the identified PFMs.

Spillway

1. (C&S)Spillway slab jacking (drain concerns) – normal flow conditions, erodible material
2. (C&S)Spillway sill downstream scour on left side – normal flow conditions, erodible foundation and concrete irregularity at the location
3. (C&S)Spillway basin scour – normal flow conditions, no survey data, previous scour (is it on rock/seam?)
4. (C&S)Spillway upstream sill scour – normal flow conditions, happened before, clay blanket may not be fully present, can lead to uplift of spillway slab
5. (C&S)Spillway right upstream wall joint –
6. (C&S)Spillway right downstream training wall offset/stability – normal flow, wall falls, erosion and headcutting
7. (C&S)Spillway left downstream training wall offset/stability
8. (C&S)Spillway tailwater/channel capacity-PMF conditions
9. Spillway foundation seepage/stability/settlement (potential for differential settlement due to different foundation upstream and downstream) – combine with PFMs 1,2,5 and 6
10. (C&S)Debris blockage – PMF conditions, have bumper but no log boom; consider placing boom upstream of clay blanket.

Right Abutment

1. (NC)Surface runoff erosion – normal flow conditions, no exit for water on right abutment,
2. (NC)Abutment seepage, Integrity of upstream clay blanket, low hydraulic gradient
3. (NC)Inadequate training of water on right abutment (upstream of spillway) – PMF flow conditions, abutment scour.
4. (C&S)Low spot adjacent to right abutment wall (ground appears to be around 438 (438.5). Scour at high pools. Shallow embedment of wall, lose wall, this could lead to release at pool level at El. 430*****OPS ISSUE*******
5. (NC)Landslide presence and creep movement.
6. (NC)Seismic stability/liquefaction – Cornforth report
7. (C)Seepage at right wall, no core, going through landslide deposit with rock fragments, low head, low gradient.

Fish Ladder

1. (C)Spillway drain on the right hand side of the ladder. Drain is a preferential seepage pathway alongside the drain through the granular backfill around the pipe; settlement has been observed. Normal flow conditions, slow head cut, lots of warning time.
2. (C)Wall stability – differential movement between adjacent blocks observed. Flow in ladder is low.
3. (C)Ball milling within the fish ladder chambers (cobbles and boulders observed). Low Q and velocity of flow.******OP ISSUE******
4. (C)Operability of fish ladder gates. Ladder only, no life safety consequences.*****OP ISSUE*****

Outlets/Conduit/Controls

1. (C)Reliability of hydraulic lines and controls, including submerged hydraulic cylinder on the gate. Happened before where the gate breaks, Normal flow, 1 in 20 chance of failure, no drawdown capabilities, stuck open, drain pool, lose drinking water capability, *******OP ISSUE********
2. (C&S)Seepage on both sides of the outlet, around seepage collars. Normal flow conditions *********must address********
3. (C&S)Conduit integrity – earthquake loading at joints, internal erosion; founded on bedrock, reinforced, cast-in place, seepage collars******OP ISSUE*****
4. Hydraulic capacity of the outlets, 200 cfs is max discharge (operation at PMF – could create problems if operating during PMF. Contributing factor to other PFMs (not a PFM on its own)*****OP ISSUE*****
5. Inability to know what the gate position is. Contributing factor to other PFMs (not a PFM on its own)********OP ISSUE********
6. Misoperation of outlet valve – PMF conditions – does not add consequences to overtopping in PMF *****OP ISSUE*****(not a separate PFM)
7. Seismic induced failure of the intake tower – failure of the intake does not result in overtopping or release greater than downstream channel capacity.

Embankment

1. (NC)Stability – static and EQ, 1981 report and 1999 Cornforth report, high freeboard (not likely to lose due to deformation)
2. (NC)Foundation seepage and piping – seem at 398, expect seepage but not piping due to bedrock foundation, no evidence of instability

3. (NC)Core stability/overtopping - height of core about 5 feet below crest, analyzed in stability, tested for 40 years.
4. (NC)Filter zone size, capacity, stability in EQ; designed filter, historically performed
5. (C&S)Overtopping (core less than crest)-Lack of consistent survey on vertical settlement – potential low spots.
6. (C&S)Embankment seepage and piping (11 drains that flow, 3 drains/berm/'75 trench/blanket/2 working piezometers) - burrowing animals, trees and vegetation******OPS ISSUE*****

Left Abutment

1. (NC)Seepage and piping, stability of interflow zone at Elev. 398; stable, shouldn't fail due to seepage and stability, has plastic fines (same material as core).
2. (C&S)Silt foundation – seepage and piping, piping at Elev. 398 seam causes internal erosion of silt, creates a pipe in silt and uncontrolled release.

Review Geotechnical of Initiation Mechanisms

Of the 28 IMs for seepage and piping, the following IMs were deemed applicable to this structure (the others do not apply).

IM1 – (C)Cross valley differential settlement – credible, not significant based on good performance (no evidence) and most likely to be contributing to seepage and piping failure mechanism which is covered elsewhere, uniform abutment slope – outlet #2.

IM14 – core foundation/abutment contact at right abutment – poor compaction results in possible seepage and piping along conduit Outlet #2 PFM (covered elsewhere).

IM17 – seepage adjacent to conduit – covered under outlet #2 PFM

IM18 –(C)features allowing seepage into a non-pressurized conduit – not significant because more likely to seep along conduits

IM19 – seepage adjacent to spillway or abutment wall – all ready covered under spillway PFMs 5, 6, 7

IM20 – seepage due to crack or gap adjacent to spillway or abutment wall – all ready covered in spillway PFMs 5,6,7

IM22 –(NC)backward erosion and piping through a cohesionless foundation – not credible, have core trench that cuts it off

IM27 – (C)Scour along the contact in bedrock

Credible and Significant FMs

Failure modes that are credible and significant as voted by the team which should be addressed in a risk assessment for this project

16 Significant Failure Modes

Spillway

1. (C&S)Spillway slab jacking (drain concerns) – normal flow conditions, erodible material
2. (C&S)Spillway sill downstream scour on left side – normal flow conditions, erodible foundation and concrete irregularity at the location
3. (C&S)Spillway basin scour – normal flow conditions, no survey data, previous scour (is it on rock/seam?)
4. (C&S)Spillway upstream sill scour – normal flow conditions, happened before, clay blanket may not be fully present, can lead to uplift of spillway slab
5. (C&S)Spillway right upstream wall joint – C/S for greater than 100 year event
6. (C&S)Spillway right downstream training wall offset/stability – normal flow, wall falls, erosion and headcutting
7. (C&S)Spillway left downstream training wall offset/stability – same as #7
8. (C&S)Spillway tailwater/channel capacity-PMF conditions
9. Spillway foundation seepage/stability/settlement (potential for differential settlement due to different foundation upstream and downstream) – combine with 1,2,5 and 6
10. (C&S)Debris blockage – PMF conditions, have bumper but no log boom; consider placing boom upstream of clay blanket.

Right Abutment

1. (C&S)Low spot adjacent to right abutment wall (ground appears to be around 438 (438.5). Scour at high pools. Shallow embedment of wall, lose wall, this could lead to release at pool level at El. 430

Fish Ladder

(none)

Outlets

1. (C&S)Seepage on both sides of the outlet, around seepage collars. Normal flow conditions *********must address********
2. (C&S, low likelihood)Conduit integrity – earthquake loading at joints, internal erosion; founded on bedrock, reinforced, cast-in place, seepage collars

Embankment

1. (C&S)Overtopping (core less than crest)-Lack of consistent survey on vertical settlement – potential low spots.
2. (C&S)Embankment seepage and piping (11 drains that flow, 3 drains/berm/’75 trench/blanket/2 working piezometers) - burrowing animals, trees and vegetation

Left Abutment

1. (C&S)Silt foundation – seepage and piping, piping at Elev. 398 seam causes internal erosion of silt, creates a pipe in silt and uncontrolled release

Number of Significant Failure Modes at Normal Pool (El. 427 -10 yr pool and lower)

- 11 at normal load
- 12 at normal load and 100 year flood (so 1 at 100 year flood)
- 4 at PMF
- Seismic concerns at spillway walls, conduit

Focus on what occurs under normal loading

16 Credible and Significant Failure Modes (re-ordered)

A. Spillway left downstream training wall offset/stability - normal flow, wall falls, erosion and headcutting
B. Spillway right downstream training wall offset/stability – normal flow, wall falls, erosion and headcutting
C. Spillway slab jacking (drain concerns) – normal flow conditions, erodible material
D. Spillway sill downstream scour on left side – normal flow conditions, erodible foundation and concrete irregularity at the location
E. Spillway basin scour – normal flow conditions, no survey data, previous scour (is it on rock/seam?)
F. Spillway upstream sill scour – normal flow conditions, happened before, clay blanket may not be fully present, can lead to uplift of spillway slab
G. Spillway right upstream wall joint – C/S for greater than 100 year event
H. Spillway tailwater/channel capacity-PMF conditions
I. Spillway foundation seepage/stability/settlement (potential for differential settlement due to different foundation upstream and downstream) – combine with 1,2,5 and 6
J. (C&S)Debris blockage – PMF conditions, have bumper but no log boom; consider placing boom upstream of clay blanket.

K. (C&S)Low spot adjacent to right abutment wall (ground appears to be around 438 (438.5). Scour at high pools. Shallow embedment of wall, lose wall, this could lead to release at pool level at El. 430*****OPS ISSUE*******

L. (C&S)Seepage on both sides of the outlet, around seepage collars. Normal flow conditions *********must address********

M. (C&S, low likelihood)Conduit integrity – earthquake loading at joints, internal erosion; founded on bedrock, reinforced, cast-in place, seepage collars******OP ISSUE*****

N. (C&S)Overtopping (core less than crest) - Lack of consistent survey on vertical settlement – potential low spots

O. (C&S)Embankment seepage and piping (11 drains that flow, 3 drains/berm/'75 trench/blanket/2 working piezometers) - burrowing animals, trees and vegetation

P. (C&S)Silt foundation – seepage and piping, piping at Elev. 398 seam causes internal erosion of silt, creates a pipe in silt and uncontrolled release

Develop detailed descriptions of Significant PFMs

SILVER CREEK DAM **POTENTIAL FAILURE MODE ANALYSIS** **PFM # A** PFM A – LEFT SPILLWAY WALL DEFLECTION AND EMBANKMENT EROSION
(PFM # A)
Loading: Loading – Normal pool and above 427+
Description: The existing left spillway wall/training wall yields and deflects along its length, resulting in a crack/void on the embankment side of the wall (most detrimentally at the impervious core). Pool rises above spillway crest (the base of the wall footing) Seepage between the core and the deflected wall (upstream to downstream) initiates erosion of the core. Core material is carried downstream past the filter zone which fails to act as a filter. Erosion enlarges the crack. Progression through gross enlargement results in a continuous crack to the pool and breach to the base of the wall. Erosion would continue until the pool recedes below the crest.
Background and Evidence: • Existing walls deflected in several locations. • No visual evidence of gaps between the left spillway training wall and soil backfill against the wall was observed during the site visit. • Wall is 16 ft tall with varying thickness and reinforcement.

- Existing wall was patched at spillway crest joint
- Joints in the wall were pre-formed and nailed. Joints are missing/materials pulled/plucked from the joints.
- Existing waterstops appear broken in places.
- Footing slab width varies with wall height.
- No signs of seepage currently.
- Wall has keys adjacent to the core.
- Filter downstream of the core only goes to El 430.
- Spalled concrete showed corroded reinforcement.
- Wall founded on landslide deposit.

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Existing walls deflected in several locations • Existing wall was patched at spillway crest joint • Joints in the wall were pre-formed and nailed. Joints are missing/materials pulled/plucked from the joints. • Existing waterstops appear broken in places. • Wall has keys adjacent to the core. • Filter downstream of the core only goes to El 430. • Spalled concrete showed corroded reinforcement • Wall founded on landslide deposit. • Wall not designed for current earthquake.	• Wall heel is 10 ft wide. • Gradients are low. • Crack would be narrow @ Elev. 424 • No visual evidence of gaps between the left spillway training wall and soil backfill against the wall was observed during the site visit. • Upstream shell can act as a flow limiter.

* - Major Contributing Factors	

Knowledge Gaps and uncertainty:

- No known measurement data (settlement)
- No existing calculations
- No construction photos (for wall construction and compaction of embankment fill against the wall.
- Concrete mix and quality unknown and a concern based on spalling.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Sinkholes/visual inspection more frequently (currently 3 inspections per year by Operations/State)
- Settlement data
- Wall surveys
- Wall drain seepage changes (quantity/turbidity)

Ability to Intervene:

- Lower pool in Summer only.
- Stockpile earthwork materials, place materials in attempt to choke the failure off. (KEY)

Interim Risk Reduction Measures:

- Lower pool (takes away water supply)
- Anchor wall (coupled with excavating embankment materials to repair void/cracks).
- Inspect more frequently.

Anticipated Warning Time and Breach Width:

You can't see this happen.

With low gradients and clay present, breach will take few days.

SILVER CREEK DAM

POTENTIAL FAILURE MODE ANALYSIS

PFM #J& K & N

PFM J& K & N – OVERTOPPING

(PFM # J&K & N)

Loading: Loading – Pool above 435 ft.

Description: Pool rises above the El. 435 (top of core), wave action initiates erosion of sandy/gravel in the embankment upstream shell and crest. Material sloughing upstream and downstream decreases the crest width/seepage path leading to overtopping. Continued overtopping leads to downcutting of the embankment. Breach occurs, down-cutting to the valley floor leading to uncontrolled release and downstream consequences.

Background and Evidence:

- Core only designed to El. 435.
- Historical debris blockage could raise the pool.
- Actual crest elevation varies and is unknown.
- Low spot occurs at right abutment at El. 438 would permit overtopping at lower elevations than PMF or rest of project.
- Max pool elevation to date is 430.8 (5620 cfs) – 1996 may have been higher (no data)
- Project cannot pass the PMF
- Flashy pool
- Spillway has bumper constructed to prevent debris blockage.
- Insufficient free board
- Overtopping duration should be approx. 7 hours.
- Short fetch for wave action
- Sandy gravel on upstream face
- Insufficient draw down capacity
- Landslide prone areas in the basin (surge)
- No forecasting data

Conditions making PFM Likely *Or Unfavorable Factors*	*Conditions making PFM Unlikely* *Or Favorable Factors*
• Core only designed to El. 435. • Historical debris blockage could raise the pool. • Insufficient free board • Project cannot pass the PMF • Flashy pool • Actual crest elevation varies and is unknown. • Low spot occurs at right abutment at El. 438 would permit overtopping at lower elevations than PMF or rest of project. • Insufficient draw down capacity • Landslide prone areas in the basin (surge)	• Max pool elevation to date is 430.8 (5620 cfs) - 1996 may have been higher (no data) • Spillway has bumper constructed to prevent debris blockage. • Overtopping duration should be approx. 7 hours. • Short fetch for wave action • Event that would cause overtopping is infrequent.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- No current surveying data
- Elevations unknown
- PMF unknown

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Visual observation only (impaired at night).
- Flooding

Ability to Intervene:

- None

Interim Risk Reduction Measures:

- Raise low spots
- Armor the upstream face
    - Armor the downstream face

•
Anticipated Warning Time and Breach Width:

Warning time – hours

Breach time – 2 hours

We need several triggers for flood warning and overtopping

1) Trigger for 24 hour surveillance
2) Downstream levels that are critical to flooding for nuisance.
3) Downstream levels that are critical for life safety.
4) Pool elevations that create these downstream levels for overtopping.
5) Stop Prediction.
6) Communication with Public.

SILVER CREEK DAM **POTENTIAL FAILURE MODE ANALYSIS** **PFM #L** PFM# L – Seepage and piping adjacent to outlet conduit
(PFM # L)
Loading: Loading – Normal pool and above 427+
Description: Under normal pool, hydraulic gradient exists across the core zone. Seepage through the core is designed to exit through the downstream filter zone. Due to poor compaction during construction, voids are present adjacent to the conduit downstream of the filter zone. Sufficient gradient exists to initiate erosion of the fines in the zone 2 embankment or conduit backfill material into the voids. Continued erosion of the fines results in more porous rock fragments. The remaining open framework and rock permits continued erosion of fines as it works upstream to the filter. The open backfill/zone 2 materials allows the vertical filter drain material to erode into zone 2. Loss of filter initiates erosion of the clay core. Erosion of the core continues by plucking material from the core and stoping. Stoping progresses toward the upstream face through continued stoping and sloughing. Breach occurs through loss of freeboard and continued downstream sloughing resulting in uncontrolled release of pool and consequences.

Background and Evidence:

- Seepage is presently observed at the outlet structure on both sides of the conduit.
- A pipe was installed to capture seepage on the right hand side of the outlet structure in Feb. 2010.
- The filter drain downstream of the core is designed to filter the core material and permit seepage to exit downstream through a 4' wide drain located at the lowest point in the foundation (old river channel) and exits at the toe of the dam on the left side of the outlet conduit.
- Clay core is compacted against the conduit around collars placed at 10 foot centers.
- Filter was designed (well graded, 1.5-in. to #50 sieve, less than 4% passing the No. 200 sieve)
- Clay core is sandy clayey silt.
- Zone 2 shell material is reworked landslide debris from the spillway excavation.
- Conduit backfill was hand compacted
- Zone 1 material is silty sandy gravel.
- No construction records are present, no construction photos.
- Pool has been at spillway crest for 35 years.
- Observed seepage to date is clear.
- No collection/measurement of seepage is present in this area.
- Seepage can only be observed standing at the toe of the dam which requires boat access
- Project operations staff are physically on the embankment 3 to 4 times per year.
-

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Seepage is presently observed at the outlet structure on both sides of the conduit. • Seepage has increased on the right side of the conduit in recent years. • Clay core is compacted against the conduit around collars placed at 10 foot centers. • Clay core is sandy clayey silt. • Conduit backfill was hand compacted • Zone 1 material is silty sandy gravel.	• Filter was designed (well graded, 1.5-in. to #50 sieve, less than 4% passing the No. 200 sieve • The filter drain downstream of the core is designed to filter the core material and permit seepage to exit downstream through a 4' wide drain located at the lowest point in the foundation (old river channel) and exits at the toe of the dam on the left side of the outlet conduit. • Pool has been at spillway crest for 35 years. • Observed seepage to date is clear.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- Quality of construction of QC unknown, no photos, minimal construction records.
- Quantity and change in seepage is unknown.
- Lack of in-situ data prevents filter compatibility evaluation.
- Other potential sources of seepage (runoff, conduit, leakage, etc) could exit at the outlet structure as well making detection and trending difficult.
- Rate of seepage is monitored twice per year.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Would not be seen during an inspection until the hole is big enough.
- Cloudy flow would/could only be observed with a boat ride over to the toe of the embankment.
- Project staff does target this area all ready as a known concern.

Ability to Intervene:

- Can only lower the pool in Summer
- No access for emergency repairs.

Interim Risk Reduction Measures:

- Enhanced monitoring for seepage and piping.
- Collection box and weirs to separate and measure flows and measure turbidity.
- Educate community and City regarding reasoning for seepage. It should seep here. This was how the dam was designed.

Anticipated Warning Time and Breach Width:

- Breach formation time – time from initiation breach to loss of dam. Once it starts to breach, the warning time begins, it will take 4 hours from breach initiation to full breach (note: should undertake study to determine the breach formation time).
- Warning opportunity time is 0 or negative because the dam is not monitored constantly. Pipe can form, cloudy flow before you notice it.

SILVER CREEK DAM

POTENTIAL FAILURE MODE ANALYSIS

PFM #D & E

PFM# D & E – Downstream Sill and Stilling Basin Scour
(PFM # D & E)
<u>Loading:</u> Loading – All pools above El. 424
<u>Description:</u> Spillway flows initiate erosion of the basalt and spillway stilling basin concrete, continues to erode materials, undermining the spillway concrete and foundation. Failure/undermining of the spillway foundation at the toe results in loss of slab support. Loss of slab support permits slab failure, exposing the talus/landslide foundation. Exposed talus is highly erodible and scour will progress. Continued loss of talus results in failure of additional slabs and additional foundation exposure and erosion. Erosion progresses to the upmost slab, resulting in all spillway slabs having been displaced and eroding down to basalt resulting in uncontrolled release.
<u>Background and Evidence:</u> • Spillway centerline was turned 40 feet south during construction due to poor foundation conditions. • Spillway was extended due to poor foundation conditions (talus) • Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes). • Oct. 1975 inspection mentions scour at the sill. • The first/lowest slab is shown founded on basalt. • Visual observation during the site visit showed turbulence/flow disturbance on the left side of the spillway at the toe. • Anchors are 8 foot centers on bottom slab, 10 foot centers above. • Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs). • Foundation bedrock was described as poor to fair quality. • Spillway flows occur approximately 9 months out of the year. • Original inspection manual is concerned about erosion of the stilling basin and recommends frequent inspections and monitoring for erosion. • Inspections/records are not available and inspections have not been done in recent years. • High flows are infrequent. • According to City, historical peak pool is Elev. 430, corresponds to 5,000 cfs based on spillway discharge rating curve (1981 USACE Report). • Pool was very calm immediately downstream of end of spillway then turbulent downstream of calm area (possible deep pool).

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Spillway was extended due to poor foundation conditions (talus) • Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes). • Oct. 1975 inspection mentions scour at the sill. • Visual observation during the site visit showed turbulence/flow disturbance on the left side of the spillway at the toe. • Foundation bedrock was described as poor to fair quality. • Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs). • Original inspection manual is concerned about erosion of the stilling basin and recommends frequent inspections and monitoring for erosion. • Spillway flows occur approximately 9 months out of the year. • Pool was very calm immediately downstream of end of spillway then turbulent downstream of calm area (possible deep pool).	• The first/lowest slab is shown founded on basalt. • Spillway flows occur approximately 9 months out of the year. • High flows are infrequent.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- Current extent of scour is unknown.
- Unclear what is causing the flow disturbance at the left toe.
- No as-built drawings that show spillway changes or as-built elevations.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Failure is underwater all year.
- Would only see this after slab moves.
- No diver or survey information

Ability to Intervene (during failure):

- Cannot lower pool or stop spill.
- Could place rock with crane.

Interim Risk Reduction Measures:

- Monitor for scour/survey the area.
- Armor stilling basin.
- Anchor the slabs.
- Fill voids/scour holes with concrete (holes around and under).

Anticipated Warning Time and Breach Width:

- Breach formation time – time from initiation breach to loss of dam. For normal pools – months, for high flows greater than 100 yrs – days (maybe hours).
- Warning opportunity time is 0 or negative. You will see this after a slab has failed (maybe).

SILVER CREEK DAM

POTENTIAL FAILURE MODE ANALYSIS

PFM #C

PFM# C – Slab Jacking

(PFM # C)

Loading: Loading – All pools above El. 424

Description: Failure modes is similar to D&E except for different initiation mechanism. Spillway flows impact on offset in spillway slabs which result from uplift pressure or slab settlement (either under long term static conditions or seismically induced. Landslide foundation materials are exposed initiating erosion. Erosion and continued slab failure due to loss of support continue and progress to the pool.

Background and Evidence:

- Spillway centerline was turned 40 feet south during construction due to poor foundation conditions.
- Spillway was extended due to poor foundation conditions (talus)

- Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes).
- Oct. 1975 inspection mentions scour at the sill.
- The first/lowest slab is shown founded on basalt.
- Visual observation during the site visit showed turbulence/flow disturbance on the left side of the spillway at the toe.
- Rock anchors were installed beneath the spillway slabs between the downstream end of the spillway and approximately 50 feet upstream of the end. The anchors are on 8 foot centers on the bottom slab, and 8 foot centers longitudinally and 10 foot centers transversely above the bottom slab.
- Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs).
- Foundation bedrock was described as poor to fair quality.
- Spillway flows occur approximately 9 months out of the year.
- Original inspection manual is concerned about erosion of the stilling basin and recommends frequent inspections and monitoring for erosion.
- Inspections/records are not available and inspections have not been done in recent years.
- High flows are infrequent.
- Pool was very calm immediately downstream of end of spillway then turbulent downstream of calm area (possible deep pool).
- No known offsets
- No data/inspection except visual flow disturbances documented during site visit.
- Drains are not inspected/cleaned.
- Drains travel underneath the slab across to a 6-in. pipe which runs down the ladder and empties into the ladder.
- Uplift pressure unknown.

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes). • Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs). • Visual observation during the site visit showed turbulence/flow disturbance on the	• No known offsets • Spillway flows occur approximately 9 months out of the year. • High flows are infrequent.

left side of the spillway at the toe. • Spillway flows occur approximately 9 months out of the year. • Pool was very calm immediately downstream of end of spillway then turbulent downstream of calm area (possible deep pool). • No data/inspection except visual flow disturbances documented during site visit. • Drains are not inspected/cleaned.	

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- Presence of offsets.
- Design uplift pressures.
- Current uplift pressures.
- Effectiveness of drains.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Failure is underwater all year.
- Would only see this after slab moves.

Ability to Intervene (during failure):

- Cannot lower pool or stop spill.

Interim Risk Reduction Measures:

- At times of non-spilling, inspect for offsets.
- Grind slabs flush.
- Anchor the slabs.
- Fill voids/scour holes with concrete (holes around and under).

Anticipated Warning Time and Breach Width:

- Breach formation time – time from initiation breach to loss of dam. For normal pools – months, for high flows greater than 100 yrs – days (maybe hours).

- Warning opportunity time is 0 or negative. You will see this after a slab has failed (maybe).

SILVER CREEK DAM

POTENTIAL FAILURE MODE ANALYSIS

PFM #O

PFM# O – Seepage and Piping through the Embankment - Embankment foundation seepage and piping in the landslide deposit foundation at contact with core.

(PFM # O)

Loading: Loading – All pools.

Description: An existing hydraulic gradient is sufficient near Station 4+75 to initiate silt and clay sized particles in the landslide foundation to migrate downstream into one or more of the 11 unfiltered horizontal drains installed after construction to deal with seepage after first filling. Erosion continues upstream or vertically through the landslide deposit leaving a porous open-work rock matrix. A porous openwork path is formed which is in direct contact with the core. Erosion of the core material initiates and progresses as impervious blanket is displaced downstream. Sinkhole forms as zone 1 materials collapse. Collapse of upstream sinkhole/shell material allows direct connection with the pool and significant seepage/uncontrolled release.

(After considerable discussion, the team feels this failure mode is credible where the core layer is founded on landslide deposits and core material transport may be possible into porous landslide material. Bedrock was treated with grout where core is underlain by bedrock.)

Background and Evidence:

- Seepage on first fill near Station 4+75 was observed.
- Foundation is talus landslide deposits (silty clay rock fragments).
- 11 horizontal drains and 3 surface drains installed in this area after construction.
- Core and upstream impervious blanket are thin (4’) and in direct contact with the landslide foundation, which is untreated.
- Zone 1 material is silty, sandy, gravel (cohesionless) and serves as plug for sinkhole.
- The downstream berm was installed to address this seepage but has no effect on this failure mode.
- There is no filter zone underneath the impervious blanket.
- Drains are monitored about 3 times per year.
- Gradient for this flow path exists year-round.

- This load has existed for 30 + years.
- When observed, discharge from the drains has been clear.
- Hydraulic gradient is near 1 at the contact.
- Limited access to dam.

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Seepage on first fill near Station 4+75 was observed. • Foundation is talus landslide deposits (silty clay rock fragments). • 11 horizontal drains and 3 surface drains installed in this area after construction. • Core and upstream impervious blanket are thin (4') and in direct contact with the landslide foundation, which is untreated. • There is no filter zone underneath the impervious blanket. • Hydraulic gradient is near 1 at the contact. • Gradient for this flow path exists year-round.	• When observed, discharge from the drains has been clear. • Zone 1 material is silty, sandy, gravel (cohesionless) and serves as plug for sinkhole.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- True composition of landslide deposit is unknown in this area.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Turbid flow and increased seepage in drains.
- Visual evidence of sinkholes on the embankment.
- Whirlpools near the upstream face of the dam.

Ability to Intervene (during failure):

- Place sand and gravel in sinkholes.

Interim Risk Reduction Measures:

- Monitor flow and turbidity in drains.
- Install new, filtered drains.

Anticipated Warning Time and Breach Width:

- Breach formation time – May not even breach, breach time would be days due to flow limiting. Uncontrolled release is defined here as a large seep under the core. This may not result in a true breach of the dam.
- Warning opportunity (turbidity and flow detection) time is weeks or months; is a slow process.

SILVER CREEK DAM

POTENTIAL FAILURE MODE ANALYSIS

PFM #F

PFM# F – Scour of upstream spillway sill.

(PFM # F)

Loading: Loading – All pools above El. 424.

Description:

Keys:

1) Blanket failed.
2) Drains are overwhelmed by increased seepage due to blanket failure.
3) Increased uplift on slabs.
4) Slabs fail.
5) Erosion/scour.
6) Loss of spillway to bedrock.

Scour present on the upstream sill of the spillway permits additional flow under the spillway. The resulting flow overtaxes the spillway drain system creating full uplift on the spillway and slabs. Increased uplift and cycles of loading displace spillway slabs (by offset, settlement, anchorage failure, etc.) resulting in exposed highly erodible talus foundation. Erosion progresses through continued loss of slab support and scour. Scour progresses upstream to full pool resulting in uncontrolled release down to bedrock (El. 375).

(This failure mode is similar to C, D and E only different initiating mechanism.)

Background and Evidence:

- Spillway centerline was turned 40 feet south during construction due to poor foundation conditions.
- Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes).
- The first/lowest slab is shown founded on basalt.
- Anchors are 8 foot centers on bottom slab, 10 foot centers above.
- Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs).
- Foundation bedrock was described as poor to fair quality.
- Spillway flows occur approximately 9 months out of the year.
- High flows are infrequent.
- According to City, historical peak pool is Elev. 430, corresponds to 5,000 cfs based on spillway discharge rating curve (1981 USACE Report).
- Upstream impervious blanket has historically eroded and been repaired with pit run rock.
- Each repair cycle indicates removal of impervious blanket, resulting in reduced scour but increased flow beneath the spillway.
- Piezometer level in B-2 , installed in the landslide deposit has been relatively constant since installation.

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Construction final report documents difficulty with rock anchor installation due to poor rock quality and saturated foundation (water in anchor holes). • Joints are key-shaped with pre-molded joint-filler between slabs with a plastic water-stop embedded approximately 3-inches below top of spillway slab (no doweling or structural tie between slabs). • Spillway flows occur approximately 9 months out of the year. • Upstream impervious blanket has historically eroded and been repaired with pit run rock. • Each repair cycle indicates removal of impervious blanket, resulting in reduced scour but increased flow beneath the spillway.	• Spillway flows occur approximately 9 months out of the year. • High flows are infrequent. • Piezometer level in B-2 , installed in the landslide deposit has been relatively constant since installation.

* - Major Contributing Factors

Knowledge Gaps and uncertainty:

- Condition of the blanket upstream of the sill.
- Uplift pressures.
- Slab design (designed to full uplift?).

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Visual observation of flow disturbance.
- Decreased spillway drainage downstream may indicate uplift increase.

Ability to Intervene (during failure):

- Drop boulders in the hole.

Interim Risk Reduction Measures:

- Ensure spillway drains are effective.
- Ensure blanket remains impervious.
- Anchor slabs if needed.
- Add piezometer adjacent to the spillway.

Anticipated Warning Time and Breach Width:

- Breach formation time – time from initiation breach to loss of dam. For normal pools – months, for high flows greater than 100 yrs – days.
- Warning opportunity time is 0 or negative. You will see this after a slab has failed (maybe).

SILVER CREEK DAM

POTENTIAL FAILURE MODE ANALYSIS

PFM #P

PFM# P – Internal erosion of left abutment silt foundation material.

(PFM # P)

Loading: Loading – All pools.

Description:

Sufficient hydraulic gradient exists to initiate erosion of the plastic silt material into the zone 1 downstream shell material near elevation 400 at the contact between zone 1 and silt colluvium abutment, where no filter exists.

(After much discussion, the team decided that this failure mode is not likely due to seal of core trench into the silt deposit at the left abutment. The only source of water producing hydraulic gradient to drive the mechanism is surface runoff or hillside seepage which doesn't provide sufficient gradient.)

Background and Evidence:

Conditions making PFM Likely *Or Unfavorable Factors*	*Conditions making PFM Unlikely* *Or Favorable Factors*

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

•

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

•

Ability to Intervene (during failure):

•

Interim Risk Reduction Measures:

Anticipated Warning Time and Breach Width:

- Breach formation time – time from initiation breach to loss of dam. For normal pools – months, for high flows greater than 100 yrs – days.
- Warning opportunity time is 0 or negative. You will see this after a slab has failed (maybe).

SILVER CREEK DAM **POTENTIAL FAILURE MODE ANALYSIS** **PFM #M** PFM# M – Seismically Induced deformation in outlet conduit.
(PFM # M)
Loading: Loading – Seismic
Description: Seismic loading causes displacement of conduit due to material (clay, zone 2, etc) being seismically excited at different modes. If this occurs and a gap opens in the conduit, the failure mode would progress as PFM – L with a different probability of initiation.
Background and Evidence: • Clay core is compacted against the conduit around collars placed at 10 foot centers. • Filter was designed (well graded, 1.5-in. to #50 sieve, less than 4% passing the No. 200 sieve • Clay core is sandy clayey silt. • Zone 2 shell material is reworked landslide debris from the spillway excavation. • Conduit backfill was hand compacted • No construction records are present, no construction photos. • Flow in the pipe is low (gradient is low for moving material). • Conduit has never been TV inspected. • Conduit was not designed for 0.4g. • Founded on bedrock.

- Total deformation, even @0.4g would be small.
- OBE = 0.0875g
- MCE = 0.4g
- EQ at Scott Mills was larger than OBE.

Conditions making PFM Likely ***Or Unfavorable Factors***	***Conditions making PFM Unlikely*** ***Or Favorable Factors***
• Conduit backfill was hand compacted • Conduit has never been TV inspected. • Conduit was not designed for 0.4g.	• Flow in the pipe is low (gradient is low for moving material). • Total deformation, even @0.4g would be small. • Founded on bedrock.

*** - Major Contributing Factors**

<u>Knowledge Gaps and uncertainty:</u>

- Condition of conduit.
- Capacity of the conduit to handle deformation.
- Extent of deformations in a seismic event is unknown.

Potential Risk Reduction Actions

<u>Ability to Detect Failure Mechanisms:</u>

- Respond due to earthquake.
- Turbidity in flow from conduit.

<u>Ability to Intervene:</u>

- Close the outlet gate.
- TV inspect the outlet pipe.

<u>Interim Risk Reduction Measures:</u>

- TV inspect the outlet pipe.

Anticipated Warning Time and Breach Width:

- Breach formation time – time from initiation breach to loss of dam. Once it starts to breach, the warning time begins, it will take 4 hours from breach initiation to full breach (note: should undertake study to determine the breach formation time).
- Warning opportunity time is 0 or negative due to inability to predict earthquakes.

Reconsidering Ratings of 16 Credible and Significant Failure Modes

A. Credible, not significant. Spillway left downstream training wall offset/stability –Credible failure mode, but not significant for normal pools/flows due to low driving gradient through the embankment/impervious core adjacent to the crest of the spillway. This is a contributing factor however to PFM C and PFM D. Failure of the training walls will lead to flows not trained properly and potential increased scour of the stilling basin or the spillway slabs. Walls should be monitored and inspected for additional movement.
B. Credible but not significant (low consequences). Spillway right downstream training wall offset/stability – RT wall failure will expose the fish ladder. Consequences – fish and uncontrolled flow that would continue to flow until pool lowers in summer. Even at high spills, flow will be impacting weirs which act as baffles. No life consequences. Fish and economics. Cannot dump sufficient water downstream to be considered an independent failure mode. Contributing factor to PFM C and PFM D. Walls should be monitored and inspected for additional movement.
C. Credible and Significant - Spillway slab jacking (drain concerns) – normal flow conditions, erodible material.
D. Credible and Significant -Spillway sill downstream scour on left side – normal flow conditions, erodible foundation and concrete irregularity at the location.
E. Credible and Significant - Combined with D - Spillway basin scour – normal flow conditions, no survey data, previous scour (is it on rock/seam?)
F. Credible and Significant - Similar to C,D,E in consequences – (Spillway upstream sill scour – normal flow conditions, happened before, clay blanket may not be fully present, can lead to uplift of spillway slab
G. Credible, not significant for Normal Pools - Spillway right upstream wall joint – C/S for greater than 100 year event - High pool, load up training wall, loading up the landslide deposit. Insufficient hydraulic gradient to move material downstream, wall should not fall, just leak (this is right wall issue).
H. Credible, not significant - Spillway tailwater/channel capacity-PMF conditions - If flow is high, debris will move, no backwater effects. No routing or channel capacity evaluation done. Existing channel may not have been designed for new 100 year flood. Recommend analysis be performed for whether 100yr, 500yr etc. floods stay within existing banks etc. This is critical to property damage, evacuation routes, population awareness etc.

I. Credible, not significant - Spillway foundation seepage/stability/settlement (potential for differential settlement due to different foundation upstream and downstream) – combine with 1,2,5 and 6 - Spillway settlement and stability under seismic conditions. The 1999 stability analysis did not look at the spillway talus foundation. However, the report did look at slope stability with embankment material having frictional strength of 36 degrees. The team believes liquefaction and slope stability/sliding failure of the talus foundation is unlikely due to the composition of the talus (high friction and the shallow slope). Settlement, while possible, was or is addressed in PFM C which is slab jacking.

J. Credible and Significant - combine with K and N Debris blockage – PMF conditions, have bumper but no log boom; consider placing boom upstream of clay blanket. Will lead to overtopping at lesser flooding events – more, frequent flood overtopping.

K. Credible and Significant - SEE J and N - Low spot adjacent to right abutment wall (ground appears to be around 438 (438.5). Scour at high pools. Shallow embedment of wall, lose wall, this could lead to release at pool level at El. 430*****OPS ISSUE*******

L. Credible, not significant - Mechanism considered unlikely with respect to necessary voids forming. Seepage on both sides of the outlet, around seepage collars. Normal flow conditions Not significant – limited flow/erosion capacity based on dam construction materials.

M. Credible, not significant. Conduit integrity – earthquake loading at joints, internal erosion; founded on bedrock, reinforced, cast-in place, seepage collars Not significant flow, inspect conduit and reevaluate. If conduit has structural integrity issues could collapse and result in overtopping/crest deformation.

N. Credible and Significant - SEE J AND K(C&S)Overtopping (core less than crest) - Lack of consistent survey on vertical settlement – potential low spots. Significant and can be tied to early warning system.

O. Credible, not significant - Mode is for where core is on top of landslide (4 foot) blanket at minimum thickness – may not breach, just uncontrolled seepage -(C&S)Embankment seepage and piping (11 drains that flow, 3 drains/berm/’75 trench/blanket/2 working piezometers) - burrowing animals, trees and vegetation.

P. Considered credible not significant - Mechanism unlikely (no source of water to drive erosion) Left abutment, Silt foundation – seepage and piping, piping at Elev. 398 seam causes internal erosion of silt, creates a pipe in silt and uncontrolled release Only could occur at high pools and nowhere for material to pipe to.

Major Findings and Understandings

1. The Dam appears to be well maintained and project operations staff is maintaining the project to the best of their abilities.
2. A variety of documents were available for review for the PFMA. In general, there was a lack of construction photos associated with original construction (one aerial photo was available from original construction).

3. General access to the right side of the project is by car. Access to the right abutment of the project site (including the right spillway training wall and fish ladder) can be gained on foot. Access to the embankment, low level outlet and left abutment of the dam requires a boat.
4. Under normal operations, pool rises to spillway crest (El. 424 feet) for about nine months of every year. Pool of record is about El. 430 feet (6 feet over the crest) .
5. Downstream flooding occurs every year at Silver Gardens Retirement Home, requiring sand bagging every year. This will continue unless structural measures are taken to prevent flooding.
6. There is no stream gauging upstream of the dam or forecast data available at the project. As a result, the City is unable to predict flooding in advance from rainfall.
7. There are no weirs to measure seepage present at this project. The city currently manually measures seepage with a bucket and stopwatch periodically. This method results in inconsistent data and no plotting of seepage data has occurred to date.
8. There is no seepage collection/measuring present on the left abutment. Because of the historical seepage concerns, seepage was extensively discussed. For this PFMA, general seepage was broken down into seepage leading to specific failure mechanisms (i.e. increase seepage causes an increase uplift pressure beneath the spillway slabs leading to failure of spillway slabs allowing erosion of the underlying foundation materials to breach the dam).
9. Outlet capacity and reliability are keys to safe project operations. The project cannot dewater quickly if needed for an emergency (except in summer). In addition, there are reliability concerns based on operation history (This needs to be addressed by the City – will the outlet work when needed?).
10. Inspectors/City Staff cannot view or inspect the left side of the Dam (embankment, spillway and abutment) without a boat. This results in infrequent and inadequate inspection.
11. City staff cannot intervene to stop dam failure without the use of a helicopter or boat/barge. Placing material at the dam, such as rock or other materials to prevent or stop dam failure is difficult.
12. The current Emergency Action Plan (EAP) does not allow for full contact with the population (how is the population of the city of Silverton notified?). The call list for the current emergency public notifications system (Everbridge Call System) is not complete. According to City Operations Staff, the suppliers of the old notification system (Code Red) will not release the full list to the City. The Everbridge system will automatically call all landlines in Silverton. However, City residents won't be contacted on cellular phones unless they have signed up for the Everbridge call system (even if they signed up originally for the old Red Code system).
13. The Project Operations plan needs trigger thresholds for inspection (when to go to 24-hour surveillance, etc.) and warning. Critical elevations need to be established for this project in order to ensure adequate inspection and early warning.
14. Known foundation features will continue to seep (basalt interflow zone @ 398, landslide talus on right abutment). However, these areas are not prone to piping and dam failure.
15. Visible signs of distress are present at the dam (the spillway training walls are tilted, stilling basin scour is apparent at the site, new and/or increased seepage has been identified in recent years).

16. The City reports that seepage has increased in recent years (left and right side of outlet works, new pipe installed in Feb 2010), but there is no way for the City to quantify or measure to verify if seepage is increasing due to a lack of a weir or other measurement system that could be used to quantify this seepage.
17. The City inspects the dam twice per year and the State inspects the dam approximately once per year. Inspection requires boat access so frequent inspection is difficult.
18. Stilling basin scour is evident and has been previously reported in post construction inspections. There is no record of scour inspection or monitoring by the City. . Original recommended operations and maintenance document indicates that the stilling basin is prone to scour and should be frequently inspected. The inspections will require diverting water from the low level outlet and fish ladder and pumping from the stilling basin during periods of no flow through the spillway; or use of an ROV.
19. Power at the project is City supplied and is only currently available on the right side of the Dam. No backup power, such as an emergency generator, is available at the site. Some method of alternative power, such as a solar panel, may be needed for any proposed monitoring system.
20. Some of the piezometers are currently non-functional and some of the piezometer standpipes are small in diameter. Small diameter piezometers may prove difficult to automate.
21. Operations personnel have no means of verifying the low level outlet gate position (42-in. or 18-in outlet) – operations cannot see the outlet from the control stand located on the left bank.
22. Outlet operation during high flows (open or closed) is not defined in the operations manual. The outlet may not be structurally sound at high pools when the gate is open due to the potential for cavitation. In addition, the air intake for the outlet may be inundated in high flow events which will result in surge flow.
23. Low spots are present at the right abutment. This means overtopping may occur at lower elevations.
24. No current hydraulic modeling/routing has been performed in order to define thresholds (100 yr flood, PFM, etc.), pools and tailwaters. If modeling data was available, the ability to set meaningful thresholds for an early warning system would be improved.
25. While the top of the embankment is designed at elevation 440, the clay core within the embankment only extends up to Elev. 435; the filter extends up to Elev. 430. Increased seepage above the clay core should be anticipated with pool levels greater than El. 435. In addition, the lack of a clay core extending to the top of the dam may result in overtopping occurring at elevations below elevation 440 (i.e. overtopping may begin before the pool reaches the top of the dam due to wave/wind erosion of the embankment). The potential for overtopping to begin at a lower elevation should be considered when defining trigger points for an early warning system.
26. The City was not able to produce current survey data for true height of embankment crest, the tops of walls or abutments. Settlement of the embankment or other low spots may result in overtopping at lower elevations than anticipated. Knowing the location of low spots is important for determining locations of stocking emergency materials and to focus flood fighting efforts.

27. Based on the results of analysis performed to date by Cornforth Consultants, the embankment and abutments are expected to be adequately stable under seismic conditions and liquefaction susceptibility is low.
28. No seismic analysis of the concrete spillway or spillway wall has been performed. It is anticipated that loss of the wall may lead to failure of the embankment. (Walls designed for 0.05g, current MCE from USGS = 0. 4g).
29. There appears to be a gap in the core trench on the right abutment below the training wall. The presence of a gap at this location may result in seepage at pools above Elev. 430. The City should anticipate the possibility of increased seepage with pools above Elev. 430 and monitor this location.
30. Intervention materials (sand bags, rip rap) are not currently stockpiled on the site.
31. There are residence locations within very short travel times downstream of the dam. Warning time would not be possible for some failure modes.
32. Loss of pool in summer months will eliminate the downstream water supply and force the City to go to water conservation.
33. A log boom was installed at the end of construction at the upper end of the pool but is no longer present. Build up of reservoir rim debris could clog the spillway during high flow events.
34. Large vegetation debris is expected to continue to collect downstream of the spillway below the stilling basin, reducing channel capacity. If this material continues to collect over many years, it may create a downstream hazard during a subsequent large flood event as occurred in recent flooding events on the Sandy River resulting in downstream damage to bridges and property.
35. Project staff was unaware of the presence of 4 foot filter drain that runs from the filter zone to the left of the outlet pipe and ends downstream immediately to the left of the outlet structure (this may or may not exist since as-built drawings do not show it but it is discussed in CH2MHill correspondence). If it exists, this drain may contribute to seepage exiting near the low level outlet structure at the toe of the dam.
36. There are no records of conduit inspection/ROV inside the outlet pipe. The pipe should be inspected for structural integrity.
37. Zone 1 materials on the upstream shell of the embankment consist of well graded silty, sandy gravel and should act as a flow limiter/piping restriction (fill developed voids) should it initiate.
38. The upstream impervious blanket should be inspected for holes for its full length upstream (not just at the sill).
39. The low level conduit passes through the dam at the base of the embankment. It is founded on bedrock where it passes beneath the impervious core. The conduit is square and has seepage collars on 10 foot centers. Impervious back fill around the conduit was placed in 4 inch lifts and compacted with hand tampers.

SILVER CREEK DAM

POTENTIAL FAILURE MODES ANALYSIS (PFMA) REPORT

APPENDIX C

SITE VISIT NOTES

Background

A site visit was conducted on Tuesday, 11 January, 2011 in order to observe and familiarize the PFMA team with the site conditions. The purpose of this memorandum is to summarize the observations made during the site visit. The following people were on site to participate in the site visit.

- Andy Peters (City of Silverton)
- Travis Adams (USACE, Structures, PFMA, Facilitator)
- Matthew Craig (USACE, Dam Safety, PFMA Co-facilitator)
- David Scofield (USACE, Geotechnical)
- Thareth Yin (USACE, Hydraulic Design)
- Alison Burcham (USACE, Project Manager)

Access

The right abutment of the dam can be accessed by car. The right side of the spillway, fish ladder and right abutment can be accessed and observed from the right abutment area. A boat ramp permits access to the left side of the spillway, embankment and left abutment by boat. Crews access the embankment and left side of the project with a boat. A small boat was used to gain access to the left side of the project during the site visit.

Right Abutment Area

A wall extends from the right side spillway and extends approximately 35 feet to the right (Photo 1). The top of the wall is at Elevation 440 according to the project drawings. A low spot approximately 1.5 to 2 feet below the wall was observed immediately to the right of the wall. It was observed that this low spot could allow overtopping at pools less than what would occur if the ground elevation is at 440, same as the wall. City crews repaired the concrete wall at one of its joints.

Erosion was observed in the backfill behind the upstream end of the short training wall upstream of the right spillway wall (Photo 2). The purpose of this wall is to direct flow through the spillway away from the spillway walls. It is anticipated that, without repairing the erosion behind the wall, increased erosion may occur behind the wall during high flow events and potential and impair the function of the wall to direct flow into the spillway.

No irregular surface features such as sloughing, bulging or other features were observed.

Fish Ladder Structure

Evidence of relative lateral movement between wall segments was observed on both sides of the spillway structure. Damage was most apparent on the right side (Photo 3). It was also observed that the ground level immediately to the right of the right fish ladder wall was lower than the surrounding ground. This may be an indication of settlement of granular backfill around a 6 in. drain that runs to the right of the right fish ladder wall along its length. This drain discharges into the fish ladder structure near the downstream end of the spillway structure. At the time of site visit, no water was flowing from the drain into the fish ladder structure.

Cobbles and boulders were observed within the chambers of the fish ladder.

Stilling Basin

The stilling basin downstream of the spillway could not be observed; tailwater level was too high to allow observation of the extent of scour in the spillway. It was noted that the tailwater appeared to be relatively calm immediately downstream of the spillway (Photo 4). Such conditions may suggest that some scouring downstream has developed, resulting in a deeper pool immediately downstream and less turbulence near the water surface.

Some tree and vegetation debris has built up over time downstream o f the stilling basin (Photo 5). The vegetation is likely reducing the overall channel capacity downstream of the dam.

Spillway

At the time of the site visit, water was spilling over the spillway; it appeared that the pool was slightly above the spillway crest. Some water disruption was observed in a couple of locations; one near the upper end of the spillway and the other near the downstream end of the spillway adjacent to the left spillway wall.

On the left spillway wall, lateral offsets were observed between adjacent wall segments (Photo 6). Sufficient relative lateral deformation may result in failed water stops and a pathway for water from the spillway to flow into the backfill behind the wall.

Near the crest of the dam, concrete wall repair had previously been performed by City crews near one of the wall joints (Photo 6). Spalling had occurred at this location previously.

Embankment

No obvious signs of embankment instability were observed (no slumps or large scale ground surface irregularities). During the time of the inspection, seepage was observed from some of the 11 horizontal drains that had been installed to capture seepage beneath the right end of the earth embankment after construction (Photo 7). On first filling, seepage had been observed on the downstream face of the dam, especially on the right side of the embankment. The extent of the seepage was such that a downstream buttress and a series of horizontal drains were installed to collect seepage from beneath the embankment. Seepage was also observed on either side of the outlet structure near the toe of the dam. At this location in February 2010, City crews installed a short collection pipe into the embankment on the right side of the outlet structure in order to provide a means for obtaining a representative measurement of seepage at this location (Photo 8). It is expected that the collection pipe isn't collecting all seepage at this location but that changes in seepage conditions would be reflected in the rate of flow out of the pipe. There is some uncertainty regarding how long seepage has been flowing at this location. It is possible that flow has increased here recently.

One of the piezometers was observed near the crest of the embankment. The small size of the piezometer standpipe (drawings indicate the standpipe is ¾-in PVC pipe) may limit options for selecting sensors that can be suspended in the standpipes as part of the instrumentation for the proposed early warning system.

Photo 1. Right Abutment Wall

Photo 2. Right Abutment Training Wall

Photo 3. Deformation at Right Fish Ladder Wall

Photo 4. Relatively Calm Tailrace Water Conditions

Photo 5. Vegetation Debris in the Tailrace Area

Photo 6.   Relative Lateral Deformation, Left Spillway Wall

Photo 7. Seepage from Horizontal Drains

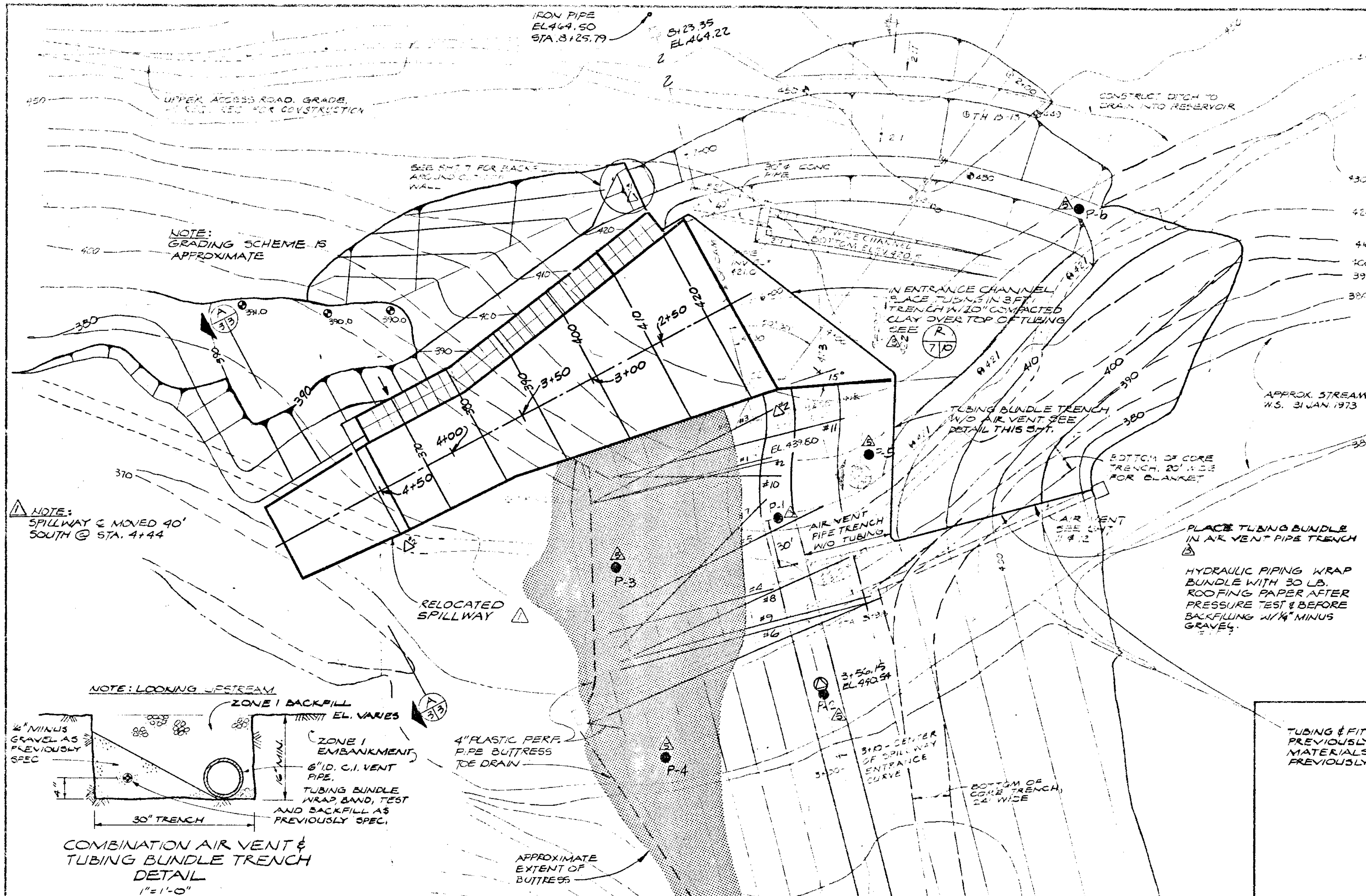
Photo 8. Seepage Around Outlet Structure

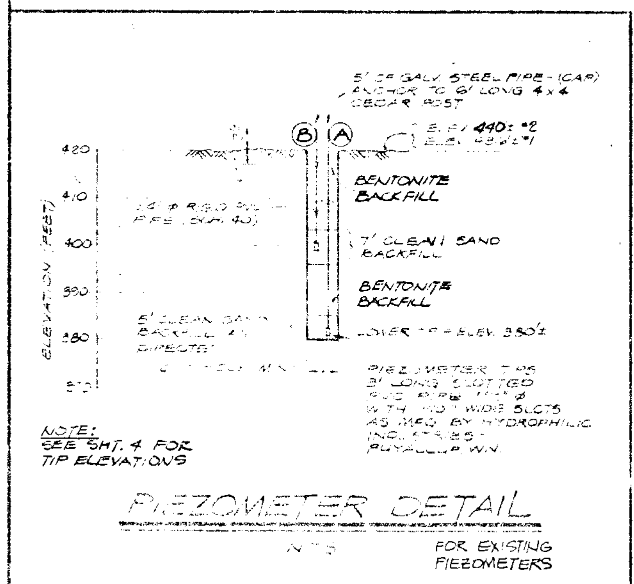
SILVER CREEK DAM

POTENTIAL FAILURE MODES ANALYSIS (PFMA) REPORT

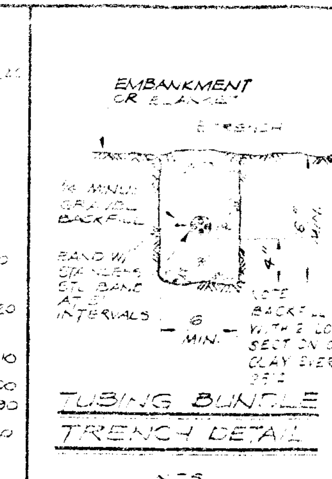
APPENDIX D

DRAWINGS





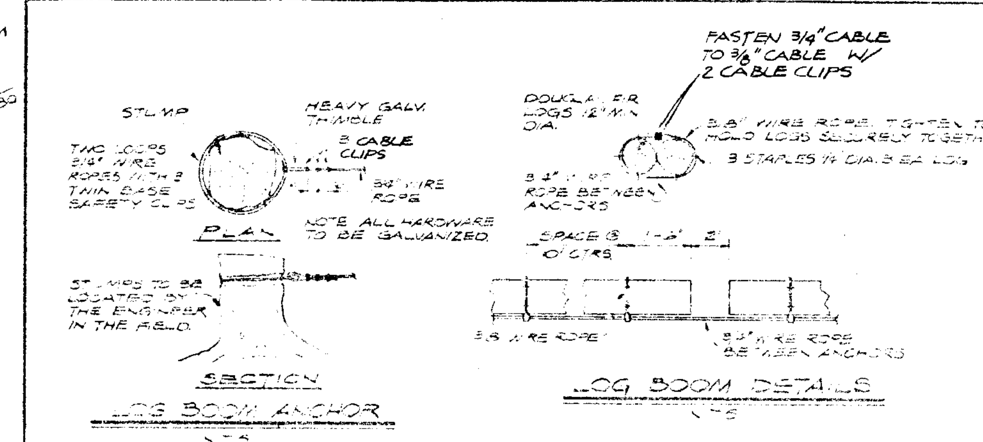
SEE SH FOR DETAIL OF NEW PIEZOMETERS



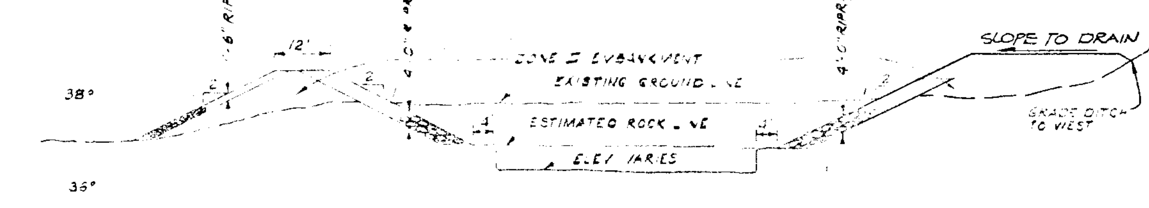
DRAIN #	FROM (STA)	@ ELEV.	TO (STA.)	@ ELEV.	LENGTH (FT.)
1	5+00	392	5+00	402	130
2	5+00	390	5+00	390	120
3	5+00	390	5+25	390	120
4	4+20	390	4+20	390	100
5	4+35	390	4+60	390	160
6*	4+00	387	4+00	395	160
7	4+10	390	4+80	400	130
8	4+00	387	4+20	387	160
9*	4+00	387	4+00	395	160
10	5+10	405	5+10	405	160
11	5+10	405	4+90	405	105

* DRAIN DRILLED TO FILTER

HORIZONTAL DRAINS FIELD LAYOUT



TUBING & FITTING TO BE 3/8" ID 304-SS AS PREVIOUSLY SPECIFIED. ALL OTHER MATERIALS AND WORKMANSHIP AS PREVIOUSLY SPECIFIED.



NOTE: THE STILLING BASIN DIKE WAS PARTIALLY REMOVED TO PROVIDE TEMPORARY ROAD TO OUTLET AREA

SPILLWAY SECTION

NOTE: SEE SHT. 14 FOR POST CONSTRUCTION MODIFICATION TO DAM

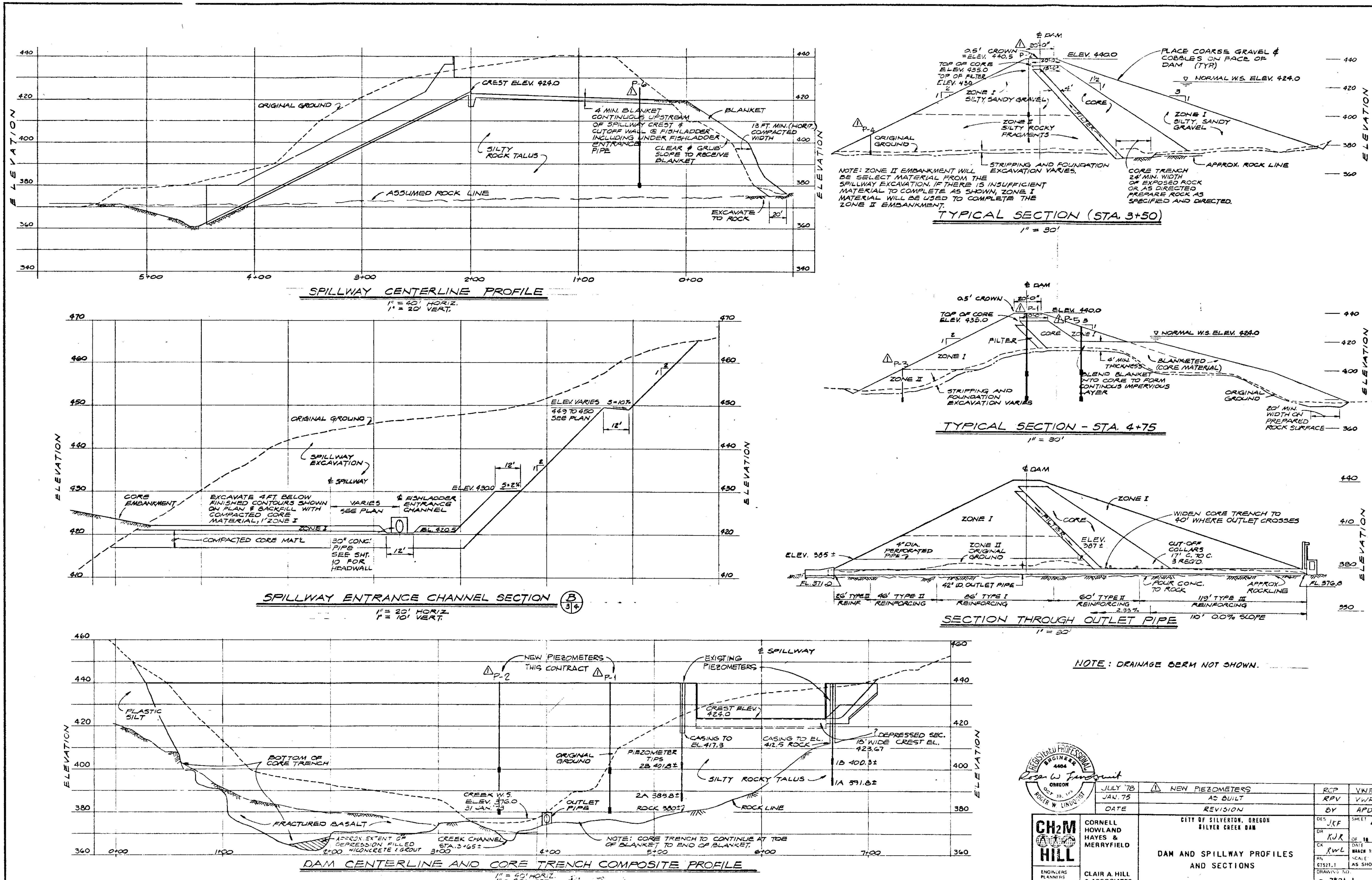
NO.	DATE	REVISION	BY	APP.
5	17 JULY '78	NEW PIEZOMETERS	RCP	VWR
4	15 JAN '75	AS BUILTS	RCP	VWR
3	22 JULY '74	CHANGE ORDER #3 TUBE BUNDLE TRENCH	RCP	VWR
2	4 SEPT '73	CHANGE ORDER #2 SLAB EXTENSION	RCP	RWL
1	23 JULY '73	CHANGE ORDER #1 SPILLWAY ROTATION	[illegible]	RWL

CORNELL HOWLAND HAYES & MERRYFIELD

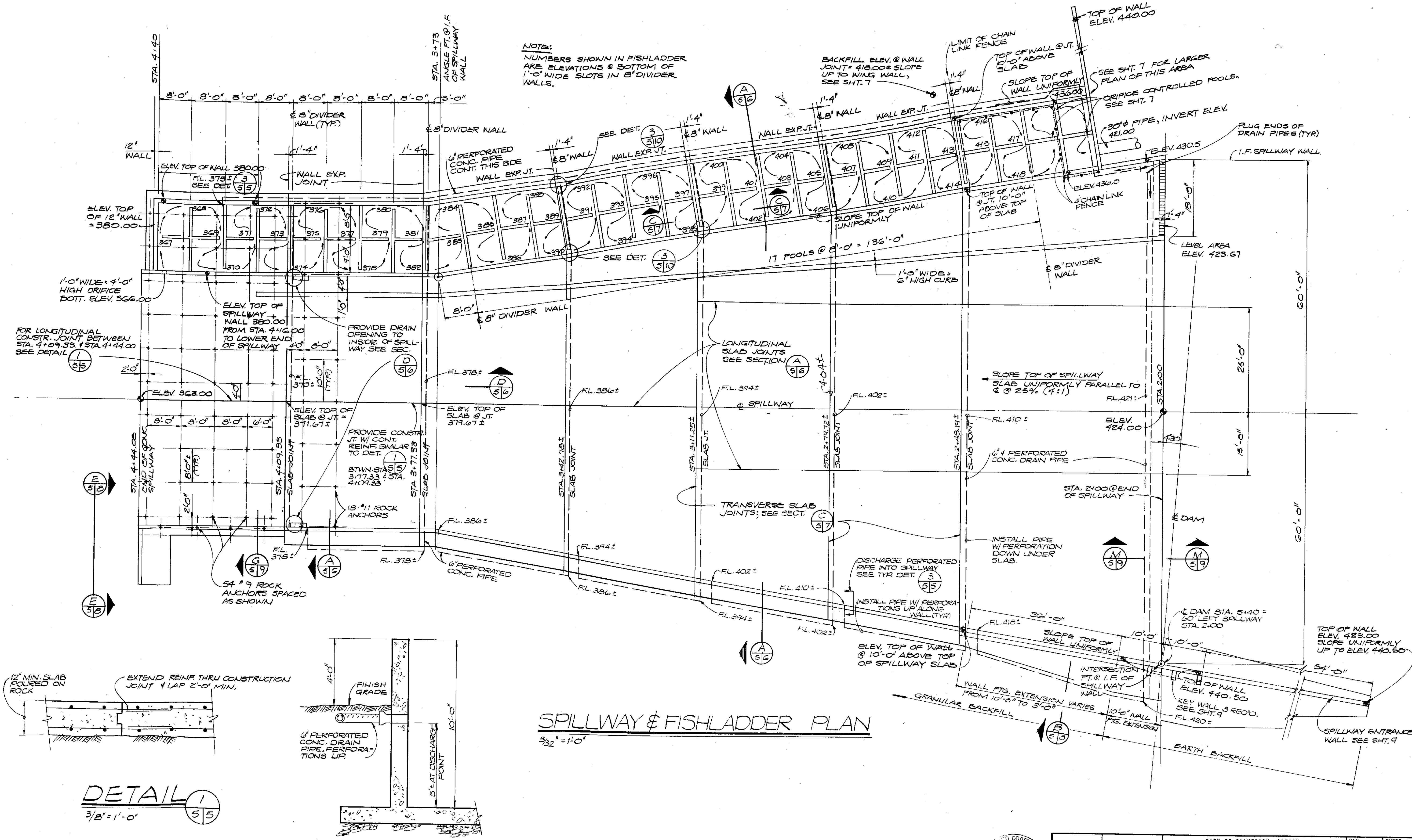
CLAIR A. HILL & ASSOCIATES

BUTTRESS AND DRAINS

14 of 16



SPILLWAY CENTERLINE PROFILE
1" = 40' HORIZ.
1" = 20' VERT.
CREST ELEV. 424.0
ORIGINAL GROUND
4' MIN. BLANKET CONTINUOUS UPSTREAM OF SPILLWAY CREST & CUTOFF WALL @ FISHLADDER INCLUDING UNDER FISHLADDER ENTRANCE PIPE
BLANKET
13 FT. MIN. (HORIZ.) COMPACTED WIDTH
SILTY ROCK TALUS
CLEAR & GRUB SLOPE TO RECEIVE BLANKET
ASSUMED ROCK LINE
EXCAVATE TO ROCK
ELEVATION
TYPICAL SECTION (STA. 3+50)
1" = 30'
℄ DAM
0.5' CROWN =ELEV. 440.5
TOP OF CORE ELEV. 435.0
TOP OF FILTER ELEV. 430
ELEV. 440.0
PLACE COARSE GRAVEL & COBBLES ON FACE OF DAM (TYP)
NORMAL W.S. ELEV. 424.0
ZONE I SILTY SANDY GRAVEL
CORE
FILTER
ZONE II SILTY ROCKY FRAGMENTS
ZONE I SILTY, SANDY GRAVEL
ORIGINAL GROUND
STRIPPING AND FOUNDATION EXCAVATION VARIES.
CORE TRENCH 24' MIN. WIDTH OF EXPOSED ROCK OR AS DIRECTED PREPARE ROCK AS SPECIFIED AND DIRECTED.
APPROX. ROCK LINE
NOTE: ZONE II EMBANKMENT WILL BE SELECT MATERIAL FROM THE SPILLWAY EXCAVATION. IF THERE IS INSUFFICIENT MATERIAL TO COMPLETE AS SHOWN, ZONE I MATERIAL WILL BE USED TO COMPLETE THE ZONE II EMBANKMENT.
SPILLWAY ENTRANCE CHANNEL SECTION
1" = 20' HORIZ.
1" = 10' VERT.
ORIGINAL GROUND
SPILLWAY EXCAVATION
℄ SPILLWAY
ELEV. VARIES 449 TO 450 SEE PLAN
ELEV. 430.0
CORE EMBANKMENT
EXCAVATE 4 FT BELOW FINISHED CONTOURS SHOWN ON PLAN & BACKFILL WITH COMPACTED CORE MATERIAL, 1' ZONE I
VARIES SEE PLAN
℄ FISHLADDER ENTRANCE CHANNEL
ZONE I
EL. 420.5
COMPACTED CORE MAT'L
30" CONC. PIPE SEE SHT. 10 FOR HEADWALL
TYPICAL SECTION - STA. 4+75
1" = 30'
0.5' CROWN
TOP OF CORE ELEV. 435.0
ELEV. 440.0
FILTER
CORE
ZONE I
ZONE II
NORMAL W.S. ELEV. 424.0
4' MIN. THICKNESS
BLANKETED (CORE MATERIAL)
BLEND BLANKET INTO CORE TO FORM CONTINUOUS IMPERVIOUS LAYER
STRIPPING AND FOUNDATION EXCAVATION VARIES
ORIGINAL GROUND
20' MIN. WIDTH ON PREPARED ROCK SURFACE
SECTION THROUGH OUTLET PIPE
1" = 30'
℄ DAM
ZONE I
CORE
FILTER
ELEV. 387 ±
WIDEN CORE TRENCH TO 40' WHERE OUTLET CROSSES
4" DIA. PERFORATED PIPE
ZONE II ORIGINAL GROUND
CUT-OFF COLLARS 17' C. TO C. 3 REQ'D.
ELEV. 385 ±
FL. 371.0
42" I.D. OUTLET PIPE
POUR CONC. TO ROCK
APPROX. ROCKLINE
FL. 376.8
26' TYPE III REINF.
46' TYPE II REINFORCING
86' TYPE I REINFORCING
60' TYPE II REINFORCING
119' TYPE III REINFORCING
2.33%
110' 0.0% SLOPE
NOTE: DRAINAGE BERM NOT SHOWN.
DAM CENTERLINE AND CORE TRENCH COMPOSITE PROFILE
1" = 40' HORIZ.
1" = 20' VERT.
NEW PIEZOMETERS THIS CONTRACT
P-2
P-1
EXISTING PIEZOMETERS
℄ SPILLWAY
PLASTIC SILT
CREST ELEV. 424.0
CASING TO EL. 417.3
CASING TO EL. 412.5 ROCK
DEPRESSED SEC. 18' WIDE CREST EL. 423.67
BOTTOM OF CORE TRENCH
ORIGINAL GROUND
PIEZOMETER TIPS 2B 401.8 ±
SILTY ROCKY TALUS
1B 400.3 ±
1A 391.8 ±
CREEK W.S. ELEV. 376.0 31 JAN. 73
OUTLET PIPE
2A 389.8 ±
ROCK 380 ±
ROCK LINE
FRACTURED BASALT
APPROX. EXTENT OF DEPRESSION FILLED W/CONCRETE & GROUT
CREEK CHANNEL STA. 3+65 ±
NOTE: CORE TRENCH TO CONTINUE AT TOE OF BLANKET TO END OF BLANKET.
REGISTERED PROFESSIONAL ENGINEER 4464 OREGON ROGER W. LINDQUIST
JULY '78 NEW PIEZOMETERS
JAN. 75 AS BUILT
DATE REVISION BY
CH2M HILL ENGINEERS PLANNERS ECONOMISTS
CORNELL HOWLAND HAYES & MERRYFIELD
CLAIR A. HILL & ASSOCIATES
CITY OF SILVERTON, OREGON
SILVER CREEK DAM
DAM AND SPILLWAY PROFILES AND SECTIONS
SHEET 4 OF 18
DATE MARCH 1973
SCALE AS SHOWN
DRAWING NO. C 7521-1



THIS PRINT IS REDUCED TO ONE-HALF OF THE ORIGINAL SCALE
IF THE SCALE READS:
1" = 1'-0" USE 1/2" = 1'-0" OR 1" = 10' USE 1" = 20'

REGISTERED PROFESSIONAL ENGINEER — OREGON — GEORGE F. DOTSON

CH2M HILL — ENGINEERS PLANNERS ECONOMISTS

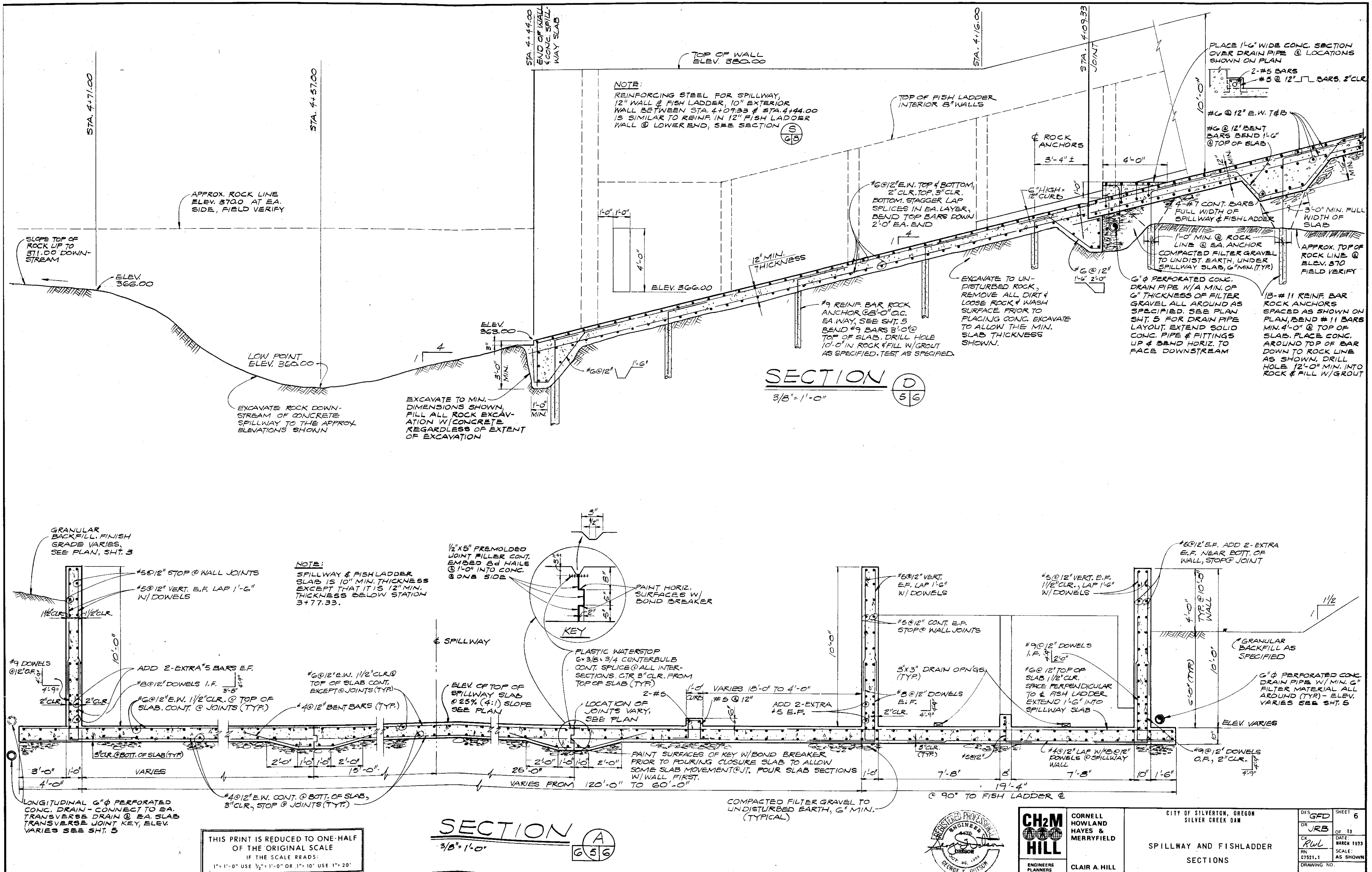
CORNELL HOWLAND HAYES & MERRYFIELD

CLAIR A. HILL & ASSOCIATES

CITY OF SILVERTON, OREGON
SILVER CREEK DAM

SPILLWAY AND FISHLADDER PLAN

DES. GFD	SHEET 5
DR. JRB	OF 13
CK. RWL	DATE: MARCH 1973
RN C7521.1	SCALE: AS SHOWN
DRAWING NO. C 7521-1	


STA. 4+71.00
STA. 4+57.00
STA. 4+44.00 END OF WALL & CONC. SPILLWAY SLAB
STA. 4+16.00
STA. 4+09.33 JOINT
TOP OF WALL ELEV. 380.00
NOTE: REINFORCING STEEL FOR SPILLWAY, 12" WALL & FISH LADDER, 10" EXTERIOR WALL BETWEEN STA. 4+09.33 & STA. 4+44.00 IS SIMILAR TO REINF. IN 12" FISH LADDER WALL @ LOWER END, SEE SECTION S 6 8
TOP OF FISH LADDER INTERIOR 8" WALLS
PLACE 1'-6" WIDE CONC. SECTION OVER DRAIN PIPE @ LOCATIONS SHOWN ON PLAN
2-#5 BARS
#5 @ 12" BARS, 2"CLR.
#6 @ 12" E.W. T&B
#6 @ 12" BENT BARS BEND 1'-6" @TOP OF SLAB
¢ ROCK ANCHORS
3'-4" ±
4'-0"
10'-0"
6" HIGH x 12" CURB
4-#7 CONT. BARS FULL WIDTH OF SPILLWAY & FISH LADDER
3'-0" MIN. FULL WIDTH OF SLAB
1'-0" MIN. @ ROCK LINE @ EA. ANCHOR
COMPACTED FILTER GRAVEL TO UNDIST. EARTH, UNDER SPILLWAY SLAB, 6" MIN. (TYP.)
APPROX. TOP OF ROCK LINE @ ELEV. 370 FIELD VERIFY
APPROX. ROCK LINE ELEV. 370.0 AT EA. SIDE, FIELD VERIFY
SLOPE TOP OF ROCK UP TO 371.00 DOWNSTREAM
ELEV. 366.00
#6@12" E.W. TOP & BOTTOM, 2" CLR. TOP, 3" CLR. BOTTOM. STAGGER LAP SPLICES IN EA. LAYER, BEND TOP BARS DOWN 2'-0" EA. END
12" MIN. THICKNESS
ELEV. 366.00
#6 @ 12" 1'-6" 2'-0"
6" ϕ PERFORATED CONC. DRAIN PIPE W/A MIN. OF 6" THICKNESS OF FILTER GRAVEL ALL AROUND AS SPECIFIED. SEE PLAN SHT. 5 FOR DRAIN PIPE LAYOUT. EXTEND SOLID CONC. PIPE & FITTINGS UP & BEND HORIZ. TO FACE DOWNSTREAM
18-#11 REINF. BAR ROCK ANCHORS SPACED AS SHOWN ON PLAN, BEND #11 BARS MIN. 4'-0" @ TOP OF SLAB. PLACE CONC. AROUND TOP OF BAR DOWN TO ROCK LINE AS SHOWN. DRILL HOLE 12'-0" MIN. INTO ROCK & FILL W/GROUT
EXCAVATE TO UNDISTURBED ROCK, REMOVE ALL DIRT & LOOSE ROCK & WASH SURFACE PRIOR TO PLACING CONC. EXCAVATE TO ALLOW THE MIN. SLAB THICKNESS SHOWN.
#9 REINF. BAR ROCK ANCHOR @ 8'-0" O.C. EA. WAY, SEE SHT. 5 BEND #9 BARS 3'-0" @ TOP OF SLAB. DRILL HOLE 10'-0" IN ROCK & FILL W/GROUT AS SPECIFIED. TEST AS SPECIFIED.
ELEV. 363.00
3'-0" MIN.
1'-0" MIN.
#6@12"
LOW POINT ELEV. 360.00
EXCAVATE ROCK DOWNSTREAM OF CONCRETE SPILLWAY TO THE APPROX. ELEVATIONS SHOWN
EXCAVATE TO MIN. DIMENSIONS SHOWN, FILL ALL ROCK EXCAVATION W/CONCRETE REGARDLESS OF EXTENT OF EXCAVATION
SECTION D 5 6
3/8" = 1'-0"
GRANULAR BACKFILL, FINISH GRADE VARIES, SEE PLAN, SHT. 3
#5@12" STOP @ WALL JOINTS
#5@12" VERT. E.F. LAP 1'-6" W/ DOWELS
NOTE: SPILLWAY & FISH LADDER SLAB IS 10" MIN. THICKNESS EXCEPT THAT IT IS 12" MIN. THICKNESS BELOW STATION 3+77.33.
1/2" x 5" PREMOLDED JOINT FILLER CONT. EMBED 8d NAILS @ 1'-0" INTO CONC. @ ONE SIDE
PAINT HORIZ. SURFACES W/ BOND BREAKER
KEY
¢ SPILLWAY
#9 DOWELS @12" O.F.
ADD 2-EXTRA #5 BARS E.F.
#8@12" DOWELS I.F.
#6@12" E.W. 1 1/2" CLR. @ TOP OF SLAB. CONT. @ JOINTS (TYP.)
#6@12" E.W. 1 1/2" CLR @ TOP OF SLAB CONT. EXCEPT @ JOINTS (TYP.)
#4@12" BENT BARS (TYP.)
ELEV. OF TOP OF SPILLWAY SLAB @ 25% (4:1) SLOPE SEE PLAN
PLASTIC WATERSTOP 6 x 3/8 x 3/4 CENTERBULB CONT. SPLICE @ ALL INTERSECTIONS. CTR 3" CLR. FROM TOP OF SLAB (TYP.)
LOCATION OF JOINTS VARY, SEE PLAN
2-#5
VARIES 18'-0" TO 4'-0"
#5 @ 12"
ADD 2-EXTRA #5 E.F.
#5@12" VERT. E.F. LAP 1'-6" W/ DOWELS
#5@12" CONT. E.F. STOP @ WALL JOINTS
3"x3" DRAIN OPN'GS (TYP.)
#8 @12" DOWELS E.F.
#9@12" DOWELS I.F.
#6 @ 12" TOP OF SLAB 1 1/2" CLR. SPACE PERPENDICULAR TO ¢ FISH LADDER EXTEND 1'-6" INTO SPILLWAY SLAB
#5@12" VERT. E.F. 1 1/2" CLR., LAP 1'-6" W/ DOWELS
#6@12" E.F. ADD 2-EXTRA E.F. NEAR BOTT. OF WALL, STOP @ JOINT
TYP. @ 10'-0" WALL
GRANULAR BACKFILL AS SPECIFIED
6" ϕ PERFORATED CONC. DRAIN PIPE W/ MIN. 6" FILTER MATERIAL ALL AROUND (TYP.) - ELEV. VARIES SEE SHT. 5
ELEV. VARIES
#9@12" DOWELS O.F., 2" CLR.
#4@12" LAP W/ #8@12" DOWELS @ SPILLWAY WALL
3" CLR. @ BOTT. OF SLAB (TYP.)
PAINT SURFACES OF KEY W/BOND BREAKER PRIOR TO POURING CLOSURE SLAB TO ALLOW SOME SLAB MOVEMENT @ JT. POUR SLAB SECTIONS W/ WALL FIRST.
#4@12" E.W. CONT. @ BOTT. OF SLAB, 3" CLR., STOP @ JOINTS (TYP.)
VARIES FROM 120'-0" TO 60'-0"
19'-4"
@ 90° TO FISH LADDER ¢
LONGITUDINAL 6" ϕ PERFORATED CONC. DRAIN - CONNECT TO EA. TRANSVERSE DRAIN @ EA. SLAB TRANSVERSE JOINT KEY, ELEV. VARIES SEE SHT. 5
COMPACTED FILTER GRAVEL TO UNDISTURBED EARTH, 6" MIN. (TYPICAL)
SECTION A 6 5 6
3/8" = 1'-0"
THIS PRINT IS REDUCED TO ONE-HALF OF THE ORIGINAL SCALE
IF THE SCALE READS:
1" = 1'-0" USE 1/2" = 1'-0" OR 1" = 10' USE 1" = 20'
REGISTERED PROFESSIONAL ENGINEER OREGON GEORGE T. DOTSON
CH2M HILL
ENGINEERS PLANNERS ECONOMISTS
CORNELL HOWLAND HAYES & MERRYFIELD
CLAIR A. HILL & ASSOCIATES
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SECTIONS
DES. GFD
DR. JRB
CK. RWL
RN C7521.1
SHEET 6 OF 13
DATE: MARCH 1973
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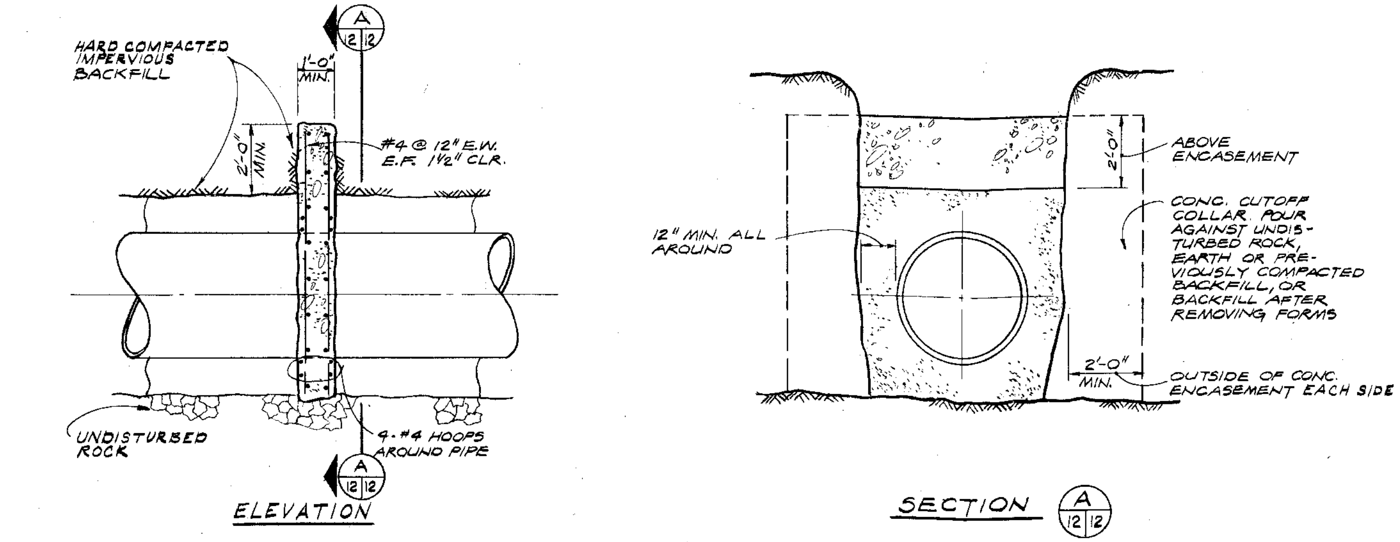
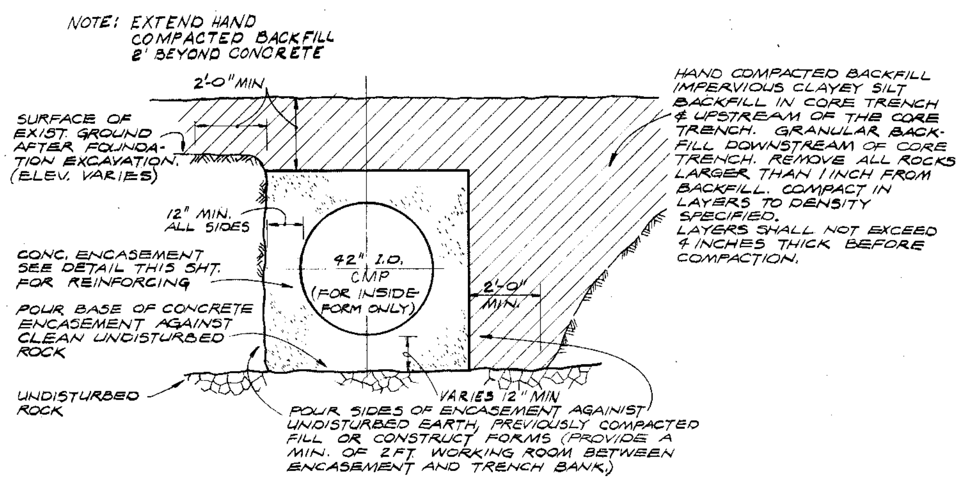


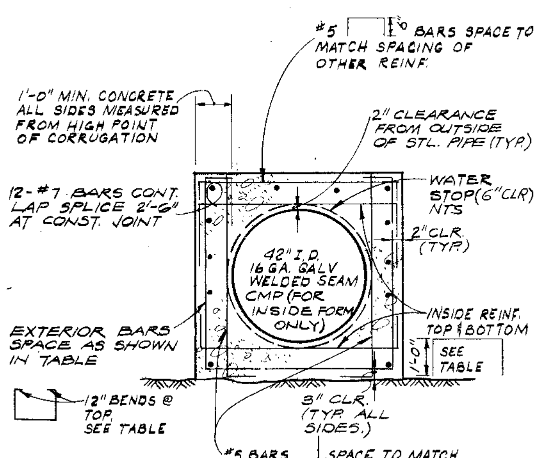
OUTLET PIPE CONCRETE CUT-OFF COLLAR DETAIL

3/8" = 1'-0"



OUTLET PIPE TRENCH AND BACKFILL DETAIL

3/8" = 1'-0"



REINFORCING TABLE		
TYPE REINFORCING	EXTERIOR BARS	INSIDE REINF. TOP & BOTTOM
1	#7 @ 10"	#8 @ 10"
2	#6 @ 10"	#7 @ 10"
3	#6 @ 12"	#7 @ 12"

SEE SHT. 4 FOR LOCATION OF REINFORCING TYPES.

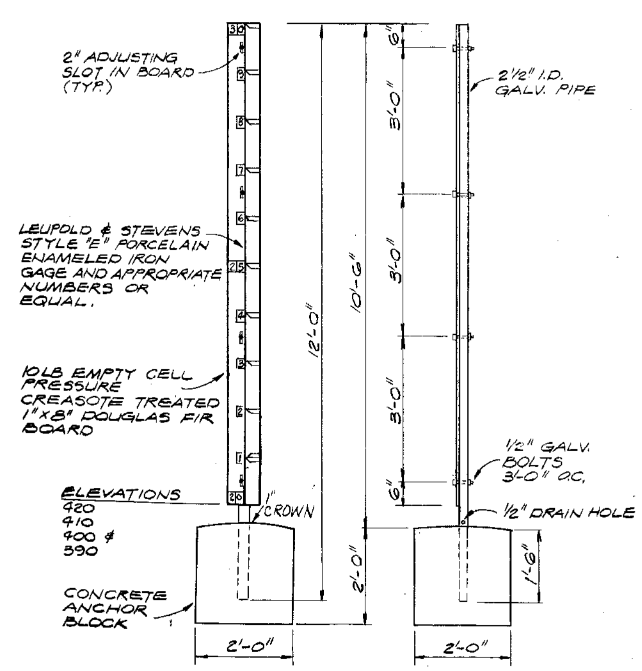
NOTE: CLEARANCE FROM OUTSIDE OF CORRUGATED PIPE IS FROM HIGH POINT OF CORRUGATION.

CAST-IN-PLACE CONCRETE OUTLET PIPE DETAILS

3/8" = 1'-0"

NOTES:

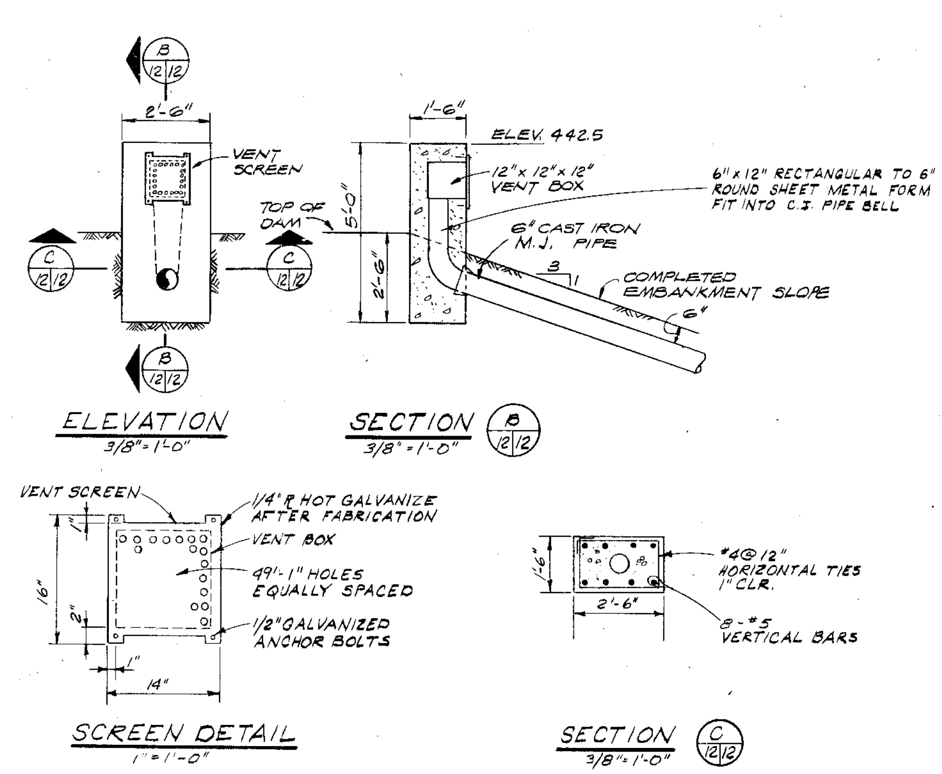
1. CONSTRUCTION JOINT SPACING 30' MAX., POUR ALTERNATE SECTIONS, ALLOW 7 DAYS BETWEEN ADJACENT POURS.
2. LONGITUDINAL STEEL CONTINUOUS THROUGH JOINT.
3. 6"x3/8"x3/4" BULB, PLASTIC W.S. CONT. SPLICE AT JOINT.



NOTE: STAFF GAGE LOCATIONS TO BE DETERMINED IN FIELD SO THEY ARE READILY VISIBLE FROM THE HYDRAULIC GATE CONTROLS.

STAFF GAGE DETAIL

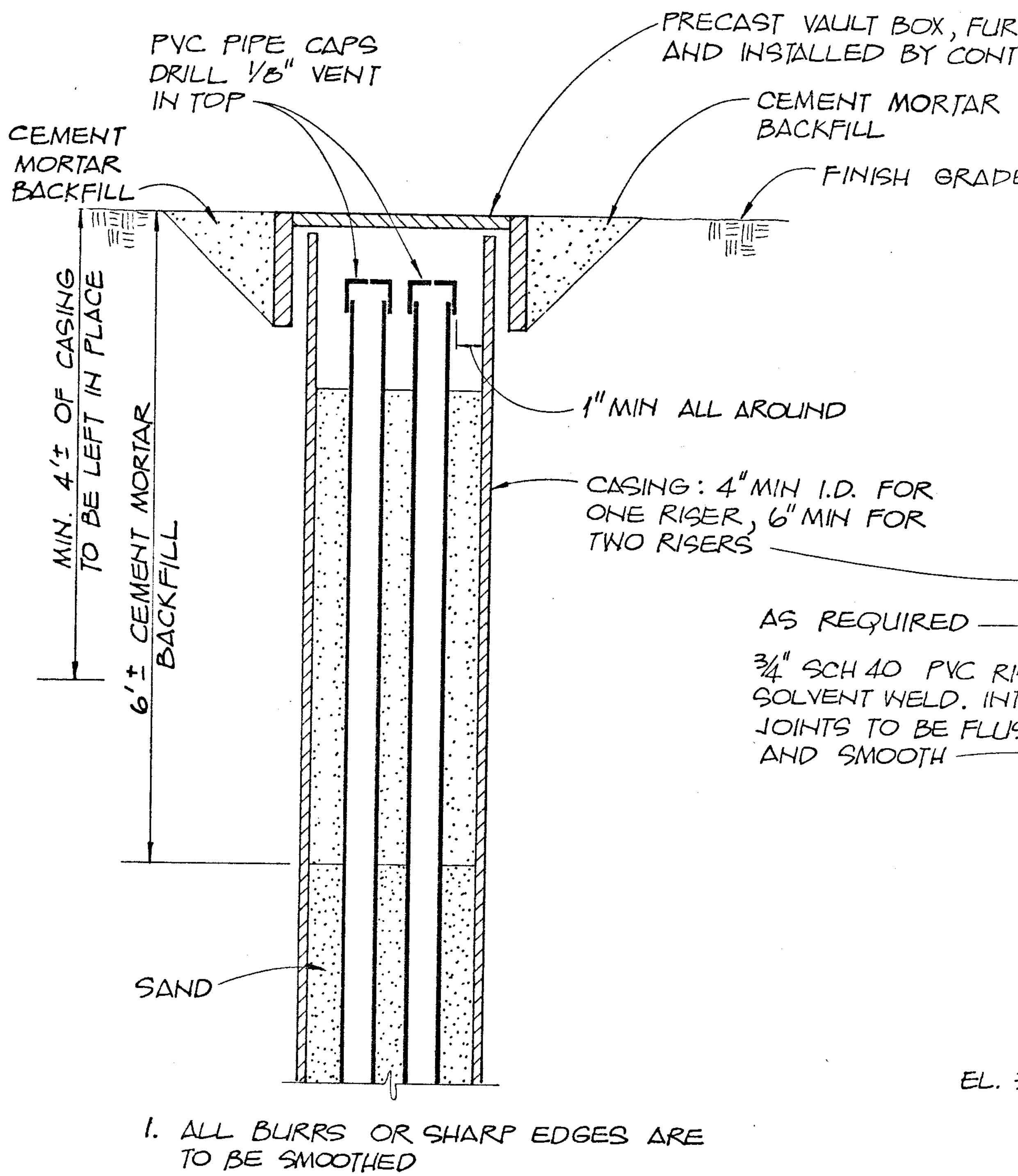
½" = 1'-0" 4 REQ'D.



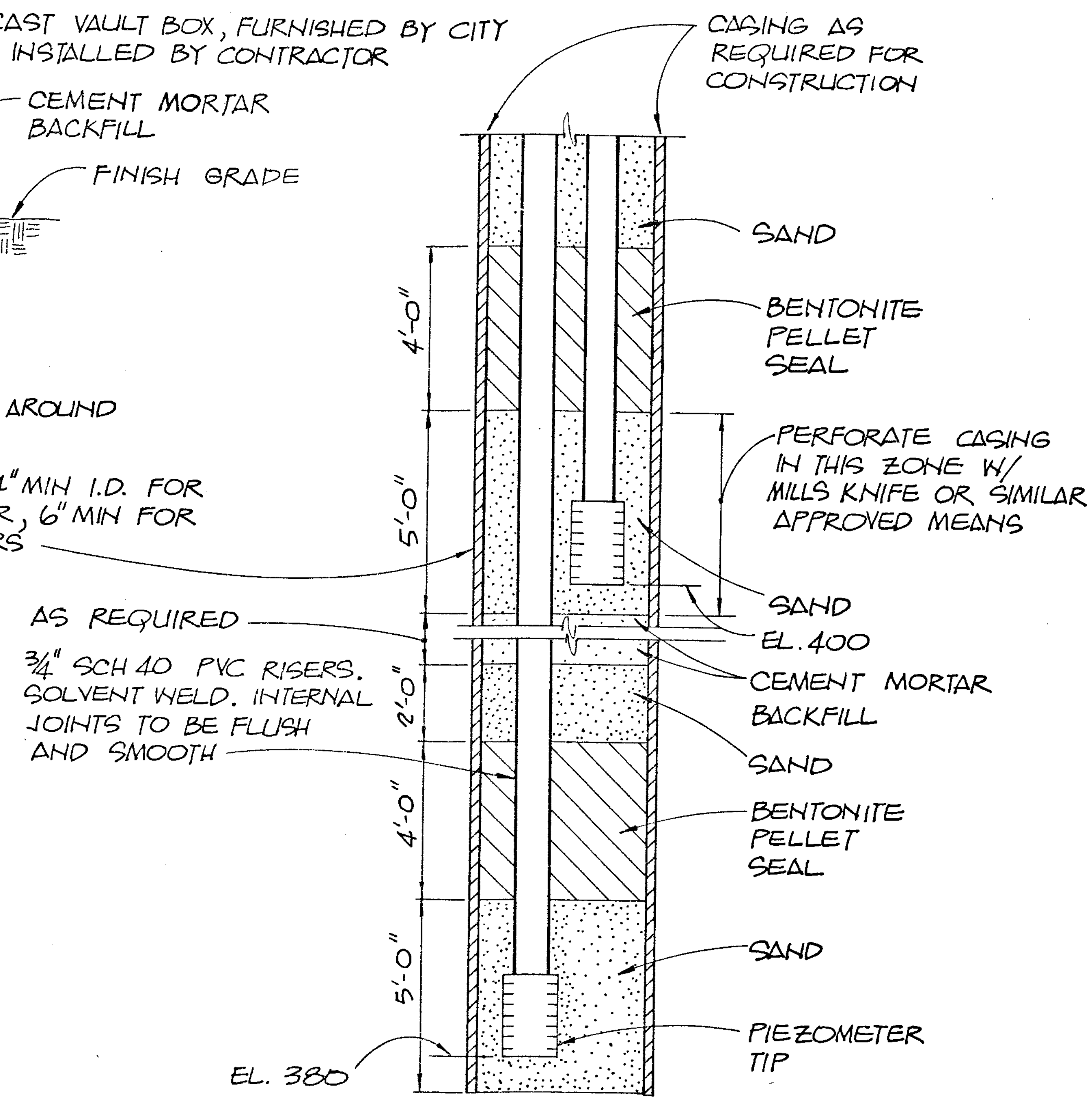
AIR VENT DETAILS

THIS PRINT IS REDUCED TO ONE-HALF OF THE ORIGINAL SCALE
IF THE SCALE READS:
1" = 1'-0" USE ½" = 1'-0" OR 1" = 10' USE 1" = 20'

CH2M HILL ENGINEERS PLANNERS ECONOMISTS	CORNELL HOWLAND HAYES & MERRYFIELD / CLAIR A. HILL & ASSOCIATES	CITY OF SILVERTON, OREGON SILVER CREEK DAM — OUTLET PIPE DETAILS	DES RWL; DR KJR; CK JKF/RWL; RN C7521.1; SHEET 12 OF 13; DATE MARCH 1973; SCALE AS SHOWN; DRAWING NO. C7521-1



TYPICAL PIEZOMETER TOP
NTS (6 REQD)



TYPICAL DAM PIEZOMETER TIPS
NTS

PIEZOMETER NUMBER	NUMBER OF PIEZOMETERS IN HOLE	TIP ELEVATION
P-1	2	380-400
P-2	2	380-400
P-3	1	370
P-4	1	370
P-5	2	380-400
P-6	2	380-400

PIEZOMETER SCHEDULE

CH2M HILL