RECLAMATION
Managing Water in the West

Final Risk Assessment

Truckee Canal Issue Evaluation Report of Findings

Newlands Project, Nevada
Mid-Pacific Region

Truckee Canal Headworks and Derby Diversion Dam

U.S. Department of the interior
Bureau of Reclamation

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MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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

Summary of Issue Evaluation Results

Scope

Derby Diversion Dam is located on the Truckee River, about 20 miles east of Reno, Nevada. This dam serves as the headworks for the Truckee Canal (Canal), a Newlands Project facility owned by the Bureau of Reclamation and operated and maintained by the Truckee-Carson Irrigation District (TCID). The 32.5 mile long Canal was constructed between 1903 and 1906 and was originally designed to convey approximately 1,200 cubic feet per second (ft^3/s). It conveys prearranged monthly quantities of water released from Derby Diversion Dam to serve two purposes: (1) to provide a supplemental supply to Lahontan Reservoir, located on the Carson River, with Truckee River water in years when the Carson River does not provide a sufficient supply for downstream demand; and (2) to deliver irrigation water to agricultural lands along the Canal during the irrigation season. The conveyance features include three tunnels and both concrete-lined and unlined earthen canal sections. There are two spillway structures (Pyramid and Gilpin Wasteways), two flow measurement features (Wadsworth and Hazen, located approximately 7.6 miles and 27.9 miles, respectively, downstream from Derby Dam), five check structures, and an unspecified number of turnout structures.

At approximately 4:00 a.m. on January 5, 2008, a portion of the Canal embankment failed. A breach occurred in a reach of the Canal that passes through the City of Fernley (Fernley), Nevada, located about 12 miles downstream of Derby Diversion Dam. Approximately 11.7 miles of the Canal passes through Fernley. When the failure occurred, the Canal was conveying 700 ft^3/s to 750 ft^3/s of water. The flow had rapidly increased from approximately 375 ft^3/s to 750 ft^3/s over the 18-hour period prior to the breach as a result of an effort to capture storm flows occurring on the Truckee River. This breach resulted in an uncontrolled water release into the middle of recently constructed residential housing development, flooding 590 homes, of which about 138 suffered moderate to severe damage and the remainder suffered minor damage. No fatalities occurred. Operations of the Canal were suspended about nine hours after the breach occurred.

After shutting down the Canal, various studies and investigations were initiated. Among these were investigations conducted by an independent forensic team to determine the most likely cause of the failure, a detailed inspection of the entire Canal embankment to evaluate its condition, and a risk assessment evaluation. These studies were conducted throughout January and February 2008.

Design efforts were initiated immediately after the failure to repair the failed portion of the embankment. Embankment repairs were initiated upon completion of the onsite forensic investigations. These repairs were completed by mid-February 2008.

The *Preliminary Draft Truckee Canal Embankment Forensic Evaluation Report* dated February 15, 2008, noted evidence of high rodent activity and found that the most likely cause for the failure was that the high water flows of January 4-5 surged into the animal burrows and opened seepage paths through the embankment (known as "piping"), which lead to collapse. The embankment inspection teams also reported numerous rodent burrows along much of the Canal embankment, as well as a large number of trees and other woody vegetation growing on or near the Canal embankment. Tree roots can promote embankment piping by providing seepage pathways through an embankment. Based on these findings, Reclamation was concerned about the immediate and long-term structural integrity of the Canal and the potential risk of a similar failure.

Reclamation formed a Risk Assessment Team (RA Team) to assess the risk results associated with resuming Canal operations. The team was asked to identify the likelihood and consequences under various operating scenarios of another canal breach. The risk assessment provides a tool for management decisions on what level of operations might be safely resumed. In addition to evaluating the risks associated with resuming Canal operations, the RA Team was also tasked by the Regional Engineer to address the following questions:

1. In order to resume operations of the Canal what other repairs need to be done immediately?

2. What are the criteria, standards, risks, and engineering judgments that will go into assessing the ability of the Canal to pass a range of flows, ranging from zero to full capacity with some acceptable risk?

3. From Item 2, what operational restrictions should be imposed, and ensure that the basis of these restrictions are fully reasonable and justified?

4. What are the short- and long-term recommendations for needed actions to reinitiate operations of the Canal?

5. What procedures should be recommended and followed in resuming flows in the Canal?

In addition to responding to these five questions, this Report of Findings presents the following:

- The risks associated with operating the Canal;
- Structural and non-structural alternatives that might reduce the probability of the failure modes and associated consequences;
- Recommendations for implementation of these structural and non structural alternatives as may be necessary to reinitiate initial and long-term operation of the Canal, and;
- A summary of the answers to the Regional Engineer's questions.

The RA Team met during the week of February 18, 2008. The Risk Assessment concluded on February 22, 2008 with a close-out meeting to brief management on the RA Team's preliminary findings. The team was composed of Reclamation staff from the Mid-Pacific Regional Office (MPRO) in Sacramento, California; Lahontan Basin Area Office (LBAO) in Carson City, Nevada; and the Technical Service Center (TSC) in Denver, Colorado; including:

Alan Stroppini	Civil Engineer, Design	MPRO	Team Leader
Bill Bouley	Civil Engineer	TSC	Team Member
John Cyganiewicz	Geotechnical Engineer	TSC	Team Facilitator
Bob Davis	Geotechnical Engineer	TSC	Team Member
Dave Edwards	Civil Engineer	TSC	TSC Team Leader
Dave Gore	Regional Engineer	MPRO	Observer
Locke Hahne	Civil Engineer, Facilities O&M	LBAO	Team Member
Rich Kristof	Civil Engineer, Facilities O&M	MPRO	Team Member
Ken Lally	Mech. Engineer, Facilities O&M	MPRO	Team Member
Mike McCulla	Geologist	MPRO	Team Member
Jeff Rieker	Civil Engr., Hydraulics/Hydrology	LBAO	Team Member
Chris Slaven	Geotechnical Engineer	TSC	Team Member

A. Risk Evaluation Process

Prior to evaluating the risks associated with operating the Canal, the RA Team reviewed available data stemming from the Forensics Evaluation Team and from the Canal Inspection Team. The RA Team also visited the breach site and other key sites along the portion of the Canal through Fernley prior to performing their risk evaluation.

No specific canal risk evaluation parameters exist, so the RA Team proposed a qualitative risk assessment process that combined other methodologies. The RA Team applied procedures and concepts adapted from Reclamation's *Dam Safety Risk Analysis Methodology*, dated September 1999. This risk evaluation system is based on the assignment of a relative descriptor (High, Moderate, or Low) to a given circumstance or physical condition that could lead to the failure of a structure or facility (known as a "failure mode"). The consequences that may occur as the result of a given failure mode were evaluated utilizing an evaluation criteria presented in *Federal Information Processing Standards Publication 199* (FIPS 199), dated February 2004. The RA Team's proposed system was discussed with decision makers prior to the team's meetings. It was decided that, lacking a system specific to canals, this was an appropriate approach.

The RA Team initiated the risk evaluation process by developing a list of possible Canal failure modes. Using the Failure Evaluation System described in section I(C) below, the RA Team evaluated each potential failure mode and assigned a relative likelihood of failure using the descriptors High, Moderate, and Low. The team then evaluated the relative consequences stemming from each failure mode.

Each of the potential failure modes and consequences were discussed at length by the RA Team, and consensus was obtained on each evaluation. Once the failure modes and consequences had been assigned likelihood of occurrence values, risk was assigned a value ranging from I to V (one to five). The failure mode likelihood and consequences of failure were combined into an evaluation matrix, as shown in Table 1.

Table 1. Failure Mode Risk Evaluation Matrix

CONSEQUENCES OF FAILURE	FAILURE MODE LIKELIHOOD		
	LOW Likelihood ≤ 10^{-5}	MODERATE 10^{-3} ≤ Likelihood ≤ 10^{-5}	HIGH Likelihood > 10^{-3}
HIGH Consequence Category	III Low Likelihood High Consequence	II Moderate Likelihood High Consequence	I High Likelihood High Consequence
MODERATE Consequence Category	IV Low Likelihood Moderate Consequence	III Moderate Likelihood Moderate Consequence	II High Likelihood Moderate Consequence
LOW Consequence Category	V Low Likelihood Low Consequence	IV Moderate Likelihood Low Consequence	III High Likelihood Low Consequence

Once the risk values were determined, the RA Team proposed remediation measures and assessed these measures against each of the failure modes and consequences. The team then evaluated the possibility that a remediation measure might lower the ratings for either failure mode likelihood or consequence, and thus lower the risk rating. These changes are noted in section II below, along with RA Team's views on possible costs and level of difficulty of construction for each remediation measure. These evaluations are provided to assist in making future decisions on which, if any, remedial measures might be effective in further reducing risks for the initial and long term operation of the Canal.

B. Failure Evaluation Process

To ensure a consistent application of the rating descriptors of High, Medium, and Low, the RA Team established a probability scale, as shown in Table 2.

Table 2. Relative Likelihood of Failure Separating Failure Descriptors

Descriptor	Likelihood of Failure
Low	Likelihood $\leq 10^{-5}$
Moderate	$10^{-3} \leq$ Likelihood $\leq 10^{-5}$
High	Likelihood $> 10^{-3}$

Several RA Team members had difficulty applying these probabilities to a specific canal failure mode. These members had extensive experience with operation, maintenance, and repair activities associated with Reclamation canals within the Mid-Pacific Region. Their experience indicated that canal failures occur for a variety of reasons and they happen more frequently than suggested by the probability values described in Table 2. These members were able to accept the descriptor evaluation system, so long as they were able to relate the difference between the three descriptors as changes in the relative magnitude of the likelihood of failure and not the specific probabilities that were provided.

C. Consequence Evaluation Process

As described in section I(B) above, the consequence evaluation process selected was based upon FIPS 199, a process in use by the Department of Commerce Computer Security Division that is applicable to electronic and non-electronic forms of information. This consequence evaluation system evaluates the severity of loss and potential impacts to a government agency when their computer information system suffers a loss of confidentiality, integrity, and/or availability of information. In many ways that type of loss is analogous to the loss of a canal that delivers water to customers of a Federal water project. The system losses are similar in that the government agency loses the ability to accomplish its mission. For Reclamation, a canal failure may impact the agency's ability to deliver water, maintain day-to-day functions, and protect individuals and their property. The RA Team determined that an adaptation of the FIPS 199 consequence evaluation system was more appropriate for this risk assessment than commonly used dam-based risk evaluation systems based solely on loss of life. The FIPS 199 consequence evaluation system was adopted by the RA Team as follows:

1. Consequences were judged to be **LOW** if the loss of the facility could be expected to have a **LIMITED ADVERSE EFFECT** on operations, assets, or individuals.

   A **LIMITED ADVERSE EFFECT** means that the loss of the facility might:

   (i) Cause a degradation in mission capability to an extent and duration that Reclamation is able to perform its primary functions, but the effectiveness of the functions is noticeably reduced;
   (ii) Result in minor damage to Reclamation assets;
   (iii) Result in minor financial loss; or
   (iv) Result in minor harm to individuals.

2. Consequences were judged to be **MODERATE** if the loss of the facility could be expected to have a **SERIOUS ADVERSE EFFECT** on operations, assets, or individuals.

   A SERIOUS ADVERSE EFFECT means that, the loss of the facility might:

   (i) Cause a significant degradation in mission capability to an extent and duration that Reclamation is able to perform it primary functions, but the effectiveness of the functions is significantly reduced;
   (ii) Result in significant damage to Reclamation assets;
   (iii) Result in significant financial loss; or
   (iv) Result in significant harm to individuals (property damage) that does not involve loss of life or serious life threatening injuries.

3. Consequences were judged to be **HIGH** if the loss of the facility could be expected to have a **SEVERE OR CATASTROPHIC ADVERSE EFFECT** on operations, assets, or individuals.

   A SEVERE OR CATASTROPHIC ADVERSE EFFECT means that the loss of the facility might;

   (i) Cause a severe degradation in or loss of mission capability to an extent and duration that Reclamation is not able to perform one or more of its primary functions;
   (ii) Result in major damage to Reclamation assets;
   (iii) Result in major financial loss; or
   (iv) Result in severe or catastrophic harm to individuals involving loss of life or serious life threatening injuries.

D. Potential Failure Modes and Risk Issues

The RA Team initially listed four major canal failure categories; static, hydrologic, seismic, and sabotage. The failure modes identified by RA Team were:

Static Failure Modes

Failure through the embankment caused by erosive forces
Failure through the foundation caused by erosive forces
Failure through the embankment caused by loss of slope stability

Hydrologic Failure Modes

Failure due to overtopping caused by a large sudden increase in the Canal water surface elevation during a hydrologic event
Failure due to internal erosion and piping caused by a large sudden increase in the Canal water surface during a hydrologic event

Seismic Failure Modes

Failure of an embankment due to seismically induced forces

Failure of an embankment due to faulting motion immediately under the Canal

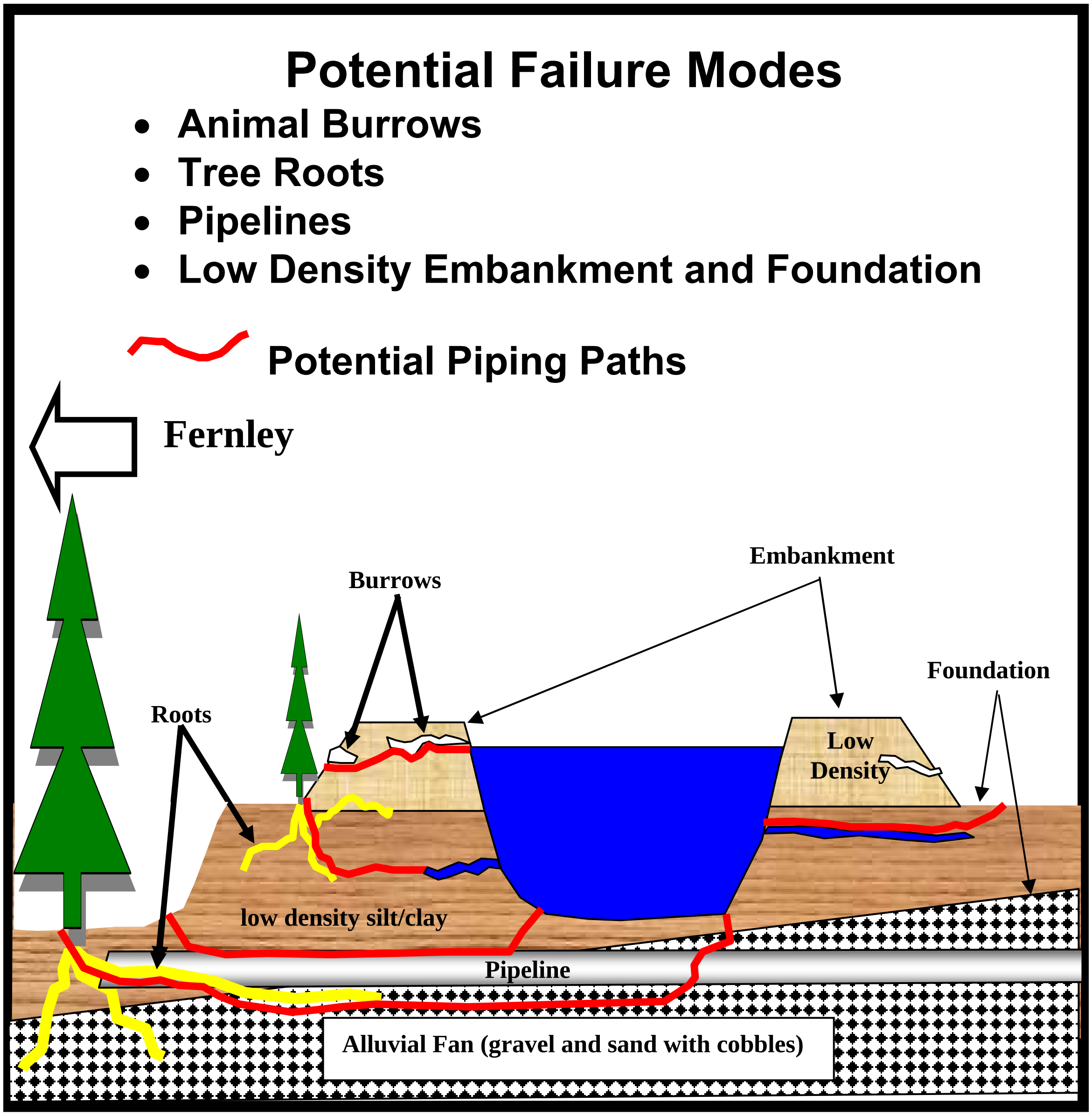
Sabotage Failure Modes

The RA Team determined such modes beyond the scope of this study

Static Failure Modes Evaluated

Due to the Forensic Evaluation Team's preliminary draft report finding that the most probable cause of the Canal's failure was water flowing through animal burrows penetrating the embankment, and the need for a timely initial risk evaluation, the RA Team focused their evaluation on the two static failure modes caused by internal erosive forces; (1) failure through the Canal embankment, and (2) failure through the Canal foundation. Figure 1 depicts the possible internal erosion failure modes.

Figure 1. Potential Internal Erosive Failure Modes



For each of the two failure modes, the RA Team formulated a series of scenarios, which included causes, conditions, and other potential factors of concern. They then assigned likelihood of failure descriptors and consequence values, as described in sections I(B) and I(C) above. Once a conclusion was reached, the team documented the probable consequences. Decision makers asked the team to limit their evaluation to the Fernley reach of the Canal.

Failure Mode 1: Canal Failure Caused by Erosive Forces through the Embankment

The RA Team defined Failure Mode 1 as a concentrated seepage pathway forming within the Canal embankment. The concentrated seepage could be caused by one or more reasons, including animal burrows, decomposing tree roots, and discontinuities. The concentrated seepage pathway extends almost or completely through the embankment. Water in the Canal rises above the entrance to the seepage point. Water flow out of the landside face of the Canal embankment begins and initiates erosion of embankment materials (piping). The type of soil or embankment condition contributes to erosion acceleration. The pipe widens rapidly. Erosion is neither found nor observed by the public nor TCID staff. Intervention is belated or unsuccessful. The Canal fails and consequences result.

The team listed possible initiating causes of the embankment seepage pathways (flaws), which include:

- Animal burrows
- Tree roots
- Discontinuities (pipelines, turnouts)
- Embankment-foundation interface
- Unknown flaws covered by vegetation or debris
- Poor construction of original embankment
- Lenses of permeable material
- Poorly constructed embankment repairs
- Differential settlement with cracking
- Desiccation cracking
- Potential connection to drainage areas about Canal
- Excessive gullying that shortens the seepage path or reduces stability
- Unknown construction practices
- Slumping that thins embankment section

Other factors that could raise concern included:

- No defensive design
- No designed filter
- Embankment constructed of erodible material (silts)

To aid the RA Team's consideration factors such as Canal flow, checked up storage, restricted flow levels, and Canal conditions, five operating scenarios were developed to help reasonably bracket possible combinations. Many more combinations could have been studied, but the scenarios were chosen that would provide sufficient information to assess the risks and inform decision makers. Appendix I provides further detailed information on the likely and less likely factors considered by the RA Team. Each of the following scenarios presents the scenario parameters, the team's conclusion about the probable level of risk, and potential foreseeable consequences.

OPERATIONAL SCENARIO NO. 1

Parameters

1. Analysis limited to the 11.7 mile Fernley reach of Canal.
2. One full season (12 months) of operation.
3. No operational restrictions.
4. Normal operations as indicated by past years of operation.

Conclusion

The RA Team estimates the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **HIGH**. The key reasons for this judgment are:

- Canal could experience a rapid stage increase this season (Spring 2008 to Spring 2009).
- Evidence of numerous flaws in the embankment (animal burrows, tree root systems, pipe penetrations).
- History of failures over the past 100 years of operation.
- Once started, piping would progress to failure rapidly; reducing the amount of time to intervene even if the piping was noticed (as evidenced by the 2008 failure).
- No defensive measures in the embankment design or construction to prevent piping.
- The probable existence of critical flaws within the embankment not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the embankment.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within the inundation area similar to those of 2008 breach.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.

- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 2

Parameters

1. Analysis limited to only the 11.7 mile Fernley reach of Canal.
2. One full season (12 months) of operation.
3. Operational restriction to reduce or eliminate rapid Canal stage increases (spiking) by limiting increases in Canal stage to no more than one measured foot per day in any reach. This restriction would most likely require telemetry and the ability to operate Derby Diversion Dam in timely manner.
4. No other operational restrictions on the stage elevation (Canal could be fully filled).

Conclusion

The RA Team estimates that the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **HIGH**. The key reasons for this judgment are:

- Data indicates the likelihood that rapid flow increases (spiking flows) occurred in the period immediately before the Canal failures of January 1921, 1996, and 2008.
- It is not clear if spiking flow conditions were present, but high or higher than normal Canal flow conditions likely existed prior to the Canal failures identified in 1918, 1951, and 1975.
- There was insignificant evidence of spiking flows in the Truckee River surrounding the event of 1919. Due to lack of data, the RA Team could not determine what hydrologic conditions existed during the 1957 and 1959 failures.
- If there were no spiking events in 1919, it is possible that the Canal failed at 450 ft^3/s or less.
- Evidence of numerous flaws in the embankment (animal burrows, tree root systems, pipe penetrations).
- History of failures over the past 100 years of operation.
- Once started, piping would progress to failure rapidly reducing the amount of time to intervene even if the piping flows were noticed prior to embankment breaching (as evidenced by the 2008 failure).
- No defensive measures in the embankment design or construction to prevent piping.

- The probable existence of critical flaws within the embankment not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the embankment.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within the inundation area similar to those of 2008 breach.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 3

Parameters

1. Analysis limited to only the 11.7 mile Fernley reach of Canal.
2. One full season (one year) of operation.
3. Operational restriction to reduce or eliminate rapid Canal stage increases (spiking) by limiting increases in Canal stage to no more than one measured foot per day in any reach. This would most likely require telemetry and the ability to operate Derby Diversion Dam in timely manner.
4. Restriction of stage/freeboard equivalent to a normal flow of 450 ft^3/s.

Conclusion

The RA Team estimates that the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **MODERATE TO HIGH**. The key reasons for this judgment are:

- The Canal has apparently operated for much of its life at or about the flow range of 200 to 500 ft^3/s.
- Data indicates the likelihood that rapid flow increases (spiking flows) occurred in the period immediately before the Canal failures of January 1921, 1996, and 2008.
- It is not clear if spiking flow conditions were present, but high or higher than normal Canal flow conditions likely existed prior to the Canal failures identified in 1918, 1951, and 1975.
- There was insignificant evidence of spiking flows in the Truckee River surrounding the event of 1919. Due to lack of data, the RA Team could not determine what hydrologic conditions existed during the 1957 and 1959 failures.
- If there were no spiking events in 1919, it is possible that the Canal failed at 450 ft^3/s or less.
- Much evidence of serious flaws in the embankment (animal burrows, tree root systems, pipe penetrations), but that at this flow level the effect would be less significant due to greater embankment cross section and less static head.
- History of failures over the past 100 years of operation.
- Once started, piping would progress to failure rapidly reducing the amount of time to intervene even if the piping flows were noticed prior to embankment breaching (as evidenced by the 2008 failure).
- No defensive measures in the embankment to prevent piping.
- Amount of critical flaws within the embankment not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the embankment.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within inundation area only slightly less to than those of 2008 breach.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.

- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 4

Parameters

1. Analysis limited to only the 11.7 mile Fernley reach of Canal.
2. One full season (12 months) of operation.
3. Operational restrictions to reduce or eliminate rapid Canal stage increases (spiking) by limiting increases in Canal stage to no more than one measured foot per day in any reach. This would most likely require telemetry and the ability to operate Derby Diversion Dam in timely manner.
4. Canal water surface (checked or unchecked conditions) is not to exceed that produced by the unchecked Canal flowing at 150 ft^3/s.

Conclusion

The RA Team estimates that the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **MODERATE**. The key reasons for this judgment are:

- At the 150 ft^3/s level, the minimum freeboard is estimated to be in the range of 7 to 8 feet or more.
- Potential increase in the ability to intervene by taking flows off at turnouts.
- The embankment section is wider at this water surface and will take longer to fail.
- The Canal has apparently operated for much of its life at or about the range of 200 to 500 ft^3/s.
- Data indicates the likelihood that rapid flow increases (spiking flows) occurred in the period immediately before the Canal failures of January 1921, 1996, and 2008.
- It is not clear if spiking flow conditions were present, but high or higher than normal Canal flows conditions likely existed prior to the Canal failures identified in 1918, 1951, and 1975.
- There was insignificant evidence of spiking flows in the Truckee River surrounding the event of 1919. Due to lack of data, the RA Team could not determine what hydrologic conditions existed during the 1957 and 1959 failures.
- If there were no spiking events in 1919, it is possible that the Canal failed at 450 ft^3/s or less.

- Much evidence of serious flaws in the embankment (animal burrows, tree root systems, pipe penetrations) but that at this flow level the effect would be less significant due to greater embankment cross section and less static head.
- History of failures over the past 100 years of operation.
- Once started, piping would progress to failure rapidly reducing the amount of time to intervene even if the piping flows were noticed prior to embankment breaching (as evidenced by the 2008 failure).
- No defensive measures in the embankment to prevent piping.
- Amount of critical flaws within the embankment not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the embankment.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within inundation area would be less than those of 2008 breach, but still severe.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 5

Parameters

1. Restrict Canal to no flow.

Conclusion

The RA Team estimates that the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **LOW**. The key reason for this judgment is:

- With no water in the canal, a piping failure is impossible.

Consequences

The RA Team estimates the consequences of this scenario to be **LOW TO MODERATE.** The key factors contributing to this judgment are:

- Reclamation's mission to deliver water will not be significantly impacted in the next year because the Carson River watershed (with an above normal snowpack) will be used to fill Lahontan Reservoir and meet the National Wildlife Refuge and Indian Trust responsibilities. Farmers using Canal water upstream of Lahontan Reservoir would be impacted by an inability to receive irrigation water.
- No flooding consequences to individuals.
- No damage to the facility.
- No financial loss to non-farm community.
- No catastrophic harm to individuals or serious life threatening situation develop due to flooding.
- There will be financial impacts to the farm community, TCID, and supporting business community.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

The results of the RA Team's evaluation of Scenarios 1 through 5 are plotted below on the Risk Matrix (Table 3).

Table 3. Failure Mode 1 Risk Matrix - Canal Failure Caused by Erosive Forces through the Embankment

CONSEQUENCES OF FAILURE	FAILURE MODE LIKELIHOOD		
	LOW	MODERATE	HIGH
HIGH Consequence Category	III Low Likelihood High Consequence	II Moderate Likelihood High Consequence Scenario 4 Scenario 3 ⟷	I High Likelihood High Consequence Scenarios 1&2
MODERATE Consequence Category	IV Low Likelihood Moderate Consequence Scenario 5	III Moderate Likelihood Moderate Consequence	II High Likelihood Moderate Consequence
LOW Consequence Category	V Low Likelihood Low Consequence	IV Moderate Likelihood Low Consequence	III High Likelihood Low Consequence

Failure Mode 2: Canal Failure Caused by Erosive Forces through the Foundation

The RA Team defined Failure Mode 2 as a concentrated seepage pathway forming through the Canal foundation. The concentrated seepage could be caused by one or more reasons, including animal burrows; tree roots; discontinuities; jointed foundation rock or other geologic features; and weak, porous or erodible foundation layers. The concentrated seepage pathway extends almost or completely through the foundation. The water in the Canal rises above the entrance of the seepage point. Water flow out of the foundation downstream of embankment toe or the landside face of Canal embankment begins and initiates erosion of foundation materials (piping). The foundation condition contributes to erosion acceleration. The pipe widens rapidly. Erosion is neither found nor observed by public or TCID staff. Intervention is belated or unsuccessful. The Canal fails and consequences result.

The team listed possible initiating causes of the foundation seepage pathways (flaws), which include:

- Animal burrows
- Tree roots
- Discontinuities (pipelines, turnouts)
- Embankment-foundation interface
- Unknown flaws covered by vegetation or debris
- Lenses of permeable material
- Poorly constructed embankment repairs
- Differential settlement with cracking
- Desiccation cracking
- Potential connection to drainage areas about Canal
- Excessive gullying that shortens the seepage path or reduces stability
- Non-Reclamation/TCID construction

Other factors that could raise concern included:

- No defensive design
- No designed filter

To evaluate Failure Mode 2, the RA Team applied the evaluation criteria to the same five scenarios. Appendix II provides further detailed information on the likely and less likely factors considered by the team. Each of the following scenarios presents the scenario parameters (the same as Failure Mode 1), the team's conclusion about the probable level of risk, and potential foreseeable consequences.

OPERATIONAL SCENARIO NO. 1

Parameters

1. Analysis limited to the 11.7 mile Fernley reach of Canal.
2. One full season (12 months) of operation.
3. No operational restrictions.
4. Normal operations as indicated by past years of operation.

Conclusion

The RA Team estimates the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **MODERATE TO HIGH**. The key reasons for this judgment are:

- Geologic exploration data are poor to nonexistent.
- The piping pathways process progresses slower than Failure Mode 1 (embankment internal erosion failure modes).
- 1921 breach at Farm District Road may have been an example of a foundation failure mode.

- Some evidence of serious flaws in the foundation (animal burrows, tree root systems, pipe penetrations).
- History of failures over the 100 years of operation.
- Once started, piping would not progress as fast as the 2008 breach, potentially providing increased time for intervention.
- No defensive measures in the embankment or foundation area to prevent piping.
- Number of critical flaws within the foundation not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the foundation.
- Numerous seepage areas.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within the inundation area similar to that of 2008 breach.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 2

Parameters

1. Analysis limited to only the 11.7 mile Fernley reach of Canal.
2. One full season (12 months) of operation.
3. Operational restriction to reduce or eliminate rapid Canal stage increases (spiking) by limiting increases in Canal stage to no more than one measured foot per day in any reach. This restriction would most likely require telemetry and the ability to operate Derby Diversion Dam in timely manner.

4. No other operational restrictions on the stage elevation (Canal could be fully filled).

Conclusion

The RA Team estimates the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **MODERATE TO HIGH**. The key reasons for this judgment are:

- Geographic exploration data are poor to nonexistent.
- The piping pathways process progresses slower than Failure Mode 1 (embankment internal erosion failure modes).
- 1921 breach at Farm District Road may have been an example of a foundation failure mode.
- Some evidence of serious flaws in the foundation (animal burrows, tree root systems, pipe penetrations).
- History of failures over the 100 years of operation.
- Once started, piping would not progress as fast as the 2008 breach, potentially providing increased time for intervention.
- No defensive measures in the embankment or foundation area to prevent piping.
- Number of critical flaws within the foundation not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the foundation.
- Numerous seepage areas.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within the inundation area similar to that of 2008 breach.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.

- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 3

Parameters

1. Analysis limited to only the 11.7 mile Fernley reach of Canal.
2. One full season (one year) of operation.
3. Operational restriction to reduce or eliminate rapid Canal stage increases (spiking) by limiting increases in Canal stage to no more than one measured foot per day in any reach. This would most likely require telemetry and the ability to operate Derby Diversion Dam in timely manner.
4. Restriction of stage/freeboard equivalent to a normal flow of 450 ft^3/s.

Conclusion

The RA Team estimates the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **MODERATE TO HIGH**. The key reasons for this judgment are:

- Geologic exploration data are poor to nonexistent.
- The piping pathways process progresses slower than Failure Mode 1 (embankment internal erosion failure modes).
- 1921 breach at Farm District Road may have been an example of a foundation failure mode.
- Some evidence of serious flaws in the foundation (animal burrows, tree root systems, pipe penetrations).
- History of failures over the 100 years of operation.
- Once started, piping would not progress as fast as the 2008 breach, potentially providing increased time for intervention.
- No defensive measures in the embankment or foundation area to prevent piping.
- Number of critical flaws within the foundation not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the foundation.
- Numerous seepage areas.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within inundation area only slightly less than that of 2008 breach.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 4

Parameters

1. Analysis limited to only the 11.7 mile Fernley reach of Canal.
2. One full season (12 months) of operation.
3. Operational restrictions to reduce or eliminate rapid Canal stage increases (spiking) by limiting increases in Canal stage to no more than one measured foot per day in any reach. This would most likely require telemetry and the ability to operate Derby Diversion Dam in timely manner.
4. Canal water surface (checked or unchecked conditions) is not to exceed that produced by the unchecked Canal flowing at 150 ft^3/s.

Conclusion

The RA Team estimates that the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **LOW TO MODERATE**. The key reasons for this judgment are:

- Known seepage areas can be monitored.
- Existing seepage areas appear to have a substantially reduced flow at lower Canal flows.
- Greatly increasing ability to intervene by ability to divert flow via turnouts.
- The foundation seepage path is longer and will take longer to fail.

- The Canal foundation has apparently operated for much of its life at or about the range of 200 to 500 ft^3/s.
- Some evidence of serious flaws in the foundation (animal burrows, tree root systems, pipe penetrations), but that at this flow level the effect would be lees significant due to greater embankment/foundation cross section and less static head.
- History of failures over the 100 years of operation.
- Once started, piping would not progress as fast as the 2008 breach, providing an increased time for intervention.
- No defensive measures in the foundation to prevent piping.
- Amount of critical flaws within the foundation not identified by observation or inspection. The extent and combination of these flaws are unknown as to the integrity of the foundation.
- Favorable piping conditions (vegetation growth with deep root systems, animal burrows, embankment sloughing) resulting from inadequate maintenance by TCID.

Consequences

The RA Team estimates the consequences of this scenario to be **HIGH.** The key factors contributing to this judgment are:

- Consequences to individuals within inundation area would be less than those of 2008 breach, but still severe.
- Lost mission capacity to the point of not being able to deliver decreed water rights.
- Major damage to the facility occurs.
- Community experiences major financial loss.
- Catastrophic harm to individuals or serious life threatening situations develop.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

OPERATIONAL SCENARIO NO. 5

Parameters

1. Restrict Canal to no flow.

Conclusion

The RA Team estimates that the probability of failure from this type of operation in the Fernley reach during the next season of operations (Spring 2008 to Spring 2009) is **LOW**. The key reasons for this judgment are:

- With no water in the canal, a piping failure is impossible.

Consequences

The RA Team estimates the consequences of this scenario to be **LOW TO MODERATE.** The key factors contributing to this judgment are:

- Reclamation's mission to deliver water will not be significantly impacted in the next year because the Carson River watershed (with an above normal snowpack) will be used to fill Lahontan Reservoir and meet the National Wildlife Refuge and Indian Trust responsibilities. Farmers using Canal water upstream of Lahontan Reservoir would be impacted by an inability to receive irrigation water.
- No flooding consequences to individuals.
- No damage to the facility.
- No financial loss to non-farm community.
- No catastrophic harm to individuals or serious life threatening situation develop due to flooding.
- There will be financial impacts to the farm community, TCID, and supporting business community.
- Reclamation at risk of not meeting Indian Trust responsibilities and refuge water deliveries.
- The potential for a reduction in groundwater supplies to the cities of Hazen and Fernley, due to lack of recharge from the Canal.

The results of the RA Team's evaluation of Scenarios 1 through 5 are plotted below on the Risk Matrix (Table 4).

Table 4. Failure Mode 2 Risk Matrix - Canal Failure Caused by Erosive Forces through the Foundation

CONSEQUENCES OF FAILURE	FAILURE MODE LIKELIHOOD		
	LOW	MODERATE	HIGH
HIGH Consequence Category	III Low Likelihood High Consequence Scenario 4	II Moderate Likelihood High Consequence Scenarios 1, 2, and 3	I High Likelihood High Consequence
MODERATE Consequence Category	IV Low Likelihood Moderate Consequence Scenario 5	III Moderate Likelihood Moderate Consequence	II High Likelihood Moderate Consequence
LOW Consequence Category	V Low Likelihood Low Consequence	IV Moderate Likelihood Low Consequence	III High Likelihood Low Consequence

Other Potential Failure Modes

The RA Team did not formally evaluate the other failure modes initially identified; hydrologic, seismic, and sabotage. The hydrologic mode was informally discussed and considered; the seismic and sabotage modes were not.

Hydrologic Failure Modes

Two hydrologic failure modes were briefly discussed by the RA Team: (1) overtopping of the Canal caused by a large sudden increase in the Canal water surface elevation during a hydrologic event, and (2) a sudden increase in the Canal water surface caused by a hydrologic event results in failure of the Canal due to internal erosion and piping. These hydrologic failure modes only involve the higher elevation drainage basins above the south side of the Canal and do not involve large diversions into the Canal from the Truckee River during a hydrologic event.

For Failure Mode 1 - Scenario No. 4, the RA Team estimated a MODERATE probability of failure in the Fernley reach. The RA Team acknowledges that the water surface elevation in the Canal may increase during a hydrologic event. However, no information was available that could be utilized to provide an estimate for the hydrologic risks posed during Failure Scenario No. 4. The team is concerned that if a large spike in the Canal water surface is created during a flood event with a return period of 100 years or more, the probability of a hydrologic failure mode may be rated as HIGH.

The RA Team recommends that a hydrologic study of the drainage basin above the Canal be completed for several frequencies of floods to see if the levels of risk estimated for piping failure modes should be adjusted for increased water surface elevations in the Canal during a hydrologic event. A hydrologic study would also assist in determining a risk level for the overtopping failure mode.

Seismic Failure Modes

A seismic failure of the Canal embankment was not discussed by the RA Team. The Canal embankment is constructed of low-density materials for some, if not all, of the Canal length. The Canal embankment materials are known to have a high moisture content based on the geologic investigations performed at the 2008 failure site. This combination of low density and high moisture content materials strongly suggest that the Canal embankment is susceptible to liquefaction and/or a cyclic failure during a seismic event. However, there is not enough information available at this time to evaluate these risks.

Sabotage Failure Modes

The RA Team determined sabotage failure modes as beyond the scope of this study.

Recommendations Resulting from this Issue Evaluation

The RA Team recommendations include a relative assessment of the cost of implementation. The cost assessment designations utilized were High, Moderate, and Low. They are based upon the cost ranges determined by the RA Team, as presented in Table 5. The value ranges are arbitrary, with agreement among of the team and are based neither on actual current prices nor on actual quantities.

Table 5. Cost Assessment Designations and Associated Cost Ranges

Cost Assessment Designation	Cost Range
High	> $10 million
Moderate	$5 million to $10 million
Low	< $5 million

Recommendation No. 1

In the 11.7 mile Fernley reach of the Canal, the water surface (operating in either checked or unchecked conditions) should be restricted to a level not to exceed that produced by the unchecked flow at 150 ft^3/s. Canal stage increases or decreases should not be allowed to exceed 1-foot per day in any reach of the Canal. There are no direct costs associated implementing this recommendation.

Discussion

The RA Team estimated the implementation of Recommendation No. 1 to have a risk value rating of II (Moderate Likelihood-High Consequence). At this level of flow, there would be substantial freeboard on the Canal embankment. This would greatly reduce the probability that concentrated seepage paths would penetrate the embankment to an extent that internal erosion would initiate and progress to a breach. At this level of flow, the time it would take to fail the embankment was judged to be prolonged enough that intervention might be successful to preclude complete breach. The stage restriction contained in this recommendation is not imposed on the other 21+/- miles outside the Fernley reach. The RA Team did not specifically evaluate the likelihood of failure or the consequences of a Canal failure in these other reaches. Based on the findings of the Canal Inspection Team, the RA Team's evaluation of the likelihood of failure of the embankment would probably remain unchanged in those reaches of the Canal; however, the consequences would be lower as there few residences below these reaches of canal. It should be recognized that the most likely cause of failure, as indicated by the Forensic Analysis Team, is seepage initiating erosion within the embankment caused mainly by concentrated seepage through flaws (animal burrows, decaying tree roots, pipe penetrations) that currently exist within the embankment. Operations personnel should operate those reaches of the Canal with extreme care and consider the RA Team's stage recommendations in the Fernley reach when developing operating criteria and procedures for these other reaches.

Recommendation No. 2

To further lower the estimated risk value rating to **III** (Low Likelihood-High Consequence), a temporary lining system should be added to the north side Canal embankment from the invert to a stage level equal to the unchecked Canal flow of 150 ft^3/s, plus some freeboard, through the entire Fernley reach. The temporary lining system is estimated to last approximately 3 years; the length of time estimated to implement a permanent Canal structural fix (see Recommendation No. 6 below). Additionally, known seepage locations should receive a similar temporary lining covering the entire wetted perimeter, plus freeboard, at the 150 ft^3/s flow level. The cost assessment rating to implement this lining addition is **LOW.**

Discussion

The RA Team determined that the addition of a geomembrane lining system would reduce the risk value rating of Recommendation No. 1 from **II** (Moderate Likelihood-High Consequence) to a risk value rating of **III** (Low Likelihood-High Consequence). The lining would block the entrance to existing discontinuities, reducing the likelihood of failure. Such a lining system could be implemented in a short time frame and would survive under the low flow conditions associated with 150 ft^3/s.

Recommendation No. 3

Truckee-Carson Irrigation District's operations procedures for the Canal should be thoroughly reviewed and revised to provide the necessary and timely response to emergency situations similar to the January 5, 2008, event. In order to adequately address this recommendation, a Standing Operating Procedure (SOP), an Emergency Action Plan (EAP), and a Facility Improvement Plan (FIP) should be prepared by TCID, then reviewed and approved by Reclamation. The cost assessment rating to develop and implement the SOP and the EAP is considered **LOW.** The cost assessment rating to develop and implement the FIP is considered **MODERATE to HIGH.**

Discussion

One of the operational weaknesses revealed by the January 5, 2008, event was TCID's inadequate ability to respond and intervene on the established Canal operating conditions. Given the physical condition of the control structures at the time and the reaction time to shut down the Canal, the RA Team is concerned about the existing operating policies and procedures for the facilities.

A SOP should be developed that considers all aspects of a possible Canal flow scenario similar to the recent failure event; including staffing, reaction times, times to close or open control structures, turnouts and wasteways, use of turnouts as possible wasteways; evaluation of drainage systems to convey water away from the facility when emergency discharges through wasteways or turnout are required, expansion of these drainage facilities if required, and any other means or methods to assist with controlling the facility in the event of a failure.

An EAP should be developed that itemizes appropriate contact people, delineates roles and responsibilities, and lists all available modes of communications to interface people and the transfer of information. After development of the EAP, initiation of one or more emergency trial runs that test the requirements of SOP and the EAP should be implemented. With the existing Canal facilities, operational reactions are significantly limited to on-site personnel. This document should recognize and address this weakness. Both the SOP and EAP must be reviewed and approved by Reclamation, and finalized before flows are allowed to return to the Canal.

If loss of control of the Canal were to occur late at night, mobilization of staff to appropriate facilities is limited by a lack of information regarding the operating status of the Canal. New facilities to operate, monitor, and control the existing control structures of the Canal system are required to minimize the impact of operational failures of this nature. A FIP should be prepared to evaluate, plan, and cost the necessary improvement that will minimize these impacts in the future. This document should be completed before Canal flows are allowed to be increased above those discussed in Recommendation No. 1.

Recommendation No. 4

In coordination with the SOP and EAP mentioned in Recommendation No. 3, a surveillance program should be developed, exercised, and implemented prior to the reintroduction of any flows into the Canal. This program should interface with the SOP and the EAP; it should delineate staffing requirements, patrolling procedures, and monitoring and recording requirements. The program should present procedures and schedules for cleaning of the downstream Canal embankment slopes to allow for observation and inspection. The surveillance program must be approved by Reclamation prior to implementation. The cost assessment rating to develop and implement the required surveillance program is considered **LOW.**

Discussion

A proper operational surveillance program, including emergency action planning, yields efficiencies in staging personnel, equipment, and materials that helps facilitate proper facility operations that lessen spikes in Canal flow, avoid structure failures, and improve response to possible future Canal failures.

Recommendation No. 5

A comprehensive maintenance plan must be developed. The plan must include components that ensure an aggressive approach to removing vegetation and limiting the animal damage.

The plan should include an accountability system in which TCID would show Reclamation schedules for completion milestones, including intermediate status reports. The cost assessment rating to develop and implement the required maintenance program might be considered **MODERATE.**

Discussion

A maintenance program will provide short-term and long-term assurances for scheduling personnel, equipment, and materials for regular Canal cleaning, rodent eradication, tree and other vegetation removal, and structure repair. Investing in aggressive maintenance discourages future animal activity, and eliminates roots before large systems develop, thus protecting the Canal embankment integrity long-term.

Recommendation No. 6

Repair the Canal through the Fernley reach with a full structural fix that will address all piping failure modes. The cost assessment rating to develop and implement a full structural fix in the Fernley reach is considered **HIGH.**

Discussion

A properly selected, designed, and constructed structural fix will lower the risk value rating to the III (Low Likelihood-High Consequences) for full, unrestricted Canal operations. The selection should address all of the potential “flaws” identified in the risk analysis. Once constructed, the repair will greatly lower the potential for piping as a “hard” barrier would be in place to prevent the initiation of piping into existing flaws. Furthermore, the potential for full breach is reduced as the repair would greatly slow the progression of piping, allowing for intervention to successfully preclude complete failure.

Recommendation No. 7

Determine the risk of other failure modes not addressed by this report (hydrologic and seismic).

Discussion

Although the scope of this report was limited to two static failure modes, the RA Team believes that evaluation of other failure modes (hydrologic and seismic) could be beneficial and could provide additional input for the various structural repairs currently under consideration. If the risk values for these other failure modes are rated HIGH, such additional evaluations would be very beneficial, and should be addressed by any future structural repairs.

Recommendation No. 8

Determine the risk of those reaches of the Canal that were not evaluated in this report.

Discussion

The RA Team believes there is a likelihood of failure for other locations along the Canal should be similar to that determined for the Fernley reach. Reclamation should determine if the consequences of a failure in these reaches of the Canal are unacceptable.

Summary of Answers to Regional Engineer's Questions

As discussed in the Scope above, n addition to evaluating the risks associated with resuming Canal operations, the RA Team was tasked by the Regional Engineer to address the following questions:

1. In order to resume operations of the Canal what other repairs need to be done immediately?

2. What are the criteria, standards, risks, and engineering judgments that will go into assessing the ability of the Canal to pass a range of flows, ranging from zero to full capacity with some acceptable risk?

3. From Item 2, what operational restrictions should be imposed, and ensure that the basis of these restrictions are fully reasonable and justified?

4. What are the short- and long-term recommendations for needed actions to reinitiate operations of the Canal?

5. What procedures should be recommended and followed in resuming flows in the Canal?

A summary of the team's answers (notes) follows:

1. In order to resume operations of the Canal what other repairs need to be done immediately?

Action:

A. Limit canal capacity to no more than 150 ft^3/s
B. Limit canal filling rate to no more than 1 foot per day
C. Line the north canal embankment over the 11.7 mile reach through the City of Fernley and line the entire wetted perimeter at known seepage locations
D. Implement a surveillance program that includes the following:
   i. EAP

ii. SOP
iii. Clearing of vegetation from the canal slopes to permit improved observation

By completing these actions, the team judged that risk would be LOW. Prudent measures would be implemented to monitor the canal performance and plans would be in place to deal with emergency operations in the event of the beginning of a canal failure.

2. What are the criteria, standards, risks, and engineering judgments that will go into assessing the ability of the Canal to pass a range of flows, ranging from zero to full capacity with some acceptable risk?

This report describes a risk analysis process that was used to evaluate the existing canal. This process identifies criteria, detailed minimum standards to be met, estimated risks, and documented engineering judgment used.

The present analysis only evaluates risks in the 11 miles of canal passing thru the city of Fernley. Other studies would be required to address the risks associated with possible canal failures in the remaining 20 miles of the Truckee Canal. Generally, from our existing observations and analysis, it appears that the failure modes and the probabilities of those failures would be similar to those identified in the Fernley Reach.

3. From Item 2, what operational restrictions should be imposed, and ensure that the basis of these restrictions are fully reasonable and justified?

Item 1 addresses the recommended operational restrictions.
Item 2 describes the process of how the RA Team arrived at the restrictions.

4. What are the short- and long-term recommendations for needed actions to reinitiate operations of the Canal?

Short term recommendations are presented in item 1.
Long term recommendations include the following:

A. This report identifies failure modes associated with embankment failures. Significant and costly structure repairs appear to be required to address the failure mechanisms that have been identified. Alternatives that have been identified in the report, but which may require further engineering analysis to refine selection include: (These alternatives impart risk reduction)
   i. Sheetpile cutoff wall in the embankment
   ii. Slurry cutoff wall in the embankment
   iii. Embankment repairs combined with a canal lining

B. Further studies are necessary to address the seismic and hydrologic failure modes. These failure modes may also require structural repairs should the resulting risks prove to be unacceptable.

Other alternatives were evaluated but did not impart a significant amount of risk reduction.

5. What procedures should be recommended and followed in resuming flows in the Canal?

To best answer this we assume that his implies the implementation of various Best Management Practices (non-structural). These activities can be initiated during and after implementation of long term structural repairs. These measures could include but are not limited to:

A. Development and implementation of EAP. SOP,
B. Initiation of an aggressive maintenance program that includes
    i. Clearing vegetation and trees from the slope and within the canal right-of-way.
    ii. Repair of animal burrows as may be necessary.
    iii. Implementation of an animal removal program.

C. Improvement of drainage systems thru the city of Fernley – Involves working with Fernley and Reclamation.
D. Incorporation of structural repairs to existing check structures and turnouts including the addition of automation facilities, that will aid canal system control and response as required to assist with emergency response activities.
E. Addition of new check structure and wasteway facilities as may be necessary to further assist canal operations and emergency control and response procedures as are defined in items A and D above.

Appendix I

Failure Mode 1

Canal Failure Caused by Erosive Forces through the Embankment

To aid the Risk Assessment Team's consideration factors such as Canal flow, checked up storage, restricted flow levels, and Canal conditions, five operating scenarios were developed to help reasonably bracket possible combinations. Many more combinations could have been studied, but the scenarios were chosen that would provide sufficient information to assess the risks and inform decision makers. This appendix provides further detailed information on the likely and less likely factors considered by the team.

The team listed possible initiating causes of the embankment seepage pathways (flaws), which include:

- Animal burrows
- Tree roots
- Discontinuities (pipelines, turnouts)
- Embankment-foundation interface
- Unknown flaws covered by vegetation or debris
- Poor construction of original embankment
- Lenses of permeable material
- Poorly constructed embankment repairs
- Differential settlement with cracking
- Desiccation cracking
- Potential connection to drainage areas about Canal
- Excessive gullying that shortens the seepage path or reduces stability
- Unknown construction practices
- Slumping that thins embankment section

Other factors that could raise concern included:

- No defensive design
- No designed filter
- Embankment constructed of erodible material (silts)

The hydrologic causes listed include:

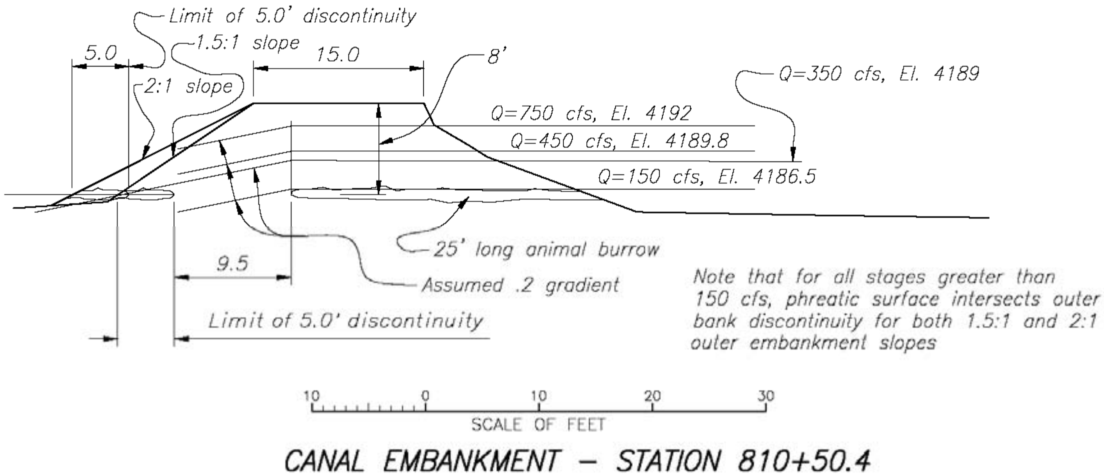
- Overtopping
- Siltation from side drainages
- Ice dams
- Slope failure blocking flow
- Loss of check structure

- Misoperation of features

The RA Team defined Failure Mode 1 as a concentrated seepage pathway existing within the Canal embankment. The concentrated seepage could be caused by one or more reasons, including animal burrows, decomposing tree roots, and discontinuities. The concentrated seepage pathway extends almost or completely through the embankment. Water in the Canal rises above the entrance to the seepage point. Water flow out of the landside face of the Canal embankment begins and initiates erosion of embankment materials (piping). The type of soil or embankment condition contributes to erosion acceleration. The pipe widens rapidly. Erosion is neither found nor observed by the public nor TCID staff. Intervention is belated or unsuccessful. The Canal fails and consequences result.

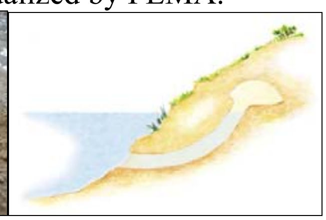
The RA Team spent a great deal of time discussing seepage gradients through the Canal embankment. The team concluded that a reasonable seepage gradient through an embankment of this material would be 0.2 feet/foot. Figure A-1 below represents a section through the left canal embankment at Station 810+50.4. The 15.0 foot operation and maintenance (O&M) road width is assumed. The figure also depicts outboard side slopes for the embankment of both 2:1 and 1½:1. The Canal section shows a 25-foot long animal burrow into the embankment from the canal side. At least one animal burrow of this length is documented on the Canal. A 5-foot long discontinuity is depicted on the outboard side of the embankment. This discontinuity could be the result of decaying tree roots, erosion, excavation, or even another animal burrow. Also depicted on the section are water surface stages for 750 ft^3/s, 450 ft^3/s, 350 ft^3/s, and 150 ft^3/s. The figure shows the likely phreatic water surfaces through the embankment for all of the flow levels, along with the gradient of 0.2 feet/foot for flows downstream of the 25-foot long animal burrow. For all stages greater than 150 ft^3/s, the gradient exits into the outboard discontinuity; a condition that would be conducive to piping.

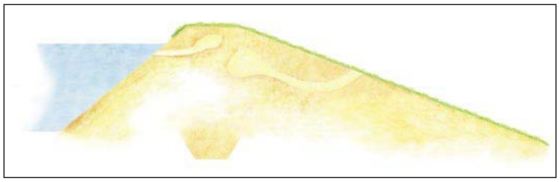
Figure A-1. Embankment Seepage



Stage	Water Depth Above Animal Burrow (ft)
750	6
450	3.8
350	3
150	0.5

Likely Factors	Unlikely Factors
Animal burrows	
The entire Canal system is riddled with burrows. The inspection team estimated they probably only documented 20% of the burrows that exist in the Fernley reach due to difficult inspection conditions.	During 2008 inspections, no burrows were found that penetrated completely through the embankment, but inspection conditions were difficult.

Likely Factors	Unlikely Factors
A burrow was found only 250 feet from the 2008 breach site that penetrated 12 feet (about one-half the embankment width). The "inlet" of the burrow was about at the 350 ft^3/s flow line. The burrow was "cast" by grouting it with polyurethane grout. Upon excavation, the cast indicated that the burrow penetrated about 25 feet, be open all the way, and have a diameter of about 2 to 6 inches. Some gullying was found directly opposite this burrow and a delta of sand had been deposited at the base of the gully.   Multiple side channels were found. The layout of the hole was similar to that conceptualized by FEMA.   Source: FEMA Manual 473, September 2005	Excavation of the embankment crest at this burrow/gully location did not find evidence that the burrow penetrated completely through the embankment. Based upon survey data, the crest at this location looks to have a dip that would collect and concentrate rainfall. Eventually the dip could overflow and over time cause erosion to the embankment. The thinning embankment could promote seepage/piping conditions.
Some burrows were found to be >25 feet long (site inspection report stations).	Reported by TCID that past operations (slow filling of canal) tends to cause the burrows to collapse.
The 1996 breach was reportedly due to animal burrowing.	Cause of previous breaches, including 2008 breach, have not and cannot be determined for certain.
The embankment was constructed from silt with sand to sandy silt (give properties) and is thus very erodible (I_{HET} = 3.6 to 3.8, indicating potential for moderately rapid erosion). Compaction was poor, found to be between 70% to 84% compaction. Current Reclamation standard practice would require 95% (Standard Proctor). It is conceivable that a full breach could happen in the 3 to 4 hours from water rise to complete breach.	Most burrows found by the special inspection were measured to be 5-feet deep or less.

Likely Factors	Unlikely Factors
Very possible that animals burrowed from each side of canal embankment.  Source: FEMA manual 473, September 2005	
The canal embankment has been there for 100 years. It is likely there are burrows where the entrance has been covered or collapsed that were not observed by the inspection team. Presumably, muskrats and other animals started burrowing when the canal was built and that process has continued for the 100-year life of the canal.	Has operated successfully under certain operational conditions with 100 years of muskrat holes in place. Operation conditions would be low flows.
Ramping quickly (within 12 hours) to very high levels (freeboard associated with anything above 350 ft^3/s) seems to correlate to past failures.	During the summer months, the canal is checked up to store water. History shows that the canal fails in the winter and not in the summer.
Inboard burrows may intersect discontinuities, such as root systems, extending to the outboard face of embankment.	Rodent burrows tend to be higher on embankment.
Necessary operation of the canal to deliver water promotes water elevation conducive to perpetuate animal populations.	
Lack of vegetation control has promoted the perpetuation of animal habitat.	
Lack of defenses against animal burrowing has promoted animal burrows.	
Tree roots	
Lack of maintenance has allowed growth of numerous large trees.	Trees allow roosting locations for raptors, which then feed on burrowing rodents.
Trees have been cut down or died, leaving decaying root systems.	Sometimes tree root system is all that is holding the crest together.
Long history of canal means that there may be many more root systems not observed.	
The presence of trees indicates potential seepage areas. Trees may be an indicator of seepage.	
Cottonwood, saltcedar, Russian olive, and willow trees have a lateral spreading root system that would penetrate embankment.	

Likely Factors	Unlikely Factors
Trees could blow over causing damage to the embankment. The damaged embankment would be narrower than the original, leaving it more susceptible to seepage/piping.	
Clumps of trees mask potential flaws.	
Manmade discontinuities	
The fact that there are discontinuities increases the likelihood of seepage.	
Many of the pipelines were constructed by nontechnical contractors/individuals unaware of proper construction techniques.	
Pipelines are not maintained.	
Location of discontinuities is not documented (lack of structures list).	
Trespassing laws has not been enforced.	
Sand bedding for embedded pipelines parallel to canal may connect to many potential flaws running transverse to canal (Gustafson Drive, abandoned gas pipeline at breach location).	
Utility crossings running transverse to canal may have sand bedding or poorly constructed leading to seepage pathways.	
Lack of uniform, or identified, process for canal crossing(s).	
Other Factors	
No defensive design measures.	TCID has access to heavy equipment and materials.
Debris and vegetative cover inhibits observations and inspection.	Many eyes on Canal (Canal is in a populated area, recreational use (bikers, hikers, children).
Maintenance practices have over-steepened and thinned the embankment and masked potential flaws in the canal embankment. This practice may be cutting away compacted embankment and getting closer to exposing spoil cast-off that would be uncompacted material. Masking of severed roots and rodent holes in the embankment.	For normal operation, the canal has been checked up during summer months. This has happened over many years in the past without failure.
Much of the stretch of Canal through the Fernley reach is composed of a higher percentage of loosely compacted fine grained material (erodible silts).	Low stage creates a lower head and longer seepage path, thereby reducing gradient lowering the

Likely Factors	Unlikely Factors
	volume in the canal, increasing checking ability, slows the whole failure process down allowing for a higher percentage of successful intervention.
Sedimentation of canal bottom has caused a higher stage level for same flow (Q).	Some sections of the canal have wide crest decreasing the seepage gradient.
Checked up condition creates higher gradients and time to develop phreatic levels in embankment. Moving wetted front farther downstream, exacerbating the situation.	Embankment at the breach site appears to have some plasticity and as such may not be as erodible as a silty sand.
Sedimentation promotes algae growth, increasing roughness coefficient, increasing water elevation.	Flow velocities do not change significantly between low and high Qs.
Intervention is likely to be unsuccessful (the 2008 breach was too rapid to do anything about). The ability to safely and quickly discharge a large amount of water from the canal (through wasteways) for the purpose of reducing flooding impacts due to a breach is not available, because the wasteways are too far away and because the gates are manually operated. There is not enough venting capacity in turnouts to make a difference, there is a manual operator, not enough checks, ability to take action is very limited, ability to activate them is limited (no automation, limited wasteways, limited check structures).	
2008 event has raised the awareness of potential security issues.	
Data indicates the likelihood that rapid flow increases (spiking flows) occurred in the period immediately before the Canal failures of January 1921, 1996, and 2008.	
1918, 1951, and 1975 events were not clearly spiking, but appear related to high, or higher, flows prior to breaches.	
There were insignificant evidence of spiking flows in the Truckee River surrounding the event of 1919. Due to lack of data, the RA Team could not determine what hydrologic conditions existed during the 1957 and 1959 failures.	

Risk Reduction Measures

The Risk Assessment Team used the following matrix to gauge the adequacy of the risk reduction measures they considered. On the following tables, "X" indicates the team believed that the measure reduced the risk by one full step (one colored box) on the Failure Mode Risk Evaluation Matrix (Table 1), "XX" indicates a two full step reduction (two colored boxes), and "XXX" indicates a three full step reduction (three colored boxes). For example, one X shows the reduction of risk from HIGH to MODERATE if that specific remedial measure were implemented. "¼ X" and "½ X" indicates the team considered the remedial measure and believed there was some risk reduction, but not a significant amount. Lines with a strikeout indicate that the team considered the remedial measure, but did not feel the measure applied to the option under consideration.

Risk Reduction Measures Operational Scenarios 1, 2, and 3						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Structural Alternatives						
Sheet pile	XX	XX	High	Common construction. Has been done before. Reclamation has employed this method before. Potential liquefaction of embankment materials.	1.5 years	Positive cutoff. Catastrophic failure is unlikely. Mission capability is maintained.
Slurry cutoff wall (Cement Bentonite)	XX	XX	High	Common construction techniques employed. Reclamation has employed this method before. Potential of hydro-fracturing during construction.	1.5 years	Positive cutoff. Catastrophic failure is unlikely. Mission capability is maintained.

Risk Reduction Measures Operational Scenarios 1, 2, and 3						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m Medium $5-$10m High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Concrete liner	X	No reduction	High	Canal required to be dewatered. Common construction to Reclamation	2 years	Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff.
Grouted rock liner	(½ X)	No reduction	Medium	Canal required to be dewatered. Common construction to Reclamation	2 years	High maintenance. Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff.

Risk Reduction Measures Operational Scenarios 1, 2, and 3						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m Medium $5-$10m High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Pipe	XX	X	High	Dewatering required. Common construction to Reclamation. May be lead-time issues on pipe.	2 years	Complication to mission continuity. Low maintenance. Groundwater recharge issues.
Add checks and wasteways	No reduction	(¼ X)	Medium	Dewatering required. Common construction to Reclamation.	1 year	Complication to mission continuity. No reduction of maintenance. Develop hydraulic study to locate applicable sites for checks and wasteways.

Risk Reduction Measures Operational Scenarios 1, 2, and 3						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Excavate and replace (assumes good maintenance	XX	(¼ X)	High	Dewatering required unless parallel construction performed. Common construction to Reclamation.	2 years	Complication to mission continuity. Nonpositive cutoff. Has defensive design measures.
Filters and drains and berm	XX	(¼ X)	High	Right-of-way issues. Common construction to Reclamation.	2 years	Nonpositive cutoff. Has defensive design measures
Riprap and bedding	(¼ X)	No reduction	Medium	Canal required to be dewatered. Common construction to Reclamation	1 year	Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff

Risk Reduction Measures Operational Scenarios 1, 2, and 3						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Repair animal hole	(¼ X)	No reduction	Low	Requires dewatering.	< 1 year	Complication to mission continuity. Nonpositive cutoff.
Canal reshaping (grading, desiltation, etc.)	No reduction (may increase or reduce)	No reduction	Low	Requires dewatering	2 years	Complication to mission continuity. Nonpositive cutoff
Geomembrane and slope protection	XX	No reduction	High	Canal required to be dewatered. Common construction to Reclamation.	2 years	Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff.

Risk Reduction Measures Operational Scenarios 1, 2, and 3						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Non-Structural						
Automated controls and measurement (SCADA)	(1/4X) some reduction by control of potential surges	No reduction	Low	Common installation for Reclamation.	1 year	Has to implemented in support of a operational plan and EAP

Risk Reduction Measures Operational Scenario 4						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m Medium $5-$10m High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Structural Alternatives						
Repair animal hole	(¼ X)	No reduction	Low	Requires dewatering.	Less then a year	Complication to mission continuity. Nonpositive cutoff.
Temporary lining (3-year lifespan with aggressive maintenance program)	X	No reduction	Low	Construction would be fairly simple. Common construction to Reclamation. May have supply problems	months	Complication to mission continuity. Lining of sides slopes only (to 150 ft^3/s stage level)
~~Sheet pile~~	~~X X~~	~~X X~~	~~High~~	~~Common construction. Has been done before. Reclamation has employed this method before. Potential liquefaction of embankment materials.~~	~~Year and a half~~	~~Positive cutoff. Catastrophic failure is unlikely. Mission capability is maintained.~~

Risk Reduction Measures
Operational Scenario 4

Remediation measure	Reduces probability of failure by (1, 2 or 3 blocks)	Reduces consequences	Cost of remediation Low < $5m Medium $5-$10m High >$10m	Construction considerations	Likely duration of construction	Notes
~~Slurry cutoff wall (Cement Bentonite)~~	~~X X~~	~~X X~~	~~high~~	~~Common construction techniques employed. Reclamation has employed this method before. Potential of hydro-fracturing during construction~~	~~Year and a half~~	~~Positive cutoff. Catastrophic failure is unlikely. Mission capability is maintained~~
~~Concrete Liner~~	~~X~~	~~No reduction~~	~~High~~	~~Canal required to be dewatered. Common construction to Reclamation~~	~~Two years~~	~~Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff.~~
~~Grouted rock liner~~	~~(½ X)~~	~~No reduction~~	~~Medium~~	~~Canal required to be dewatered. Common construction to Reclamation~~	~~Two years~~	~~High maintenance. Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff.~~

Risk Reduction Measures Operational Scenario 4						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
~~Pipe~~	~~XX~~	~~X~~	~~High~~	~~Dewatering required. Common construction to Reclamation. May be lead-time issues on pipe.~~	~~Two years~~	~~Complication to mission continuity. Low maintenance. Groundwater recharge issues.~~
~~Add checks and wasteways~~	~~No reduction~~	~~(¼ X)~~	~~medium~~	~~Dewatering required. Common construction to Reclamation.~~	~~One year~~	~~Complication to mission continuity. No reduction of maintenance. Develop hydraulic study to locate applicable sites for checks and wasteways.~~
~~Excavate and replace (assumes good maintenance~~	~~XX~~	~~(¼ X)~~	~~High~~	~~Dewatering required unless parallel construction performed. Common construction to Reclamation.~~	~~Two years~~	~~Complication to mission continuity. Nonpositive cutoff. Has defensive design measures.~~
~~Filters and drains and berm~~	~~XX~~	~~(¼ X)~~	~~High~~	~~Right-of-way issues. Common construction to Reclamation~~	~~Two years~~	~~Nonpositive cutoff. Has defensive design measures~~

Risk Reduction Measures Operational Scenario 4						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
~~Riprap and bedding~~	~~(¼ X)~~	~~No reduction~~	~~Medium~~	~~Canal required to be dewatered. Common construction to Reclamation~~	~~One year~~	~~Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff~~
~~Canal reshaping (grading, desiltation, etc.)~~	~~No reduction (may increase or reduce)~~	~~No reduction~~	~~low~~	~~Requires dewatering~~	~~Two years~~	~~Complication to mission continuity. Nonpositive cutoff~~
~~Geomembrane and slope protection~~	~~XX~~	~~No reduction~~	~~High~~	~~Canal required to be dewatered. Common construction to Reclamation~~	~~Two years~~	~~Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff.~~
Non-Structural						

Risk Reduction Measures Operational Scenario 4						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
24/7 Monitoring, surveillance and intervention plan and cleaning downstream slope of vegetation	(½ X to X) depends on how robust implementation plan is.	X	Low	Maintenance required prior to implementation	months	Will required development and implementation of SOP that includes EAP
~~Automated controls and measurement (SCADA)~~	~~(1/4X) some reduction by control of potential surges~~	~~No reduction~~	~~Low~~	~~Common installation for Reclamation~~	~~One year~~	~~Has to implemented in support of a operational plan and EAP~~

Appendix II

Failure Mode 2

Canal Failure Caused by Erosive Forces Through the Foundation

To evaluate Failure Mode 2, the Risk Assessment Team applied the evaluation criteria to the same five scenarios. This appendix provides further detailed information on the likely and less likely factors considered by the team. Each of the following scenarios presents the scenario parameters (the same as Failure Mode 1), the team's conclusion about the probable level of risk, and potential foreseeable consequences.

The team listed possible initiating causes of the foundation seepage pathways (flaws), which include:

- Animal burrows
- Tree roots
- Discontinuities (pipelines, turnouts)
- Embankment-foundation interface
- Unknown flaws covered by vegetation or debris
- Lenses of permeable material
- Poorly constructed embankment repairs
- Differential settlement with cracking
- Desiccation cracking
- Potential connection to drainage areas about Canal
- Excessive gullying that shortens the seepage path or reduces stability
- Non-Reclamation/TCID construction

Other factors that could raise concern included:

- No defensive design
- No designed filter

The team defined Failure Mode 2 as a concentrated seepage pathway existing through the Canal foundation. The concentrated seepage could be caused by one or more reasons, including animal burrows; tree roots; discontinuities; jointed foundation rock or other geologic features; and weak, porous or erodible foundation layers. The concentrated seepage pathway extends almost or completely through the foundation. The water in the Canal rises above the entrance of the seepage point. Water flow out of the foundation downstream of embankment toe or the landside face of Canal embankment begins and initiates erosion of foundation materials (piping). The foundation condition contributes to erosion acceleration. The pipe widens rapidly. Erosion is neither found nor observed by public or TCID staff. Intervention is belated or unsuccessful. The Canal fails and consequences result.

Likely factors	**Unlikely factors**
Animal Burrows, Tree Roots, Manmade Discontinuities	
Referencing discussions regarding penetration as discussed in "Failure Mode 1: Canal Failure Caused by Erosive Forces through the Embankment" (animal burrows, tree roots, manmade discontinuities); the foundation These types of factors would be less likely to impact the foundation except possible for areas of pipe-jacking,	
Rodents have been known to burrow into the foundation (but frequency is less than in the embankment)	
Trees and other vegetation exist and have grown into the foundation material, but frequency is less than in the embankment,	
Other Factors	
There are identified areas of observed seepage (Farm District Road; about Station 565+00; numerous areas of heavy vegetation downstream of embankment; wet area at Ricci Lane; the Gay property).	
At the 2008 breach site, the upper siltstone was tested (block #2) and had a HET test between 2 and 3 (moderately erodible).	That same material was observed to be unjointed with no observable flaws as exposed in the breach.
At the 2008 breach site, the jointed claystone was observed to have many discontinuities and seepage pathways.	The lower claystone was tested (block #1) had a HET test greater then 6 (very non erodible).
At the 2008 breach site, observed gravel network below may provide a pathway for piping of upper foundation materials.	At the 2008 breach site, had the claystone been saturated the discontinuities would have been closed, making a foundation failure less likely.
Past sediment/algae removal operations within the Canal may have damaged the existing foundation layers exposing more permeable/erodible layers below.	Typical canal operations result in a water elevation frequently above the foundation and preclude animal burrowing
	Siltation may reduce seepage into foundation.
	Sand deposits in canal may provide filter capability to potential seepage pathways.

Likely factors	Unlikely factors
	Special inspection performed after the 2008 breach did not note observation of sinkholes.
	Artesian pressures on land-side toe of embankment are likely minimal.
	No soluble materials likely in this area.

Risk Reduction Measures

The Risk Assessment Team used the following matrix to gauge the adequacy of the risk reduction measures they considered. On the following tables, “X” indicates the team believed that the measure reduced the risk by one full step (one colored box) on the Failure Mode Risk Evaluation Matrix (Table 1), “XX” indicates a two full step reduction (two colored boxes), and “XXX” indicates a three full step reduction (three colored boxes). For example, one X shows the reduction of risk from HIGH to MODERATE if that specific remedial measure were implemented. “¼ X” and “½ X” indicates the team considered the remedial measure and believed there was some risk reduction, but not a significant amount. Lines with a strikeout indicate that the team considered the remedial measure, but did not feel the measure applied to the option under consideration.

Risk Reduction Measures Operational Scenario 4						
Remediation measure	**Reduces probability of failure by (1, 2 or 3 blocks)**	**Reduces consequences**	**Cost of remediation** **Low < $5m** **Medium $5-$10m** **High >$10m**	**Construction considerations**	**Likely duration of construction**	**Notes**
Structural alternatives						
Repair animal hole	(¼ X)	No reduction	Low	Requires dewatering.	< 1 year	Complication to mission continuity. Nonpositive cutoff.
Temporary lining (3-year lifespan with aggressive maintenance program) additional lining of hot spots	X	No reduction	Low	Construction would be fairly simple. Common construction to Reclamation. May have supply problems. Lining of hot spot areas would include the wetted perimeter. Seam welding would be required.	Months	Complication to mission continuity. Lining of slopes and wetted perimeter of hot spots (to 150 ft^3/s stage level)
~~Sheet pile~~	~~X X~~	~~X X~~	~~High~~	~~Common construction. Has been done before. Reclamation has employed this method before. Potential liquefaction of embankment materials.~~	~~Year and a half~~	~~Positive cutoff. Catastrophic failure is unlikely. Mission capability is maintained.~~
~~Slurry cutoff wall (Cement Bentonite)~~	~~X X~~	~~X X~~	~~high~~	~~Common construction techniques employed. Reclamation has~~	~~Year and a half~~	~~Positive cutoff. Catastrophic failure is unlikely. Mission~~

~~Filters and drains and berm~~	~~XX~~	~~(¼ X)~~	~~High~~	~~Right of way issues. Employed this method before. Potential for hydrofracturing during Reclamation construction~~	~~Two years~~	~~Nonpositive cutoff. Has defensive design measures~~
~~Riprap and Cobble~~	~~(¼ X)~~	~~No reduction~~	~~Medium~~	~~Canal required to be Construction~~	~~One year~~	~~Complication to~~
~~Geogrid Liner~~	~~X~~	~~No reduction~~	~~High~~	~~Canal required to be dewatered. Common construction to Reclamation~~	~~Two years~~	~~Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff~~
~~Canal reshaping~~	~~No reduction~~	~~No reduction~~	~~low~~	~~Requires dewatering~~	~~Two years~~	~~Complication to~~
~~Grouted rock (grading, desiltation, etc.)~~	~~(¼ X) (may increase or reduce)~~	~~No reduction~~	~~Medium~~	~~Canal required to be dewatered. Common construction to Reclamation~~	~~Two years~~	~~High maintenance. Nonpositive cutoff. Complication to mission continuity. Lining side-slopes only~~
~~Geomembrane and slope protection~~	~~XX~~	~~No reduction~~	~~High~~	~~Canal required to be dewatered. Common~~	~~Two years~~	~~Only. Nonpositive cutoff. Complication to mission continuity.~~
~~Pipe~~	~~XX~~	~~X~~	~~High~~	~~Dewatering required. Common construction to Reclamation. May be lead-time issues on pipe.~~	~~Two years~~	~~Complication to mission continuity. Lining side-slopes only. Nonpositive cutoff. Low maintenance. Groundwater recharge issues.~~
Non-Structural						
~~Add checks and wasteways~~	~~No reduction~~	~~(¼ X)~~	~~medium~~	~~Dewatering required. Common construction to Reclamation~~	~~One year~~	~~Complication to mission continuity. No reduction of cutoff and maintenance. Develop hydraulic study to locate applicable sites for checks and wasteways.~~
24/7 monitoring, surveillance, and intervention plan and cleaning for the downstream (outboard) slope of vegetation	(½ X to X) Depends on how robust implementation plan is.	X	Low	Maintenance required prior to implementation	Months	Will require development and implementation of SOP that includes EAP.
~~Excavate and replace embankment slope maintenance~~	~~XX~~	~~(¼ X)~~	~~High~~	~~Dewatering required unless parallel construction performed. Common construction to Reclamation.~~	~~Two years~~	~~Complication to mission continuity. Nonpositive cutoff. Has defensive design measures.~~

~~Automated controls and measurement (SCADA)~~	~~(1/4X) some reduction by control of potential surges~~	~~No reduction~~	~~Low~~	~~Common installation for Reclamation~~	~~One year~~	~~Has to implemented in support of a operational plan and EAP~~