A. INTRODUCTION

The Truckee Canal was constructed between 1903 and 1905 as part of the Newlands Project and is among the United States Bureau of Reclamation's (Reclamation's) oldest structures. Water is diverted into the Truckee Canal from the Truckee River at the Derby Diversion Dam, about 20 miles east of Reno, Nevada (NV). The canal is about 31 miles long and discharges into Lahontan Reservoir, near Silver Springs, NV. Water flows are used to deliver irrigation water to agricultural lands along the length of the canal and to supplement inflows into Lahontan Reservoir from the Carson River. The canal is operated and maintained by the Truckee-Carson Irrigation District. The canal is divided into three reaches; the Derby reach (approximately 10.3 canal-miles from Derby Diversion Dam to the city of Fernley, NV), the Fernley reach (approximately 11 canal-miles within the city of Fernley, NV), and the Lahontan reach (approximately 9.7 canal-miles from the city of Fernley to Lahontan Reservoir). The original design capacity of the canal was about 1,200 cubic feet per second (ft^3/s).

On January 5, 2008, a portion of the Truckee Canal embankment failed, causing flooding and property damage within Fernley, NV. Following the failure, numerous studies were completed to evaluate the cause (internal erosion likely exacerbated by animal burrows), to evaluate the risk of future failures, and to develop feasible alternatives for improving the safety of the Truckee Canal. Following the canal failure, a flow restriction of 350 ft^3/s has been established through a court order. In addition, Reclamation imposed a stage restriction. The court order was lifted in April 2016 when the litigation was settled. Reclamation's stage restriction remains in place.

Reclamation's Technical Service Center, at the request of the Lahontan Basin Area Office, has updated previously made risk estimates for the Truckee Canal and developed recommended long-term corrective actions and risk-managed short-term flow/stage restrictions. The Advisory Review Team (Team) has been asked to review the current Truckee Canal risk analysis and proposed risk reduction and design criteria including an assessment of whether canal safety risks are being managed comprehensively. The Team was provided documents (listed in Section B) to review on August 25, 2016, and participated in a Reclamation led briefing September 1, 2016.

The Advisory Review Team consisted of the following members:

- John Cyganiewicz (Cyganiewicz Geotechnical); Senior Geotechnical Engineer; Dams, Levees and Canal Embankment and Risk Analysis Expertise
- William Engemoen (Reclamation), Senior Geotechnical Engineer, Risk Analysis Expertise, Reclamation Risk Cadre Member
- Richard Millet, (AECOM) Senior Consultant/Project Director, Dam and Levee Design and Analysis Expertise

B. DOCUMENTS REVIEWED

The following Reclamation documents were reviewed by the Team:

1. Truckee Canal Issue Evaluation "Design, Estimating and Construction Review" dated March 2008.
2. "Truckee Canal Safe Flow Determination Panel Report" dated April 2013.
3. "Proposed Risk Analysis Process for the Truckee Canal" dated July 2014.
4. Technical Memorandum No. QY-2015-8311-9, "Truckee Canal Updated Risk Analysis" dated June 15, 2015.
5. "Proposed Long-term Risk Reduction and Design Criteria for the Truckee Canal" dated December 2015.
6. "Flow/Stage-level Restriction Recommendations for the Truckee Canal" dated June, 2015.

As indicated in Reclamation's Statement of Work (SOW), reference documents 3, 4, and 5[1] from this list were the primary documents subject to this Team. Reference documents 1 and 2 were "… included for information and background but are not the focus of this review" (SOW). Reference document 6 was not included in the SOW list of documents to be reviewed but was included in the documents transmitted by Reclamation to the Team and falls under the SOW's "Other support and background documents as requested and as necessary".

C. RECLAMATION QUESTIONS AND RESPONSES

In the SOW Reclamation provided, the following questions were to be answered by the Team. Team responses are provided for each question.

Question 1: Were appropriate canal failure modes developed and explored comprehensively based on specific canal facts?

Response

The risk analysis process for the Truckee Canal has extended over a period of time starting soon after the 2008 failure and proceeding until recently. There appears to have been five separate risk analyses conducted with the latest completed in August 2014 [Ref. 4]. Risk Estimating Team (RET) members have apparently changed during the various team meetings. All of the risk analyses appeared to build upon previous analyses, critically review previous risk analyses, adopt previous results as appropriate, and include any new information since the last analysis as available. The 2015 updated analysis is the current one upon which Reclamation is using to inform them of risk considerations when making decisions regarding the project.

The 2014 RET reviewed and reassessed all potential failure modes (PFMs) developed by previous RETs and added appropriate new PFMs resulting in a total of 22 PFMs. Most (but not all) of the 22 PFMs are discussed in the reference documents provided to the Team. The

[1] Reference numbers refer to the list of documents received for review that are cited at the beginning of Section B.

identified PFMs address all three typical loading conditions, including normal operations (static loading), large precipitation events and floods (hydrologic loading), and earthquake events (seismic loading). In general, Reclamation appears to have developed and explored appropriate PFMs associated with the canal. There do not appear to be any PFMs missing from this compiled list and no additional PFMs are suggested by the Team. The most recent RET appeared to comprehensively explore and include available 'specific canal facts' when making the risk estimates. It does appear that a great deal of physical, geotechnical, hydrogeological, past performance, and seismic facts and data have been collected and used in the analysis. However, as is the case for most risk analyses associated with long, linear structures such as canals, the RET's judgment was heavily relied upon when making final risk estimates. This judgement not only used facts but also considered the RET's experience and many other factors when making the final risk estimates.

The current level of data collection and study appears to provide a reasonable basis to identify areas of the Truckee system requiring attention. Identified future remediation(s) coupled with ongoing surveillance and operation and maintenance attention would likely reduce failure risk to the levels that Reclamation has targeted.

For PFMs associated with piping and internal erosion (primarily PFM 1), risk estimates of the canal were based largely on the average gradient through the canal embankment (for instance Ref. 4, Table 21). The gradient was calculated based on an assumed amount of damage from burrowing animals, tree roots, etc., equal to an open flaw penetrating 25 feet into the embankment. This amount of assumed damage, when assessing PFMs associated with internal erosion, appears to be reasonable for the data available.

The PFM 1 risk estimates are also guided by the observation that "Past failures of the Truckee Canal have typically corresponded to conditions when the seepage gradient was approaching or exceeding 0.2…" [Ref. 4, pg. 98]. Presumably, the calculation of gradient that accompanies this observation uses the assumption of a 25-foot flaw in the embankment. It should be noted that if the existing flaws at the failure sites were less than 25 feet, the calculated gradient at the time of failure would be less, which in turn may impact most of the estimates of risk presented in the report for PFM 1.

Given the apparent importance of gradient calculations when assessing the risk for PFM 1, it should be noted that Reclamation's 'Best Practices' for risk analysis of dams and levees contains significant guidance on the likelihood of soil erosion based on soil properties (gradation, plasticity, density, etc.) relative to average gradient. Presumably, much of this guidance could be applied to the canal embankments. There has also been considerable work in the dam's industry regarding actual testing of soil erodibility relative to gradient that also could be applied to the canal embankments. Reclamation also acknowledges that clouding the assessment are the suspected low density and variability of the canal embankment soils. To improve on the comprehensiveness of the risk estimates, as presented in tables similar to Table 21 [Ref. 4], Reclamation could consider utilizing some of the guidance provided in the 'Best Practices' documents.

To provide for a more comprehensive study and prior to implementation of any corrective actions, Reclamation should consider providing additional justification for the use of 0.2 as the

'threshold' gradient. In addition, Reclamation should consider performing a sensitivity study to determine what the resulting risks would be if the threshold gradient were 0.1. It may be of interest to decision makers to see if additional high-risk areas appear with a lower gradient assumption.

Regarding Table 21 (and similar), the discussion of why the risk estimates are higher for conditions where the freeboard is less than 4 feet for the same average gradient is somewhat unclear. Reclamation should consider improving the discussions on this issue, similar to the way it was explained in the team briefing (i.e., higher likelihood of burrows from smaller animals and ice-dam considerations).

Potential failure modes associated with mis-operation of the canal were apparently considered by Reclamation's decision makers as beyond the scope of the most current risk analysis [Ref. 4, pg. 93]. However, it is noted that the report cites instances where the Truckee Canal Irrigation District (TCID) has exceeded the existing 350 ft^3/s flow restriction in the recent past. If stage restrictions are exceeded on a somewhat regular basis, that potential can be accounted for in the risk analysis.

Question 2: Were the consequences of canal failure and associated failure risks explored comprehensively?

Response

For the Truckee Canal risk analyses, Reclamation developed a semi-quantitative risk analysis methodology that borrows from the 'Best Practices' semi-quantitative methodology used for dams and levees. The methodology uses a qualitative assessment of consequences that were modified from the 'Best Practices' to better fit conditions associated with the Truckee Canal.

Reclamation has estimated the consequences for the Truckee Canal by subdividing the canal into many discrete sections based on many factors that relate to the estimate of consequences. Factors such as density of homes, distance of homes from the canal, etc., were considered. This is similar to the process utilized by the California Department of Water Resources in the recent completion of a 9-year effort to forensically review the condition of over 1,500 miles of levees in Central California. The RET's estimates of consequences appear in general to be comprehensive.

The lack of life loss associated with the 2008 failure of the canal in the Fernley area despite many homes being flooded was also a key part of the consequence analysis. An important note in this regard is that most of the homes in the area of Fernley flooded by the 2008 incident did not have basements. Should there have been more homes with basements, which could include bedrooms that would possibly have flooded, the potential life loss may have been higher. As an additional factor when estimating consequences, Reclamation could consider the potential of increased life loss when there are homes with basements that could be flooded by a canal failure.

The proposed consequence estimates also include a consideration of 'Agency credibility' to address the detrimental impact to Reclamation and TCID of another failure. This new consideration would appear to be an appropriate one to include in making the consequence estimates more comprehensive. If one more breach in the Fernley reach would have a huge

impact on agency credibility, it may be worth considering the impacts of assigning a Consequence Level 3 to the entire Fernley reach.

Given the possibility of additional life loss that could result from a breach into an area of houses with basements and considering the effect of any breach having a severe impact on credibility, Reclamation should consider a sensitivity study to determine what impacts to risks and remedial actions would result if the entire Fernley reach was assigned a Level 3 consequence rating.

Question 3 (A): Were the assessment and evaluation of risks comprehensive?

Response

In general, the RET's assessment and evaluation of risks was very comprehensive. The geotechnical and seismic treatment of evaluations and risk assessment was quite thorough and complete. It is noted that although the hydraulic evaluation of flood risk was comprehensive, the risks associated with hydrologic PFMs are planned to be analyzed further during Corrective Action Studies (CAS) and will be more thoroughly vetted at that time. As presented in the Team briefing, it is apparent that Reclamation has made important strides toward improving the hydrologic loading estimates (e.g., additional infiltration tests and calibration with the 2013 large thunderstorm event).

Risks were assessed for numerous discrete portions of the canal throughout its entire reach. The PFMs identified as being risk drivers, PFMs 1, 5, 10, 11, and 18, appeared to be appropriately and comprehensively assessed. Some specific comments on the assessments are included in the following discussions for this question.

As described in Reference 3, Reclamation decided to borrow from the semi-quantitative risk analysis methodology used for dams and levees as described in the 'Best Practices' documents. The methodology was further modified to adjust the methodology for Truckee Canal to consider perceived differences between canals and dams/levees.

In addition to the approach being well defined and reasonable, the resulting conclusions regarding the relative ranking or identification of risk-driving failure modes appear reasonable. The number of past failures due to internal erosion builds a compelling case for the high risks in several sub-reaches of the canal embankment. In addition, the number of past failures during winter months support the relatively high risks of an overtopping failure resulting from ice jams.

Furthermore, the relatively high seismic loading, the limited compaction and erodible nature of the embankment soils, and the limited freeboard in some sub-reaches make seismic-induced cracking and internal erosion as potentially high risk PFMs. The process and logic used to identify which areas of the canal were most subject to these PFMs appears sound.

The hydrologic failure modes, although judged to be high, are yet to be resolved due to the identified lack of confidence in the flood loadings. Addressing the PFMs associated with the storm-water inflow from the 'pours' and the specific design parameters to be used in remediation (and their risk status) still need to be clarified (e.g., 50-year, 100-year, etc.). Flood loadings are important contributors to the overall risk at the Truckee Canal. It will be important to commit

sufficient resources to the careful re-evaluation of the hydrologic loading in subsequent analyses of the risk and development of corrective actions.

Finally, the majority of the identified 22 PFMs were found to be of relatively low risk. It appears that the RET has provided reasonable justifications for why specific PFMs at specific locations appear to pose relatively low risks. However, given the 31-mile length of this feature and the infeasibility of ever acquiring sufficient data to fully evaluate the risks at all locations, it must be recognized that there will always be some risk of an unanticipated incident.

Question 3 (B): Were the assessment and evaluation of the Corrective Actions comprehensive?

Response

The documents provided for this review did not appear to contain definitive discussions of what corrective actions were being planned but only general suggestions of what to consider in a future CAS. The corrective actions identified in the documents essentially consist of a short list of potential actions to achieve either short-term or long-term risk reduction. Short-term corrective actions include such alternatives as flow/stage restrictions, enhanced monitoring, stockpiling of filter materials, sediment removal, and others. Long-term measures identified to be considered during CAS include such alternatives as cutoff walls, seepage berms, embankment reconstruction, canal lining, and similar alternatives.

Reference 3, Figure 5 presents the risk matrix with recommended actions that will be used for the upcoming CAS. For specific combinations of failure likelihood and consequences, the matrix identifies potential short- and long-term risk reduction actions to be implemented. The matrix also addresses how the decision to implement canal flow/stage restrictions will be made as based on a combination of failure likelihood and consequences. The semi-quantitative risk matrix is used to categorize the general nature of the risk of each PFM as well as identify potential risk reduction actions. This matrix appears reasonable and appropriate, and appears to be a useful tool for directing potential risk reduction actions for canal failure modes. The Team considers this a comprehensive approach to reducing risk.

Regarding the guidance for ‘Long-term Structural Risk Reduction Measures’ and specifically if the estimated risk of a PFM falls above or below the ‘red line’ guidance. If a PFM falls just below the line in the ‘orange’ zone, no flow/stage restrictions are necessary and the guidance suggests a variety of short- and long-term risk reduction actions be considered with structural modifications taking up to a 5-year period to complete. If a PFM plots above the line flow/stage restrictions are implemented that will presumably result in the PFM to be below the line while structural measures are completed. This matrix therefore appears to be comprehensive.

Reference 5 discusses the long-term risk reduction criteria that the future CAS will use as guidance during the design of alternatives to address the PFMs of concern. Except as noted in the following comments, the document appears comprehensive.

Reference 5 also discusses the criteria to be used when developing CAS alternatives. In general, the document does not specifically state what the post structural modification risk for each PFM will be as related to the risk matrix chosen for Truckee Canal [Ref. 5, Figure 5]. It would appear

that Reclamation is aware that given the criteria in Reference 5, the risk reduction alternatives may not achieve risk below tolerable guidelines for all PFMs (e.g., see discussions for PFMs 10 and 11 below). While it is Reclamation's prerogative to make this type of determination, the documents would be more comprehensive if the expected post modification risk was explicitly discussed for PFMs of concern. The Team briefing on September 1, 2016, included a discussion of a triangular portion of the risk matrix where hydrologic risks would be below the probability criteria but would exceed the 0.001 annualized life loss line. It would be helpful to include that plot and discussion in the documents. This situation would also appear to impact what the flow/stage restrictions would be following completion of structural modifications (i.e., it appears flow/stage restrictions would not be required in addition to a structural modification).

To address PFM 1 (Internal Erosion), Reference 4 suggests structural alternatives that could be included in a future CAS would be: 1) seepage cutoff wall, 2) lined canal, 3) embankment reconstruction, and 4) widening the embankment. This list would appear to be appropriate to move forward into a CAS study. When conducting the CAS, it will be important to design against factors that may have led to the previous canal failures (e.g., animal burrows and tree roots) and to provide an otherwise state-of-the-practice design.

To address PFM 5 (Ice Dam), the document suggests structural alternatives that could be included in a future CAS would be: 1) reconstructing the upper portion of the embankment to remove any flaws, 2) raising the embankment crest, 3) replacing the check structures with designs to pass ice, 4) lining the canal, and 5) constructing a seepage cutoff wall. In addition to this list, Reclamation may want to consider constructing 'wasteways and spillways' in areas potentially affected by ice jams. Otherwise, this list would appear to be sufficiently comprehensive to move forward into a CAS study. Since the issue with ice dams is primarily one of both overtopping and piping through flaws, any structural alternative would need to consider both of these threats. It is likely that a combination of these alternatives would be needed to comprehensively address the issues of overtopping and internal erosion risks caused by ice dams.

To address PFMs 10 & 11, Reference 5 states a "… risk based process for sizing the flood protection features, while limiting the hydrologic loading to what would be selected for a new medium sized canal has been proposed". From this, Table 2 [5] indicates that the hydrologic loading conditions would be "Flood protection features designed for the 6-hour, 100-year flood event". Part of this selection was apparently based on the deterministic criteria from Reclamation's Design Standard No 3, Chapter 7. Based on these decisions, it appears that Reclamation is aware that the tolerable risk criteria guidelines chosen for Truckee Canal may not be met. To make Reference 5 more comprehensive, Reclamation could consider including a specific discussion for these PFMs of what the post modification risk would be as related to the risk matrix for these PFMs.

To address PFM 18, Table 2 [Ref. 5] indicates that a 2,500-year seismic event has been selected to design structural modifications for the PFM. Based on the document, it is unclear if this level of seismic loading will achieve risk reduction in accordance with the risk matrix [Ref. 3] for this PFM once the loading is combined with the system response and consequences in a risk context. Reclamation could consider addressing this issue to make Reference 5 more comprehensive. To

address PFM 18 (Seismic Induced Cracking), the document suggests that structural alternatives in a future CAS could be: 1) canal lining, 2) seepage cutoff wall, and 3) embankment reconstruction. Because the PFM is one in which seismic-induced movements cause embankment cracking and displacement, in order to be comprehensive, the CAS would need to ensure that any proposed alternative be robust and flexible/resilient enough to ensure the canal embankment is able to survive these movements.

When assessing the risk estimates for dams, there are provisions in Reclamation's 'Best Practices' for dams and levees documents to consider 'confidence' when discussing the estimated risk of PFMs. As described in the 'Best Practices', the RET would address their confidence in their risk estimates by determining if additional information could be reasonably obtained that has the potential to significantly alter their estimates of risk for any particular PFM. Statements of the RET's confidence are included in Reference 4 but the topic of confidence is not addressed uniformly among PFMs. Therefore, Reclamation could consider adding an assessment of confidence to each of the PFMs to help decision makers determine if additional information should be obtained and possibly follow these with actual recommendations that address obtaining the additional information to make Reference 4 more comprehensive.

The RET has made it clear that selection of any short- and long-term actions will be made via discussions of Reclamation decision makers and TCID representatives. This is appropriate, as acceptable or tolerable canal risks are not currently clarified within Reclamation protocols. Whereas Reclamation has Public Protection Guidelines for use in judging dam safety risks, similar methodology for Reclamation canals has yet to be developed. Hence, collaboration among Reclamation decision makers from Denver, the Mid-Pacific Region, Lahontan Basin Area Office, and canal district representatives will be a key part of corrective action selection.

With regard to risk associated with the mis-operation of the canal, although this risk has been considered beyond the scope of current study, it should be pointed out that two significant dam failures in the last decade (Tam Sauk and Silver Lake) both occurred because of mis-operation. Data that was presented to the Team also indicated that current flow/stage restrictions in the canal have been exceeded. Consequently, as much as possible, a passive corrective action system can be considered by Reclamation. The additional work necessary to address hydrologic PFMs will not only include additional hydrology, but will also likely include the investigation of the feasibility of additional wasteways and spillways. It would appear that additional wasteways at various locations would not only help in reducing the risk of storm-related overtopping, but would also serve to minimize the likelihood of overtopping due to inadvertent mis-operation of the canal.

D. OTHER COMMENTS

The Truckee Canal risk team is to be complemented on their outstanding job of compiling key historical events, loading conditions, exploration results, and analyses to bring to bear on the identification and evaluation of potential failure modes, as well as the associated risks of these PFMs. The effort undertaken and the resulting rational approach to portraying potential failure risks is much appreciated.

E. LIMITATIONS

The Advisory Review Team functioned as independent reviewers and provided a limited review of Reclamation reports and other applicable information. The Advisory Review Team contributed their expertise through discussions and collaboration with the other reviewers and the Reclamation Team. However, the ultimate decisions concerning risks and appropriate actions remains with Reclamation.

Given the large amount of documentation, it was not possible to perform a detailed review of all of the material in the time allotted.

Services were performed within the limits prescribed by Reclamation in a manner consistent with the level of care and skill normally exercised in the current standard of professional engineering practice. No other representation to Reclamation, expressed or implied, and no warranty or guarantee is included or intended.