EWEB

MEMORANDUM

EUGENE WATER & ELECTRIC BOARD

Rely on us.

TO:	Commissioners Schlossberg, Brown, Carlson, Barofsky and McRae
FROM:	Mike McCann, Electric Generation Manager; Patty Boyle, Generation Contracts Supervisor; and Mark Zinniker, Generation Engineering Supervisor
DATE:	February 2, 2021
SUBJECT:	Leaburg/Walterville Evaluation Project Update (2021 Organizational Goal 4b)
OBJECTIVE:	Board discussion and feedback

Issue

These materials have been prepared to provide an update on the progress made to study and provide information to the Board regarding the Leaburg-Walterville Project. The materials describe and update the progress for achieving the 2021 EWEB organizational goal # 4b to develop directional guidelines and decision criteria on a TBL-based plan for the lower McKenzie River Hydroelectric Project in compliance with the Federal Energy Regulatory Commission (FERC) and collaboration with the McKenzie Valley community. This goal is continued from 2020.

Background

With approximately 20 years remaining on the FERC-issued operating license for the Leaburg-Walterville Project, EWEB must evaluate the near- and long-term options to resolve dam safety concerns associated with the Leaburg Canal. When in operation, water diverted at Leaburg Dam for power generation passes through a downstream migrant fish screen and enters the five-mile-long, 15-foot deep cut and fill, Leaburg Canal leading to the power plant forebay. The Leaburg Powerhouse contains two Francis turbines with a total installed capacity of 15.9 MW and produces approximately nine (9) average MW.

In July of 2020, EWEB, our consultants and FERC participated in Semi-Quantitative Risk Analysis (SQRA) workshops for the Leaburg Canal. Due to its length, variable geometry and foundation conditions, the canal was divided into ten reaches, with each reach evaluated separately. The SQRA was performed to identify and evaluate potential failure modes (PFMs) for the canal and their likelihood of occurrence, severity of the consequences, level of confidence in the estimates, and the possible controls to reduce the risk of failure. PFMs were evaluated for the canal under normal operating measures, flood conditions and conditions present during and after an earthquake. When complete, any PFM can be summarized and graphically depicted to represent the likelihood of occurrence and the consequence of failure. The SQRA efforts and results, which provided the basis for developing potential path forward scenarios, are described in detail in Attachment A. This attachment also includes details on the path forward scenarios as well as information about the planning level cost estimates.
The highest risk PFMs identified during the Leaburg Canal SQRA effort were associated with seismic loading. Updated seismic analyses relying on the latest seismic loading criteria indicate that

portions of the canal embankments could be severely damaged or destabilize during an earthquake. In order to achieve adequate seismic design safety factors, these portions of the canal embankment would need to be buttressed by stability berms or perhaps entirely reconstructed.

Another category of high-risk PFMs includes those associated with internal erosion, which is the type of embankment deterioration that led EWEB to take the canal out of service in late 2018. These internal erosion vulnerabilities result from the original design and construction techniques, adverse embankment soil properties, and adverse foundation conditions. Appropriate mitigation measures for these PFMs are variable by location and include exterior filter berms, interior liners and additional site-specific methods of seepage mitigation.

Other high risk PFMs that were identified during the Leaburg Canal SQRA include landslide blockages of the canal (triggered by seismic loading or severe wet weather), debris blockages of the canal during tributary stream flood conditions (at the flow outlet structures and bridges in particular), and seismic damage to flow control structures (canal head gates and flow outlets). Each of these failure modes has a unique set of mitigation measures ranging from engineered improvements (seismic retrofits and new/modified outlet structures) to ongoing operation and maintenance efforts (such canal bank vegetation removal and enhanced earthquake response protocols and training).

The Walterville Canal is in better condition, was constructed through more favorable geological terrain, and presents substantially lower risk due to lower levels of development along its length. However, the Walterville Canal has similar known seepage issues and will likely be subject to the same level of inspection and improvement requirements as the Leaburg Canal for the remainder of the license term. The canal embankment construction methods and materials are similar to those found at Leaburg. As such, the Walterville Canal is vulnerable to the same potential failure modes as the Leaburg Canal and EWEB's dam safety team is closely monitoring those risks, including internal erosion, accordingly.

In 2020, staff also completed a baseline financial analysis that established the expected value of the Leaburg power generation system as a stand-alone asset if returned to service or if converted to water conveyance facility. This baseline analysis was reviewed in January 2021 and has been updated to reflect the net present value of a return to service scenario of 2026 at the earliest, which unfavorably impacts generation in the next several years. This evaluation did not include the investments that will be required to return the canal to safe operation or convert the canal to a water conveyance structure.

2021 Financial Evaluation	NPV[1] –
High Power Value	Return to Service (negative $5 million)
Medium Power Value	Return to Service (negative $12 million)
Low Power Value	Return to Service (negative $14 million)
Water Conveyance Facility	(negative $17 million)

The estimated range for the value of energy was based on an industry standard approach using the natural gas price forecast and incorporating major economic indicators such as level of demand and

[1] Net present value over 20 years of remaining life

policy and technology changes. Because the analysis is based on the remaining life of the operating license, there is considerable uncertainty and variability in the value of power.

It is also important to acknowledge additional potential value streams associated with this plant although none are either certain enough or large enough to make a significant difference in the analysis at this time.

Capacity Value
Although EWEB currently has sufficient resources to meet load on an average basis, under certain peak load conditions there are forecasted shortages. This condition is not unique to EWEB and there is an effort to ensure the region has sufficient resources to meet peak load. While we recognize that there is a value of capacity to Leaburg, as it can be relied on to produce power during peak load periods, it is difficult to estimate a value on it at this time.

Carbon Value
Based on research conducted by E3, a WECC wide carbon tax imposed in 2031 that is structurally similar to the carbon tax currently in place in California would add $2 million in value to the value of energy produced at Leaburg.

Renewable Portfolio Standard (RPS)
Under Oregon's current renewable standards, the Leaburg Plant qualifies as legacy hydroelectricity. Production associated with our legacy hydroelectricity projects offsets our RPS requirement. Based on its legacy status, EWEB may avoid approximately $200,000 over the remaining life of the plant.

Discussion

Financial Considerations
In addition to completing the SQRA, our staff and consultants completed cost estimate ranges for a refined set of scenarios for remediation of the canal. These estimates are preliminary but include construction, permitting, engineering and construction oversite. The range represents the low and high ends of the cost of mitigation as measured by scope (i.e., length and depth) and programmatic/regulatory requirement (construction method). Programmatic risk represents the largest driver of variability in the cost estimates. Because the seismic strength of canal foundation materials is currently unknown for most areas, there is a very wide range of cost estimates for repair. For each reach our consultants used the limited information available to identify a baseline option and created a range of possibilities. In most cases, the recommended contingency for line items sensitive to embankment/foundation soil properties range up to three times the expected baseline cost.

The most common example of programmatic mitigation is a stability berm intended to buttress the existing embankment against failure in an earthquake. They are relatively inexpensive, but geotechnical investigations could reveal that we need to do more than buttress the canal and instead end up entirely rebuilding the existing embankments. With additional subsurface investigations, we will be able to narrow the cost estimate ranges.

Materials provided to the Board in 2020 assumed two basic scenarios that would either return to the

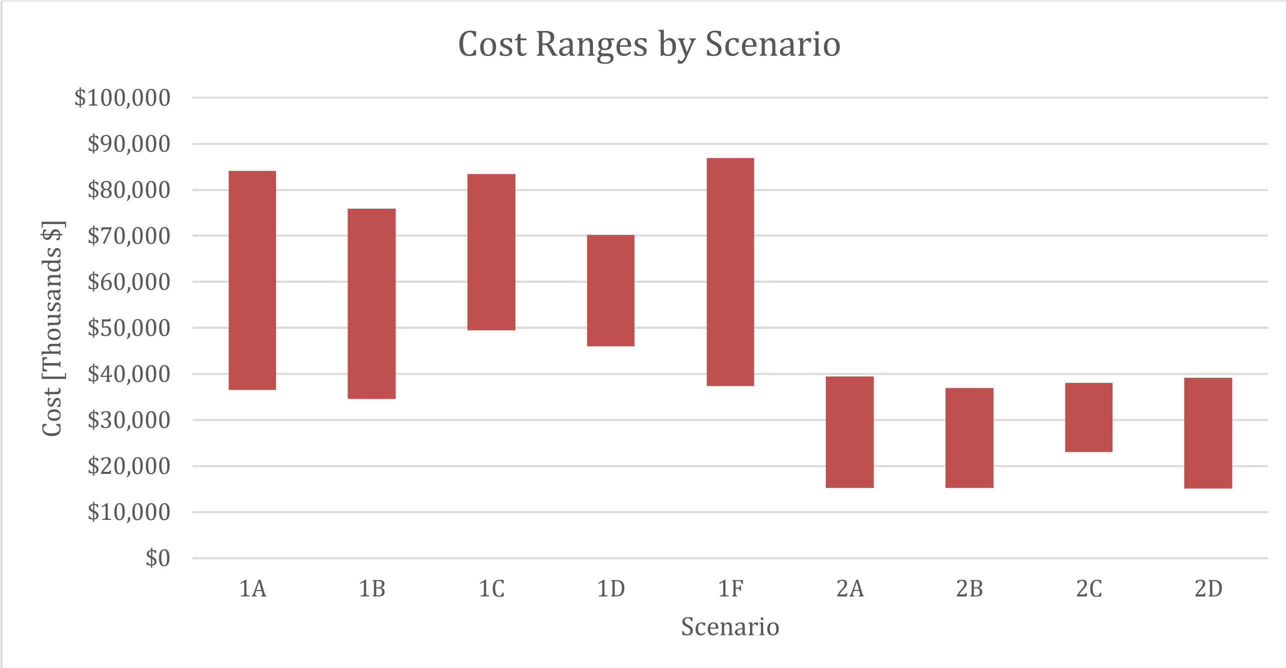
Leaburg Canal to service or convert it to a stormwater conveyance facility to route streams intercepted by the canal back to the McKenzie River. Those scenarios have been expanded to reflect options that allow for greater flexibility in approach that would allow EWEB to adjust the pace of deployment and level of risk reduction. Those scenarios are summarized below.

Return to Service (RTS) Scenarios:

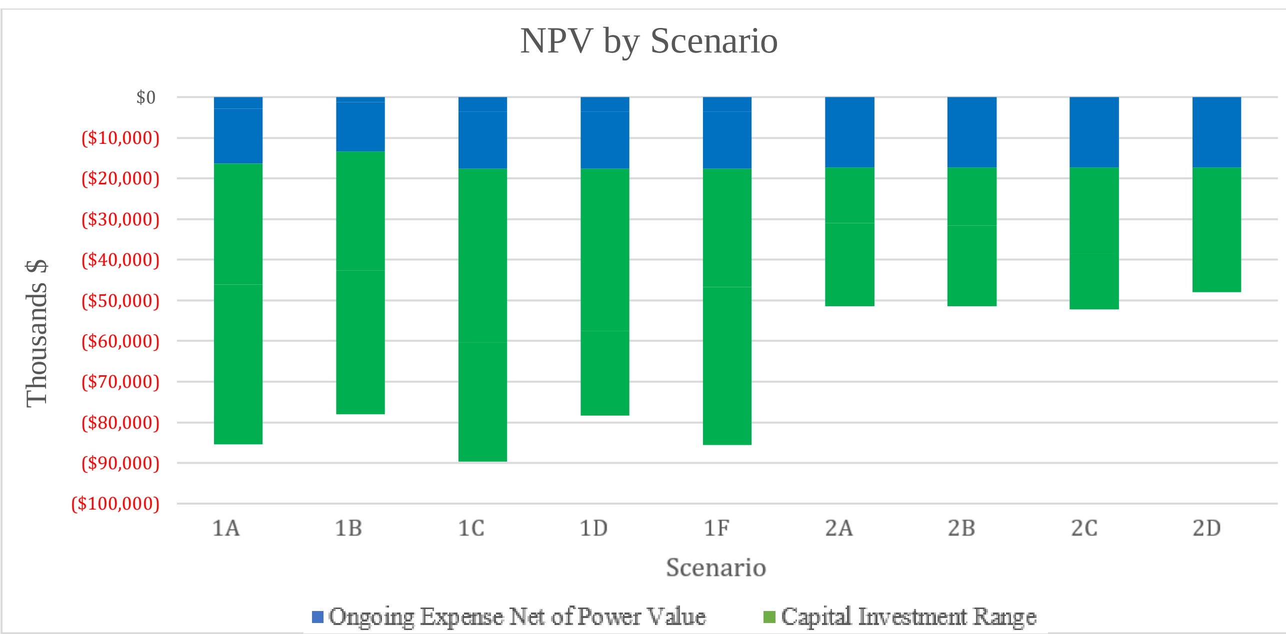
- RTS 1a – Incremental return to service. Standard construction timing that addresses known risk factors focusing on higher likelihood/higher consequence areas. Restricted operation assumed as soon as possible.
- RTS 1b – Rapid return to service. Construction in all problematic seepage areas in order to promote full capacity operation as soon as possible.
- RTS 1c – Major rehabilitation (2,500 cfs). Modernize the conveyance with significant and widespread earthen embankment improvements along the length of the canal; maintain the current operating level of 2,500 cfs or approximately 9 aMW.
- RTS 1d – Major rehabilitation (1,300 cfs) Modernize the conveyance with significant and widespread earthen embankment improvements along the length of the canal; reduce the operating level to 1,300 cfs or approximately 6 aMW.
- RTS 1e – Conversion to concrete flume. Drastically reduces the risk profile by fully reconstructing utilizing a concrete flume. This scenario was not included in tables below as a result of high cost range of $240-400 million.
- RTS 1f—Slow incremental return to service. Similar to 1a but limits and spreads out capital requirements; delays return to service.

Conversion to a Stormwater Conveyance (SWC):

- SWC 2a – Phased conversion. Direct streams through existing water control structures, improve seepage areas during single-season construction assumptions.
- SWC 2b – Rapid conversion. Same as scenario SC 2a except rapidly convert to stormwater conveyance utilizing continuous construction project.
- SWC 2c – Major rehabilitation conversion. Perform major rehabilitation work on water retaining reaches; continuous construction and subsequent largest overall risk reduction.
- SWC 2d – Slow conversion. Similar in content to 2a but limits and spreads out the investment over a longer period of time.



The table below displays the ongoing expense of operating the project net of any power value and combines it with the range of capital investment associated with each scenario. Because the range of costs do not yet indicate a clear path forward, it will be important to work with our regulators to better understand the acceptable methods of mitigation to improve our confidence in the cost estimates of RTS scenarios. Similarly, it will also be important to establish EWEB's obligations under scenarios where the power production of this facility is decommissioned. Decommissioning cost obligations have not been included in the current estimates.



Close coordination with state and federal regulators will be required to implement either primary strategy including the resolution of existing water rights agreements with private parties that EWEB has historically served along the Leaburg Canal.

Post License Considerations

Typically, within 10 years of License expiration the owner of a hydroelectric project will initiate a process to determine if relicensing is appropriate. Power market projections combined with capital investment requirements for reliable operation will inform the option to relicense. In this situation, EWEB will also need to develop an understanding of post license operating or decommissioning responsibilities for the option not to relicense. Similarly, EWEB would need to understand any differences in operation and decommissioning obligations under a stormwater conveyance scenario. Those obligations could vary between continued operation and maintenance of the remaining features to a complete decommissioning of the remaining canal, dam, and powerhouse, as well as restoration of the river and other Project-impacted environmental features. Many decommissioning requirements have directed owners to return the land to its natural state. For the Leaburg Project, this will be difficult if not impossible to accomplish as the community has developed with the Project in place. In some cases, the natural streambeds are no longer viable water conveyance facilities and the lake is a feature of the community surrounded by private development and important recreational features.

While the Leaburg Project has served the community well for more than 90 years, the comparative value of RTS scenarios relative to the SWC scenarios based on current energy price projections cannot justify pursuit of strategies that would restore power generation. Like many other small-scale hydroelectric facilities, the combination of the low forecasted power value and the amount of electricity produced does not currently justify the approximately $30 million additional reinvestment required for a return to service. At this point, pursuit of the stormwater conveyance strategy while EWEB develops a better understanding and determination of our decommissioning obligations is the most appropriate direction.

Triple Bottom Line Considerations

Since the initial reporting in March 2020, staff have made progress on the triple bottom line (TBL) analysis designed to support the Board's determination of the most beneficial approach to resolving the infrastructure issues and plan for the long-term management of the Project. This particular TBL will combine the financial forecast of the Project with a qualitative evaluation of the impacts to the environment and community. Our goal is to provide the Board with information that articulates the complex tradeoffs between the economic, community and environmental factors.

Societal Considerations

Both the Leaburg and Walterville Projects have been fixtures in the lower McKenzie valley for almost 100 years, and the communities around the Projects have grown and developed with the Projects in place. The public uses of the canals include recreation (walking and biking) and the withdrawal of water for irrigation. The local fire department uses the lake and canals as emergency water supply. Neighborhoods have developed in areas below the canals, along the Leaburg Lake shoreline and along the Walterville tailrace. Leaburg Park and the river access associated with the park are important recreational features in the McKenzie Valley. Any change to Project operations will ultimately impact these other areas and uses in the vicinity of the Project.

The local community will likely have strong opinions on what should happen to the Project facilities and will need to be an engaged partner in the development of a plan moving forward. When the financial and environmental aspects of this issue are better established, EWEB Communications staff will launch a public information and outreach process directed at the upriver community. Major components of the outreach will include education and community engagement that inspires customer confidence. The outreach plan will include a wide variety of tools such as direct outreach to the upriver customers via EWEB meeting and other community group meetings, published articles in EWEB's Pipeline publication and news outlets, on-line surveys, etc. Some tactics may be modified depending on the extent of COVID 19 precautions and guidance at any particular time.

Environmental Considerations

Because development over the past 100 years has been made with the canals in place, there are no historic streambeds between the canals and the river that would allow precipitation-derived water to pass freely to the McKenzie River without impacting current residential and agricultural development. As the water conveyance strategy is better developed, the environmental impacts of rerouting streams and creeks can be evaluated.

The Leaburg Project serves as an unofficial demarcation between the lower and upper portions of the McKenzie River. Hatchery chinook and steelhead are not supposed to exist above Leaburg Dam. The dam and associated fish ladders provide a point of separation. The Leaburg Project also serves as a source of gravity fed water for both ODFW fish hatcheries near Leaburg. Both hatcheries would need to procure alternate water supplies should the Project cease to exist.

The Walterville Canal diversion and tailrace facilities are located on alluvial material that is subject to changes in the McKenzie River route. Over time the river may move away from either or both the diversion and tailrace facilities, rendering them ineffective and requiring a significant reinvestment in those facilities by EWEB. Should EWEB decommission the Project, this risk and obligation to maintain the facilities will end, but EWEB will still have to fund the removal of the facilities from the environment.

Both Projects also impact water temperature in the lower McKenzie. The impacts, however, are most pronounced with respect to the operation of the Walterville Canal. During the critical low flow periods in the summer and fall, water diversion can increase stream temperatures in the bypassed reaches. Elevated temperatures are known to be detrimental to cold water species such as salmonids and other aquatic organisms. With Oregon summers expected to get hotter and dryer, these impacts are only expected to get worse over time. Removing the Projects will result in additional McKenzie River streamflow in the area of the existing canals that will likely help keep the river colder in this reach and further downstream.

This analysis is intended to provide the Board with the information it needs to provide direction on the identified scenarios that would either invest in the canal to return the Leaburg Powerhouse to operation or to invest in the canal to convert it to a system to convey water back to the river from creeks and springs that are currently intercepted by the canal.

Conclusions & Recommendations

Given the breadth of the issues, it is unlikely that there will be a clear path that is easily and economically implemented.

There are areas of the canal that need repair regardless of which strategic direction that EWEB ultimately selects. Staff recommends Board support for making investments in the canal for stormwater conveyance that will reduce risk, while investigating decommissioning and power planning questions in parallel, followed by a relicensing or decommissioning decision in the 2028 – 2030 timeframe. Staff further recommend support for continued engineering investigations that will allow staff to propose to acceptable risk mitigation projects to D2SI-PRO that are consistent with the stormwater conveyance strategy. Examples of near term work that would benefit both potential paths forward include subsurface investigations, updated engineering analyses to support remediation designs for reaches of the canal needing rehabilitation in both scenarios, and the development of emergency stormwater discharge outlet features near historical stormwater drainage systems such as the remnant portion of Johnson Creek that runs between the canal and river. These efforts would result in projects authorized as part of the Board's normal planning and budgeting responsibilities.

Significant regulatory questions remain regarding either approach. Staff recommends Board support to initiate a dialogue with FERC Licensing staff that would help determine EWEB's current and future obligations under a SWC scenario. This work would likely be completed with the support of a consultant more familiar with Licensing and Decommissioning processes.

Requested Board Action

No Board action is requested at this time, but it would be helpful if the Board could provide a sense of support for pursuing a SWC strategy.

Please contact Mike McCann, Mark Zinniker or Patty Boyle with questions.

Semi-Quantitative Risk Analysis
Eugene Water & Electric Board
Leaburg Canal

1. Introduction

1.1. Purpose

A Semi-Quantitative Risk Analysis (SQRA) was conducted for Leaburg Canal in 2020. The intent of the SQRA Workshop was to develop a better understanding of the canal-related elements of the Leaburg Project, understand the baseline qualitative risks, and prioritize potential future projects at the canal. The SQRA followed the Federal Energy Regulatory Commission (FERC) Risk Informed Decision Making (RIDM) process and was considered a Level 3 Risk Analysis in accordance with the FERC's RIDM guidelines.

The FERC ordered the canal be drawn down in 2018 over concerns of increased seepage and possible internal erosion through the embankment. The SQRA was performed to determine and evaluate potential failure modes (PFMs) for the canal and their likelihood of occurrence, severity of the consequences, level of confidence in the estimates, and the possible controls to reduce the risk of failure.

Due to its length and variable geometry and foundation conditions, the canal was divided into ten separate reaches with the intention of evaluating each reach separately. The first two reaches evaluated during the workshop were Ames reach and Cogswell Creek reach based on previously identified issues at these locations, more available information, and potentially higher consequences at these locations as well. During July 2020 workshops, the group was able to complete the SQRA on the Ames Reach and Cogswell Creek Reach but did not have time to evaluate the other reaches in detail. Following the SQRA workshop, additional work was performed outside the workshop to evaluate the other reaches.

1.2. Participants

The Ames and Cogswell Creek reaches were evaluated in the SQRA workshop that occurred the weeks of July 13-17, 2020 and July 27-31, 2020. An additional one day workshop was performed to evaluate the control structures on December 3, 2020. The workshop participants included consulting engineers with specialties including geotechnical, seismic, hydraulic/hydrologic, mechanical, and structural disciplines. The consulting team also include expert risk analysis facilitators. The consultants were joined by EWEB engineering and operations staff as well as dam safety engineers from the FERC and the FERC's risk analysis program lead.

1.3. Canal Description

The Leaburg Canal is located near Leaburg, Oregon along the McKenzie River and Oregon Route 126 East. The canal was originally constructed in the 1920's to supply water to the hydroelectric powerplant, 5 miles downstream of the canal intake. A general layout of the canal is shown in Figure 1. The main purpose of the canal is to divert water from the McKenzie River to supply the Leaburg Powerhouse. The canal also supplies water for irrigation as well as a fish hatchery. There are several outlet structures along the canal of varying capacity that divert water from the canal to supply the water users.

The canal was constructed using early 20th century techniques and was cut into the natural landscape just north of the McKenzie River. The canal has a capacity of 2,500 cubic feet per second (cfs) under full flow conditions and can be passed through both the powerhouse and seven siphons with a total capacity of 2,950 cfs. Due to increasing seepage and potential internal erosion observed in the Cogswell Creek reach, the canal intake was closed and has been out of service since 2018. Typically, the canal is drawn down once a year for maintenance and general inspection. Since taking the canal offline in 2018, this has been the longest drawdown period for the canal in its 90-year history.

For the purposes of the SQRA, the canal was divided into ten reaches as shown in Figure 2.

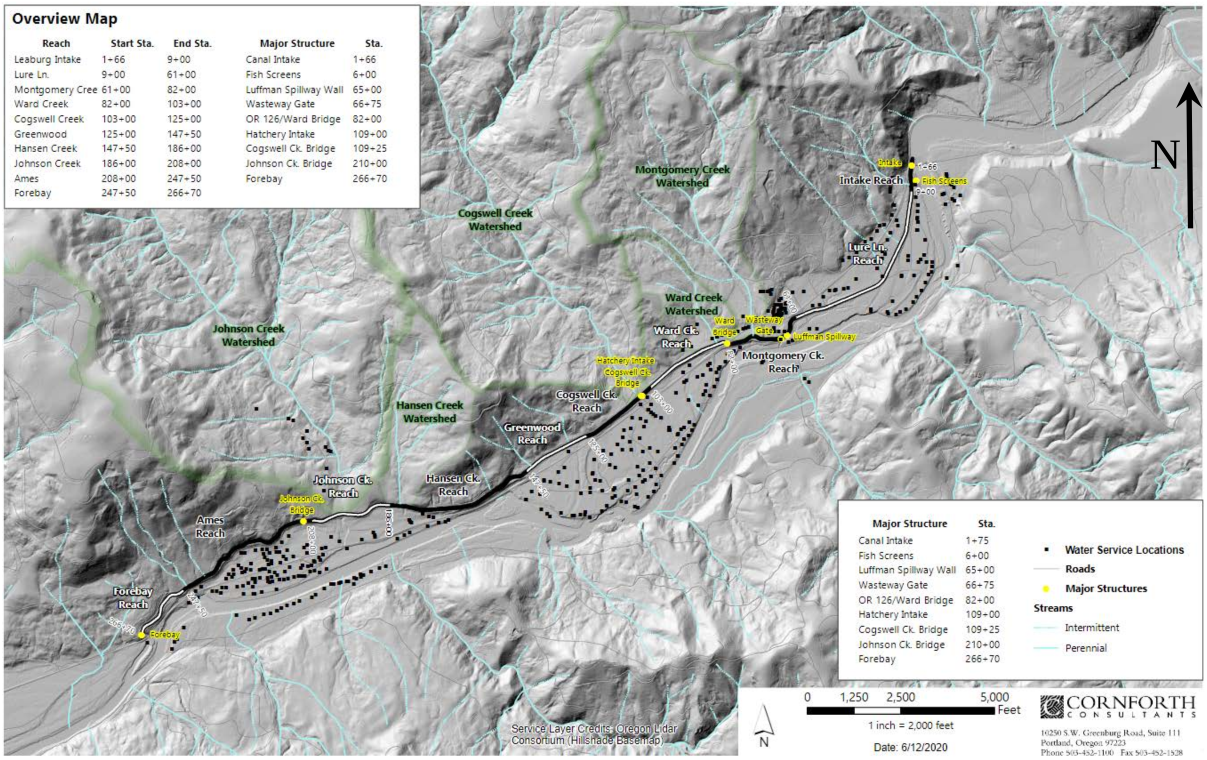


Figure 1: Site Location and Layout

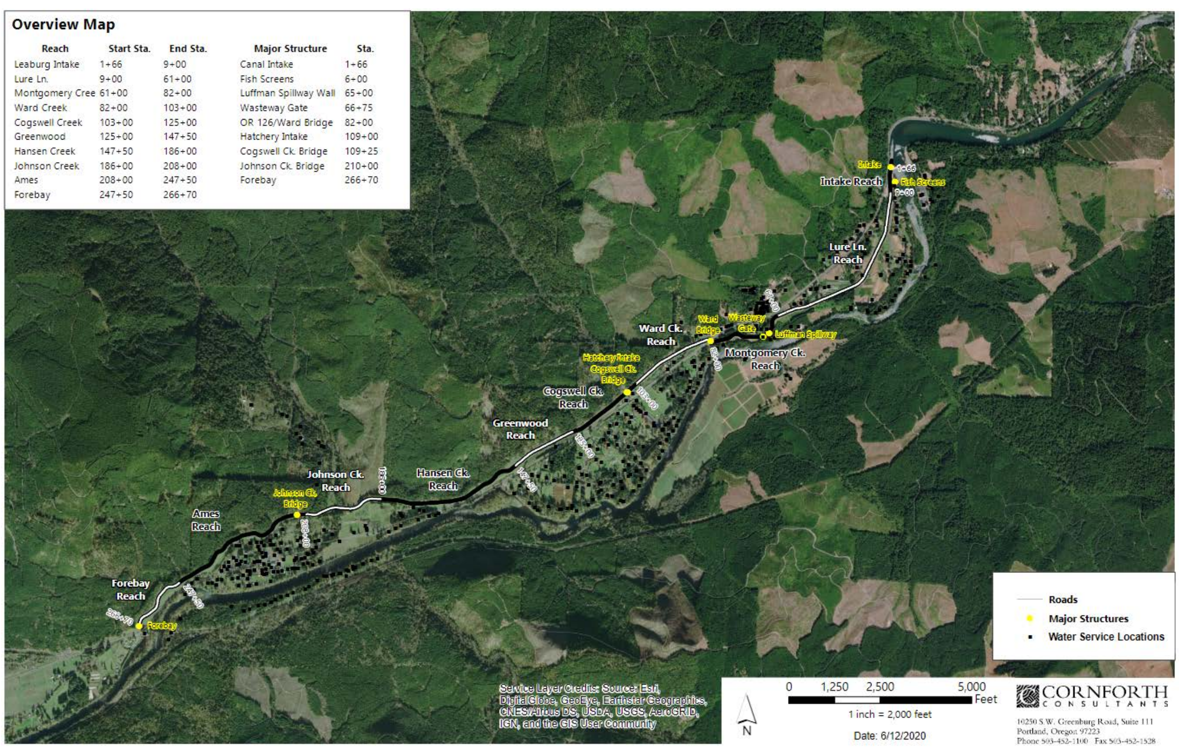


Figure 2: Leaburg Canal and Reaches

2. Loading

Potential failure modes (PFMs) were evaluated for the following loading conditions:

- **Normal:** Normal, or usual, loading is the condition that can be expected to occur at any time throughout the life of the structure. Activities associated with the expected operations of the canal are included under Normal loading. Static conditions, as well as routine operation and construction activities were considered Normal loading.
- **Seismic:** Seismic loading refers to earthquake loading and considers all earthquakes, up to and including the design criteria which has been selected to be the maximum credible earthquake (MCE). Failures that occur during the earthquake as well as those that soon develop afterwards as a result of the earthquake were considered under Seismic loading.
- **Hydrologic:** Under flood conditions, the canal head gates are closed, so the water in the canal is supplied from the intercepted tributaries only. Information related to the estimation of risk associated with the hydrologic loading conditions considered in the SQRA are provided in the following paragraphs.

Flood Loading and Frequency Determination: Five tributaries were identified as primary contributors to the hydraulic loading on the canal. The peak flows in the five tributaries were calculated using USGS StreamStats software. These equations use a regional regression analysis to relate peak discharge in an ungaged watershed to known distributions for gaged watersheds by comparing climatological and physical characteristics (USGS 2005). The software provided peak flood discharges at 2, 5, 10, 25, 50, 100, and 500-year return intervals.

The probable maximum flood (PMF) peak flows for the five tributaries were estimated by extrapolating the peak flows determined by USGS StreamStats out to the 1,000,000-year return interval (also referred to as the 10^{-6} annual exceedance probability) using a log-probability plot method. Table 1 and Figure 3 present the peak flows in each tributary for various annual exceedance probabilities.

Table 1. Peak Flows in Tributaries

	24" culvert	Montgomery Creek	Ward Creek	Cogswell Creek	Johnson Creek
Drainage Area (square miles)	0.0622	0.76	0.23	3.46	6.62
Return Interval (years)	**Peak Flows from USGS StreamStats (cfs)**				
2	4.44	45.3	14.4	193	387
5	6.5	66.9	21.2	285	568
10	7.87	81.4	25.7	346	690
25	9.6	99.7	31.4	424	845
50	10.9	113	35.7	482	960
100	12.1	127	39.9	540	1070
500	15.1	158	49.6	674	1340
Return Interval (years)	**Peak Flows Extrapolated from Probability Plot (cfs)**				
1000	17	180	55	740	1600
10000	21	220	70	950	1900
100000	28	280	90	1400	2400
1000000	33	350	110	1600	3000

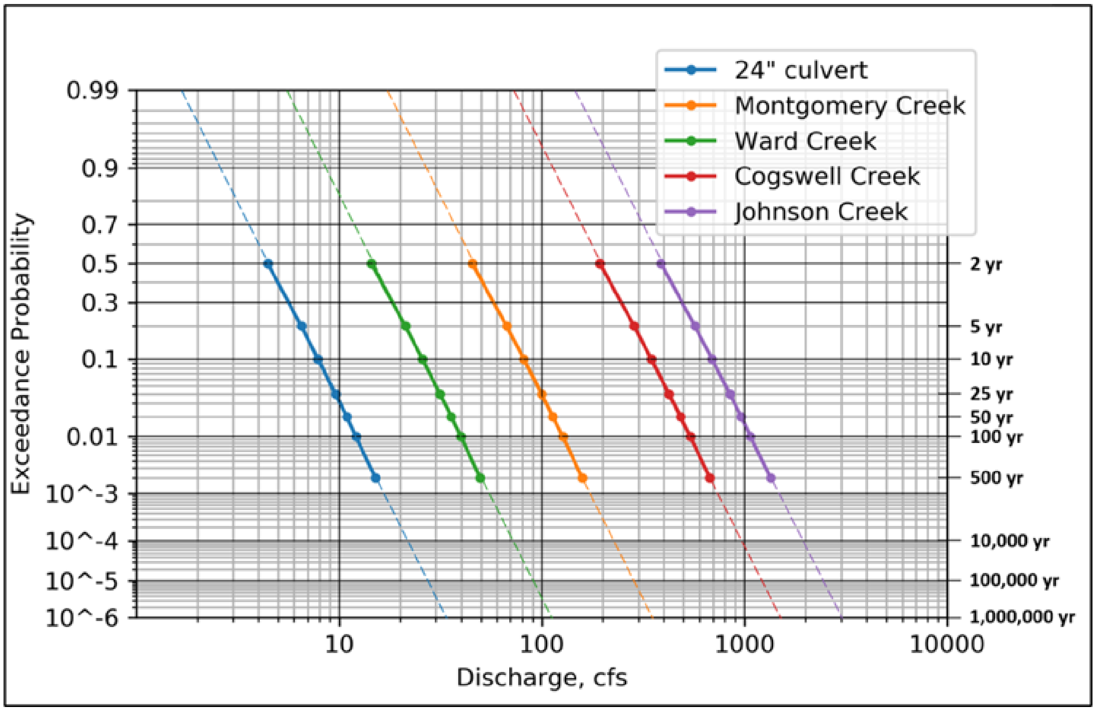


Figure 3. Tributary Probable Maximum Flood Determination

Siphon Spillways at Forebay Dam: There are seven siphon spillways at the Leaburg Canal forebay, the terminus of the canal above the powerhouse. The siphon spillways are designed to pass normal canal flow in case of a sudden stoppage of the turbines at the power plant, and to mitigate flood risk in the canal. The siphon spillways are self-regulating, meaning that the flow through the siphon spillways is adjusted to maintain the water level at the forebay at its operating level of 734.2 ±0.1 feet. The seven siphon spillways together can pass approximately 3000 cfs of flow, while maintaining the water surface elevation in the canal.

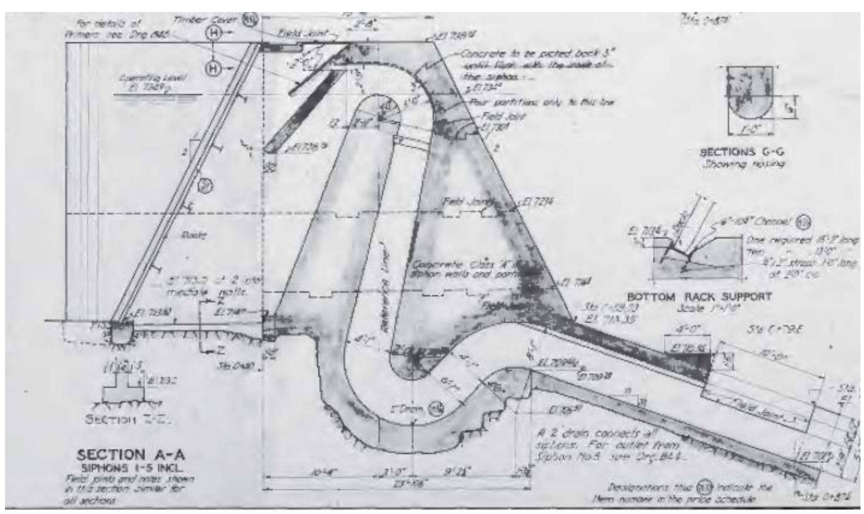


Figure 4. Cross Section of a Siphon Spillway at the Leaburg Canal Forebay

Hazard Mitigation Control System: The Hazard Mitigation Control System (HMCS) is an automated system that will drain the Leaburg Canal if abnormal water level conditions (too high or too low) are detected. The Wasteway Gate and the canal head gates are operated manually but can also be operated automatically when the HMCS is triggered by a high or low canal level reading. There are four remote telemetry unit (RTU) stations along the canal that allow for real-time monitoring of water surface elevations. Closure time of the head gates is 11 minutes, while the opening time of the wasteway gate is 6.5 minutes.

3. Consequences

Failure scenarios were developed in preparation for the SQRA using canal breach modeling for normal operating conditions (Sunny-Day Failure), 100-year flood, and probable maximum flood (PMF) conditions at the canal. Breaches were modeled in at least one location in each of the reaches, and locations considered to be the "worst case" for potential loss of life (PLL). The PMF scenario is actually based on the probabilistic flood for the one million year event. The PLL estimates were determined using the PMF breach results. However, based on the flood frequency plots, the normal operating canal level is similar to the water level modeled for a 10,000 to 100,000 year flood. Therefore, a breach under normal conditions is not expected to be as different from flood breach conditions as typically expected.

Fatality rate estimates for each scenario were developed using the 2015 revision of the Reclamation's Consequence Estimating Methodology (RCEM, 2014). As an example, the estimated PLL consequences for the Ames Reach and Cogswell Creek Reach are summarized in Table 2.

Table 2: Potential Life Loss Estimates for Cogswell Creek and Ames Reaches

Cogswell PMF RS 112+00

Max DV	# Structures	PAR	DV Group	Fatality Rate	Life Loss
5	17	40	1	0	0
10	5	12	1	0	0
15	2	5	2	0.0001	0.000464
20	1	3	3	0.0005	0.00116

Ames PMF RS 212+00

Max DV	# Structures	PAR	DV Group	Fatality Rate	Life Loss
5	31	72	1	0	0
10	3	7	1	0	0
15	3	7	2	0.0001	0.000696

As shown in 2, the estimated PLL values for both reaches evaluated are very small. During the SQRA workshop, there was discussion by the group regarding the estimated consequence level. The group believed that even with the very small PLL estimate using the breach model and RCEM, the potential for at least one loss of life could not be ruled out for failure of the canal in these reaches due to the proximity of houses at the toe of the canal embankment.

4. Potential Failure Modes

The last Potential Failure Modes Analysis (PFMA) report update for the Project prior to the SQRA workshop was prepared by Dr. R. Craig Findlay, PE, GE, and was dated December 17, 2017. In the 2017 PFMA update, there were a total of 39 PFMs, consisting of seven Category I (Highlighted), nineteen Category II (Considered but not Highlighted), eight Category III (More Information Needed to Categorize), and five Category IV (Ruled Out).

Prior to the SQRA workshop, the consulting team developed a list of PFMs for each reach of the canal based on the PFMs in the 2017 PFMA report. Additionally, prior to the workshop, postulated PFMs were solicited from participants, through a questionnaire. During the workshop, the participants further brainstormed a list of PFMs for all loading conditions. The importance of fresh thinking regarding PFMs rather than simply relying on previously developed PFMs was emphasized. The facilitation team took the PFMs from fresh brainstormed list, the list from the questionnaires, and the 2017 PFMA list and consolidated these PFMs into one comprehensive list. From this comprehensive list, the group screened the PFMs into a shorter list of PFMs to carry forward into the SQRA. The diagram provided below in Figure 5 depicts the process of screening PFMs for inclusion in the risk analysis.

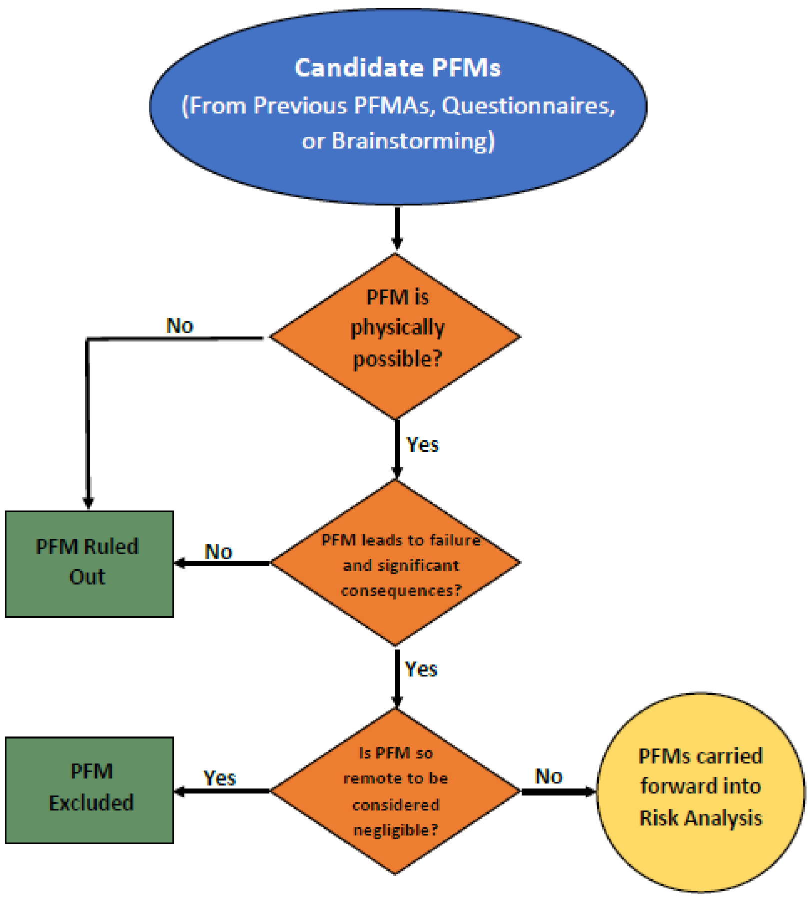


Figure 5: Process for Screening Potential Failure Modes

Depending on the canal reach, a variable number of PFMs were carried forward for risk estimating. For example, a total of sixteen PFMs were carried forward to the SQRA for Cogswell Creek reach and a total of twelve were carried forward for Ames reach.

5. SQRA Workshop

The SQRA workshop was held over the course of two weeks from July 13 to July 17, 2020 and from July 27 to July 31, 2020 online using Microsoft Teams as the virtual meeting hosting platform. During the SQRA workshop, a list of PFMs was brainstormed and screened by the group. In addition to the two-week workshop conducted in July, and additional one day workshop was held on December 3, 2020 to evaluate failure modes specifically associated with the hydraulic control structures on the canal. The workshop participants varied between the two groups, with more mechanical/structural experience needed for the control structure portion.

For the PFMs carried forward, each was further developed and analyzed using the collective experience of the group. Development of each PFM consisted of listing the sequence of events in a step by step progression from the initial loading to the failure event. Relevant information for each PFM was discussed, captured and input into the following categories for documentation on the PFM tables:

- Additional Information
- Positive and Adverse Factors
- Potential Surveillance and Monitoring
- Data Information Needs
- Potential Risk Reduction Measures

The final step in development of each PFM was to estimate the likelihood and consequences of the PFM. The process for estimating the likelihood and consequences associated with each PFM is further discussed in the following section.

5.1.1. Estimation of Likelihood and Consequence

The canal was divided into ten separate reaches with the intention of evaluating the PFMs at each reach separately. The first two reaches evaluated during the workshop were the Ames reach and Cogswell Creek reach based on performance history, availability of subsurface information, and potentially higher consequences at these locations. Due to the overall length of the canal and time constraints of the workshop, it was not possible to cover the PFMs at all the reaches during the two weeks allotted. Failure modes at the other reaches were evaluated by a smaller group outside of the workshop using the information developed for Ames and Cogswell Creek during the workshop.

For dam safety, risk is generally comprised of three parts:

1. The likelihood of occurrence of a given loading condition (e.g., flood, earthquake, canal elevation, etc.)
2. The likelihood of an adverse structural response (e.g., dam failure, damaging spillway discharge, incorrect operation, etc.) given the load, and
3. The magnitude of the consequences resulting from the adverse event (e.g., life loss, economic damages, environmental damages, etc.) given that it occurs.

In the SQRA workshop, the participants estimated the likelihood using an electronic polling method. Relevant design information and site characterization information for the failure modes were discussed by the group prior to additional discussion about the likelihood and consequence of the particular failure mode. Participants of the discussion where then polled anonymously using an online survey tool. Following the polling, the participants discussed the results with the intent of moving toward consensus. The participants also provided their confidence for the likelihood based on whether additional information was necessary or would potentially change the estimated likelihood and consequence.

5.1.2. Likelihood of Failure

The Annual Failure Likelihood is used to describe the probability of a PFM occurring. The likelihood is estimated using the frequency of the initiating condition (i.e., the 100-yr flood or the 10,000-yr seismic event), and the likelihood of failure given the load. For normal conditions, the probability of the load is assumed to be 1.

The likelihood descriptions used during the SQRA workshop were based on the criteria presented in Table 3. The likelihood for each PFM was selected by the workshop participants using individual polling during the meeting.

Table 3: Failure Likelihood Descriptions

Category	Annual Failure Likelihood	Descriptor of Evidence
Level 8	$> 1x10^{-1}$	There is direct evidence to suggest or substantial indirect evidence to suggest it certain to nearly certain that failure is eminent or extremely likely in the next few years.
Level 7	$1x10^{-1}$ to $1x10^{-2}$	There is direct evidence or substantial indirect evidence to suggest that failure has initiated or is very likely to occur during the life of the structure.
Level 6	$1x10^{-2}$ to $1x10^{-3}$	There is direct evidence or substantial indirect evidence to suggest that failure has initiated or is likely to occur.
Level 5	$1x10^{-3}$ to $1x10^{-4}$	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward "more likely" than "less likely."
Level 4	$1x10^{-4}$ to $1x10^{-5}$	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward "less likely" than "more likely."
Level 3	$1x10^{-5}$ to $1x10^{-6}$	The possibility cannot be ruled out, the fundamental condition or defect is postulated. Evidence indicates it is very unlikely.
Level 2	$1x10^{-6}$ to $1x10^{-7}$	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to initiation.
Level 1	$< 1x10^{-7}$	Several events must occur concurrently or in series to cause failure, and most, if not all, have negligible likelihood such that the failure likelihood is negligible.

5.1.3. Consequence of Failure

The group used their judgement and experience to estimate the consequence for the individual failure modes. Consequence classifications were estimated based on generalized Potential Loss of Life (PLL) using the criteria in Table 4.

Table 4: Life Safety Consequence Descriptions

Life Safety Consequence Classification	Incremental Life Loss	Descriptor of Evidence
Category 1	< 1	Although life-threatening releases occur, direct loss of life is unlikely due to severity or location of the flooding, or effective detection and evacuation
Category 2	1 to 10	Some direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists/travelers and small population centers
Category 3	10 to 100	Large direct loss of life is likely, related primarily to difficulties in warning and evacuating recreationists/ travelers and smaller population centers, or difficulties evacuating large population centers with significant warning time
Category 4	100 to 1,000	Extensive direct loss of life can be expected due to limited warning for large population centers and/or limited evacuation routes
Category 5	1,000 to 10,000	Extremely high direct loss of life can be expected due to limited warning for very large population centers and/or limited evacuation routes

5.1.4. Confidence

The group provided their degree of confidence following estimation of likelihood and consequence for each PFM. The confidence categories were low, moderate, and high. Confidence descriptors, as provided to workshop participants, are listed below.

- Low Confidence – The individual/team is not confident in the order of magnitude for the assigned category, and it is entirely possible that additional information could change the estimate.
- Moderate Confidence – The individual/team is relatively confident in the order of magnitude for the assigned category, but key additional information might possibly change the estimate.
- High Confidence – The individual/team in confident in the order of magnitude for the assigned category and it is unlikely that additional information would change the estimate.

5.2. SQRA Results

A total of twenty-eight plausible PFMs were developed during the July 2020 SQRA Workshop:

- For Cogswell Creek Reach
  - Nine (9) PFMs were developed under normal loading conditions;
  - Five (5) for seismic loading; and
  - Two (2) for hydrologic loading.
- For Ames Reach:
  - Seven (7) PFMs were developed under normal loading conditions;
  - Four (4) for seismic loading; and

- One (1) for hydrologic loading.

A total of five plausible PFMs were developed for the Leaburg Control Structures during the December 2020 SQRA Workshop:

- For the Leaburg Canal Control Structures:
  - Two (2) for seismic loading; and
  - Three (3) for hydrologic loading.

The PFM summaries were developed for each of the individual plausible PFMs. The PFM summaries include the following elements and decision factors:

- a description of the development of the PFM,
- positive and adverse factors,
- surveillance and monitoring,
- data information needs,
- potential risk reduction measures, and the
- likelihood and consequence values.

As an indication of the work completed, Table 6 summarizes the plausible PFMs identified and developed.

Table 5: Summary of Potential Failure Modes

Loading Cond.	PFM	SQRA Workshop Description	Reach
Normal	CC-01-N	Backward erosion piping through non-plastic fine grained embankment material where there is a coarser downstream shell material (Sta 103 to 114)	Cogswell
	CC-02-N	Backward erosion piping through non-plastic fine grained embankment material in seepage area from Sta. 114 to Sta. 123 where there is a coarser downstream shell material	Cogswell
	CC-03-N	Internal erosion through flaw in embankment (estimate for Sta. 103 to 114, area with less seepage)	Cogswell
	CC-04-N	Internal erosion through flaw in embankment (estimate for Sta. 114 to 123, area with more seepage)	Cogswell
	CC-05-N	Seepage leads to contact erosion between the terrace gravels and fine-grained alluvium in the section from Sat. 114 to Sta. 123	Cogswell
	CC-06-N	Seepage leads to contact erosion between the terrace gravels and fine-grained alluvium (general location, not seepage area)	Cogswell
	CC-07-N	Seepage and concentrated leak erosion along the Hatchery Water Intake Structure side wall concrete interface due to flaw in the backfill	Cogswell
	CC-08-N	Concentrated leak erosion through a flaw around the Abandoned Irrigation Withdrawal Vault pipe (Sta. 120+00)	Cogswell
	CC-09-N	Slope instability of downstream slope of left embankment	Cogswell
	AM-01-N	Backward erosion piping through non-plastic fine grained embankment material where there is coarser downstream shell material	Ames
	AM-02-N	Suffusion erosion of embankment material in seepage area from Sta. 240+00 to 246+00	Ames
	AM-03-N	Internal erosion through flaw in embankment (low density zone due to low compaction)	Ames
	AM-04-N	Leakage out of the Abandoned Water Right pipe near Sta. 215+00 leads to seepage into the embankment and then exiting the embankment near the toe leading to internal erosion (suffusion or contact erosion)	Ames
	AM-05-N	Contact erosion between the core material and the underlying foundation (colluvium or andesite)	Ames
	AM-06-N	Slope instability of downstream slope of left embankment	Ames
	AM-07-N	Internal erosion due to burrowing animal activity	Ames
Seismic	CC-01-S	Concentrated leak erosion through transverse crack in embankment caused by earthquake	Cogswell
	CC-02-S	Rupture of the Cogswell Creek Upper Supply Pipe (new pressurized pipe) due to earthquake leads to seepage and internal erosion in the embankment	Cogswell
	CC-03-S	Slope instability of downstream slope of left embankment during earthquake	Cogswell

Loading Cond.	PFM	SQRA Workshop Description	Reach
	CC-04-S	Loss of strength in embankment / foundation (liquefaction) leads to slope failure	Cogswell
	CC-05-S	Loss of strength in embankment / foundation (cyclic softening) leads to slope failure	Cogswell
	AM-01-S	Concentrated leak erosion through transverse crack in embankment caused by earthquake	Ames
	AM-02-S	Slope instability of downstream slope of left embankment during earthquake	Ames
	AM-03-S	Loss of strength in embankment (liquefaction) and foundation (cyclic softening) leads to slope failure	Ames
	AM-04-S	Landslide on right side of canal leads to blockage of canal and overtopping during an earthquake	Ames
	CS-01-S	Canal headgates cannot be closed due to seismic damage	Control Structures
	CS-02-S	Wasteway gate cannot open due to seismic damage	Control Structures
Hydrologic	CC-01-H	Erosion of left embankment due to flow from Cogswell Creek	Cogswell
	CC-02-H	Trees fall into the canal (may accumulate at bridge) and lead to blockage of canal and overtopping during flood	Cogswell
	AM-01-H	Landslide on right side of canal leads to blockage of canal and overtopping during flood	Ames
	CS-03-H	Mechanical failure leaves Wasteway gate stuck in closed position	Control Structures
	CS-04-H	Siphons become blocked and canal overtops during flood (small debris)	Control Structures
	CS-05-H	Trees fall into the canal, leading to blockage of canal and overtopping during flood (large debris)	Control Structures

The likelihood and consequence values for each PFM can be plotted on a risk matrix to show the relative risk associated with the PFM (Figure 6). The y-axis of the risk matrix represents the likelihood value and the x-axis the consequence value. PFMs considered low risk would plot towards the lower left corner, and those with higher likelihood move upward on the plot and those with higher consequence move to the right.

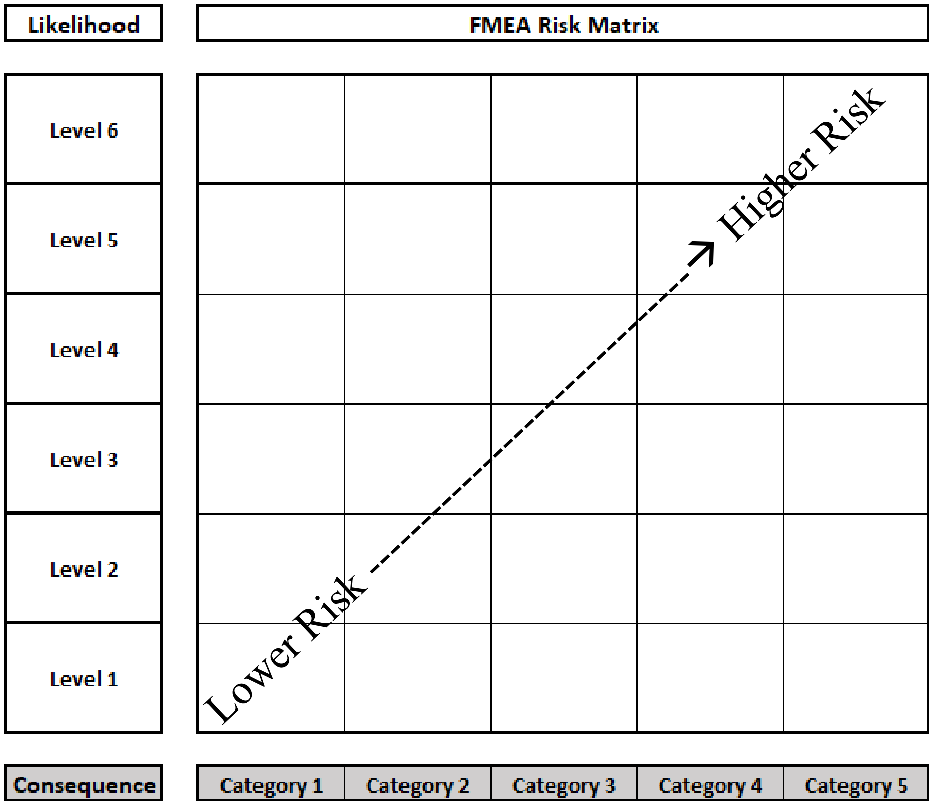
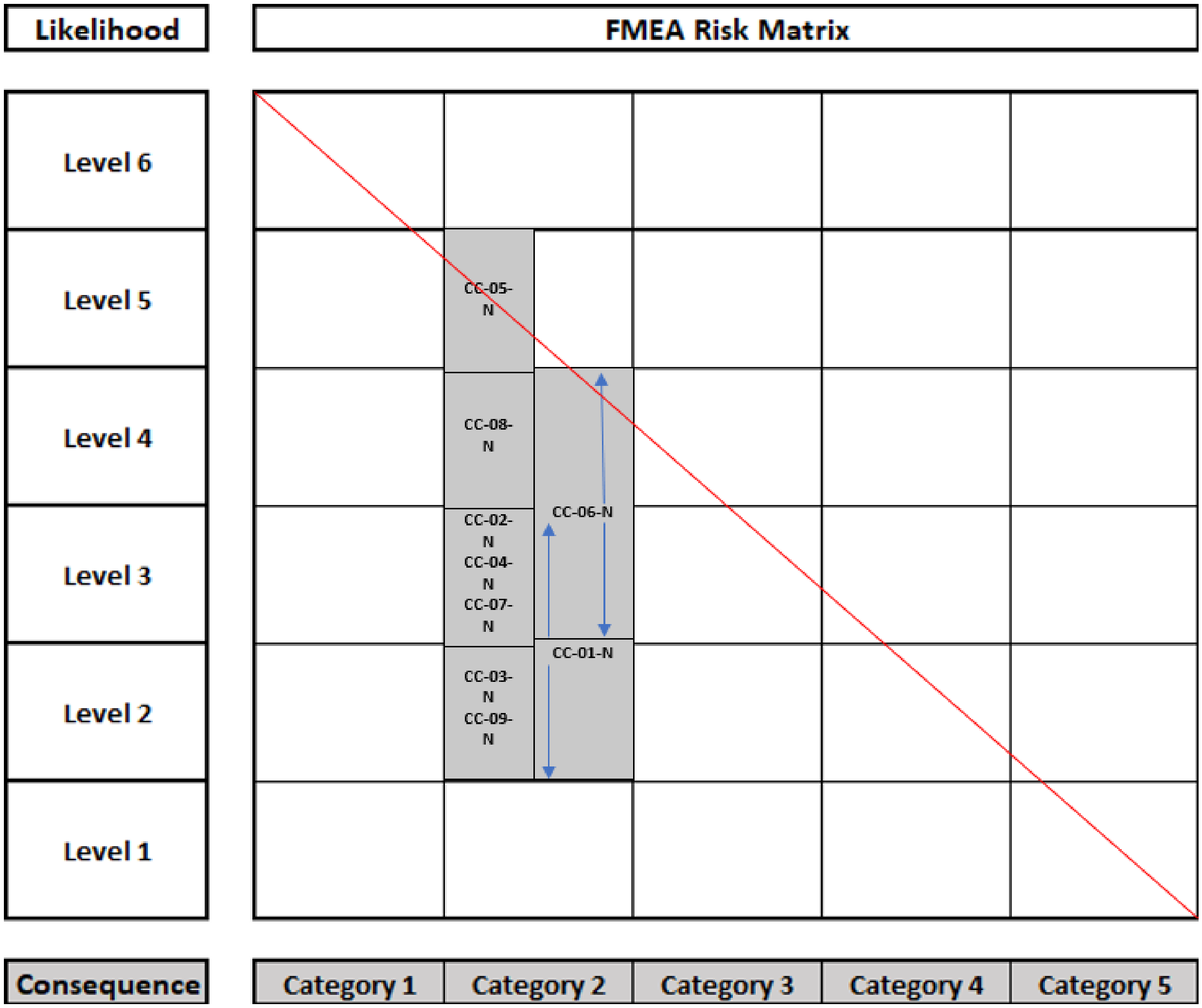


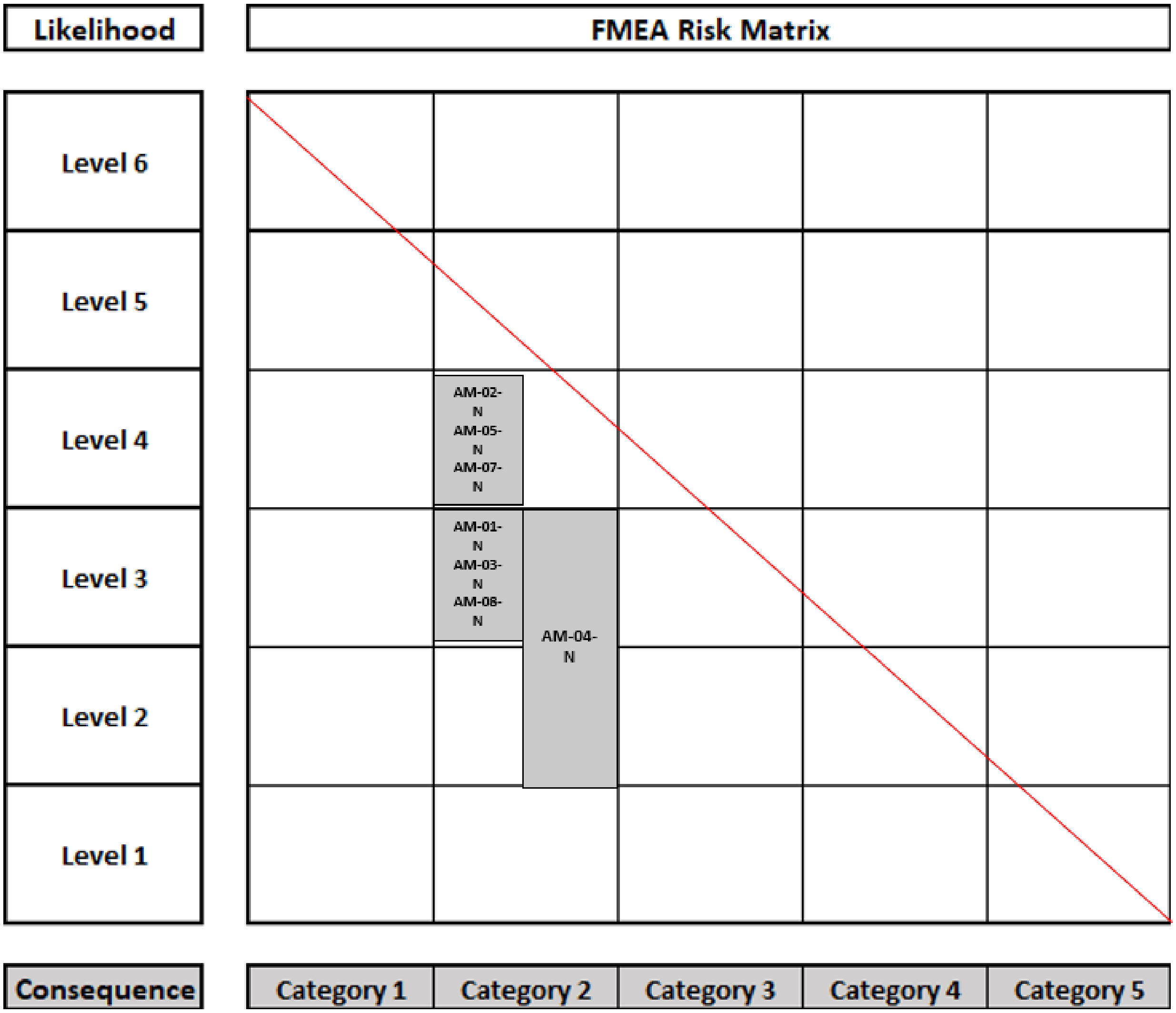
Figure 6: Risk Matrix for the SQRA

The 2020 Leaburg Canal SQRA workshop carried twenty-eight PFMs forward to the risk analysis for the Ames and Cogswell Creek reaches. These PFMs are discussed below, organized by loading condition and reach. The estimates for likelihood and consequence were developed by blind polling as well as discussion of the initial poll results, following the polling. A Risk Matrix has been provided for each failure mode with a box has been placed where the PFM likelihood and consequences intersect. Some of the failure modes straddle two classifications (such as Level 2 to Level 3) and some encompass two classifications (such as Level 2 and Level 3). Summary charts of PFMs estimated during the 2020 SQRA workshop are provided in Figures 7 through 12.



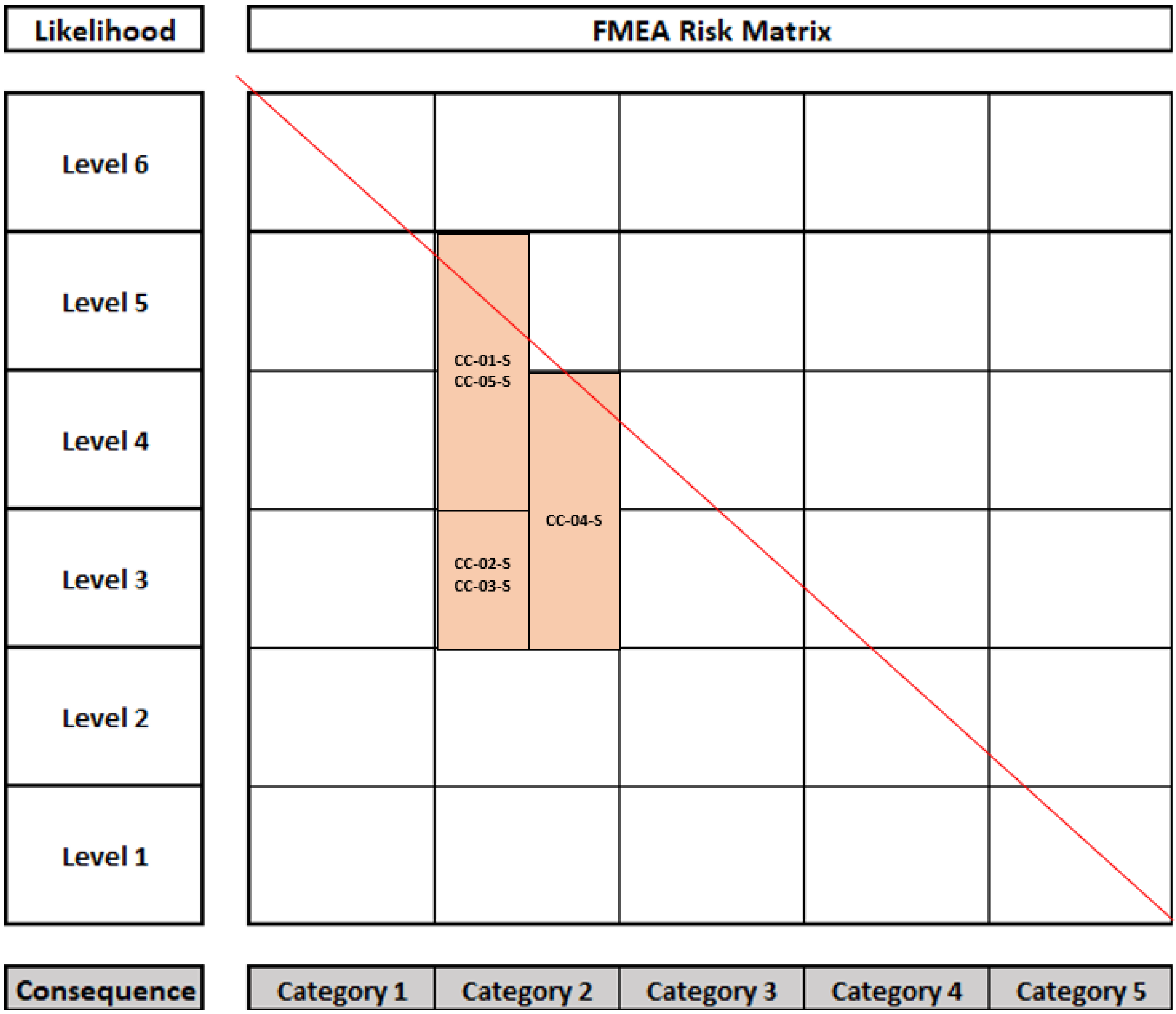
Note: The locations of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop.

Figure 7: Cogswell Creek Normal Risk Matrix



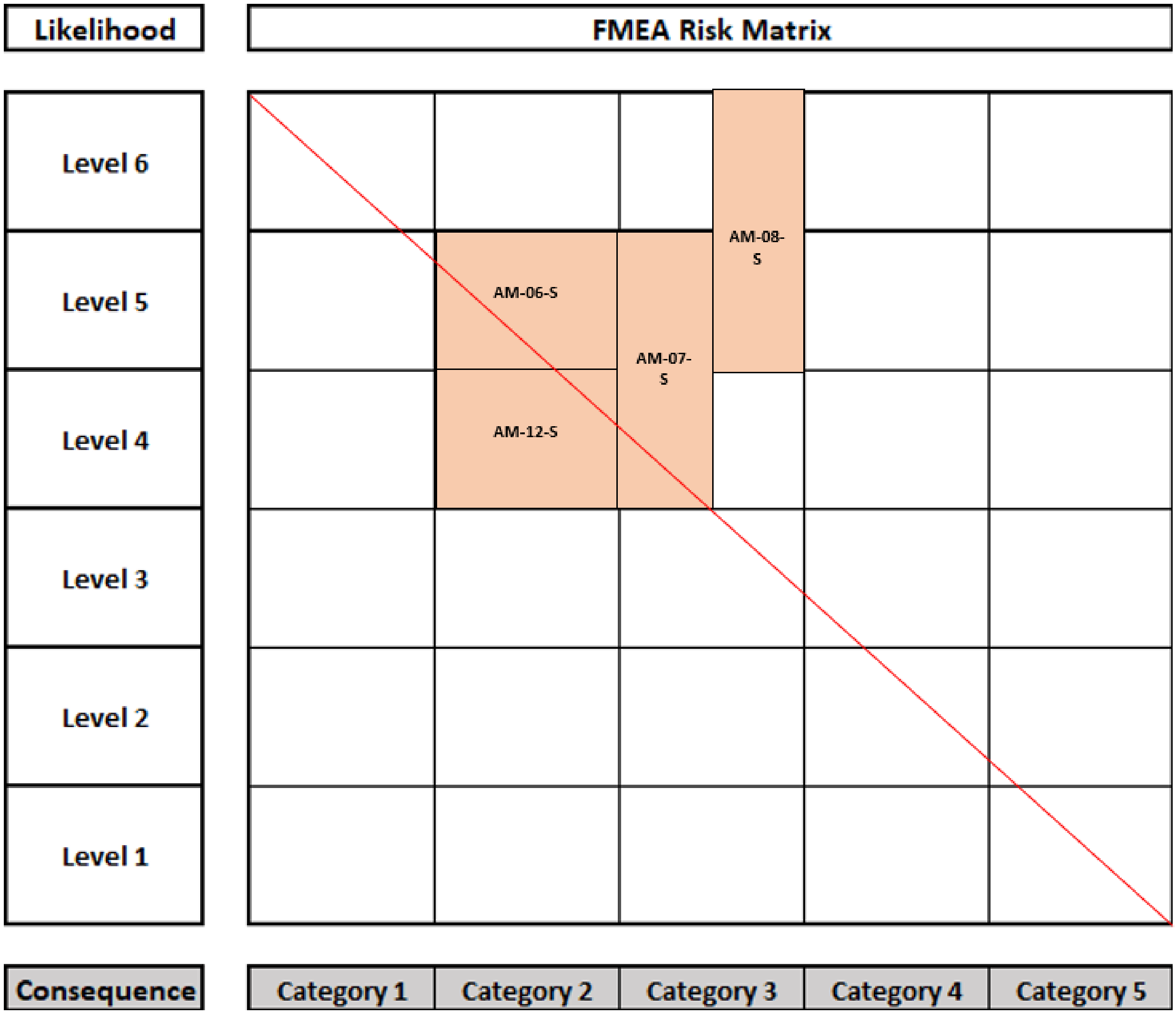
Note: The locations of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop.

Figure 8: Ames Reach Normal Risk Matrix



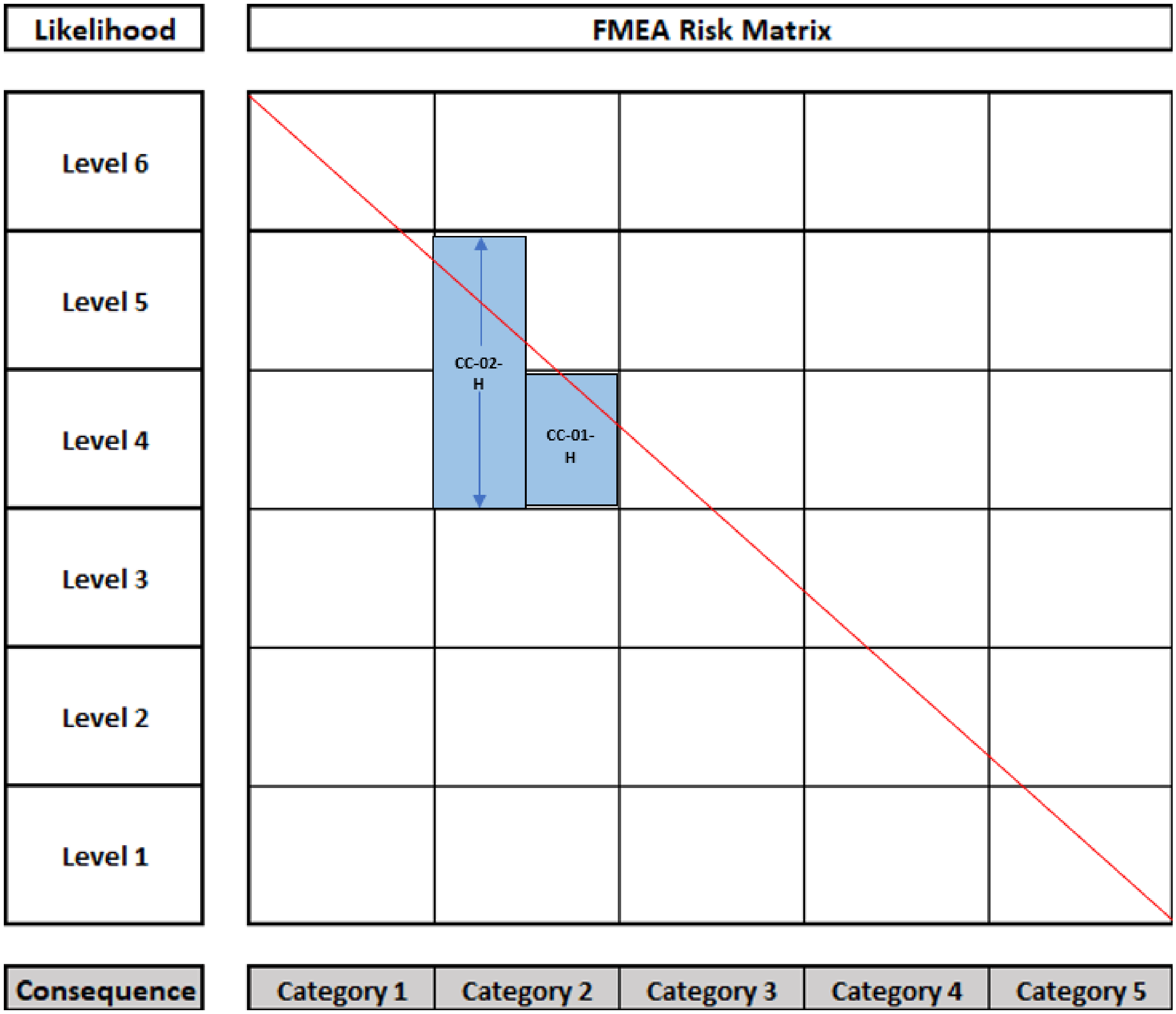
Note: The locations of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop.

Figure 9: Cogswell Creek Seismic Risk Matrix



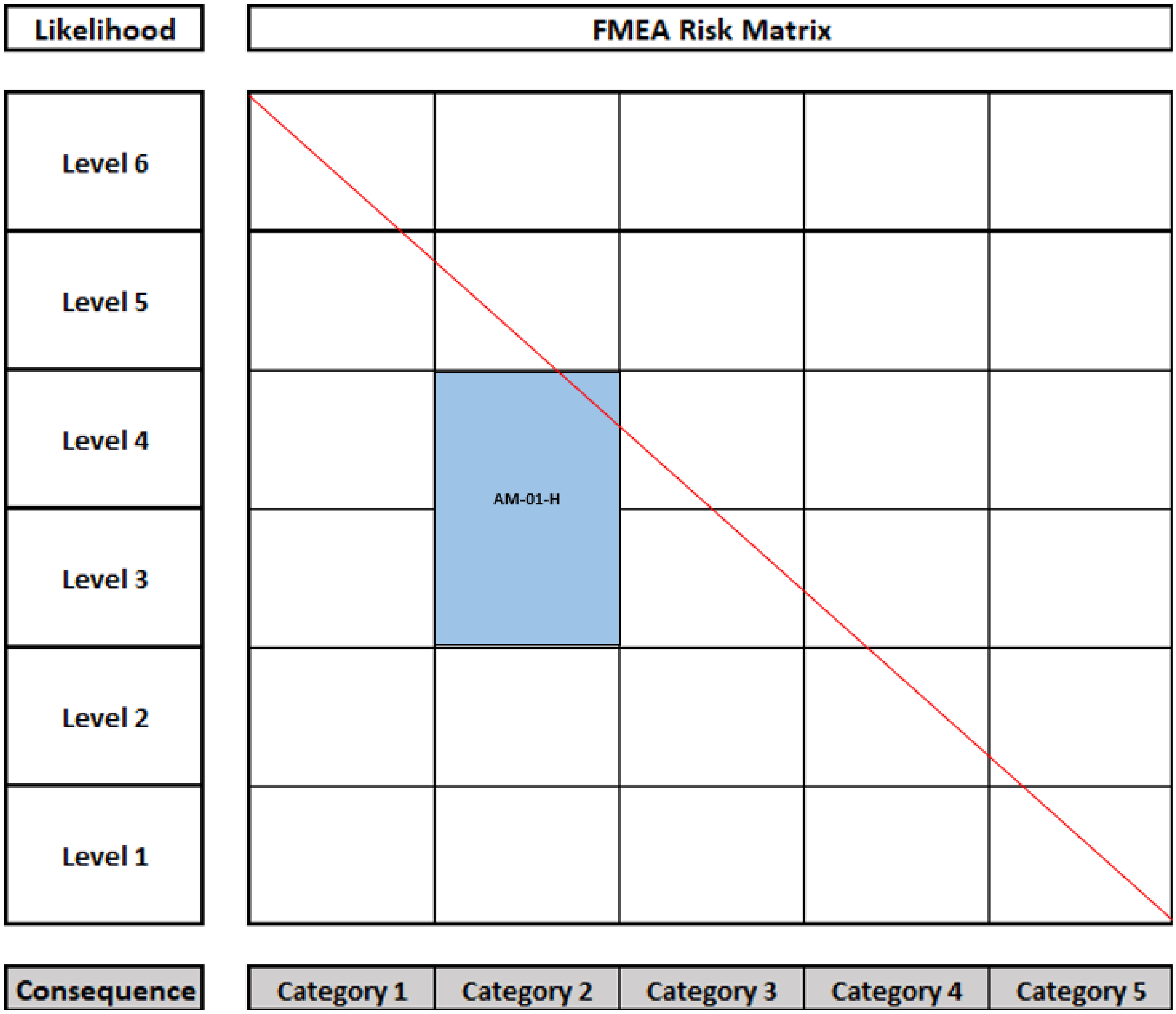
Note: The locations of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop.

Figure 10: Ames Reach Seismic Risk Matrix



Note: The locations of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop.

Figure 11: Cogswell Creek Hydrologic Risk Matrix



Note: The locations of the failure modes are approximate and intended to provide a relative location of the risk for all the failure modes discussed during the workshop.

Figure 12: Ames Reach Hydrologic Loading Risk Matrix

PFMs that plot towards the upper right of the chart are considered higher risk. Actions could be considered including further investigation or analysis to better understand the PFM, active monitoring of the PFM, or an action that reduces the likelihood or consequence of the PFM. It is possible that additional information or studies could better inform the risk analyses associated with those PFMs, particularly if the confidence in the likelihood and consequence is low. Once the additional information is obtained, the risk associated with those PFMs could be reevaluated.

The highest risk failure modes identified during the 2020 Leaburg Canal SQRA workshop are summarized as follows:

- Level 6
  - Seismic slope failure at Ames – cyclic softening and/or liquefaction of the canal embankment. Potential life loss consequences might be greater than 10 due to close proximity of homes at the toe of the embankment
- Level 5
  - Seismically induced internal erosion at Ames – transverse crack through the embankment
  - Seismic slope failure at Cogswell – cyclic softening/liquefaction of the embankment
  - Internal erosion failure at Cogswell (animal burrowing exacerbates)
- Level 4
  - Internal erosion failure at Ames (animal burrowing exacerbates)
  - Landslide blockage at Ames during flood or seismic event
  - Concentrated leak erosion along conduit that penetrates the embankment at Cogswell

Other significant failure risks identified during the workshops include:

- Tributary Creek Flood Scenarios - Overtopping Potential Failure Modes
  - Failure to close the canal head gates during a flood
  - Debris blockage at the siphon spillway
  - Debris blockage at wasteway gate
  - Debris blockage at a canal bridge
  - Large tree or debris blockage anywhere along the canal
- Seismic Intervention Failures Scenarios
  - Failure to close the canal head gates due to seismic damage
  - Failure to open wasteway gate due to seismic damage

6. Reaches Covered Outside of the Workshop

Due to schedule constraints, only the Cogswell Creek and Ames reaches were completed during the July 2020 SQRA workshop. A brainstorming of PFMs for the other reaches was performed on the last day of the workshop with the full risk analysis team. The eight additional reaches of the canal were then evaluated outside of the workshop by a smaller team including consultants and EWEB. The additional reaches include: Intake, Lure Lane, Montgomery Creek, Ward Creek, Greenwood, Hansen Creek, Johnson Creek, and Forebay.

The failure modes for the additional reaches are generally presented as parent failure modes developed during the workshop for the Cogswell Creek or Ames reaches, with changes noted for the specific reach based on available information (or lack thereof). In general, little information is available regarding the embankment and foundation materials compared with Ames and Cogswell due to the lack of previous subsurface explorations.

Where differences in available information or performance history were noted, this information was used to modify the PFM progression and more and less likely factors, as applicable. An estimate of likelihood and consequences was then made. Where the likelihood and consequence estimate for a given reach differed from that estimated for the parent PFM, a rationale for the change was provided.

The likelihood estimates at the remaining reaches were generally similar to those at Cogswell Creek and Ames, with seventeen lower likelihood estimates and six higher estimates. The consequence estimates at the other reaches were the same or lower as for Cogswell Creek and Ames.

7. Major Understandings and Key Findings

The following discussion describes the key findings regarding the Leaburg Canal and identifies factors affecting canal performance.

7.1. Breach Characteristics

Breach of a canal is fundamentally different than the breach of a dam with an impounded reservoir. While the potential failure modes leading to breach (slope instability, internal erosion, etc.) are similar, the ability of the canal to deliver water to the breach site is limited by the relatively small volume of water and the hydraulics of the canal. In contrast, an impounded reservoir behind a dam represents a significant source of water which will enlarge the breach.

7.2. Consequence and Life Loss Estimates

Breach modeling was performed at several locations in each reach. Using the RCEM methodology, the calculated life loss was generally much less than 1. However, several factors led the group to increase the life loss estimate. Based on discussions of the specifics of individual breaches, the workshop participants generally agreed that the most appropriate category for consequence was a Level 2, corresponding to a potential life loss (PLL) between 1 and 10. In many cases, this increase was based on the proximity of a single dwelling located very near to the breach location, where depth times velocity (DV) values were high or there was a perceived likelihood of a fatality along the highway. It should be noted that flooding water from the breach spreads over a large area, but the limited ability of the canal to deliver a large volume of water resulted in low DV values and hence low estimates of fatalities.

7.3. Unique Siphon

The Leaburg facility is unique in that its siphon spillways at the downstream end of the canal are "over-sized" for the capacity of the canal. The discharge capacity of the siphon spillways is nearly twice that of the maximum normal operating flow prior to overtopping of the canal. With the head gates closed, a very rare event (i.e. 100,000 to 1,000,000-year storm) is required to exceed the combined capacity of the siphon spillway and wasteway gate and result in overtopping. This siphon capacity/canal capacity mismatch is an asset, provided the siphon intake is not blocked by debris. The ability to control the flow in the canal in a timely fashion is a key to successful operation, and the reliability of the siphons under canal debris loading is a critical factor.

7.4. Debris Loading

The canal traverses the flatter terrain of the McKenzie floodplain before moving towards the edge of the valley to maintain grade. Within both landscapes, there are large trees adjacent to the canal. In addition, several substantial tributary streams outlet directly into the canal. Recently, during the winter of 2018/2019, several large trees were overloaded with snow and dropped into the canal. During the SQRA, it was identified that debris loading within the canal had the potential to play a significant role in the function of the canal, either by impeding the flow control structures or blocking the canal at another location.

Additional evaluation of the debris issue revealed that these two mechanisms (impeding the siphon spillway and blocking the canal) were estimated to have similar likelihoods and consequences. It was further recognized that the ability to operate the siphon and detect any debris blockages within the canal were important considerations for safe operation.

7.5. Limited Available Information

The Leaburg Canal has been in operation for over 90 years. Records from original construction are typical of the era, and do not provide a complete record of the methods used and conditions during initial construction or first filling. Overall, there is limited information and the variation in performance along the 5-mile length could be explained by understanding more about how the materials, geometry, and foundation materials vary under the canal. It is understood that areas along the canal have been improved over time, but documentation of these improvements prior to 2005 is largely missing. Detailed records more consistent with the modern standard of practice have been kept since about 2005. There have been a few subsurface investigations of the canal in the Cogswell Creek and Ames reaches, but the available information on the embankment and foundation materials is limited. Areas with observed performance issues (i.e. Cogswell and Ames) are the only locations that have been investigated.

7.6. Factors Required for Good Performance and Risk Mitigation

- Robust and successful surveillance and monitoring is a key aspect for a structure like the Leaburg Canal, which crosses a variety of geologic conditions with an embankment of variable shape and construction. Like many structures, it is not feasible to have complete knowledge of these variations, and thus vigilance in the surveillance program is required to identify the onset of potential issues.
- Hydraulic control of the canal level must be positively maintained by EWEB operations. The function of the intake gates, wasteway gate, and particularly the siphon spillways is critical to the safe operation of the facility.
- Animal burrows can be present where canal riprap armoring is not present. When the burrowing occurs, it can lead to sloughs and increased seepage. Safe operation requires that animal burrowing be pro-actively mitigated.
- Vegetation control is necessary to facilitate the visual surveillance and monitoring requirements. For visual surveillance to be an effective monitoring tool, the areas where seepage may exit must be both visible and accessible for routine observation. If the visual monitoring is done from the crest, it must be possible to view and evaluate from a distance when closer investigation of the toe area is warranted.
- EWEB has Standard Operating Procedures for managing high flow events which limits the likelihood of adverse loading conditions. Forecasting of significant rain events, McKenzie River flood stage, and debris loading are keys to maintaining the hydraulic control over the inflow

hydrograph. In addition, the Hazard Mitigation Control System monitoring of the level within the canal is an important protective system for reducing response time to unforeseen incidents.

7.7. Factors Leading to Poor Performance and Increased Risk

General:

- Local geologic foundation conditions have an effect on the performance of the canal embankment. Areas of local variation can explain the differences in performance noted in several locations along the canal. The interaction of the canal embankment and cut-sections of the canal profile with more pervious foundation materials can explain some of the seepage observed. In addition, the effect of the regional groundwater flow from the adjacent hillside to the McKenzie River varies along the length of the canal.
- The presence of liquefiable or strain-softening materials along the length of the canal is a major contributor to the overall risk, especially in the downstream portions of the canal where the embankment is generally higher. These loose or weak materials may be present in the embankment or in the foundation materials, and may be difficult to detect prior to the initiation of seismic loading and resulting slope deformation.

Site Specific:

- At Cogswell Creek, an old meander feature of the McKenzie River was identified under the embankment where seepage and internal erosion mechanisms have been observed. This feature shortens the seepage path and exacerbates semi-confined groundwater flow regimes, resulting in artesian pressures. These pressures and the resulting seepage have resulted in poor performance of the embankment between approximately Stations 114+00 and 124+00.
- At Ames, construction of the outer portions of the canal embankment involved side casting excavated rock spoils down the existing slope. As the material segregated from uncontrolled placement, coarser (boulder-sized) rock fragments accumulated near the bottom of the slope. These boulders were then infilled with loose, uncompacted silt. The construction method for the Ames reach resulted in tall over-steepened slopes constructed of loose material. These slopes are likely unstable under seismic loading and present a higher risk of damage and life loss than other areas of the canal due to their geometry as well as the proximity of homes and structures near the toe.

8. Potential Paths Forward

To ensure safe and reliable operation in both the near term and long term, significant investments along the full length of the Leaburg Canal will be necessary regardless of the selected path forward for the facility, whether the canal returns to service or is converted to a stormwater conveyance. Even with the canal out of service, there are near term needs to invest in risk reduction measures due to ongoing deterioration of the facility while it continues to convey intercepted stormwater flows to the river.

8.1. Scenario 1: Return to Service Option

The canal was dewatered in response to performance issues identified at Cogswell and Ames and associated uncertainty about subsurface conditions and embankment performance. Scenario 1 seeks to address risk factors by improving the reliability of the canal embankments and control structures, increasing emergency discharge capability, reducing subsurface uncertainty through test pits and borings, and evaluating stability of embankments and structures against FERC criteria. The options below provide different paths to a return-to-service, as detailed in the descriptions.

Scenario 1A – Incremental Return-to-Service

This scenario performs an incremental roll-out of mitigations that address seepage areas and other performance issue areas along the canal. This incremental roll-out is intended to restore restricted operation to the canal as soon as practical, with full flow restored after additional improvements.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions and identify problem areas
2. Quantify risk and uncertainty reduction resulting from explorations
3. Address known, distinct risk factors first (Sta. 50+00 undercrossing, trash rake, etc.)
4. Focus remediation sequencing on higher likelihood/higher consequence areas
5. Facilitate single-season construction projects with limited access
6. Promote a restricted operation return-to-service (1,300 cfs) as soon as possible

Scenario 1B – Rapid Return-to-Service

This scenario performs a condensed roll-out of mitigations at seepage areas and other performance issue areas along the canal. The rapid roll-out requires a front-loaded capital investment and carries more construction risk related to weather delays, as the construction would take place year-round.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions and identify problem areas
2. Quantify risk and uncertainty reduction resulting from explorations

3. Focus remediation sequencing on facilitating construction schedule in seepage areas
4. Promote a full-capacity operation return-to-service as soon as possible, while only addressing seepage areas

Scenario 1C – Major Rehabilitation (2,500 CFS)

The canal could be converted to a modern conveyance, with significant and widespread improvements made along the length of the canal. Embankments would be improved using a combination of seepage blankets and stability berms. In areas where stability berms are impractical or are insufficient to address localized problems, a concrete flume would be constructed that would allow removal of the embankment and its associated hazards.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions and gather information for design
2. Address known, distinct risk factors first (Sta. 50+00 undercrossing, trash rake, etc)
3. Perform multi-season major rehabilitation of entire reaches of the canal embankment
4. Focus remediation sequencing on construction access restrictions
5. Provide substantial risk reduction by major remediation with limited (but continuing) investment in risk reduction measures
6. Return canal to full operation as soon as possible

Scenario 1D– Major Rehabilitation (1,300 CFS)

Lowering flow in the canal will reduce the phreatic levels in the embankment, generally lowering the likelihood of failure. This scenario is similar in concept to 1C, above, but attempts to achieve costs savings through a load reduction in lieu of full embankment remediation. It is likely that some of the mitigations could be smaller and still meet the target factors of safety.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions and gather information for design
2. Address known, distinct risk factors first (Sta. 50+00 undercrossing, trash rake, etc)
3. Perform multi-season major rehabilitation of entire reaches of the canal embankment
4. Focus remediation sequencing on construction access restrictions
5. Recognize cost savings and added risk reduction through canal capacity restriction
6. Provide risk reduction by major remediation and load restrictions with limited (but continuing) investment in risk reduction measures
7. Return canal to restricted operation as soon as possible

Scenario 1E – Conversion to a Concrete Flume

Performance issues and uncertainty resulting from the limited documentation on the canal could be mitigated by reconstructing the facility as a modern conveyance. Several options were evaluated including circular pre-cast concrete pipe, corrugated metal pipes, arch pipes, and a reinforced concrete rectangular flume. Due to the flat slope of the canal, large diameters in excess of 20 feet were required. At the concept phase, a reinforced concrete flume was the most economical. In this scenario, the canal embankments would be removed or regraded to remove slope stability concerns. This scenario assumes that the foundation conditions would be suitable to support the flume on shallow foundations at grade.

The goals of this scenario are to:

1. Replace the embankments with a modern conveyance to reduce the effect of subsurface uncertainty
2. Drastically reduce risk profile by fully reconstructing the conveyance to modern standards

Scenario 1F – Slow Incremental Return to Service (Distributed Investment)

In the event that funding resources are limited, it may be advantageous to spread the mitigation investment effort out over a longer period. This scenario is similar to 1A in content. The sequence of mitigations has been modified to equalize investment to the extent practicable. This scenario delays generation until much later than the other scenarios, but lowers yearly capital requirements.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions and identify problem areas
2. Limit expenditures to spread out capital requirements
3. Perform one or two projects per year on seepage areas in specific reaches
4. Return canal to restricted operation as soon as possible

8.2. Scenario 2: Conversion to Stormwater Conveyance (Mothball) Option

A major factor in the canal operations is the presence of significant tributaries which flow directly into the canal. When the canal is out of operation, large storms can still contribute enough water into the tributaries to result in full flow and even over-topping of the canal at very long return periods. Even if the canal is not generating power, it still must control and discharge these tributary flows back into the McKenzie River. In this scenario, the canal is modified explicitly to handle these flows and is removed from service. The modifications to the canal for this process include:

1. Blocking and sealing the head gates at the intake dam
2. Breaching the embankment at Station 50+00 to drain surface flows into a natural drainage
3. Constructing a canal plug embankment at Station 61+50
4. Permanently opening the Wasteway Gate
5. Constructing a canal plug embankment at Station 112+00
6. Constructing a new stormwater outfall at Station 152+50

7. Constructing a canal plug embankment at Station 192+00

These actions limit the flows of major tributaries to two outlets: the Wasteway Gate (Cogswell Creek, Ward Creek, Montgomery Creek) and the Siphon/Low Level outlet at the Forebay Dam (Johnson Creek). Minor surface flows discharge into the natural drainage at Station 50+00 or out through the new Hansen stormwater outfall. The overall length of the in-service conveyance is 26,670 feet. With the above modifications, the length of the conveyance for the major tributaries is reduced to 5,050 feet in the Cogswell-Ward-Montgomery reaches and 7,420 feet in the Johnson-Ames-Forebay reaches. Overland flows and minor streams are not expected to put enough water into the remaining reaches where hydraulic loads on the canal embankment would be significant.

In terms of overall canal risk, this conversion represents a substantial risk reduction. Approximately half of the canal is no longer retains any significant water volumes. The loading of canal embankments is reduced to fairly infrequent storm events as opposed to normal canal loading every day. Further, seismic PFMs can be evaluated with the canal empty which would significantly lower the likelihood and consequences of failure. Certain areas, where houses are immediately at the toe of the embankment, would still have to be evaluated for the potential of mass movement of a marginally stable embankment under seismic loading.

Despite the considerable reduction described above, risks associated with the performance of the conveyance during the infrequent storm events would still need to be mitigated to nearly the same standard as normal operations to meet FERC guidelines. Due to the relative infrequency of loading, a more protracted implementation may be acceptable to the regulator.

The options below provide different paths to a conversion to a stormwater conveyance, as detailed in the descriptions.

Scenario 2A – Phased Conversion to Stormwater Conveyance

This scenario performs risk reduction measures on seepage areas while redirecting flows in the canal toward new or alternative outlets. The risk reduction measures focus on seepage areas while new construction isolates portions of the canal and redirects flows.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions for reaches to remain
2. Remove operational ability, greatly reducing loading on embankments
3. Direct significant tributaries through existing control structures
4. Improve seepage areas in sections of embankment that will carry tributary flows during storms
5. Perform single-season construction projects with limited access

Scenario 2B – Rapid Conversion to Stormwater Conveyance

This scenario accelerates the conversion to a stormwater conveyance by performing multiple operations simultaneously and working year-round. Risk reduction measures focus on seepage areas.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions for reaches to remain
2. Remove operational ability, greatly reducing loading on embankments
3. Direct significant tributaries through existing control structures
4. Improve seepage areas in sections of embankment that will carry tributary flows during storms
5. Perform continuous construction projects

Scenario 2C – Major Rehabilitation of the Remaining Reaches

This scenario converts the facility to a stormwater conveyance and performs major rehabilitation work on the remaining water-retaining reaches. This scenario would result in the largest overall risk reduction, since the remaining embankment is improved to handle significantly reduced and infrequent flows.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions for reaches to remain
2. Remove operational ability, greatly reducing loading on embankments
3. Direct significant tributaries through existing control structures
4. Improve sections of embankment that will carry tributary flows during storms
5. Perform continuous construction projects

Scenario 2D – Slow Conversion to Stormwater Conveyance (Distributed Investment)

In the event that funding resources are limited, it may be advantageous to spread the mitigation investment effort out over a longer period. This scenario is similar to 2A in content. The sequence of mitigations has been modified to equalize investment to the extent practicable. The major component of risk reduction results from taking the canal out-of-operation, with planned mitigation measures further reducing risk in the sections of embankment that remain as water-retaining reaches.

The goals of this scenario are to:

1. Reduce uncertainty in subsurface conditions for reaches to remain
2. Remove operational ability, greatly reducing loading on embankments
3. Direct significant tributaries through existing control structures
4. Improve sections of embankment that will carry tributary flows during storms
5. Perform a series of single-season construction projects to gradually lower risk

9. Cost Estimating

The baseline estimates are reflective of a conceptual construction cost. Slightly conservative but realistic construction approach assumptions were used to develop these estimates. Most estimates were performed with little to no subsurface information. No design calculations were completed as part of this study. Thus, the type, size, and location of individual risk reduction measures was derived from a general understanding of geology and embankment performance, along with engineering judgement based on similar features constructed at other projects. It is expected that the true budget-level cost for the mitigation will be between the low and high contingency values, as described below.

In a typical conceptual-level cost estimate, some degree of design and/or investigation is undertaken to evaluate a few options at one or two sites. It is common for planning level cost contingencies of 20-50% for these types of projects. In this study, over 150 individual risk mitigation measures were evaluated across ten canal reaches and twenty-seven individual seepage areas. These areas could be combined into "funded projects" in any number of ways, the detail of which could have a significant effect on the cost of individual mitigation measures, as well as the cost of the overall project.

The future of the Leaburg Canal will likely require a series of mitigations conducted over several years. Currently, there is considerable subsurface and regulatory uncertainty. As a result, the actual costs incurred are expected to vary significantly from the conceptual estimate values described above. Individual contingencies were not incorporated into the unit rates used to compile the estimate. Rather, a direct estimate of construction cost assuming no modifications was completed so that contingencies could be distinctly evaluated. This approach allows for a more direct and transparent evaluation of potential cost-risks. The sources of uncertainty and the associated contingencies are described in more detail below.

9.1. Construction Cost Uncertainty

Key Uncertainty Addressed: What if the mitigation measure as proposed is more or less expensive?

The estimates do not include built-in contingencies for uncertainty in material costs, labor, capital, or project scope. At the time of the estimate, the Engineering News Record (ENR) Construction Cost Index was 11,579.02. The ENR Labor Index was 24,037.06. These values are current as of 11/16/2020 and are considered representative of the costs provided.

In the detailed contractor costs estimates, line items for "Contingency" are reflective of typical contractor estimates for unknown construction related issues (e.g. handrail, additional signage, sandbags, etc.) and should not be interpreted as a measure of uncertainty related to the main mitigation measure itself. The mitigation measure uncertainty and contingency is discussed below.

9.2. Mitigation Cost Uncertainty

Key Uncertainty Addressed: What if the mitigation measure needs to be larger to meet design criteria?

In the estimates provided for the mitigation measures, an optimistic set of subsurface conditions, mitigation geometries, and construction methods are assumed. It is anticipated that additional subsurface investigation, design, and analysis will revise the size and exact location of the mitigations. The Mitigation Cost Contingency values reflect the uncertainty associated with the construction of a single mitigation using the assumed dimensions. Percentages are assigned based on the presumed sensitivity of the mitigation to geometric and material property uncertainties, construction methods and difficulty, and overall complexity and uncertainty in the design.

9.3. Program Level Cost Uncertainty

Key Uncertainty Addressed: What if the mitigation needs to be supplemented based on subsurface findings, risk reduction goals, or regulatory requirements?

The estimates assume that the proposed type and extent of mitigation measure is sufficient to adequately mitigate the project risk to the desired level. This contingency is intended to address subsurface information or regulatory feedback that indicates the extent of mitigation needs to be expanded. As an example, baseline cost estimates presume that buttressing of the existing canal embankments will be sufficient to stabilize them during a seismic event. However, subsurface investigations could reveal that buttressing will not be sufficient or regulatory reviews could insist on higher factors of safety which would necessitate reconstruction of the embankments rather than simply buttressing the existing slopes.

9.4. Combining Uncertainties and Contingency Values

The three types of uncertainties described above are intended to be mutually exclusive and therefore can be directly combined. For example, if aggregate prices rise, the Construction Cost Uncertainty would be increased. If analysis shows the stability berm needs to be widened from 15 feet to 25 feet, the Mitigation Cost Contingency would be activated. If the regulator requires the area treated to go from the planned 800 feet to 1,600 feet to address certain risk factors, the Program Level Contingency would be activated. In this example, Total Cost = (Conceptual Estimate) * (1 + Construction Cost Uncertainty) * (1 + Mitigation Cost Contingency) * (1 + Program Cost Contingency).

In Table 6 that follows, a range of cost contingencies are provided consisting of a ‘low’ and ‘high’ estimate for both the Mitigation Cost and Program Cost contingencies. These values have been estimated for each risk reduction action. Note that the Construction Cost Uncertainty was not included in the estimates below. The range of potential comparative costs are calculated by combining the two low contingencies and the two high contingencies to arrive at the estimated cost (e.g. Net Low Contingency = Conceptual Cost * (1+Low Mitigation Cost Contingency) * (1+Low Program Cost Contingency)). In our opinion of the probable cost, the preliminary budget-level estimates would be between the low and high contingency values reported below. The conceptual estimate (with no contingency) should not be used for financial decision making, as it is unrealistically low given the current level of uncertainty.

Table 6 also provides a relative risk ranking for each scenario with respect to the likelihood/consequence of a potential uncontrolled release of water. Risk is lowered with more robust repair approaches or with lower/less frequent loading as occurs when only conveying stormwater.

Table 6: Capital Cost Estimates

Goal	Scenario	Conceptual Estimate through 2040 [2020 $]	Mitigation Cost Contingency Range	Program Cost Contingency Range	Net Cost Contingency Range	Opinion of Probable Cost [2020 $]	Return to Service	Relative Risk Reduction Rank (1=Greatest Risk Reduction)
Return to Service	**1A - Phased Return-to-Service**	$25.0M	10 - 50%	10 - 300%	46 - 236%	**$36.6M - $84.2M**	1,300 CFS in 2026 (Year 4) 2,500 CFS in 2028 (Year 6)	6
	1B - Rapid Return-to-Service	$24.1M	10 - 50%	10 - 300%	43 - 215%	**$34.6M - $75.9M**	2,500 CFS in 2026 (Year 4)	6
	1C - Major Rehab (2,500 CFS)	$39.3M	10 - 50%	10 - 300%	26 - 113%	**$49.4M - $83.5M**	2,500 CFS in 2027 (Year 5)	5
	1D - Major Rehab (1,300 CFS)	$38.8M	5 - 50%	10 - 200%	19 - 81%	**$46.1M - $70.2M**	1,300 CFS in 2027 (Year 5)	4
	1E - Convert to Concrete Flume	$181.3M	10 - 50%	10 - 50%	32 - 123%	**$238.8M - $405.0M**	2,500 CFS in 2026 (Year 4)	2
	1F - Distributed Investment	$25.4M	10 - 50%	10 - 300%	47 - 242%	**$37.3M - $86.9M**	2,500 CFS in 2030 (Year 8)	6
Stormwater Conveyance	**2A - Phased Conversion**	$10.3M	10 - 50%	10 - 300%	61 - 294%	**$16.6M - $40.7M**	n/a	3
	2B - Rapid Conversion	$10.3M	10 - 50%	10 - 300%	61 - 294%	**$16.6M - $40.7M**	n/a	3
	2C - Major Rehab Remaining Reaches	$17.5M	10 - 50%	10 - 300%	37 - 123%	**$24.0M - $39.0M**	n/a	1
	2D - Distributed Investment	$10.1M	10 - 50%	10 - 300%	60 - 298%	**$16.2M - $40.3M**	n/a	3