Final Report for

February 25, 2021

Big Meadow Lake Dam
2020 Dam Safety Review Report

For Regional District of Okanagan-Similkameen

H362819-00000-228-230-0002

Report

Big Meadow Lake Dam - 2020 Dam Safety Review Report

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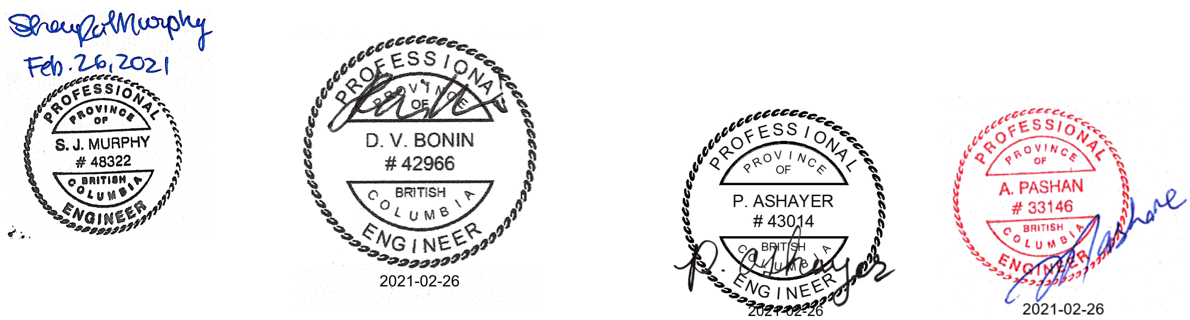

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Disclaimer

The Naramata Dam – 2020 Dam Safety Review report and all associated reference files have been prepared by Hatch Ltd. for the sole and exclusive use of the Regional District of Okanagan-Similkameen (RDOS) (the "Client") for the purpose of assisting the management of the Client in making decisions with respect to this structure. Any use which a third party makes of this report and all associated reference files, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Hatch accepts no responsibility or liability for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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a) The report and associated reference files being read in the context of and subject to the terms of contract RDOS-20-PW-04 between Hatch Ltd. and the Client dated May 8, 2020 (the "Agreement"), including any methodologies, procedures, techniques, assumptions and other relevant terms or conditions that were specified or agreed therein.

b) The report being read as a whole, with sections or parts hereof read or relied upon in context.

c) The conditions of Naramata Dam may change over time or may have already changed due to natural forces or human intervention, and Hatch takes no responsibility for the impact that such changes may have on the accuracy or validity or the observations, conclusions and recommendations set out in this report.

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Executive Summary

A Dam Safety Review (DSR) of the Big Meadow Dam and associated works was carried out by Hatch. The review has been completed in compliance with the Engineers and Geoscientists B.C. (EGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews V3.0 [EGBC, 2016], Canadian Dam Association – Dam Safety Guidelines published in 2007 (revised 2013) [CDA, 2013a], meeting the requirements of the B.C. Water Sustainability Act and the B.C. Dam Safety Regulation [Reg. 44/2016], and generally accepted engineering practice.

A dual classification system was adopted for this dam, as described in the report “Naramata Dam Breach Assessment and Inundation Mapping” (Hatch, 2021) carried out as part of this study. Under this type of system, spill capacity is solely determined based upon the potential incremental consequences of failure during a potential flood. A second classification, used for establishing the level of care for other aspects of dam safety, is determined through an evaluation of the worst case of potential incremental consequences of failure – whether caused by a Sunny Day event or failure during one of the IDF Flood events. This worst case will govern for dam classification for all aspects of dam safety except spill capacity. Big Meadow Dam is considered to be a Very High classification dam in terms of loss of life and potential damage in the event of an uncontrolled release of the impounded water for all aspects of dam safety except for spill capacity, where it is considered a High classification. Therefore, the associated Inflow Design Flood (IDF) for this classification is 1/3 between the 1,000 year flood and PMF with a peak flow of 6.5 m^3/s which can be discharged at a reservoir level of 1605.3 m.

This report represents the condition of the dam and ancillary structures at the time of the site visit on July 9, 2020. The geotechnical analysis is representative of the site conditions during construction and previous field investigations as no drilling program was included as part of this study. This constitutes the second formal DSR completed for the Big Meadow Dam. The first was completed in 2010 by EBA.

The discussion, conclusions and recommendations of this DSR are based on a review of selected project information including drawings, reports, manuals, photographs, instrumentation records and other miscellaneous documents as well as detailed visual site observations/assessments of all accessible components of the site and discussions with operating and surveillance staff.

This review follows a full dam breach analysis, consequence classification and inundation mapping study conducted as part of this project. The dam breach study includes an updated assessment of the hydrology/hydraulic aspects of the project, including an assessment of the IDF, and a review of the hydraulic capacity of the project. This report can be found under separate cover in Naramata Dam Breach Assessment and Inundation Mapping (2021). Results from this analysis are used to inform the studies within this report. In addition, this dam safety review includes a review of freeboard considerations to ensure capability to safely pass the specified IDF.

This review includes a review and assessment of the geotechnical and concrete components of the works, including an evaluation of the performance of the dam and foundations up to the time of the site visit, the nature, condition and suitability of the instrumentation and monitoring systems, and the process of evaluating and reporting on data. Recent geotechnical investigation testing results by EBA (2013) were used to determine the appropriate soil strength parameters for evaluation of the stability of the structures.

This report recommends that the next independent DSR be done in 2030 to comply with the B.C. Dam Safety Regulation [B.C. Reg 44/2016] under the Water Sustainability Act.

As stated in the DSR assurance statement this DSR found that the “Dam is reasonably safe but the dam safety review did reveal deficiencies and non-conformances as set out in Section 12 of the attached dam safety review report”. These items are summarized along with recommended actions in the following List of New and Existing Outstanding Deficiencies and Non-Conformances. The issues identified were classified based on non-conformance, actual deficiency or potential deficiency. The actual and potential deficiencies were given an overall priority rating of the risks, defined as high, medium and low, based upon the potential of the issue leading to a critical failure of the structure. The non-conformances were assigned a ranking of high, medium or low based on how they impact dam safety. The actual or potential deficiencies and non-conformances are summarized in Table E-1.

Table E-1: List of New and Existing Outstanding Deficiencies and Non-Conformances

Issue No.	Dam	Deficiency/Non-Conformance	Originator	Type	Status	Recommendation	Priority Rating
BM-1	Big Meadow	Dam is currently classified as a High consequence facility (EBA, 2010) and dam classification should be updated.	2020 DSR	N/A	New	Classify the Big Meadow Lake Dam as a Very High consequence dam. For the determination of the Inflow Design Flood only, a High classification is recommended, which equates to a flood with annual exceedance probability 1/3 between the 1000 year flood and the PMF. Ensure frequency of review of OMS and DEP is updated for the requirements of revised dam classification.	Medium
BM-2	Big Meadow	Documented history of toe seepage at downstream toe of the dam (EBA, 2010), observed again during the 2020 inspection as wet areas downstream of the low level outlet location.	2010 DSR, 2020 DSR	NCi	Outstanding	Construct a toe berm, filter and drain system at the downstream toe in areas where seepage has been observed. This includes particularly the area of the downstream toe adjacent to the Low Level Outlet. The drain system should be designed to convey seepage flows to the low level outlet.	High
BM-3	Big Meadow	There is currently no ability to measure quantity of seepage in areas where seepage has been observed historically.	EBA, 2013 2020 DSR	NCs	Outstanding	Install or reinstate the weir at the outlet of the drain to allow for quantitative measurement of seepage flows.	Medium
BM-4	Big Meadow	Insufficient as-built documents and geotechnical data to conduct a complete geotechnical assessment of the dam	2010 DSR	N/A	Resolved	As recommended in the 2010 DSR, a geotechnical investigation consisting of four boreholes and six CPTs/SCPTs was conducted in June/July 2012 (EBA, 2013). The results of this investigation and subsequent geotechnical analyses were reviewed.	N/A
BM-5	Big Meadow	No performance instrumentation is installed to monitor the performance of the dam. Previous DSR recommended one piezometer at minimum be installed, or a system be developed to quantify seepage.	2010 DSR	N/A	Resolved	Piezometer was installed as part of the 2013 Geotechnical Assessment (EBA, 2013). The current OMS manual calls for piezometer readings to be taken on a weekly basis between May and November. These readings are found in the weekly routine dam inspection report. No assessment of information was carried out so far.	Low
BM-6	Big Meadow	Using updated survey data, the 2020 DSR analysis indicates that the existing dam is able to pass the IDF including wind and wave effects with an available freeboard of 0.31 m to the lowest portion of the dam, which meets CDA requirements. Note that stop log use is no longer implemented.	2010 DSR, Updated 2020	N/A	Resolved		N/A
BM-7	Big Meadow	Topographic survey data from 2012 shows the dam crest elevation is lower than the design elevation of El. 1606.33 (EBA, 2013). However, freeboard requirements are met.	EBA, 2013 Updated 2020 DSR	NCm	Outstanding	Place material to re-grade the crest to the design/typical elevation to provide additional freeboard.	Medium
BM-8	Big Meadow	Upstream erosion of embankment and woody debris accumulation noted adjacent to the left abutment, should be cleaned out and protected with rip-rap (EBA, 2010)	2010 DSR	N/A	Resolved	The eroded areas as noted by EBA (2010) was repaired.	N/A
BM-9	Big Meadow	Vegetation observed in the weir downstream end of Low Level Outlet and on the downstream face. Vegetation inhibits detailed inspection of the toe of the dam.	2010 DSR 2020 DSR	NCo,s	Outstanding	Increase vegetation clearing at the downstream end of the Low Level Outlet to allow for proper inspection of the seepage/piping areas downstream of the dam.	Medium
BM-10	Big Meadow	Security/access issues leading to damage on dam crest and face from ATV traffic	2010 DSR EBA 2013 2019 Risk Survey 2020 DSR	NCp	Outstanding	Review security protocols and implement appropriate restrictions including those set out in the 2019 Risk Control Survey (Precise Services, 2019) to prevent damage or vandalism.	High
BM-11	Big Meadow	No Operations, Maintenance and Surveillance (OMS) manual was prepared for the dam as of the previous Dam Safety Review.	2010 DSR	NCs	Resolved	An OMS manual has been published since the previous review (RDOS, 2017). The contents of the OMS were reviewed and revised as part of the 2020 review.	N/A
BM-12	Big Meadow	Dam Safety Review schedule	2020 DSR		New	In accordance with the Very High consequence classification, the next Dam Safety Review should be conducted in 2030, and every 10 years subsequently.	Medium
BM-13	Big Meadow	Seismic and post-seismic stability issues were raised by EBA during the 2013 geotechnical assessment report. The assessments need to be implemented.	EBA 2013		New	As shown by EBA (2013), construct a free draining toe berm to mitigate seismic and post-seismic stability concerns.	Medium
BM-14	Big Meadow	Lack of sufficient instrumentation monitoring for performance assessment of the dam.	2020 DSR	NCs	New	Reinstate the weir downstream of the dam along the tailrace channel. Perform instrumentation monitoring program which should include continuous records, plotting, and interpretation of piezometer data and seepage flow quantities against reservoir elevation.	Medium

Issue No.	Dam	Deficiency/Non-Conformance	Originator	Type	Status	Recommendation	Priority Rating
BM-15	Big Meadow	Currently no rip-rap or erosion protection layer on the dam crest or upstream slope.	2020 DSR	NCm	New	Provide appropriately sized armour protection along the upstream face of the dam from the crest to 1 m below the low water level.	Low
BM-16	Big Meadow	LLO structure is unprotected from vandalism and accidental damage from ATVs or other traffic at dam crest.	2020 DSR	NCm	New	Provide protection to the screw stem by adding bollards or a steel cover to prevent damage from ATV traffic.	Low
BM-17	Big Meadow	No information is available for the rate of drawdown and the procedures that should be used to accommodate lowering the reservoir for emergency drawdown.	2020 DSR	NCo	New	It is recommended to determine a better understanding of the rate of drawdown that can be achieved for emergency drawdown scenarios such as after a seismic event. A plan to utilize a portable syphon or one or more high volume pumps to provide capacity and emergency drawdown would be a cost effective way to providing required drawdown capacity. This should be evaluated for operations planning as well as potential sources for emergency pumps if needed. Under the CDA guidelines, it is recommended to provide information on staffing requirements and the time required to complete system operations. Add syphon Standard Operating Procedure (SOP) to OMS Manual.	Medium
All-1	All Dams	OMS could be improved by including supporting confirmation that highlighted maintenance activities are being completed.	2020 DSR	NCs	New	Regular verification of the completion of maintenance items recorded in the weekly site surveillance form would further support that maintenance items are being completed.	Low
All-2	All Dams	OMS does not have a table with positions and associated names describing roles and responsibilities.	2020 DSR	NCo	New	Update table in OMS to include positions and associated names describing roles and responsibilities.	Medium
All-3	All Dams	Routine Dam Inspection Report format does not contain all aspect of BC Dam Safety Office's Site Surveillance Form for weekly inspections.	2020 DSR	NCp	New	Routine Dam Inspection Report format should be improved to more closely follow the BC Dam Safety Site Surveillance Form for weekly inspections.	Low
All-4	All Dams	No formal Dam Safety Policy is in place for their dam safety program.	2020 DSR	NCp	New	The RDOS appears to be meeting the intent of a dam safety management system and should continue to improve and develop their system and adopt a formal policy statement on Dam Safety for their program to satisfy the CDA Dam Safety Guidelines. This will demonstrate a commitment to the regulation and provide a reason to perform necessary works.	Medium
All-5	All Dams	OMS could be improved by including more information to assist Dam Safety inspectors in detecting and responding to an emergency situation.	2020 DSR	NCp	New	In the OMS, inflow forecasting should include alarm limits on what scenario of Snow Survey combined with reservoir levels would create a need for action. Actions to be taken should be described. Any recommended drawdown in anticipation of large spring runoff events should also be documented.	Medium
All-6	All Dams	Emergency notification systems to alert the public should be expanded to include a text message template to facilitate public notification in the event of an emergency.	2020 DSR	NCp	New	It is recommended that the RDOS emergency call alert system, CivicReady be setup to allow for public signup in order to receive external text message notifications during an emergency.	Medium
All-7	All Dams	No available documentation provided to show if regular dam safety training is provided to the inspector(s).	2010 DSR, 2020 DSR	NCs	Outstanding	RDOS staff responsible for the DEP should regularly attend BC Dam Safety Dam Management seminars on dam safety and inspections (understood to be provided annually in most areas of BC, including Penticton). Records of attendance at these inspection workshops should be documented along with information on any additional training completed. This could include review of material provided on BC Dam Safety website.	Medium
All-8	All Dams	No available documentation to show that exercises are carried out regularly to test the emergency procedures.	2020 DSR	NCp	New	Provide documented training to staff in emergency procedures, and carry out and document regular exercises to test the emergency procedures. Follow additional recommendations in proposed new Dam Emergency Plan (DEP) procedure.	Medium

Refer to Table 12-1 *for legend and definitions of the type of deficiencies and non-conformances.*

1. Introduction

1.1 DSR Report Purpose and Scope

This report has been prepared by Hatch Ltd. (Hatch) for the Regional District of Okanagan-Similkameen (RDOS) to document the Dam Safety Review (DSR) that was conducted for the Big Meadow Lake Dam. The review has been completed in compliance with the Engineers and Geoscientists B.C. (EGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews V3.0 [EGBC, 2016], Canadian Dam Association – Dam Safety Guidelines published in 2007 (revised 2013) [CDA, 2013a], and meeting the requirements of the B.C. Water Sustainability Act and the B.C. Dam Safety Regulation [Reg. 44/2016]. The scope of services provided are outlined in RDOS contract RDOS-20-PW-04 between Hatch Ltd. and the Client dated May 8, 2020 and in accordance with Hatch Proposal No. 031390 dated March 23, 2020.

1.2 Previous Dam Safety Reviews

The most recent Dam Safety Review for Big Meadow Dam was completed in 2010 by EBA Engineering under the previous version of the B.C. Dam safety regulation. According to the B.C. Dam Safety Regulation (B.C. Reg 44/2016) under the Water Sustainability Act, a new Dam Safety Review is required in 2020.

1.3 Objective

The objective of this Dam Safety Review is to determine if the dam facilities meet the recommendations in the Engineers and Geoscientists B.C. (EGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews V3.0 [EGBC, 2016], Canadian Dam Association – Dam Safety Guidelines [CDA, 2013a], and the requirements of the B.C. Water Sustainability Act and the B.C. Dam Safety Regulation [Reg. 44/2016], and to present the findings as either confirmation of the dam's safety, or identification of deficiencies, non-conformances and issues for further investigation. The scope of the complete Naramata Dams study includes a dam breach and inundation study including dam failure consequence classification, Inflow Design Flood (IDF) selection and inundation zone mapping. Results from this work are used to inform this DSR.

The major conclusions and recommendations of this DSR for the Big Meadow Dam components have been summarized at the end of this report. The recommendations have been ranked using the prioritization system outlined in Section 13.

2. Description of Development

2.1 General

There are four Naramata area dams located from elevations 900 m to over 1250 m above the main populated regions along Okanagan Lake in British Columbia. These dams include:

- Big Meadow Lake Dam
- Elinor Lake North (Saddle) Dam
- Elinor Lake South Dam
- Naramata Lake Dam.

The locations of these dams are shown in Figure 2-1.

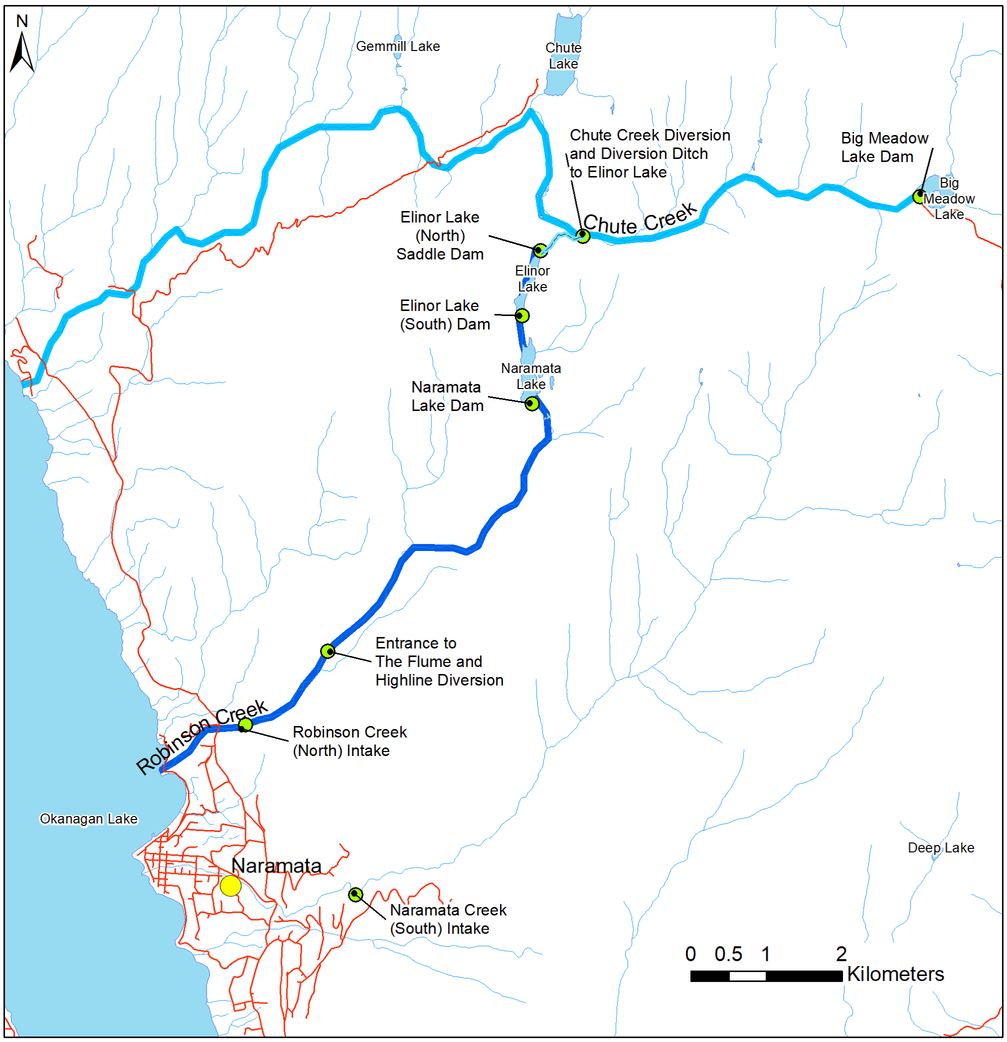

Figure 2-1: Naramata Dams Location Map

The Big Meadow Dam is a part of a four-dam system which forms three interconnected reservoirs that provided a historical upland source of potable water to the Township of Naramata. The dams were constructed during the first half of the twentieth century by the Naramata Irrigation District (NID), which has been subsequently incorporated into the Regional District of Okanagan-Similkameen (RDOS). These dams are no longer required for the potable water due to the construction of Naramata UV Water treatment Facility in 2006, and the RDOS continues utilizing these facilities for maintaining essential creek flows, emergency backup supply of water and supplying irrigation water to agricultural lands.

2.2 Site Description

The Big Meadow Lake Dam is the most upstream dam of the four dams in the Naramata system. It is located in within a bowl-shaped feature near the headwaters of the Chute Creek catchment, approximately 13 km to the northeast of Naramata Township. The dam is approximately 256 m long and 6.7 m high at its maximum height with a design crest elevation of 1613.9 m above mean sea level. Vehicle access to the dam is provided via Arawana Road, which extends off North Naramata Road to the southwest. A diversion structure is situated downstream of Big Meadow Lake Dam, which can divert flow from Chute Creek into the downstream Elinor Lake reservoir.

Figure 2-2: Big Meadow Lake Dam Major Component Layout

2.2.1 Instrumentation

Based on the data provided as part of this review, the following historical instrumentation was installed at the dam site as part of the construction and post construction performance assessment.

2.2.1.1 Piezometer

Two piezometers were installed in the Big Meadow Dam during the 2012 Geotechnical Investigation by EBA (2013). One of piezometers (BH12-08) have two tips (P12-02 and -03) and the second piezometer (BH12-07) has one tip (P12-01).

2.2.1.2 Survey Monuments

Three survey monuments exist on the dam abutments of the Big Meadow Dam. These monuments were surveyed by Okanagan Survey (2012); however, they were not referenced in the OMS (2017). A list of the monuments is provided below:

- Monument (Mon) 1: Upstream of right abutment
- Monument (Mon) 2: Downstream of right abutment
- Monument (Mon) 1: Downstream of left abutment.

No other survey monuments exist on the dam crest or slopes.

2.2.2 Dam and Reservoir Summary Information

The key physical dimensions of Big Meadow Dam are in Table 2-1 below:

Table 2-1: Key Dimensions of Big Meadow Dam

Structure	Details
Type of Dam	Embankment Dam (Homogeneous with central concrete wall)
Maximum Height	Approximately 6.7 m
Crest Length	256 m
Crest Width	3.7 m
Crest Elevation	1605.56 m minimum to 1606.33 m maximum; Generally above 1606.0m; Average 1606.1 m
Upstream Slope	Typically 3H:1V
Downstream Slope	Typically 2.75H:1V Variable in the lower half
Retained Water (at spillway crest)*	518,800 m^3
Low Level Outlet	Concrete with metal gate Elevation not available 457 mm (18” diameter)

Structure	Details
Spillway	Concrete overflow, 6.1 m wide Spillway crest elevation 1604.5 m
Dam Failure Consequence Classification	Very High

*Stoplogs are no longer in use and unavailable at site.

2.3 History of Dam and Reservoir

There is some uncertainty as to when the Big Meadow Lake Dam was constructed. The existing drawings show that it was originally designed in in 1920; however, the dam information board suggest that it was constructed in 1933. A review of the oldest available aerial photography from 1938 indicated that the embankment had been constructed; however, it appears that the reservoir had not been filled yet, suggesting that the 1933 date maybe the correct time of construction.

The original embankment was designed with 2H:1V downstream and upstream slopes and modifications were undertaken in 1952 comprised of flattening the upstream slope to 3H:1V and downstream slope to 2.5H:1V, raising the core wall by 12 inches (305 mm) and grouting an 18 inch (457.2 mm) diameter steel discharge conduit into the original concrete culvert.

After reconstruction in 1952, sloughing and seepage occurred at the toe of the embankment adjacent to the low level outlet structure. Subsequently, a rock toe drain was installed to collect the seepage. In 1964, a new sliding gate control was installed as the original gate had been undermined and rendered inoperative.

In the inspection of the dam in 1991, significant seepage was noted along the toe of the embankment and an installation of a 1.0 m deep granular toe drain incorporating a 0.3 m diameter perforated pipe was recommended, but it is unknown if these works were undertaken and there was no evidence of these works observed during the dam inspection in 2010.

In 2003, during the Okanagan Mountain Park fire, a fire guard was constructed to the northwest of the dam resulting in some minor excavation into the downstream face to provide vehicle access around the spillway structure. Following the repair works to the embankment, an area of significant seepage was noted at the toe of the embankment towards the left abutment and a 0.3 m X 0.3 m X 0.025 m drain rock toe drain was recommended and constructed in 2004 to intercept the seepage as inspected by Golder (2004).

3. Dam Safety Review Methodology

This DSR is based on a review of available documentation, discussions with the RDOS staff and a site inspection at the Big Meadow Lake Dam. The scope of the review includes the dam's physical condition, operation, maintenance, surveillance, emergency planning and response, dam performance and dam safety management process, as these pertain to overall dam safety management of the Big Meadow Lake Dam.

The project commenced with document review that included the project performance expectations, including flood and earthquake criteria, based on the Canadian Dam Association – Dam Safety Guidelines [CDA, 2013a], and the B.C. Water Sustainability Act and the B.C. Dam Safety Regulation (Reg. 44/2016). Prior dam safety reports and other reports pertaining to the safety of Big Meadow Lake Dam were made available to Hatch. A full listing of documents reviewed is provided in Section 4.1.

The Hatch team performed a site inspection as discussed in Section 5.

The DSR focuses on the history of the dam with attention to issues and work that had been performed since the last DSR [EBA, 2010] and encompassed the BC Dam Safety Regulation [B.C. Reg. 44/2016] and the CDA Guidelines [CDA, 2013a]. Where the aspects of the Dam Safety Management Program were found not to conform, the issue was identified as a deficiency or as a non-conformance and a recommendation for follow-up action was made. The identified deficiencies were categorized as being: physical deficiencies (inadequate dam performance condition); or deficiencies of the physical infrastructure of the dam (such as the system for the collection of data and observations necessary to verify the physical performance of the dam); or procedural non-conformances. The priority rating of the various risks were defined as either high, medium and low based upon the potential of the issue leading to critical failure of the structure, in order to provide the RDOS recommended priorities to resolve these deficiencies.

Based on an understanding of hazards and associated failure modes, a "Hazards and Failure Modes Matrix" was created (see Section 7.1) that lists potential hazards and failure scenarios for the Big Meadow Lake Dam.

The findings of the DSR were documented in this DSR Report.

4. Data Collection and Review

4.1 Existing Information

RDOS provided available information on the dam to Hatch for this DSR. Historical data was provided as electronically scanned documents and was contained in various folders. Table 4-1 summarizes each document that was reviewed.

Table 4-1: Existing Information Summary

File Name	Data	Description
Drawings		
Chute Lake Diversion – Existing Structure	October 1993	Spillway drawings
Naramata Lake Historical Drawings	1967 – 1978	Design drawings, area maps, topography, storage capacity, cross-section drawings, borrow areas (Drawing No.226-02-1 to 226-02-8 and Kelowna No. 1203)
Naramata Lake Dam – Remedial Filter Blanket	1969	Details of drains downstream of dam (Drawing No. 226-02-100)
Naramata Lake Dam – Piezometer Location Plan	Unknown	Shows the location of test well
Eleanor Lake Dam – Details of Culvert Gate Repairs	December 1966	Culvert gate repair plans for Elinor Lake Dam (Drawing No. 1316)
Eleanor & Naramata Lakes – Plan of Storage	17 April 1964	Storage plans for Elinor and Naramata Lakes (Drawing No. Kelowna-1203)
Improvements – South and North Intakes	6 December 1979	Improvements to South and North intakes of Elinor Lake Dam
Big Meadow Reservoir Plan of Storage	8 April 1963	Storage plans for Big Meadow Dam (Drawing No. Kelowna 1114)
Big Meadow Lake Storage Dam	November 1952	Spillway cross-sections (in sketch format)
Big Meadow Lake Reservoir – Plan of Reservoir	September 1979	Plan of Reservoir (Drawing No. 4567-5)
Big Meadow Dam – Details of Repairs to Culvert Gate & Outlet	19 September 1966	Repair plans to culvert gate and outlet (Drawing No. 1315)
Big Meadow Lake Reservoir – Plan of Reservoir	March 1982	Storage tables, rating curves for Big Meadow Reservoir
Big Meadow Dam – Grill at Gates	August 31, 1920	
Topographical Survey and Mapping		
Big Meadow Dam Site Topography	17 July 2012	Topographical survey from Okanagan Survey & Design
Elinor Lake – North Dam Site Topography	24 July 2012	Topographical survey from Okanagan Survey & Design
Elinor Lake – South Dam Site Topography	24 July 2012	Topographical survey from Okanagan Survey & Design

File Name	Data	Description
Naramata Lake Dam – Site Topography	24 July 2012	Topographical survey from Okanagan Survey & Design
Naramata Creek Watershed Area – Map 5: Groundwater Sensitivity Zones	21 December 1998	Groundwater sensitivity zones, recharge and discharge zones, flow and surface hydrology sensitivity zones for the Naramata watershed
Photos		
Big Meadow Lake Dam Site Photos	2010	
Elinor Lake Dams Site Photos	2010	
Naramata Lake Dam Site Photos	2010	
Naramata Water System North and South Creek Intake Photos	12 March 2020	
Inspection Reports (by RDOS staff)		
Naramata Dams Status Reports FLNRO	2002 to 2019	Dam Status report forms
Correspondence		
Naramata Dams FLNRO Dam Audit Program	Emails to 21 November 2019	Email correspondence on Audits between 2004-2019
Big Meadow Dam	2 November 2004.	Correspondence from Golder regarding insitu density testing along a repaired section of the south east abutment of the Big Meadow Dam.
Reports		
Risk Control Survey	2019	Review of RDOS facilities to identify exposures to liability and to assist staff in managing these exposures.
Big Meadow Reservoir and Dam Operation, Maintenance and Surveillance Plan Emergency Preparedness Plan	May 2017	OMS and EPP Plan from RDOS
Elinor Lake Reservoir and Dams Operation, Maintenance and Surveillance Plan Emergency Preparedness Plan	May 2017	OMS and EPP Plan from RDOS
Naramata Lake Reservoir and Dams Operation, Maintenance and Surveillance Plan Emergency Preparedness Plan	May 2017	OMS and EPP Plan from RDOS
Naramata Uplands Waterworks (Diversion, Divide, Flume, Highline & Intakes - Maintenance and Surveillance Plan	April 2013	Maintenance and Surveillance Plan from RDOS
Big Meadow Lake Dam Geotechnical Assessment	11 January 2013	EBA Consultants 2013 Geotechnical Assessment Report
Topographical Survey of Naramata Dams	10 January 2013	EBA Consultants memo accompanying topographical survey.-EBA File: 13103018
Dam Safety Review – Big Meadow Lake Dam	17 December 2010	EBA Consultants 2010 Dam Safety Review – No. K13101459.001
Dam Safety Review – Naramata Lake Dam	17 December 2010	EBA Consultants 2010 Dam Safety Review– No. K13101459.001

File Name	Data	Description
Dam Safety Review Summary Report – Naramata Dams	21 December 2010	EBA Consultants 2010 Dam Safety Review–No. K13101459.001
Dam Safety Reviews for Elinor Lake North (Saddle) Dam and Elinor Lake South Dam	17 December 2010	EBA Consultants 2010 Dam Safety Review– No. K13101459.001
Hydrotechnical Assessment of the Naramata Dams	20 December 2010	EBA Consultants 2010 Hydrotechnical Assessment Report
Naramata Fan Study (with Robinson and Chute Creeks)	December 1994	BC MoE Naramata Fan Study
Naramata Lake Operation and Maintenance Manual	April 1993	Naramata Irrigation District Operation and Maintenance Manual.
Big Meadow Reservoir – Storage Capacity Table	26 April 1979	Storage capacity table using survey data from Kelowna Regional Office Water Rights Branch
Eleanor Lake Reservoir – Storage Capacity Table	17 August 1979	Storage capacity table using survey data from Kelowna Regional Office Water Rights Branch
Naramata Lake Reservoir – Storage Capacity Table	29 June 1979	Storage capacity table using survey data from Kelowna Regional Office Water Rights Branch

4.2 Data Gaps

RDOS provided a thorough record of information available for Big Meadow Lake Dam including engineering and dam safety studies that have been completed for the Big Meadow Lake Dam during the life of the structure. This documentation included previous dam analyses conducted by external consultants (EBA, 2013) as well as reports from inspections completed by RDOS personnel and RDOS Operations, Maintenance and Surveillance (OMS) information.

The project consists of structures that were constructed from 1920to 1952 and have largely gone unchanged throughout the intervening years. However, a series of improvements in the toe of the dam have been undertaken such as installation of a toe drain. A complete record of information on the design and construction of the dam was not available. For the analysis in this review, it has been assumed that the general information contained in the data files received from RDOS reflects the current condition of the structures.

The data gaps that were identified during this review include:

- Construction specifications
- As-built drawings
- Instrumentation evaluation (piezometers and weirs) downstream of the dam as indicated and installed in 2013 (EBA, 2013).

Recommendations to fill some of these gaps are presented in the conclusions and recommendations sections of the report but none of these prevented the completion of the DSR.

5. Site Inspection and Staff Interviews

Hatch conducted a one (1) day site inspection to Big Meadow Lake Dam for this Dam Safety Review (DSR). The site inspection was conducted on July 9, 2020 and attended by Hatch's Structural Engineer/Project Manager (Amit Pashan, P.Eng.), Geotechnical Engineer (Parham Ashayer, P.Eng.) and Hydrotechnical Engineer (Shayla Murphy, P.Eng.). The following personnel from RDOS also attended the site inspection: Shane Fenske (RDOS – Engineering Technologist and Naramata Dams Dam Safety Review Project Manager), and Jon Hillman (RDOS Dam Inspector).

The purpose of this site inspection was for the Hatch DSR Team to:

- Gain familiarity with the site.
- Inspect the various structures and equipment and document any observed deficiencies.
- Discuss aspects of RDOS's dam safety inspection and monitoring program.
- Discuss operational and dam safety aspects of the Big Meadow Lake Dam site and RDOS's operations and maintenance staff.

Photos referred to in the following sections can be found in Appendix A.

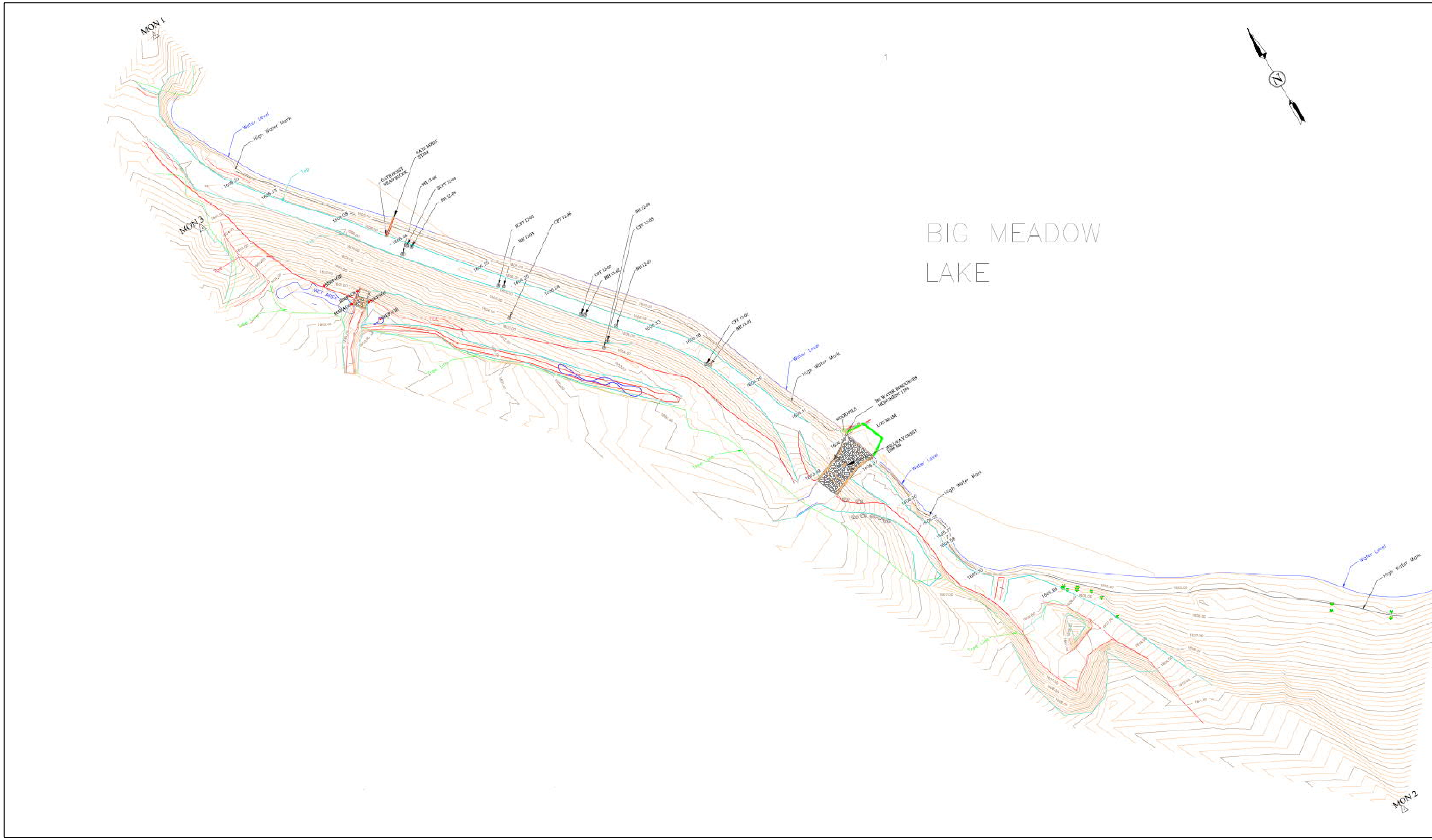

Figure 5-1: Big Meadow Lake Dam Site Plan and Topography (Okanagan Survey, 2012)

5.1 General

A general walkover and inspection of the Dam structures was performed as part of the 2020 Dam Safety Review. The Dam is within a remote area, yet clear indicators of public access were present. The reservoir rim was found to be surrounded by natural higher ground with a dense tree cover surrounding. However, the reservoir rim was generally not accessible and a full reservoir rim review could not be carried out. RDOS did not raise any issues regarding the reservoir rim. A review of the dam crest and slopes was completed and the dam was found to be well maintained in this area. No significant dead wood was observed in the lake which would supply debris that could potentially impact the structure or spillway. On the upstream (above water level) and downstream slopes of the dam, grass and small shrub growth were observed (see Photo A1 and A2 in Appendix A) which suggest that the vegetation control program was satisfactorily implemented with the exception of vegetation and shrubs growth along the Low Level Outlet channel and downstream toe. A comparison of the existing condition with the previous photos taken during the 2010 DSR [EBA, 2010] shows that the vegetation is better managed in the footprints of the embankment.

5.1.1 Freeboard

The crest of the dam varies significantly in elevation along its entire length, from 1605.56 m to 1606.33 m.

Flood routing and freeboard analyses were completed, demonstrating that the existing freeboard will provide adequate protection due to wind generated waves. Given that there is currently no rip-rap or erosion protection layer on the dam crest or upstream slope, it is recommended that RDOS inspect the dam after large wind storms to confirm if any damage has occurred and repair as necessary. This requirement has been added to the OMS. Provision of appropriately sized armor protection along the upstream face of the dam from the crest to 1 m below the low water level should be considered and is described in further detail in Section 7.2.6.

The crest itself is frequented by recreational ATV traffic. Significant rutting of the crest was observed due to this traffic.

5.2 Big Meadow Embankment Dam

The Big Meadow Lake Dam is a granular earthen embankment dam (with a central concrete core wall water barrier) which impounds the Big Meadow Lake reservoir and has been in operation since at least 1938. The exact dates of dam construction and commissioning are unknown. A review of historical reports and drawings suggests that the original Big Meadow Lake Dam was designed in the 1920s; the dam information board states that the dam was constructed in 1933. A review of the earliest available aerial photography from 1938 indicates that the embankment was constructed and the reservoir was not filled. The 1933 construction date may therefore be a reasonable estimate of when dam construction commenced.

The original embankment was designed with 2H:1V downstream and upstream slopes. A modification program was undertaken in 1952 which resulted in the following remediations:

- Flattening of the upstream and downstream slopes to 3H:1V and 2.5H:1V, respectively.
- Raising the concrete core wall by 305 mm (12 inches).
- Grouting a 457 mm (18 inch) diameter steel discharge conduit into the original concrete culvert.

The 1952 dam has a design crest width of 3.66 m (12 feet), freeboard of 1.83 m (6 feet), and maximum embankment height of 7.2 m (23.6 feet).

No information is available on the foundation conditions or preparation. The boreholes drilled during the most recent past investigation (EBA, 2013) did not penetrate into foundation material.

Riprap or other erosion protection systems on the upstream dam slope were not identified by Hatch during the 2020 site visit and were not indicated in the previous 2013 OMS (see Photos A1 and A2). However, occasional large rockfill and riprap spalls could be observed near reservoir level with some sign of beaching (see Photo A14).

Vegetation overgrowth was observed on the upstream slope and consisted of blackberry bushes and tall grasses which impeded visual inspection in select areas. It is recommended that the RDOS adhere to the existing vegetation control plan to facilitate observation and surveillance. Minor Animal burrows were also observed on the upstream slope above the reservoir water level (also see Photo A15).

The downstream slope of the Big Meadow Lake Dam is comprised of pit-run sand and gravel materials overlain by light vegetation. Areas with dense vegetation growth were noted on the slope suggesting potential seepage exit points, generally close to the lower third of the downstream slope (see Photos A3 to A8). The slope was uniform and gently sloped which is in general agreement with the shallow 3H:1V typical slope noted in the available design drawings. A few large bushes and trees are present in the vicinity of the downstream toe and along the tailrace channel. It is recommended that these trees be removed to assist the inspection of the downstream slope and tailrace channel, and prevent them from becoming a dam safety issue (see Issue BM-9 in Table 13-1). EBA (2010) reported the existence of a concrete seepage monitoring weir on the downstream channel which was covered by fallen trees and debris. Hatch did not have an opportunity to inspect this area in the 2020 investigation, however, Hatch recommends that the weir be reinstated to facilitate seepage monitoring. No erosion of the downstream slope was noted (see Issue BM-3 in Table 13-1).

The crest of the dam is a publicly accessible road and was in fair condition (see Photos A1, 3, 8, 9, 11, 12 and 13). The crest of the dam appeared to be variable in elevation; this can also be observed in the 2012 topographical survey. The crest of the dam west of the spillway structure varies from El. 1606.11 m to 1606.33 m according to the 2012 survey (Okanagan

Survey, 2012). The crest elevation is as low as El. 1606.07 m immediately east of the spillway structure. The Dam crest elevation drops to El. 1605.56 m at a distance of 15 m to 20 m east of the spillway structure. It should be noted that this depressed area is confined to areas with a higher elevation on the downstream side which is part of incoming access road on the left abutment (see Photos A12 and A13).

No barriers are placed along the upstream or downstream dam slope crests, however, these provisions for traffic control are not required due to the low height of the dam and shallow slope gradients.

The most recent topographical survey of the dam site was performed in 2012 to compare the existing dam configuration with the original design and provide reference for future evaluations. The installation of fixed settlement monuments along the dam crest is recommended. Settlement monuments should be surveyed prior to future DSRs (Issue No.8 in Table 13-1).

No issues were noticed on the right abutment of the dam apart from vegetation overgrowth which should be removed as part of the regular vegetation control plan. At the left abutment, the dam crest is slightly lower than the rest of the dam and should be raised.

Instances of significant seepage were noted at the left and right side of the Low Level Outlet (LLO) exit structure. No seepage was observed on the left and right sides of spillway.

5.3 Spillway

The spillway structure and channel were observed by Hatch during the site inspection (see Photos A10, A11 and A16) and appeared generally to be in good condition. The spillway consists of a 6.1 m wide concrete overflow drop structure. Although there are guides in place for stoplogs these have been decommissioned and are no longer used.

There is a debris boom upstream at the spillway inlet structure to prevent debris from clogging the spillway. This boom should be adequate for this purpose provided debris is removed on a regular basis and not allowed to build up excessively. Dam access is provided via a gravel road that crosses through the downstream spillway channel. The spillway drop structure includes a concrete apron that discharges across the rip-rapped access road and into a channel that travels beyond the downstream treeline, where it then runs parallel to the dam before terminating at the low level outlet channel at Chute Creek.

Erosion protection in the downstream spillway channel includes the concrete apron followed by rip rap across the gravel access road. Some vegetation at the downstream of the riprap was observed. Riprap coverage appeared to be sparse downstream of this point, however visibility was obstructed during the site visit due to spillway operation. Vegetation was quite dense on the banks of the spillway channel downstream of the access road. The spillway discharge channel was found in good condition with no sign of erosion or distress.

At the time of inspection, there was approximately 2.5” of water flowing over the spillway weir.

The concrete of all spillway elements was generally found to be in good condition with no signs of any major damage, spalling or any exposed rebar. Some damage to the concrete was however observed along the crest at the downstream end, before the stepped drop of the spillway (see Photos A10 and A18). The concrete of the spillway apron slab and the vertical wall of the drop are 12 inches thick, with a single layer of rebar. The damaged section of the crest appears very localized and no rebar was visible through the damaged portion. Due to flowing water over the spillway, a close inspection of the damage and the condition of the concrete at the crest was not possible. The depth of the concrete damage appears to be 4 to 6 inches deep, based on photos taken during the site visit. Since this damage may have reduced or compromised the cover for the rebar in the wall and the slab, it should be repaired to prevent corrosion of the rebar which can lead to further propagation of the damage. If this damage is left unrepaired and the erosion continues to full depth of concrete, the flow of the water could eventually result in erosion of foundation soil and undermining of the apron slab and vertical drop section. When the spillway is dry during low lake levels, a close inspection of the crest should be performed to ensure that the concrete in this section is of sound quality and that the surface erosion due to flowing water over time has not deteriorated the strength of the concrete. Also, the repair of the damaged section of the crest should be completed within the next 1-2 years.

The upstream inlet walls and the downstream wing walls of the outlet were visually verified and no signs of tilting or deformation were noted. An existing crack was observed along the upstream wing wall on the left side of the spillway (looking downstream), which is at approximately 35 degree angle to horizontal and runs from apron slab to the top of the sloping surface of wing wall (see Photo A19). This crack was previous repaired and further opening of the crack was not evident. The time of occurrence of this crack and its repairs is not known however after the repairs, the crack seems to be stable. It appears that this crack was possibly developed due to settlement of localized foundation base material. Since any further propagation and opening of the crack was not observed, it does not seem to be concerning however it is recommended that the condition of the crack be observed during routine inspection and any observed changes to the crack pattern be addressed. Some additional minor grouting repairs to the vertical joints of the spillway retaining walls were also observed, which are more preventative in nature and are no concern for structural stability.

The roadway downstream of the spillway section was in fair condition with no signs of settlement or localized subsidence or depressions in the roadway fill. The spillway channel was fairly clean with no large debris accumulations. As per discussion with RDOS staff, there have not been observations of any large size rock flowing over the spillway in the past. Therefore, there is no concern about damage to the spillway apron slab concrete from any rocks rolling over it during high flows. A couple of rocks observed on the downstream apron slab during the site visit were likely dropped in the spillway by trespassers, as per the site staff. The surface of the apron slab looks in fair condition with some localized damages and/or presence of minor surface erosion due to flow over time however, these conditions can be expected from structure of this type and are not a concern.

The water was flowing over the spillway in a very shallow depth during the site visit. There was no evidence of any notable seepage at the interface of the spillway retaining walls and the embankment of the dam. According to RDOS staff, there have been no observations of seepage behind the spillway walls in the past.

5.4 Intake Structure

The intake system comprises an 18-inch diameter 12-gauge steel pipe encased in concrete, which runs along the base of the embankment dam. An 18-inch Armco heavy duty slide gate is installed at the upstream/intake end of the concrete encased pipe culvert. The slide gate is connected with a 1-1/2" diameter gate rod and is operated via a rotating wheel assembly at the dam deck level. Most part of the intake structure was under water during the site visit and therefore could not be visually inspected. Only the section of the wheel assembly and its concrete anchor support at the dam crest, and some portion of the intake gate operating rod were visible above water (see Photo A17). The concrete at the wheel block support assembly appeared to be in good condition. Some signs of corrosion were observed on the gate operating rod and the wheel assembly however, no evidence of damage was noted. The operation of the intake gate was not verified during the site visit. According to site staff, the intake gates operate successfully, when required and no concerns were indicated related to the operation of these gates.

The inspection of the trash rack grill at the inlet and the concrete support structure at the inlet of the culvert is recommended to be performed during the time of low lake levels, for any signs of distress, settlement or damage. The observations from the inspections should be documented for future reference, and any concerns if found, should be addressed.

Significant ATV traffic activity appears to be present at the dam site as the dam area is open for recreational use and there is no fence around the dam crest. Some evidence of vandalism was observed on the posted signage which were badly damaged due with bullet holes by public during recreational and hunting activities. Since the operating wheel assembly is located at the dam crest, a possible concern could be potential damage to this operating structure due to accidental ATV activities or vandalism. In the event the structure is vandalized, the damage may remain unnoticed for several days as the dam site is not manned. It may be concerning if the gate operating assembly is found to be damaged/inoperable in an event a gate operation is needed to lower the reservoir in case of a dam safety emergency such as after a major seismic event or development of a piping failure. Concrete barrier blocks or fencing of the area should be considered around the wheel assembly and the gate rod as a precautionary measure. These types of solutions can prevent the potential risk of damage to the operating structure and can be implemented at a relatively low cost.

5.5 Low Level Outlet Structure

The outlet is a concrete wall structure at the downstream toe of the dam, which appears to be installed immediately downstream of the original outlet structure, as shown in the existing drawing No. 1315. This structure supports the downstream end of an 18-inch diameter culvert pipe. The space between the downstream wall of the old outlet and upstream wall of new outlet is backfilled with gravel, as per existing drawings. Due to the vegetation growth in this area, the gravel backfill was not visible during site visit.

The concrete of the outlet structure was found to be in good condition. There was no evidence of any damage, spalling of concrete or exposure of rebar (see Photos A5 and A6). The walls of the outlet structure were visually verified, and no signs of tilting or deformation were noted. The apron slab of the outlet structure had some signs of erosion due to the flow over time however no significant damage was observed. Some vegetation growth along the sides and on top of the concrete walls was observed, which should be removed during routine maintenance of the facility, to prevent deterioration of the concrete structure.

6. Consequences of Dam Failure and Dam Classification

A full dam breach analysis and consequence classification and inundation mapping study was conducted as part of this project. The results of this analysis can be found under separate cover in Naramata Dam Breach Assessment and Inundation Mapping (2021). The following subsections summarize the results of this study.

6.1 Background Information

Dam classifications are used for the purpose of general dam safety management oversight, as well as for inspection, maintenance, and surveillance programs. Dam classifications provide guidance in the selection of specific design criteria such as, in the case of this study, IDF, freeboard, and stability criteria. B.C. Dam Safety Regulations present a classification scheme, presented in Table 6-1 and Table 6-2, which are used to provide guidance on the standard of care expected of dam owners. Estimates of potential consequences of dam failure are categorized to distinguish dams where the risk is much higher than others. The dam class is determined by the highest potential consequence, whether loss of life, environmental, cultural, or economic losses.

Table 6-1: Consequence Classification Guide
(B.C. Dam Safety Regulation Under the Water Sustainability Act Dam Safety Regulation 40/2016)

Dam Failure Consequence Classification	Population at Risk	Consequences of Failure		
		Loss of Life	Environment and Cultural Values	Infrastructure and Economics
Low	None[1]	No possibility of loss of life other than through unforeseeable misadventure.	Minimal short-term loss or deterioration and no long-term loss or deterioration of: a) Fisheries habitat or wildlife habitat b) Rare or endangered species c) Unique landscapes, or d) Sites having significant cultural value.	Minimal economic losses mostly limited to the dam owner's property, with virtually no pre-existing potential for development within the dam inundation zone.
Significant	Temporary Only[2]	Low potential for multiple loss of life.	No significant loss or deterioration of: a) Important fisheries habitat or important wildlife habitat b) Rare or endangered species c) Unique landscapes, or d) Sites having significant cultural value, and restoration or compensation in kind is highly possible.	Low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction of or damage to locations used occasionally and irregular for temporary purpose.
High	Permanent[3]	10 or fewer.	Significant loss or deterioration of: a) Important fisheries habitat or important wildlife habitat b) Rare or endangered species c) Unique landscapes or d) Sites having significant cultural value, and restoration or compensation in kind is highly possible.	High economic losses affecting infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to scattered residential buildings.

Dam Failure Consequence Classification	Population at Risk	Consequences of Failure		
		Loss of Life	Environment and Cultural Values	Infrastructure and Economics
Very high	Permanent[3]	100 or fewer.	Significant loss or deterioration of: a) Critical fisheries habitat or critical wildlife habitat b) Rare or endangered species c) Unique landscapes, or d) Sites having significant cultural value, and restoration or compensation in kind is possible but impractical	Very high economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction of some severe damage to residential areas.
Extreme	Permanent[3]	more than 100.	Major loss or deterioration of: a) Critical fisheries habitat or critical wildlife habitat b) Rare or endangered species c) Unique landscapes, or d) Sites having significant cultural value, and restoration or compensation in kind is impossible.	Extremely high economic losses affecting critical infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas.

[1] There is no identifiable population at risk.
[2] People are only occasionally and irregularly in the dam-breach inundation zone, for example stopping temporarily, passing through on transportation routes or participating in recreational activities.
[3] The population at risk is ordinarily or regularly located in the dam breach inundation zone, whether to live, work or recreate.

Table 6-2: B.C. Dam Safety Regulation Downstream Dam Failure Consequence Classification DFCC Guide

DFCC	Inflow Design Flood
Extreme	PMF
Very High	2/3 between AEP 1/1,000 and PMF
High	1/3 between AEP 1/1,000 and PMF
Significant	AEP between 1/100 and 1/1,000
Low	AEP 1/100

6.2 Previous Work by Others

The Big Meadow Dam is currently classified as High. The report, "Hydrotechnical Assessment of the Naramata Dams" (2010) was produced in tandem with the previous most recent Dam Safety Reviews by EBA Engineering Consultants, which classified Big Meadow Dam as High.

However, a complete incremental damage and loss of life assessment and full dam breach and inundation study had not previously been performed for this dam. Previous classification assessments were conducted prior to the publication of the current CDA Dam Safety Guidelines [CDA, 2013a).

6.3 Recommended Classification

To determine the appropriate consequence classification, it was necessary to first assess the effect of a breach on the downstream area and inhabitants during Sunny Day and flood scenarios. This was carried out by Hatch as part of this study and is documented in a separate report entitled Naramata Dam Breach Assessment and Inundation Mapping (2020).

The CDA Technical Bulletin on Inundation, Consequences and Classification for Dam Safety (2007) and the BC Dam Safety Program "Downstream Consequence of Failure Classification Interpretation Guideline" provides guidance on the application of consequence assessments to aspects of dam design and dam safety:

- Incremental consequences of dam failure in flood conditions define the minimum requirements for the IDF.
- Consequences of dam failure in fair weather conditions define the minimum requirements for seismic loading.
- The higher of the two dictates the overall level of care in management oversight, inspection, maintenance, and safety assessment.

Big Meadow Dam has been classified according to the current B.C. Water Sustainability Act Dam Safety Regulation [B.C. Reg 44/2016] dam classification system. The consequence assessment found that the classification for flood conditions was lower than for Sunny Day conditions. Results demonstrate that the overall classification for Big Meadow Dam is "Very

High", but that the incremental damages due to a potential IDF are in line with a "High" classification (i.e. this defines the minimum requirements for IDF only).

The classifications provided in this report apply to the existing dam in its present configuration. Alterations to the dam could change parameters such as the volume and/or height of impounded water, the flood routing capacity of the dam, or potential breach characteristics. This in turn could impact the nature and magnitude of consequences of failure and therefore the appropriate classification and design criteria. In the event of substantial alterations, flood routing calculations need to be updated and the potential consequences of failure reassessed by means of additional or revised dam breach analyses as needed.

7. Dam Safety Analyses

One of the basic requirements of a DSR is the engineering analysis and assessment of the structure. The CDA Guidelines state “Safety analysis of the dam system should include the internal and external hazards, failure modes and effects, operating reliability, dam response, and emergency scenarios.”

Also as stated in the CDA Bulletin on Analysis and Assessment “The purpose of dam safety analysis is to determine the capability of the dam and systems to retain the stored volume and to pass flows around and through the dam in a controlled manner.”

The following subsections detail the dam safety analysis that were performed as part this DSR.

7.1 Failure Modes and Effects Analysis

A hazard and failure mode matrix was developed for the Big Meadow Dam and is presented in Table 7-1. In this type of assessment, the interactions between hazards and failure modes are related using a matrix representation. The hazards and failure modes matrix (H&FMM) provides a simple means of summarizing the considerations that, in principle must be embodied in every dam safety program. It provides a framework in which the various hazards and failure modes can interact and act in combination to lead to dam failure. Although the site consists of the dam and a spillway, the failure modes listed are generally applicable to the site as a whole.

In a risk based evaluation of failure modes, risk can be described as the combination likelihood of a failure mode occurring (probability of the failure mode) with the consequence of what would happen should a failure mode occur (loss of containment of the reservoir). This is calculated in a quantitative assessment as Risk = Likelihood X Consequences. The intent of a Dam Safety Review is to ensure that the dam is constructed and operated in a manner to ensure the risk to the public is within the “broadly acceptable” range or where this is not possible, to reduce the risks to as low as is reasonably practicable (ALARP).

Based upon the configuration and conditions at the dam, a number of the hazard-failure mode combinations can be ruled out. These are illustrated in Table 7-1 with cells that are hatched. There are a number of failure modes that are possible, however, can be further ruled as improbable because the dam design and operation meet the requirements laid out in the BC Dam Safety Regulation, CDA Guidelines or general industry standards for a structure with the “Very High” DFCC and risks are considered ALARP. These are presented in black text in Table 7-1.

The remaining hazard failure mode combinations are identified as being possible and either reflect deficiencies in meeting the BC Dam Safety Regulation, CDA Guidelines or general industry standards or there is insufficient information to confirm that they meet these requirements. These are illustrated in Table 7-1 with red text.

Table 7-1 can then be used as a visual reference of the state of safety of the dam. The cells with black text illustrate the items that need to be guarded against through the OMS of the dams and planned for the in the Dam Emergency Plan (DEP). The cells with red text illustrate the major items that are current deficiencies that should be addressed to ensure the safety of the dam going forward.

Table 7-1: Hazard and Failure Modes Matrix for Big Meadow Dam

Element and/or Element Function	Most Basic Functional Failure Characteristics	External Hazards				Internal Hazards (Design, Construction, Maintenance, Operation)			
		Meteorological	Seismic	Reservoir Environment	Human Attack	Water Barrier	Hydraulic Struct.	Mech/Elec.	Infrastructure & Plans
Inadequate installed discharge capacity	Meteorological inflow > buffer + outflow capacity	Improbable – Spillway can safety pass IDF							
Inadequate available discharge capacity	Inadequate reservoir operation (rules not followed)	Improbable – Debris blockage could cause over topping. Mitigated by spillway design, debris supply, debris boom, and inspection	Improbable - LLO is the only operable equipment and it is not required for flood control.	Improbable - Reservoir slopes are stable; Little debris in reservoir, and debris boom is in place upstream of spillway.		Improbable - LLO is the only operable equipment and it is not required for flood control. Spillway can pass IDF without overtopping of structure.	Improbable - LLO is the only operable equipment and it is not required for flood control.		Improbable - LLO is the only operable equipment and it is not required for flood control. Spillway can pass IDF without overtopping of structure.
	Random functional failure on demand	Improbable – no spillway gates. LLO tested regularly.	Improbable – no spillway gates.	Improbable – no spillway gates.	Improbable – no spillway gates.	Improbable – no spillway gates.	Improbable – no spillway gates.	Improbable - No mechanical or electrical equipment required for flood control.	Improbable – no spillway gates.
	Discharge capability not maintained or retained	Improbable - Debris blockage could cause over topping. Mitigated by low debris supply, debris boom, and inspection. Potential for ice blockage is improbable due to operating timeframe.		Improbable – Ice jam in front of spillway causing blockage. Grounded ice in lake floats towards spillway. Slope slide from surrounding topography (low probability). Debris blockage could cause over topping. Mitigated by low debris supply, debris boom, and inspection.	Improbable- fixed crest spillway with capacity to pass the IDF. No fence around LLO structure could lead to vandalism of that gate mechanism. Damage to the spillway channel by vandals is very unlikely and can be found during weekly inspection.	Improbable - Debris blockage could cause over topping. Mitigated by debris supply, debris boom, and inspection.	Improbable - free overflow spillway with fixed concrete crest.		Improbable – free overflow spillway with fixed concrete crest.
Inadequate freeboard	Excessive elevation due to landslide or U/S dam	Improbable –The potential for the wave created by a landslide has not been specifically studied but likely not credible. There are no dams located upstream to cause a cascade failure.	Improbable –The potential for the wave created by a landslide has not been specifically studied but likely not credible based on topographic information. There are no dams located upstream to cause a cascade failure.	Improbable – Potential for landslide into reservoir is unlikely based on topographic information.		Improbable - There are no dams located upstream to cause a cascade failure. No landslide hazard identified.			N/A
	Wind-wave dissipation inadequate	Improbable - meets freeboard for wind wave events for normal and IDF conditions. No riprap layer on upstream face of dam, but this is mitigated by the small size of lake. This failure mode would take time to form and would require repeated	Improbable - meets freeboard for wind wave events. Settlement is not expected to be greater than the normal freeboard already available.	Improbable – Freeboard analysis completed. Based on the shape of the reservoir and topography around the reservoir and the fairly short fetch distance, high winds are unlikely to produce waves that overtops the dam.		Improbable – Freeboard analysis completed. Based on the shape of the reservoir and topography around the reservoir and the fairly short fetch distance, high winds cannot produce a wave that overtops the dam.			Improbable - If wind and wave damage is not repaired freeboard could be compromised over time.

Element and/or Element Function	Most Basic Functional Failure Characteristics	External Hazards				Internal Hazards (Design, Construction, Maintenance, Operation)			
		Meteorological	Seismic	Reservoir Environment	Human Attack	Water Barrier	Hydraulic Struct.	Mech/Elec.	Infrastructure & Plans
		events. Review for benching on upper slope, could inspect full slope while empty annually.							
Safeguards fail to provide timely detection and correction	Operation, maintenance and surveillance fail to detect/prevent hydraulic adequacy	Improbable - due to weekly inspections and lack of mechanical operation. However, meteorological event could make dam inaccessible and therefore prevent the Dam Safety Engineers activities. Helicopter access should be considered in an emergency	Improbable - Likely no road access to the site following a seismic event due to loss of road. However, there are likely locations suitable for helicopter landing.	Improbable - Good OMS procedures and little expected influence from reservoir environment.		Improbable - due to weekly inspections, and lack of mechanical operation.			Improbable - due to weekly inspections and lack of mechanical operation.
	Operation, maintenance and surveillance fail to detect poor dam performance	Possible - Adequate piezometers exist, weirs are not operational and no automatic reservoir elevation detector. Mitigated by weekly inspections. Historical seepage next to spillway was addressed by repairs. Seepage is ongoing around LLO exit location. However, meteorological event could make dam inaccessible and therefore prevent the Dam Safety Engineers activities. Helicopter access should be considered in an emergency after major events.	Possible – LLO dependency becomes important if the central concrete wall is damaged during a seismic event. If distress in dam occurs after a seismic event and the LLO is damaged, there is currently no method or procedure in place to lower the reservoir. Consideration should be given to a portable siphon system to lower the reservoir in case of emergency.	Improbable - Good OMS procedures and little expected influence from reservoir environment.		Possible - Insufficient instrumentation or seepage monitoring. Mitigated by weekly inspections. Additional weir is recommended.			Possible - Insufficient instrumentation or seepage monitoring. Mitigated by weekly inspections. Additional weir is recommended.
Stability under applied loads	Mass movement (external stability:- displacement, tilting, seismic resistance)	Improbable - Dams meets stability requirements.	Improbable - Dam meets seismic stability requirements.	Improbable - A landslide induced or seiche wave large enough to overtop the dam is not considered to be a highlighted hazard.		Possible - Dam does not meet post-seismic requirements.			Improbable - regular inspections.
	Loss of support (foundation or abutment failure)	Improbable - Dams meets stability requirements.	Improbable - Dam meets seismic stability requirements.			Possible - Dam does not meet post-seismic and liquefaction requirements.			Improbable - regular inspections.
Watertightness	Seepage around interfaces (abutments, foundation, water stops)	Improbable - Dam has performed properly. Confirmed by analysis.	Possible – Central concrete wall is susceptible to damage and seepage after a seismic event.			Possible – Risk of piping is greater than the tolerable threshold. Downstream berm and filter are recommended.			Possible - Seepage/turbidity quantity monitoring not currently being conducted. Piezometers and seepage

Element and/or Element Function	Most Basic Functional Failure Characteristics	External Hazards				Internal Hazards (Design, Construction, Maintenance, Operation)			
		Meteorological	Seismic	Reservoir Environment	Human Attack	Water Barrier	Hydraulic Struct.	Mech/Elec.	Infrastructure & Plans
			Downstream berm and filter are recommended.						quantity fluctuations should be plotted and assessed annually.
	Through dam seepage control failure (filters, drains, pumps)	Improbable - Dam has performed properly. Confirmed by analysis.	Possible – Central concrete wall is susceptible to damage and seepage after a seismic event. Downstream berm and filter are recommended.			Possible - Risk of piping is greater than the tolerable threshold. Downstream berm and filter are recommended.			Possible – Insufficient seepage/ turbidity quantity monitoring. Not currently being conducted. Piezometers and seepage quantity fluctuations should be plotted and assessed annually.
Durability/ cracking	Structural weakening (internal erosion, AAR, crushing, gradual strength loss)		Possible - Dam foundation susceptible to Liquefaction. Downstream berm and filter are recommended.			Possible - Cracking and damage in the central concrete wall is possible. Downstream berm and filter are recommended.			Improbable - regular inspections. Piezometers and seepage quantity fluctuations should be plotted and assessed annually.
	Instantaneous change of state (static liquefaction, hydraulic fracture, seismic cracking)		Possible - Dam foundation susceptible to Liquefaction. Downstream berm and filter are recommended.			Possible - Dam foundation susceptible to Liquefaction. Cracking and damage in the central concrete wall are possible. Downstream berm and filter are recommended.			Improbable - regular inspections. Piezometers and seepage quantity fluctuations should be plotted and assessed after seismic events.

7.2 Hydrotechnical Assessment

7.2.1 Review of Hydrological Studies

The flood hydrology associated with the Naramata Dams basin was developed during the 2010 Hydrotechnical Assessment of the Naramata Dams [EBA Engineering Consultants, 2010], and updated as part of this study, as detailed under separate cover in Naramata Dam Breach Assessment and Inundation Mapping (2020).

Additional data collected at the active gauges since the 2010 assessment was included in Hatch's assessment. Although results of the 2010 analysis were not presented in the previous report, results of the updated flood frequency analysis are found in Table 7-2.

Table 7-2: Flood Frequency Analysis

Return Period (years)	Current Flood Frequency Analysis: Peak Flow (m^3/s)
2	1.1
5	1.5
10	1.7
20	1.9
50	2.1
100	2.2
200	2.4
1000	2.7

A PMF analysis was completed for the Big Meadow reservoir. The procedures used to assess the IDF for the past studies are generally acceptable for such a small catchment without available local gauge information. Given the lack of available data it is unlikely that a more rigorous analysis could be performed that would yield more accurate results than those obtained. Therefore, the same analysis was completed, including gauge data collected since the previous assessment.

The PMF Estimator for British Columbia provides the following equation for the Okanagan region within Zone 12B for watershed areas less than 8320 km^2 [Abrahamson & Pentland, 2010]:

$$Q = 2.1086A^{0.9240}$$

Where Q is the probable maximum flood in m^3/s and A is the area of the watershed in km^2. The results are presented in Table 7-3.

Table 7-3: PMF Peak Flows

Dam	Watershed Area (km^2)	Peak PMF (m^3/s)
Big Meadow Lake Dam	7.80	14.07

7.2.2 *Flood Operating Rules*

The Naramata Dams watershed operating system is detailed in the companion report: Naramata Dam Breach Assessment and Inundation Mapping (2021) a summary of the operation of Big Meadow Dam is provided as follows.

The only operable portion of the Big Meadow Dam is the 0.457 m diameter low-level riparian conduit structure described in Section 2. Its capacity has not been assessed. However, its capacity is far less significant during a large flood event, compared to the volume of flow that can be passed by the spillway.

However, the previous Big Meadow Dam OMS and EPP (2017) suggests that if the run-off water is excessive, the outlet gate can be opened to relieve some of the inflow. In general due to the design of these low flow outlets for more normal reservoir water levels and backwater conditions as well as the relatively small capacity of these types of structures compared to spill capacity during a flood this type of action is NOT recommended. If operated during a major flood there are dangers of excessive erosion downstream of the conduit as well as damage to the conduit and gate due to air demand exceeding available venting at the structure. As the spillway can safely pass flows in excess of the IDF operation of the conduit during a flood should not be required.

7.2.3 *Discharge Capacity*

There are two (2) structures that provide discharge capacity at Big Meadow Dam. These are the low level outlet and the uncontrolled concrete overflow spillway. Both structures were reviewed to confirm that the assumptions made in their design are appropriate.

7.2.3.1 Low Level Outlet

The low level outlet is described in Section 2. The main use of the low level outlet is to pass flow from the lake to maintain a minimum downstream riparian flow. The Big Meadow Dam OMS and EPP (2017) suggests that if the run-off water is excessive, the outlet gate can be opened to relieve some of the inflow. However, as stated above this runs the risk of damaging the structure and should not be used in this fashion. It is not required as the IDF can be accommodated through the spillway. A rating curve was not found for this structure.

7.2.3.2 Spillway

Big Meadow Dam's spillway is an uncontrolled concrete overflow weir that discharges across the rip-rapped access road and into an excavated channel that travels beyond the downstream treeline, where it then runs parallel to the dam before terminating at the low level outlet channel at Chute Creek. The spillway is 6.1 m wide.

A design spillway rating curve was not found within the available data collected during the study. The discharge capacity was assessed in the Hydrotechnical Assessment of Naramata Dams [EBA, 2010]. The broad-crested weir equation was used along with the geometry of the spillway, assuming a discharge coefficient of 1.65. A stage discharge curve for the Big Meadow Dam spillway is shown in Figure 7-1.

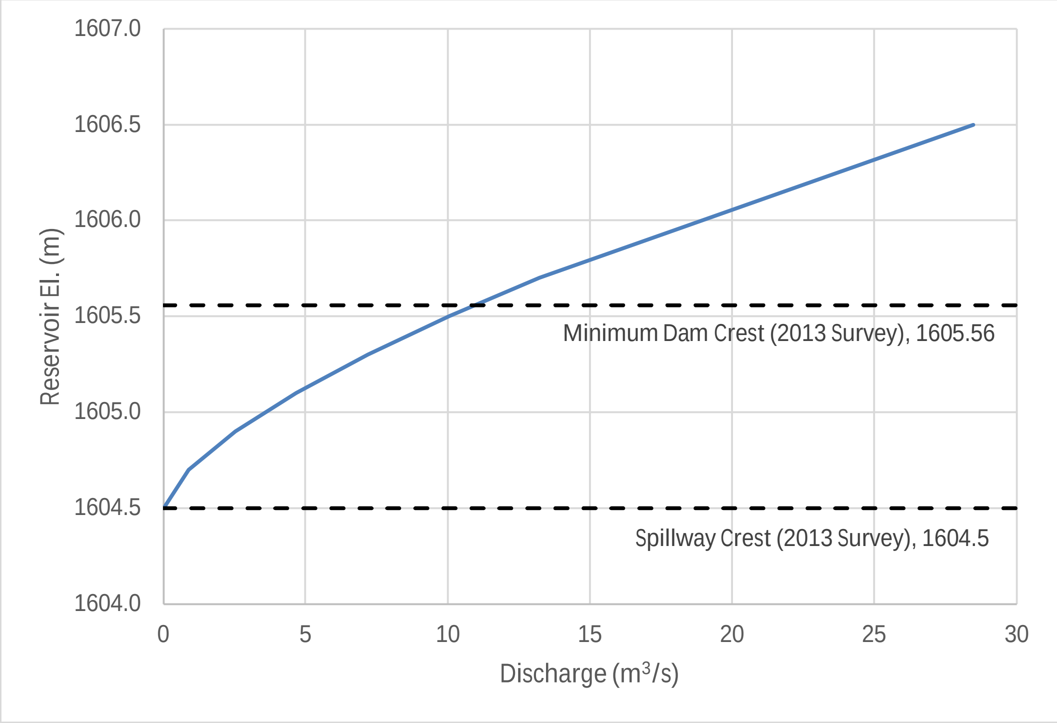

Figure 7-1: Big Meadow Spillway Stage-Discharge Curve

The spillway intake includes an excavated approach channel, and the outlet includes a concrete apron that discharges across the rip-rapped access road and into an excavated, grass-lined channel with some rock placement. The road to access the main dam crosses the downstream portion of the spillway (i.e. during operation, across the flow downs). During the IDF, 4.4 m^3/s with 0.58 m of head and approximately 1.3 m/s will pass over the spillway. This velocity may damage an unprotected grass lined channel over time; however, it is unlikely to endanger the structure, making this more of a maintenance issue. Additional studies could be completed for mitigation, but are not likely required. It is recommended that any damage that occurs during such an event be repaired as soon as possible following such an event.

7.2.4 Flood Passage Capability

The discharge capacity of the Big Meadow Dam spillway was assessed in the dam breach study by Hatch (2020), which is summarized in a stand-alone report.

A hydraulic model was set up to route the flood through the system, and concluded that the spillway can pass the IDF (equivalent to an Annual Exceedance Probability of 1/3 between

1/1,000 and PMF, with a peak inflow of 6.5 m^3/s). The maximum reservoir water level during this event would be approximately 1605.08 m, which is 0.48 m below the minimum dam crest.

7.2.5 Freeboard

The B.C. Dam Safety Regulation [B.C. Reg 44/2016] under the Water Sustainability Act does not speak directly to freeboard requirements for dams. However, according to the CDA Guidelines [CDA, 2007a], embankment structures are required to meet the following wind/wave criteria.

- No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1:1,000 year when the reservoir is at its maximum normal elevation.
- No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1:2 year when the reservoir is at its maximum extreme level during the passage of the IDF.

In BC, the document that speaks to freeboard requirements specifically is the FLNRO, Plan Submission Requirements for the Construction and Rehabilitation of Small Dams, 2018. This document provides the following requirements:

“Two types of freeboard are discussed below: normal and minimum. Regardless of which freeboard is used in the dam design, both require the spillway be able pass the IDF (see section on Spillway above).

(a) Normal Freeboard (or Gross Freeboard) is the difference of elevation between the lowest elevation of the top of the dam (or top of impervious core) and the maximum reservoir operating level (full supply level, often the spillway sill elevation).

(b) Minimum Freeboard (or Net Freeboard) is the difference of elevation between the lowest elevation of the top of the dam (or top of impervious core) and the maximum water level of the reservoir should the Inflow Design Flood (IDF) occur.

To prevent overtopping and provide redundancies in the dam design, the following freeboard standards shall be applied:

- The normal freeboard shall be at least 1.0 m in combination with a spillway width of at least 4.0 m.
- If the design engineer wants to present a case for a spillway width of less than 4.0 m wide, the minimum freeboard shall be at least 1.0 m. A spillway width of less than 4.0 m wide is not recommended for High and Very High dam failure consequence classification dams.

In addition, the Canadian Dam Association’s Dam Safety Guideline’s Technical Bulletin, Section 6.0 - Hydrotechnical Considerations for Dam Safety, should be consulted.”

Calculations for these conditions were carried out on Big Meadow Lake to determine if adequate freeboard exists.

During the site inspection, observations were made that indicated that the 1 m requirement may in fact be overly conservative for this specific dam. It was noted that the maximum effective fetch in which wind waves can be developed in the lake is less than 600 m (very short) and the lake is located in a valley. It is also understood that the 1 m requirement is largely a ‘rule of thumb’ based upon guidance provided by the United States Bureau of Reclamation as well as other jurisdictions. This or a similar rule are applied in many jurisdictions across Canada where more sophisticated analysis is not performed. For these reasons, it was deemed reasonable to perform a standard wind/wave assessment following the CDA Guidelines to determine the level of conservatism in the 1 m requirements and whether a lower standard may be acceptable.

First, fetch lengths for each cardinal and intercardinal wind direction for the most exposed location of Big Meadow Lake Dam was determined using the methodology specified in the USACE Coastal Engineering Manual (CEM) 2011. Calculated critical fetches for each cardinal and intercardinal direction are shown in Table 7-4.

Table 7-4: Big Meadow Dam Effective Fetch Calculations

Direction	Length (m)
N	214
NE	583
E	579
SE	421
S	13
SW	9
W	15
NW	93

Wind speed and direction data was taken from the Environment Canada climate gauge located at Summerland CS. This gauge is located approximately 19 km from Big Meadow Dam and has data from 1994 - 2020. This gauge was chosen over others in the area because it had the longest period of record within the vicinity of Big Meadow Lake.

A frequency analysis was conducted on the wind data to determine wind speeds for several annual exceedance probabilities and for each intercardinal direction. Annual maximum one-hour wind speed values were fitted to a Gumbel statistical distribution to determine the wind speeds associated with various return periods. The results of the frequency analysis are summarized in Table 7-5.

Table 7-5: Wind Velocities (km/h)

Return Period	Direction							
	N	NE	E	SE	S	SW	W	NW
2	25	17	17	36	46	21	24	29
10	32	23	22	43	55	27	30	35
20	35	26	23	45	58	29	33	37
30	36	27	24	47	60	30	35	38
50	38	29	25	49	62	31	36	39
100	41	31	27	51	66	33	39	41
1,000	50	39	32	60	76	40	47	48

Over-land wind speeds are converted to over-water wind speeds using correction factors based on empirical relationships found in the CEM [USACE, 2011]. These factors include corrections for non-standard anemometer elevation, minimum time required to form fetch limited waves, air-water temperature difference and surface roughness relationships.

To calculate wave characteristics the water depth was assumed to be 5.7 m, which ensured that deep water waves (conservative) were calculated

Wave characteristics were calculated for an IDF fetch combined with a 1:2-year wind event and the FSL fetch combined with a 1:1,000-year wind for all intercardinal directions to determine the critical wave condition. It was found that although the largest fetch length was found to be in the NE direction, the critical wave conditions were in the SE direction in all cases due to the higher measured wind velocities.

In addition, the wave characteristics were calculated for the 1:100-year wind event combined with the FSL shoreline fetch lengths to assess riprap requirements.

Wave height, wave period, wind setup and wave runup which are exceeded by 5% of the incoming waves were calculated using the equations found in the CEM.

To calculate wave runup, the dam slope was taken to be 3H:1V. For wind setup (wind tide), the maximum length of the reservoir that was considered was determined to be 0.42 km. The impact of wind setup is expected to be extremely small for such a small reservoir, and indeed results in an approximate 1 cm setup during a 1000 year wind.

The still water level for the extreme wind condition at FSL was assumed to be the same as the spillway crest elevation of 1604.5 m. For freeboard calculations, the still water level for the IDF was taken as 1605.08 m based on reservoir routing results shown in Section 7.2.4.

As shown, freeboard requirements are governed by the IDF case. The analysis shows that the minimum required crest elevation to account for wind/wave effect is 1605.25 m. Based on the 2010 Topographic Survey [EBA], the minimum crest elevation of the dams is 1605.56 m, meaning that there is 0.31 m of additional freeboard available after accounting for wind/wave effects. Therefore, by the CDA guidelines the freeboard to the lowest portion of the dam crest is adequate. In addition, there is 1 m of normal freeboard from the spillway crest to the minimum dam crest. Although it is still recommended that the dam crest be re-graded to its design elevation, this is a lower priority item as freeboard remains adequate. (see Issue BM-7 in Table 13-1)

Table 7-6: Big Meadow Dam Freeboard Assessment Results (CEM)

Case	Direction	Wind Event Return Period	Fetch (km)	Over Water Wind Speed (km/hr)	Still Water Level (m)	5% Wave Runup (m)	Fetch for Setup (km)	Wind Setup (m)	Total Wind Effects (m)	Maximum Water Level Including Wind Effects (m)	Structure Minimum Crest Elevation (m)	Freeboard Remaining (m)
Extreme Wind (FSL)	SE	1:1,000	0.42	59.67	1604.5	0.30	0.42	0.01	0.31	1604.81	1605.56	0.75
1/3 between 1,000-year and PMF Flood Passage	SE	1:2	0.42	35.88	1605.08	0.17	0.42	0.00	0.17	1605.25		0.31

7.2.6 Riprap

Based on the wind and wave analysis that was carried out for the freeboard portion of this review, Hatch also completed an assessment of the required riprap protection based on the CEM method and Hudson equation for the Big Meadow Lake Dam and compared the results to what was observed during the site visit.

Key assumptions that were used for the calculation of required riprap sizing included:

- A riprap density of 2,700 kg/m^3
- A Kd value of 2.2 was used to size the riprap
- The maximum mass of rock was defined as four times M_{50} (mass of the median rock) and the minimum mass of rock was defined as 0.125 M_{50}.

Based on these values, required riprap rock sizes and thicknesses were calculated for a number of return periods. The resulting minimum, maximum, and D_{50} (median rock diameter) values are shown in Table 7-7.

Table 7-7: CEM Riprap Requirements

Return Period	Diameter of Riprap (m)			Thickness of Riprap (m)
	Minimum	Maximum	D_{50}	
2	0.0	0.1	0.1	0.1
10	0.1	0.2	0.1	0.1
20	0.1	0.2	0.1	0.1
30	0.1	0.2	0.1	0.1
50	0.1	0.2	0.1	0.1
100	0.1	0.2	0.1	0.2
1,000	0.1	0.3	0.2	0.2

The CDA is not prescriptive on a specific return period required for riprap protection. Within the industry generally the return period of wind events used varies between a 1:10 (USACE) to 1:100 (USBR, USACE, SEBJ) to 1:1000 (SEBJ for tolerable damage). Generally speaking, most guidelines agree that a 1 in 100-year wind is appropriate for riprap protection. Based on the review in Table 7-7, the riprap layer should be 0.2 m thick with a D_{50} of 0.1 m (if using the assumptions provided in the above analysis) to resist wind generated waves up to a 100-year event. Since there does not appear to be existing riprap, the condition of the upstream face of the dam should continue to be monitored as part of RDOS's regular surveillance and maintenance program and any erosion problems identified and repaired in a timely fashion. In addition, the size of the riprap protection needed is very small, this is a good indicator that riprap protection is not a large concern for this structure and erosion due to wind wave action can be adequately addressed through regular inspection and repair as needed. (see Issue No. BM-15 in Table 13-1).

7.2.7 Ice and Debris

No records of debris problems at the structure have been found in the documentation.

A debris boom is in place upstream of the spillway to prevent debris accumulation at the site. Debris should be removed from this boom in a timely fashion in order to prevent excessive buildup and potential failure of the boom during a large flood event.

Due to the annual emptying of the reservoir prior to winter and its location far below the normal operating reservoir level, the intake is unlikely to experience any ice or debris issues.

7.3 Structural Assessment

7.3.1 General

As part of the DSR, the concrete and steel structures at Meadow Dam site were reviewed for condition and capability to perform their intended function. Apart from the main embankment dam, the other water control structures include a concrete spillway, an intake structure and an outlet structure. The spillway is considered an important structure to maintain the integrity of the dam as side walls of the spillway supports the embankment sections of the dam along both sides of the spillway. Therefore, as part of the DSR, a check of the stability and force demand capability of bending moments and shear forces in the spillway walls was performed.

7.3.2 Spillway Structure

Analysis was performed on the critical section of the spillway vertical retaining walls. As well, a cursory review of the floatation/uplift stability of the spillway apron slab was performed. The spillway does not include any gates, and the stoplog slots are not in use at this site. Therefore, the spillway operates as a free overflow section with no control elements.

The Spillway structure consists of a stepped crest and two retaining walls on either side, which retain the embankment dam sections. The section of the spillway is uniform along the dam crest area and wing walls slope outwards at both the upstream and downstream ends. The spillway crest has an approximate elevation of 1604.5 m and a length of 14.63 m. The drop in the crest is approximately 1.23 m at the downstream end. This can be seen in the site inspection Photos A10 and A11.

The spillway is approximately 9.14 m wide at the upstream end gradually decreasing to a width of 6.1 m for a length of 4.6 m and then remains constant for the rest of the length of the spillway. The apron slab of the spillway has a thickness of 0.3 m. At the highest section, the spillway wall is approximately 2 m tall at the dam crest and has a uniform thickness of 0.3 m. At the upstream and downstream ends, the spillway wall gradually reduces in height. Based on the available existing drawing (dated November 1952; drawing number not available), the upstream wall has a slope of 3H:1V and at the downstream end, the wall is sloped at 2.5H:1V. Figure 7-2 shows the details and the layout of the spillway structure available from the existing drawing, which was considered in this review.

Steel reinforcement is present in the apron slab of the spillway. The rebar details in the drawing are not very clear however it appears that the apron slab is reinforced with one layer of 20M bars at 300 mm center-to-center spacing. The reinforcing details in the retaining walls is not available from drawings as the drawing shows very limited design detail about the structure. Since the thickness of the apron slab and the retaining walls are same according to the existing drawing, the same rebar detail is assumed for the retaining wall sections as well, for the purpose of calculations.

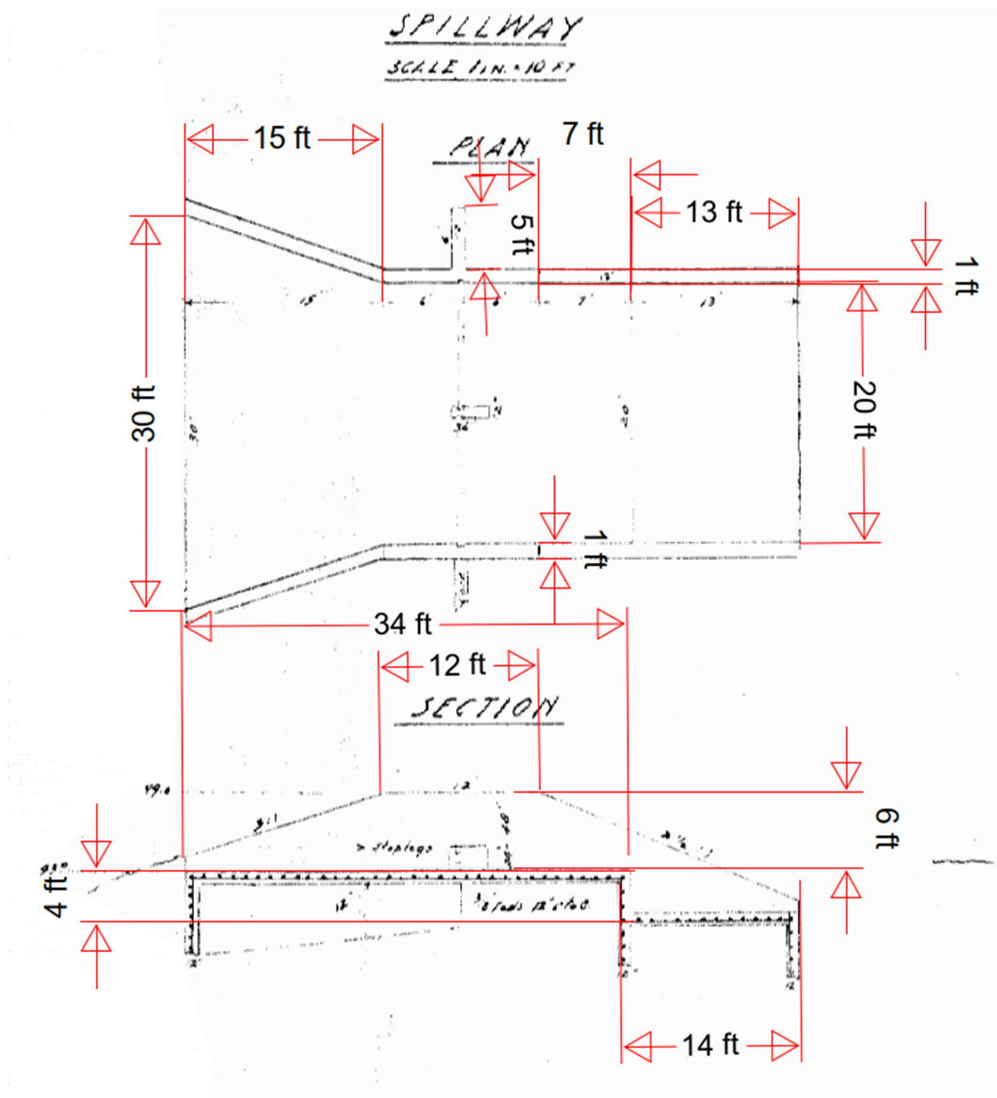

Figure 7-2: Plan and Elevation View of the Spillway Structure at the Big Meadow Lake Dam

7.3.3 Loads and Forces

The following loads and forces were used in the analysis of the spillway structure:

7.3.3.1 *Self Weight (W)*

The self-weight was based on the unit weight of concrete = 23.5 kN/m^3 (150 pcf).

7.3.3.2 *Horizontal Ice Load (I)*

As mentioned in Section 7.2.7, the ice load will not be applicable as the lake levels are lowered during winter and therefore, no ice load was considered on spillway structure.

7.3.3.3 *Soil Loads (S)*

On either side of the spillway walls, two types of soil fills are present. The shell fill is present to a depth of 0.5 m from the top and the reworked central fill is present for the next 1.5 m depth. Both these fills apply loads on the spillway wall. The properties of the soil fills used in the analysis are as follows:

Table 7-8: Properties of Soil Fills acting on Spillway Wall

Embankment Zone	Depth of Fill	Saturated Unit Weight (kN/m^3)	Friction Angle (ϕ)	Active Earth Pressure Coefficient K_a	Passive Earth Pressure Coefficient K_p
Shell Fill	0 - 0.5 m	20	32	0.30	3.25
Reworked Central Fill	0.5 – 2 m	19.5	35	0.27	3.69

7.3.3.4 *Earthquake Loads (E)*

The Big Meadow Lake Dam has been classified as a “Very High” consequence dam based on incremental consequences of failure. Under this consequence category, the seismic stability of the dam should be evaluated under an earthquake with a return period of 1/2 between 1/2,475 and 1/10,000 or Maximum Credible Earthquake (MCE) as described in the CDA Dam Safety Guidelines (CDA, 2013 revision). An average of 2,475 year and 10,000 year event was selected in this work. Correspondingly, a PGA of 0.110 g was used for earthquake loading calculations. Refer to Section 7.4.2 for additional details related to seismicity considerations.

7.3.4 Analysis

7.3.4.1 *Retaining Walls*

A critical section of the spillway retaining walls was considered for calculations. The section of the wall along the dam crest is the tallest section, with a height of approximately 2m (6’). The upstream and downstream sections of the wall taper down to lower heights although their wall thickness remains the same throughout. The 2m high section at the dam crest location was therefore deemed a critical section and this section was checked for bending moment and shear force demands.

The analysis was performed for normal load case and an exceptional load case. For normal load case the loading from the saturated soil behind the retaining walls was considered. For exceptional load case. The earthquake inertial loading due to self weight of the wall was applied, along with the soil static and dynamic loads applied by both the shell fill and the reworked central fill. A pseudo static analysis was performed to calculate the bending moment and shear force demands in the structure.

Since the retaining walls are tied to the apron slab, and are supported by the embankment dam on both sides, there is a continuous load path through the spillway structure on to the embankment dam in cross valley direction. The sliding of the walls is therefore not possible and was not considered.

As mentioned earlier in Section 7.3.2, the existing information on the rebar details in retaining walls was not available in existing drawings and therefore, an assumption of 20M bars at 300 mm c/c was made for the retaining wall section. The rebar was assumed to be located more closer to the soil side of the wall, as it would typically be expected in a cantilever type of retaining wall section. Also, due to unavailability of the connection details at the interface of the retaining wall base with the apron slab, the base of the slab was assumed to be tied with, and reinforcement continuing into, the apron slab. Based on the check performed on the bending moment and shear demands, the section of the retaining walls was found to be adequate for normal and extreme loading conditions considered in the analysis.

Table 7-9: Design Ratios (Demand/Capacity) and Capacity of Spillway Retaining Walls

	Factored Moment (kN-m)	Factored Shear Force (kN)	Moment Capacity (kN-m)	Shear Force Capacity (kN)	Design Ratio for Bending Moment	Design Ratio for Shear
Normal Load Case	31.24	36.66	49.15	40.22	0.64	0.91
Earthquake Load Case	17.14	14.26	49.15	40.22	0.35	0.35

*The forces and moments are calculated for one-meter length of the spillway wall.

Since there is no evidence of actual rebar location or layout available from existing documentation and a number of assumptions were required to be made to perform the high level evaluation of structural adequacy, the verification of these assumptions should be considered in future work, to validate these assumptions. The structure of the spillway retaining walls has performed reasonably well under the normal and high flow loading conditions over several years, any immediate concern seems highly unlikely. However due to occurrence of some cracking in the walls in the past, it is recommended that the condition of the spillway elements is closely monitored and any evidence of distress, cracking and structural movements etc., should be immediately investigated and addressed.

7.3.4.2 Apron Slab

The apron slab is very well tied to the side retaining walls, which are also keyed into the dam embankment through short wall flanges that are perpendicular to the retaining walls, and are keyed into the soil of the embankment dam. In addition, the apron slab includes a keyed in toe wall section at its upstream end, and another vertical wall section at the location of the spillway drop. These keyed sections, along with the connection of apron slab with side retaining walls provides adequate resistance to the apron slab, and the sliding of the spillway section is not deemed likely. Since the spillway does not have any gates or stoplogs, any pressure at the underside of the apron slab is balanced with the flow above the slab. The floatation/uplift of the apron slab is not deemed a concern and therefore, this check was not performed.

7.4 Geotechnical Assessment

As part of the 2020 DSR, Hatch conducted a review of the geotechnical conditions of the Big Meadow Dam. This included a review of the available information on the original geotechnical design, initial and supplementary field and laboratory investigations, site geology, design reports and as-built records. This background review along with the site visit observations made on July 9, 2020 (as provided in Appendix A) were used to determine appropriate soil properties for the seepage and stability analyses. The literature reviewed along with investigations and analyses are discussed in the following subsections.

7.4.1 Geology

As described by EBA (2010), the Geological Survey of Canada Map Surficial Geology Kooteney Lake (1984) indicates that surficial soil at Big Meadow Dam site is anticipated to be comprised of Sandy Till overlying crystalline metamorphic bedrock. The Sandy Till is described as a olive grey, grey to pale grey, weakly calcareous to non-calcareous loamy sand, sandy loam and loam, generally gravelly, cobbly or bouldery. It is mainly massive but may contain lenses of stratified sediments. It occurs as a blanket deposit with surface relief due to the shape of the underlying surface. The thickness of the soil unit varies from up to 30 m in the valley bottoms to no more than 5 m thick.

Clast lithologies reflect local bedrock which comprises mainly crystalline metamorphic and granitic rock. The surficial geology in the area of the Naramata dams is shown in Figure 1 of “Dam Safety Review – Big Meadow Lake Dam” (EBA, 2010).

7.4.2 Seismicity

The Big Meadow Lake Dam has been classified as a “Very High” consequence dam based on incremental consequences of failure. Under this consequence category, the seismic stability of the dam should be evaluated under an earthquake with a return period of 1/2 between 1/2,475 and 1/10,000 or Maximum Credible Earthquake (MCE) as described in the CDA Dam Safety Guidelines (CDA, 2013 revision).

The foundation at the dam site is expected to be comprised of glacial till not deeper than 5 m. Therefore, site Class C conditions (foundations on Very Dense Soil and Soft Rock) are considered appropriate for the Naramata Dam system.

A 2015 National Building Code of Canada (NBCC) Seismic Hazard Calculation provides an estimated Peak Ground Acceleration (PGA) for the events up to 2,475 year events. In order to determine the PGA for an earthquake event with a 1:10,000 year return period, a site-specific hazard assessment is required. Here, an estimate for the 1:10,000 year return event has been made by extrapolating from the 1:1,000 year and 1:2,475 year return period events on a log-log scale. Appendix B contains the 2015 NBCC seismic hazard assessment for the Naramata Lake Dam, which is also used for the Big Meadow Lake Dam, and an estimate of the 1:10,000 year PGA. It is noted that the validity of these extrapolated PGAs cannot be assured even though the straight-line extrapolation to the 1:10,000-year return period often provides values that are conservative.

An average of 2,475 year and 10,000 year, 0.110 g event was selected in this work. Correspondingly, a PGA of 0.110 g was used in the stability analyses of the Big Meadow Lake Dam, equivalent to full PGA value. It should be noted that this value is smaller than the PGA of 0.138 g, as was estimated and selected during 2010 DSR (EBA, 2010), which is due to refinements to the seismic model used in subsequent editions of the NBCC.

Table 7-10: National Building Code of Canada (NBCC) Seismic Hazard

Annual Exceedance Probability	NBCC 2005	NBCC 2010	NBCC 2015
1/100	0.034g	0.035g	0.010g
1/475	0.073g	0.073g	0.029g
1/1000	0.098g	0.098g	0.044g
1/2,475	0.138g	0.061g	0.070g
Selected PGA value – ½ between 1/2475 and 1/10,000	**-**	**-**	**0.110g**
Extrapolated 1/10,000	-	-	0.148g

7.4.3 *Interpreted Geotechnical Conditions*

A geotechnical investigation was carried out at the Big Meadow Dam site in 2013. EBA drilled seven test holes, advanced six dynamic cone penetration tests (CPT), installed two piezometers, and performed laboratory testing on collected samples across the entire site. The logs and test results of these samples can be found in EBA (2013). The following subsections provide a description of the embankment and foundation materials based on these subsurface investigations and testing along with supplemental existing construction drawings and other records.

7.4.3.1 *Embankment Dam*

According to a review of historical construction records and subsequent geotechnical investigations, the Big Meadow Lake Dam is a zoned earthfill dam with a central concrete core wall and granular shell zones. The embankment fills were constructed in stages beginning in 1920. The latest major modification to the dam was constructed in 1952. At this time, the top 1.5 m (5 feet) of the embankment was removed and re-placed and a zone of shell fill of unspecified thickness was added. A typal cross section of the Big Meadow Dam is shown in Figure 7-3 as prepared in 1952.

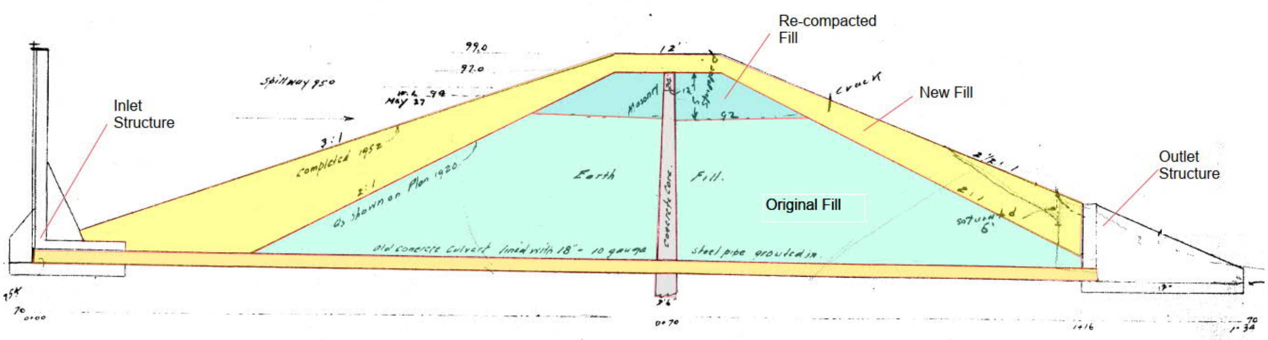

Figure 7-3: Big Meadow Lake Dam Typical Cross Section

According to historical design drawings, a concrete core wall is installed at the centerline of the embankment. The wall has a thickness of 1 m (3.5 ft) at the base, which tapers to 0.3 m (1 ft) at the top, 0.6 m below the shell fill. Further details on the construction and current condition of the wall are not known. The wall was not encountered during the 2013 Geotechnical Investigation.

The shell zone covers the upstream and downstream faces, and crest of the dam. This zone was added as part of the raise and reconstruction of the dam in 1952. The origin and borrow sources for the shell material is unknown. Based on interpretation of CPT results from the 2013 Geotechnical Investigation (EBA, 2013), the thickness of the shell zone was assumed to be 0.5 m at the dam crest. On the upstream and downstream faces, the shell fill varies in thickness. The original fill was assumed to have 2H:1V slopes in accordance with the original design drawings, while the upstream and downstream slopes of the shell fill has 3H:1V and 2.5H:1V slopes, respectively. Additionally, local profile changes have been observed on the downstream slope as part of the 2012 topographical survey. As such, the thickness of the shell varies throughout the dam, to a maximum horizontal thickness of approximately 5 m.

The central portion of the dam was constructed in the 1920s and consisted originally of a homogenous sand embankment with a central concrete core wall. The original embankment is assumed to be approximately 5.5 m in height at the tallest section. With the raise and reconstruction of the dam in 1952, the original embankment now forms the core of the dam. The top 1.5 metres of the 1920s fill was removed and reworked in 1952. Interpreted CPT results showed increased relative density of greater than 75% in this top section compared to the original fill zone, where relative density was approximately in the range of 30% to 60%. Fill materials generally consist of sand with some silt, some gravel (EBA, 2013). The reworked section in the top 1.5 m is generally compact, while the original zone from the 1920s construction is very loose to loose. The 2013 geotechnical investigation noted that the fill materials exhibited "some sort of layering or variability in their nature and/or placement," and that occasional layers of silty sand and gravelly sand were encountered based on interpretation of CPT data. There is no existing information regarding the quality control or construction procedures adopted during the construction of the original embankment.

A schematic sketch of the representative cross-section used in the seepage and slope stability analyses is shown in Figure 7-3 and sections below.

Foundation

The foundation conditions at Big Meadow dam are interpreted to consist of granular till material according to regional geology described in Section 7.4.1. During the 2013 Geotechnical Investigation, three boreholes encountered the foundation materials. The till was described as gravelly sand with some silt, brownish grey, poorly sorted moist to wet, with fine to coarse sand and fine to coarse subrounded gravel. One Standard Penetration Testing (SPT) test was taken which resulted in SPT refusal, and one grain size distribution test was conducted showing a distribution of 22% gravel, 60% sand, and 18% fines (EBA, 2013).

7.4.4 Geotechnical Seepage and Stability Assessment

A geotechnical assessment of seepage and slope stability of the dam were undertaken as part of this DSR. A review of available information pertaining to the material properties, cross section and construction history of the dam were carried out prior to the analyses. The following reports, drawings and data provided by RDOS were used to develop the cross-sectional geometries, material properties, phreatic surfaces, and foundation porewater pressures for the sections analyzed:

Geometries:

- Unknown Author. Naramata Irrigation District – Big Meadow Lake Storage Dam. November 1952.
- EBA Engineering Consultants Ltd. Big Meadow Lake Dam Geotechnical Assessment. January, 2013. (Topographic survey Figures 5 and 6).

Materials:

- EBA Engineering Consultants Ltd. Big Meadow Lake Dam Geotechnical Assessment. January, 2013.

Material Properties

The material properties of the earth embankment structures for Big Meadow Lake Dam were selected based on results from previous subsurface investigations and construction records, published values for typical materials similar to those encountered, and Hatch's engineering judgement. The embankment was considered to consist of four zones, as described in Section 7.4.3, namely:

- Concrete core wall
- New shell fill
- Original 1920s embankment fill (Fill – Original)
- Re-worked 1952 embankment fill (Fill – Reworked).

Additionally, the foundation materials were considered as a sandy till

For the seepage assessment, permeability values for the various materials were selected in accordance with the investigation data from the 2013 Geotechnical Assessment. The selected permeability values for each material are listed in Table 7-11.

Table 7-11 - Material Permeabilities

Material Name	Saturated Permeability (m/sec)
Concrete Core Wall	0
New Shell Fill	$1.0 * 10^{-5}$
Shell – Original	$1.0 * 10^{-5}$
Shell – Reworked	$1.0 * 10^{-5}$
Foundation – Sandy Till	$5.0 * 10^{-6}$

The unit weights and material strength parameters selected for each material are shown in Table 7-12. The friction angles were developed primarily from results of the geotechnical investigations.

Table 7-12: Material Properties – Mohr-Coulomb Strength Parameters

Materials	Unit Weight (kN/m^3)	Friction Angle (degrees)	Cohesion (kPa)
Concrete Core Wall	22	N/A	
New Shell Fill	20	32	0
Fill – Original	19	30	0
Fill – Reworked	19.5	35	0
Foundation – Sandy Till	21	37	0

7.4.4.1 Model Geometry

The geometries of the embankment were determined from available drawings, reports and survey data. The critical stability section was chosen immediately adjacent to the low level outlet where the embankment height is greatest. The critical geometries used in the stability analyses for Big Meadow Lake Dam are presented in Table 7-13.

Table 7-13: Maximum Embankment Section Geometry Used for Analysis

Structure	Embankment Section
Height	Overall: 6.4 m
	Core/1920s Embankment: 5.0 m
Crest Width	3.8 m
Upstream Slope	Overall: 2.75H:1V
	Core/1920s Embankment: 2H:1V
Downstream Slope	Overall: 3H:1V
	Core/1920s Embankment: 2H:1V
Dam Crest Elevation	1606.3 m

A sketch of the model geometry is shown in Figure 7-4.

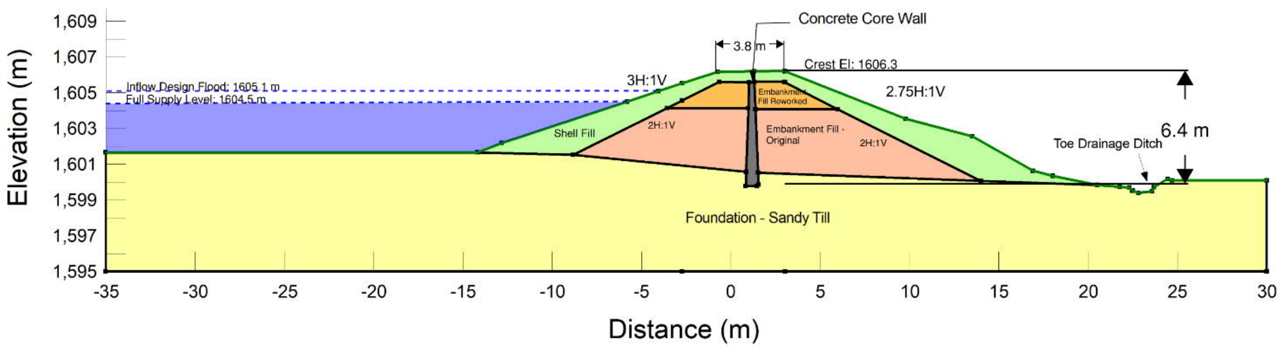

Figure 7-4 - Big Meadow Lake Dam - Model Geometry

7.4.4.2 *Seepage Analysis*

The seepage analyses were performed using SEEP/W software developed by GEO-SLOPE International Ltd. Version 10.1.1.18972. The program was used to generate the pore pressure distribution used for evaluating the exit gradients of the embankment. For evaluating the slope stability of the embankment, the porewater pressures developed in the SEEP/W program were interpreted to create a phreatic surface line in the SLOPE/W program.

The seepage analysis was performed for steady-state conditions under the following reservoir supply levels:

- Full supply level (FSL): 1604.5 m
- Inflow Design Flood (IDF): 1605.3 m.

In earthfill dams with relatively impervious earth cores, the IDF condition is not a steady-state condition as the flood conditions dissipate before pore water pressures change significantly in impervious zones of the dam. However, the Big Meadow Lake Dam is constructed with a concrete core wall. The permeability of the core wall can vary depending on the condition of the concrete, as water can flow through any cracks in the wall. If the concrete core is relatively impermeable, flood conditions may change the pore water pressure in the previous zones upstream of the wall relatively quickly. The current condition of the concrete core wall is unknown. As such, the IDF has been analyzed as a steady-state condition. This is expected to be a conservative estimation of a flood condition.

A summary of the results of the seepage analyses are shown in Table 7-14. The complete results of each of the simulations completed for the seepage analyses of Big Meadow Lake Dam are presented in detail in Appendix C.

Table 7-14: Results for Seepage Analyses

Load Case	Flow Rate per meter (m^3/s)	Maximum Exit Gradient	Factor of Safety Against Piping
FSL	1.83E-06	0.580	1.72
IDF	N/A	0.601	1.66

Piping potential for the foundation has been assessed based on exit hydraulic gradients at the toe of the dam. Water that percolates through earth dams and their foundations can carry soil particles that are free to migrate. The seepage forces tend to cause the erodible soil or soft rock to move towards the downstream face of the dam.

An adequate factor of safety against piping is required to ensure that piping does not occur. Accepted factors of safety against piping vary within engineering literature and standards. A factor of safety between 4.0 and 6.0 is generally required as per recommendations provided by Davis (1969) for exit gradients within coarse and fine sands. Both Das (1995) and the United States Bureau of Reclamation (2005) recommend a factor of safety between 3.0 and 4.0 for the design of hydraulic structures. The United States Army Corps of Engineers (USACE) suggests that if seepage quantities are low (low flux), exit gradients should be limited to 0.5 for long term design conditions which corresponds to a factor of safety of 2.0.

The results of the seepage analysis indicate that the exit gradients at the downstream toe are elevated. This is consistent with continued observations of seepage at the downstream toe, as noted by EBA (2010 and 2013). As recommended by EBA (2013), a downstream drained toe berm should be installed to lower exit gradients in this region.

7.4.4.3 Stability Modelling

The stability analyses were performed using SLOPE/W software developed by GEO-SLOPE International Ltd. Version 10.1.1.18972. The program uses the limit state equilibrium technique to model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable porewater pressure conditions using a large selection of soil strength models. Stability analyses for the Big Meadow Lake Dam were performed based on effective stress analysis. The Morgenstern-Price method of slices with a half-sine function was selected for the inter-slice force function since this method satisfies both moment and force equilibrium.

The Entry and Exit method was used to generate slip surfaces, which calculates circular slip surfaces extending between a series of points on the upper and lower portions of a slope, and with a series of increasing radii.

As noted above, the embankment section utilized interpreted pore water pressure conditions from the results of the SEEP/W analysis.

To assess the rapid drawdown condition, the phreatic surface was assumed to be the same as the Full Supply Level steady state phreatic surface downstream of the concrete core wall. In the upstream side of the dam, the phreatic surface was assumed to extend linearly from the dam toe to the upstream side of the core wall.

Loading cases in the slope stability analyses were selected based on the CDA Dam Safety Guidelines. The design loads for flood and earthquake conditions were determined based on analyses as discussed in Sections 7.2 and 7.4.2. The loading conditions used in the analysis are summarized in Table 7-15.

Table 7-15: Loading Conditions for Big Meadow Lake Dam Section

	Parameter	Design Loads
LC-1	Normal Load Condition - Full Supply Level (FSL)	Reservoir E = 1604.5 m
LC-2	Flood Condition - Inflow Design Flood (IDF)	Reservoir El. = 1605.31
LC-3	Rapid Drawdown (RDD)	Reservoir El. = 1601.8 m
LC-4	Seismic	Horizontal seismic coefficient (kh) of 0.11g corresponding to the full PGA of the EDGM**.

* Corresponds to reservoir floor elevation due to limited drawdown information.

** EDGM defined as average of 1:2,475 year and 1:10,000 year seismic events (CDA, 2013a)

A summary of the results of the stability analyses are shown in Table 7-16. The complete results of the slope stability analyses are presented in Appendix D.

Table 7-16: Results of Stability Analyses

Load Condition	Required Minimum Factor of Safety	Factor of Safety Normal Loading Conditions	
		Upstream	Downstream
LC-1 (FSL)	1.50	1.84	1.54
LC-2 (IDF)	1.30	1.91	1.67
LC-3 (RDD)	1.20	1.50	N/A
LC-4 (Seismic)	1.00	1.17	1.14

Overall, the calculated factors of safety for upstream and downstream for each load case exceed the minimum recommended values as indicated by 2007 CDA Guidelines (2013 Revision).

7.4.5 Geotechnical Considerations

Geotechnical considerations related to the dam safety of the Big Meadow Lake Dam are discussed in the following sections.

7.4.5.1 *Liquefaction Potential*

A seismic assessment and geotechnical investigation was undertaken by EBA as part of the 2013 geotechnical assessment of Big Meadow Dam. The geotechnical investigation consisted of six cone penetration tests (CPTs) including two seismic cone penetration tests (sCPT), seven boreholes with standard penetration testing and sample collection, installation of two piezometers, and laboratory testing on recovered soil samples.

The seismic assessment was performed based off the interpreted subsurface conditions and in accordance with the seismic requirements stipulated by the 2006 British Columbia Building Code (BCBC, 2006) for Site Class ‘C’ conditions and CDA (2007) recommendations for “Very High” consequence classification dams. The liquefaction susceptibility and seismic performance of the dam was assessed using both the CPT and SPT based liquefaction triggering procedure (Boulanger and Idriss, 2008) and a “quasi” 2D non-linear site response analysis performed using D-MOD2000.

The results of the EBA seismic assessment are summarized below:

- The internal embankment fill zoning consists of an approximately 4 m thick lower zone constructed in the 1920s and comprised of primarily very loose to loose native sand, some silt, and occasional layers of gravelly sand and silty sand with some gravel. The lower zone internal embankment fill is overlain by a 2 m thick upper zone comprised of the same lower zone fill which was reworked in 1952 and has a loose to compact relative density.
- The very loose to loose 1920s embankment fill is susceptible to liquefaction for the 1:2475 year design earthquake.
- Respective vertical and lateral dam deformations of 20 mm – 60 mm and 350 mm – 600 mm may be anticipated.
- Deformation of the downstream dam slope may occur during the design earthquake as the slope does not satisfy the seismic event factor of safety, however, deformations are anticipated to be less than 15 cm and the dam freeboard would be maintained.
- The concrete core may be susceptible to cracking and damage during the design earthquake.
- The downstream dam slope is susceptible to failure based on post-seismic residual strengths.

- A 3 m wide toe berm and chimney filter constructed up to elevation 1602.5 m is recommended as a remedial measure for static, pseudo-static, and post-seismic slope stability conditions, and to reduce the probability of piping failure.

The results of the EBA (2013) assessment indicate the potential for liquefaction under the design earthquake. It should be noted however that the 2013 assessment was based off historical requirements, guidelines, and risk classifications which have been updated as per the current state of practice as defined below:

- Two new revisions of the BCBC have been published since the 2013 assessment, namely, the 2012 BCBC and the 2018 (current) BCBC. The seismic practice stipulated by the current 2018 building code is based on the requirements of the 2015 National Building Code of Canada (NBCC) which utilizes the newer 5th generation seismic hazard model (Adams et. Al., 2015).
- The consequence classification of Big Meadow Dam has been upgraded from “High” (considered by EBA (2013)) to “Very High” as part of this DSR.
- The 2013 revision of the 2007 CDA Dam Safety Guidelines has issued revised guidelines for the selection of the design earthquake annual exceedance probability.

The CDA (2007, 2013 revision) recommends that the design earthquake for a “Very High” consequence dam be selected as the average of the 1:2,475 year and 1:10,000 year earthquakes. The Site Class C uniform hazard response spectra (UHRS) from the EBA (2013) design earthquake and the revised design earthquake conditions (as per CDA (2007, 2013 revision) and BCBC (2018)) are presented in Table 7-17 below. The 1:10,000 year earthquake should be determined using a site-specific probabilistic seismic hazard assessment (PSHA). In lieu of a PSHA, a preliminary estimate of the 1:10,000 year earthquake was obtained from a log-log extrapolation of the 1:475 year and 1:2,475 year return period events as recommended by the NBCC (2015).

Table 7-17: Comparison of EBA (2013) Design Earthquake and Revised 2020 Design Earthquake

Design Earthquake	PGA	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
EBA (2013)	0.138	0.278	0.175	0.101	0.060
Revised 2020 Design Earthquake*	0.109	0.229	0.182	0.135	0.099

* Based on revised “Very High” risk classification, 2018 BCBC, and CDA 2013 revision recommendations.

A comparison of the EBA (2013) and revised 2020 UHRS indicates that the liquefaction susceptibility and seismic performance of the dam may change due to updates in seismic practice and design codes. Accordingly, the liquefaction potential and seismic behaviour of the dam should be re-assessed in accordance with current updated practice. It should be noted however that liquefaction susceptibility is still likely when considering the revised 2020 design earthquake.

7.4.5.2 *Post Seismic Stability*

EBA (2013) assessed the stability performance of the Big Meadow Lake dam following a seismic event. The assessment indicated an inadequate factor of safety at the downstream slope, and potential damage and cracking of the central core wall considering post-seismic residual strengths. The assessment recommended construction of a toe berm with chimney filter to mitigate this potential failure mode. Hatch concurs with this recommendation; construction of a toe berm is a prudent measure to address this condition.

The global seismic stability of the embankment was found to be acceptable, as described in Section 7.4.4.3. The integrity of the core wall in a seismic event cannot be fully analyzed as there is no detailed information available on its construction or material properties. After a seismic event, the integrity of the core wall should be confirmed by an inspection of the dam. Piezometers readings should be taken to determine if increased seepage is occurring, indicating damage to the wall.

7.4.5.3 *Review of Instrumentation Readings*

Three piezometers are currently installed within the Big Meadow Lake Dam embankment, in two boreholes installed by EBA (2013). Details of each piezometer are listed in Table 7-18.

Table 7-18: Big Meadow Lake Dam Piezometer Details

Piezometer ID	Borehole	Collar Elevation (m)	Screen Elevation (m)
P12-01	BH12-07	1606.37	1602.20 – 1603.75
P12-02	BH12-08	1606.11	1600.00 – 1600.75
P12-03	BH12-07	1606.11	1603.00 – 1604.55

Hatch reviewed piezometer readings from RDOS weekly inspections at Big Meadow Lake Dam in summer 2017 and 2018. More recent readings were not available during this review. RDOS should continue to conduct regular inspections including reading the piezometers. During some inspections, the piezometer readings were not recorded completely. It was assumed in these cases that the piezometers were dry. Piezometer readings should be completed during each inspection and fully documented, in addition to recording the reservoir elevation. A plot of piezometer readings and reservoir levels in 2017 and 2018 is presented in Figure 7-5.

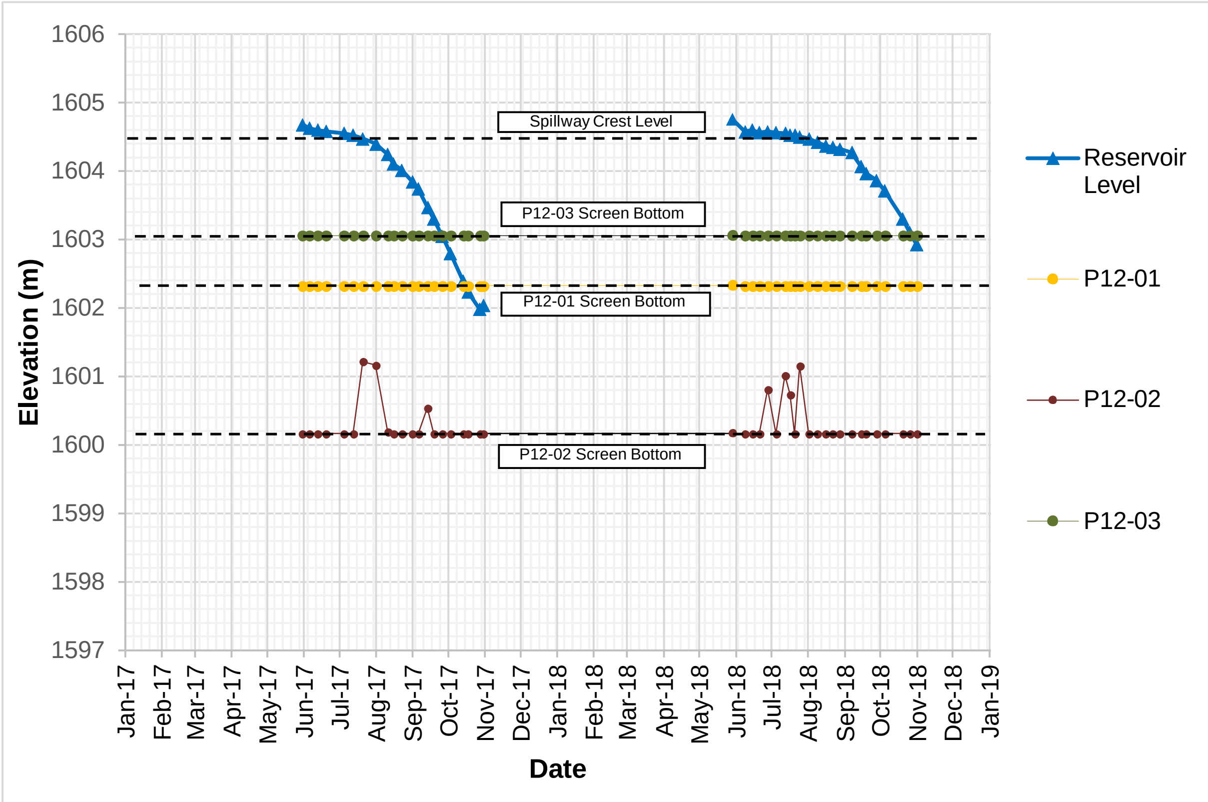

Figure 7-5: Big Meadow Lake Dam Piezometer Readings

Results of the instrumentation readings indicate that the screens of piezometers P12-01 and P12-03 were dry during all readings. These piezometers are located at higher elevations within the embankment and are downstream of the central concrete wall, indicating that the wall is acting effectively as a water barrier. Piezometer P12-02 was dry during the majority of the readings, however there were some fluctuations with water levels up to approximately 1601.25 m recorded. It is likely that the water in this piezometer is from seepage flows within the foundation passing around the bottom of the concrete core wall, which is consistent with seepage analysis results. The instrumentation readings reviewed are in line with the assumptions used in the seepage and slope stability assessments.

7.4.5.4 *Internal Stability Assessment*

An internal instability assessment was conducted to evaluate the piping susceptibility of the native foundation soil material. The assessment utilized the method proposed by Li-Fannin (2008) and recommended by the Canadian Dam Association (CDA). The Li-Fannin (2008) criteria is a modified version of the method devised by Kenny-Lau (1985). Kenny-Lau (1985) postulated that the shape of the grain-size distribution curve affects the susceptibility of a cohesionless material to internal instability. They proposed a boundary to internally stable soils, utilizing the ‘H’ and ‘F’ parameters which are defined as follows:

- F: The percent mass passing at any given grain size D
- H: The increment of percent mass passing over a designated grain size interval of D to 4D

According to Kenny-Lau (1985), a material is considered internally stable if the following condition is satisfied:

$$\frac{H}{F} \geq 1$$

After conducting experimental tests on materials from dams that had experienced internal erosion related issues, Li-Fannin (2008) proposed modifications to the Kenny-Lau (1985) method. As per Li-Fannin (2008), a cohesionless material is internally stable if:

$$\frac{H}{F} \geq 1 \; when \; F < 15\%$$

$$H \geq 15 \; when \; F > 15\%$$

Studies by conducted by Wan and Fell (2004) and indicate that soil fractions where F > 41% are beyond the maximum erodible portion of the gradation curve and need not be assessed for internal instability (CDA, 2009, 2014).

The CDA states that soil fractions where F > 41% are beyond the maximum erodible portion of the gradation curve and need not be assessed for internal instability (CDA, 2009). This is consistent with the findings of Wan and Fell, 2004. The Li-Fannin (2008) method yields the stability envelope presented in Figure 7-6.

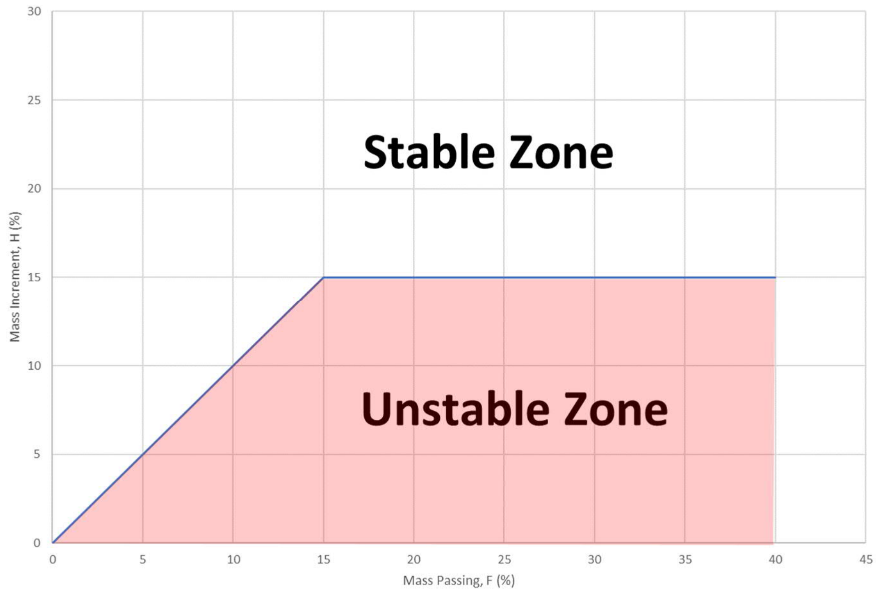

Figure 7-6: Li-Fannin (2008) Internal Stability Diagram

Data points that lie above the envelope are internally stable, whereas points that plot below the envelope are susceptible to internal erosion. It should be noted that internal erosion is not a certainty in materials that are defined as internally instable. This analysis only indicates that a risk of internal erosion exists when other key factors are also present (such as high hydraulic gradients).

The results of the internal instability assessment for Big Meadow Dam are presented in Figure 7-7 and Table 7-19.

Table 7-19: Li-Fannin Stability Analysis Results Summary

Zone	Borehole ID	Depth (m)	Li-Fannin Stability Result
Original Core	BH12-03	2.5 – 2.7	Marginally Unstable
	BH12-04	2.0 – 2.2	Unstable
	BH12-08	3.7 – 4.0	Stable
Reworked Core	BH12-07	1.5 – 2.1	Stable
	BH12-08	1.5 – 2.1	Stable
Inferred Foundation	BH12-07	3.7 – 3.9	Stable
	BH12-08	5.6 – 6.0	Stable

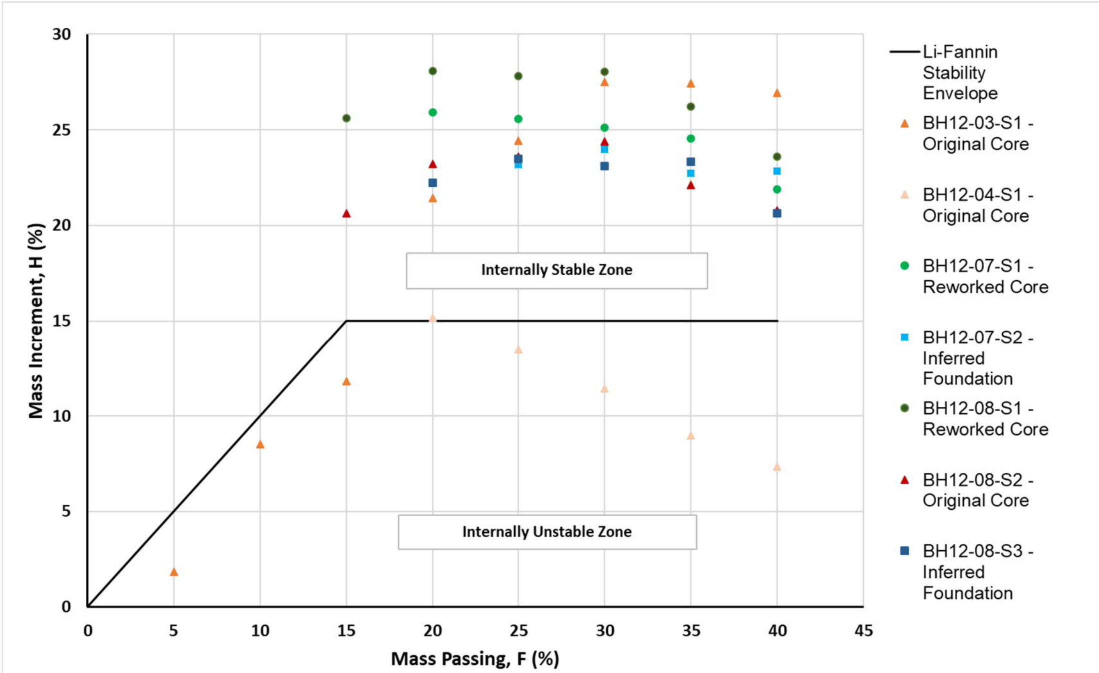

Figure 7-7: Plotted Internal Stability Results

The results indicate that the dam fill and foundation materials are generally stable, however, two gradations from the original dam core were identified as unstable, namely from BH12-03 and BH12-04. These unstable gradations may be characterized as partially gap-graded or partially uniformly graded and represent only two of the seven gradations assessed for internal instability. It should be noted that the original and reworked core gradations are anticipated to be similar, i.e., discrepancies in the internal instability classification between them may be due to sampling bias. The gradation from BH12-04 demonstrated a significantly higher gravel content and gap-graded nature that was not present in the other core gradations.

Regardless, the inclusion of the concrete core wall within the embankment and stability of the foundation gradations indicates that material instability may not significantly contribute to dam piping risk. Further geotechnical investigation is recommended to obtain representative samples of the foundation material which may be heterogenous and spatially variable and was not characterized in detail as part of the EBA (2013) investigation.

7.4.5.5 Piping Potential

EBA [2010] carry out an assessment of piping Failure Risk Assessment at the Big Meadow Lake Dam. Past inspections have not specifically identified the presence of turbid seepage downstream of each dam, particularly the most recent inspections. However, this may not have been apparent due to the way seepage is currently monitored especially downstream of the Big Meadow Dam and in the past inspectors may not have been aware that they should be looking for seepage turbidity. Even though the history doesn't indicate an issue, there is never a guarantee that turbid seepage may not start in the future.

As part of this DSR, Hatch repeated the piping risk assessment for Big Meadow Lake Dam as carried out by EBA [2010], given the new condition and relating the risks presented by the Big Meadow Lake North Dam considering the "Very High" DFCC.

The piping failure risk assessment method used is based on Foster and Fell [2000] assessment method. This method quantifies the probability of dam failure due to potential of seepage and piping events. The Foster and Fell [2000] approach estimates the relative likelihood of dam failure by piping, P_p, by quantifying the influence of several factors that affect the likelihood of piping. The approach calculates the relative probability of several piping modes, namely:

- Piping through the embankment (E).
- Piping through the foundation (F).
- Piping of embankment into foundation (EF).

Relative probabilities are determined by assessing historical failure frequencies due to piping and seepage phenomena. The method accounts for general factors influencing the likelihood of failure. The annual likelihood of failure by piping is then calculated using the following formula:

$$P_p = w_E P_e + w_F P_f + w_{EF} P_{ef}$$

Where w_x and P_x represent the weighting factor and relative annual likelihood of failure by piping, respectively. Note that the subscript 'x' denotes a mode of failure, where 'E' represents a failure of the embankment, 'F' represents a failure of the foundation, and 'EF' represents a failure from piping of the embankment into the foundation. Refer to the paper published by Foster et al., 2000 for a more detailed explanation of the methodology.

The various assumptions utilized in the Foster and Fell [2000] analysis at the dams for the three (3) discussed failure types are presented in Table 7-20 through Table 7-22. References for the weighting factors are provided in Figure 7-8 to Figure 7-10. Annual failure probabilities applicable to both dams are presented in Figure 7-11.

Table 7-20: Foster and Fell [2000] Coefficients for Piping through the Big Meadow Lake Embankment Dam

Factor	Factor Description	Score	Commentary
Embankment Filters	No embankment filter (for dams that usually have filters;	2	Dam has no filter.
Core Geological Orogin		1	N/A, central concrete wall
Core Soil		1	N/A, central concrete wall
Compaction		1	N/A, central concrete wall
Conduits	Conduit through the embankment, some poor details	2	Conduit through dam, no downstream filter, Average construction scheme assumed.
Foundation Treatment - Bedrock	Untreated vertical faces or overhangs in core foundation	2	Very unlikely to have any foundation treatments. Foundation on overburden.
Observations of seepage	Leakage gradually increasing, clear, sinkholes, seepage emerging on downstream slope	2	Seepage occurs around the outlet and toe
Monitoring and surveillance	Irregular seepage observations, inspections weekly	1	Weekly inspection, but no leakage being measured.
Type of Embankment	Earthfill with Core wall		
Age in years	50		
Embankment type factor	8		
	W_E =	16.000	Embankment Weighting Factor
	P_E =	8.00E-06	Earthfill with Core wall
	Overall Embankment Probablilty	1.28E-04	

Note: USBR refers to US Bureau of Reclamation

Table 7-21: Foster and Fell [2000] Coefficients for Piping through Foundation of the Big Meadow Lake Embankment Dam

Factor	Factor Description	Score	Commentary
Foundation Filters	No foundation filter present	1	Foundation filter blanket present; however, not effective.
Foundation below cutoff	Soil	5	Not used. Foundation is granular glacial till.
Cut-off (soil foundation)	Shallow or no core trench	1.2	No core trench exists
Cut-off (rock foundation)	Not applicable	1	N/A
Soil Geology below condut	Glacial	0.5	Glacial deposits under the foundation, granular based.
Rock Geology (below cut-off)	Not applicable	1	no cutoff
Observations of seepage	Leakage gradually increasing, clear, sinkholes, sand boils	2	Seepage occurs around the outlet and toe
Observations of pore pressure	High pressures in foundation	1	Foundation pressure monitoring and plots not available; but, high pressure expected.
Monitoring and surveillance	Irregular seepage observations, inspections weekly	1	Weekly inspection.
Embankment type factor	19		
	W_F =	6.000	Foundation Weighting Factor
	P_F =	1.90E-05	Earthfill with Core wall
	Foundation piping probability =	1.14E-04	

Note: General foundation properties of both dams were considered as a unit for this piping probability approximation.

Table 7-22: Foster and Fell [2000] Coefficients for Piping of Embankment into Foundation of the Big Meadow Lake Embankment Dam

Factor	Factor Description	Score	Commentary
Filters	Appears to be independent of presence–absence of embankment or foundation filters	1	
Foundation cutoff trench	Shallow or no trench	0.8	No cutoff trench.
Foundation	On or partly on soil	0.5	Fully on overburden.
Erosion control measures of core foundation	None, good foundation conditions	1	Non is expected; foundation, granular glacial till is expected.
Foundation Grouting	Soil foundation - not applicable	1	None.
Soil Geology Types	Glacial	2	Granular glacial till.
Rock Geology	Not applicable	1	Upstream impervious core, originated from right abutment glacial till (silty/clay origin)
Core geological orogin		1	N/A
Core soil type		1	N/A
Core compaction	Appears to be idependent of compaction	1	N/A
Foundation Treatment (rock)	Not applicable, soil foundation	2	Foundation treatment information is not available; however, likely to be poor
Observations of seepage	Leakage gradually increasing, clear, sinkholes	2	Seepage occurs around the outlet and toe
Monitoring and surveillance	Irregular seepage observations, inspections weekly	1	Weekly inspection happens.
Embankment type factor	4		
	W_{EF} =	3.200	Embankment Weighting Factor
	P_{EF} =	4.00E-06	Earthfill with Core wall
	Embankment piping into Foundation Probabiity =	1.28E-05	

	General factors influencing likelihood of failure				
Factor*	Much more likely	More likely	Neutral	Less likely	Much less likely
Embankment filters $w_{E(filt)}$		No embankment filter (for dams that usually have filters; refer to text) (2)	Other dam types (1)	Embankment filter present, poor quality (0.2)	Embankment filter present, well designed, and well constructed (0.02)
Core geological origin $w_{E(cgo)}$	Alluvial (1.5)	Aeolian, colluvial (1.25)	Residual, lacustrine, marine, volcanic (1.0)		Glacial (0.5)
Core soil $w_{E(cst)}$	Dispersive clays (5); low-plasticity silts (ML) (2.5); poorly graded and well-graded sands (SP, SW) (2)	Clayey and silty sands (SC, SM) (1.2)	Well-graded and poorly graded gravels (GW, GP) (1.0); high-plasticity silts (MH) (1.0)	Clayey and silty gravels (GC, GM) (0.8); low-plasticity clays (0.8)	High-plasticity clays (CH) (0.3)
Compaction $w_{E(cc)}$	No formal compaction (5)	Rolled, modest control (1.2)	Puddle, hydraulic fill (1.0)		Rolled, good control (0.5)
Conduits $w_{E(con)}$	Conduit through the embankment, many poor details (5)	Conduit through the embankment, some poor details (2)	Conduit through embankment, typical USBR practice (1.0)	Conduit through embankment, including downstream filters (0.8)	No conduit through the embankment (0.5)
Foundation treatment $w_{E(ft)}$	Untreated vertical faces or overhangs in core foundation (2)	Irregularities in foundation or abutment, steep abutments (1.2)		Careful slope modification by cutting, filling with concrete (0.9)	Careful slope modification by cutting, filling with concrete (0.9)
Observations of seepage $w_{E(obs)}$	Muddy leakage, sudden increases in leakage (up to 10)	Leakage gradually increasing, clear, sinkholes, seepage emerging on downstream slope (2)	Leakage steady, clear, or not observed (1.0)	Minor leakage (0.7)	Leakage measured none or very small (0.5)
Monitoring and surveillance $w_{E(mon)}$	Inspections annually (2)	Inspections monthly (1.2)	Irregular seepage observations, inspections weekly (1.0)	Weekly–monthly seepage monitoring, weekly inspections (0.8)	Daily monitoring of seepage, daily inspections (0.5)

Figure 7-8: Weighting Factors (Values in Parentheses)for Piping through the Embankment Mode of Failure

	General factors influencing likelihood of failure				
Factor*	Much more likely	More likely	Neutral	Less likely	Much less likely
Filters $w_{F(filt)}$		No foundation filter present when required (1.2)	No foundation filter (1.0)	Foundation filter(s) present (0.8)	
Foundation (below cutoff) $w_{F(fnd)}$	Soil foundation (5)		Rock, clay-infilled or open fractures and (or) erodible rock substance (1.0)	Better rock quality ⟶	Rock, closed fractures and non-erodible substance (0.05)
Cutoff (soil foundation) $w_{F(cts)}$		Shallow or no cutoff trench (1.2)	Partially penetrating sheetpile wall or poorly constructed slurry trench wall (1.0)	Upstream blanket, partially penetrating, well-constructed slurry trench wall (0.8)	Partially penetrating deep cutoff trench (0.7)
Cutoff (rock foundation) $w_{F(ctr)}$	Sheetpile wall, poorly constructed diaphragm wall (3)	Well-constructed diaphragm wall (1.5)	Average cutoff trench (1.0)	Well-constructed cutoff trench (0.9)	
Soil geology (below cutoff) $w_{F(sg)}$	Dispersive soils (5); volcanic ash (5)	Residual (1.2)	Aeolian, colluvial, lacustrine, marine (1.0)	Alluvial (0.9)	Glacial (0.5)
Rock geology (below cutoff) $w_{F(rg)}$	Limestone (5); dolomite (3); saline (gypsum) (5); basalt (3)	Tuff (1.5); rhyolite (2); marble (2); quartzite (2)		Sandstone, shale, siltstone, claystone, mudstone, hornfels (0.7); agglomerate, volcanic breccia (0.8)	Conglomerate (0.5); andesite, gabbro (0.5); granite, gneiss (0.2); schist, phyllite, slate (0.5)
Observations of seepage $w_{F(obs)}$	Muddy leakage, sudden increases in leakage (up to 10)	Leakage gradually increasing, clear, sinkholes, sand boils (2)	Leakage steady, clear, or not observed (1.0)	Minor leakage (0.7)	Leakage measured none or very small (0.5)
Observations of pore pressures $w_{F(obp)}$	Sudden increases in pressures (up to 10)	Gradually increasing pressures in foundation (2)	High pressures measured in foundation (1.0)		Low pore pressures in foundation (0.8)
Monitoring and surveillance $w_{F(mon)}$	Inspections annually (2)	Inspections monthly (1.2)	Irregular seepage observations, inspections weekly (1.0)	Weekly–monthly seepage monitoring, weekly inspections (0.8)	Daily monitoring of seepage, daily inspections (0.5)

Figure 7-9: Weighting Factors (Values in Parentheses) for Piping through the Foundation Mode of Failure

	General factors influencing likelihood of initiation of piping				
Factor*	Much more likely	More likely	Neutral	Less likely	Much less likely
Filters $w_{EF(filt)}$	Appears to be independent of presence–absence of embankment or foundation filters (1.0)	Appears to be independent of presence–absence of embankment or foundation filters (1.0)	Appears to be independent of presence–absence of embankment or foundation filters (1.0)	Appears to be independent of presence–absence of embankment or foundation filters (1.0)	Appears to be independent of presence–absence of embankment or foundation filters (1.0)
Foundation cutoff trench $w_{EF(cot)}$	Deep and narrow cutoff trench (1.5)		Average cutoff trench width and depth (1.0)	Shallow or no cutoff trench (0.8)	
Foundation $w_{EF(fnd)}$		Founding on or partly on rock foundations (1.5)			Founding on or partly on soil foundations (0.5)
Erosion-control measures of core foundation $w_{EF(ecm)}$	No erosion-control measures, open-jointed bedrock, or open-work gravels (up to 5)	No erosion-control measures, average foundation conditions (1.2)	No erosion-control measures, good foundation conditions (1.0)	Erosion-control measures present, poor foundations (0.5)	Good to very good erosion-control measures present and good foundation (0.3–0.1)
Grouting of foundations $w_{EF(gr)}$		No grouting on rock foundations (1.3)	Soil foundation only, not applicable (1.0)	Rock foundations grouted (0.8)	
Soil geology types $w_{EF(sg)}$	Colluvial (5)	Glacial (2)		Residual (0.8)	Alluvial, aeolian, lacustrine, marine, volcanic (0.5)
Rock geology types $w_{EF(rg)}$	Sandstone interbedded with shale or limestone (3); limestone, gypsum (2.5)	Dolomite, tuff, quartzite (1.5); rhyolite, basalt, marble (1.2)	Agglomerate, volcanic breccia (1.0); granite, andesite, gabbro, gneiss (1.0)	Sandstone, conglomerate (0.8); schist, phyllite, slate, hornfels (0.6)	Shale, siltstone, mudstone, claystone, (0.2)
Core geological origin $w_{EF(cgo)}$	Alluvial (1.5)	Aeolian, colluvial (1.25)	Residual, lacustrine, marine, volcanic (1.0)		Glacial (0.5)
Core soil type $w_{EF(cst)}$	Dispersive clays (5); low-plasticity silts (ML) (2.5); poorly graded and well-graded sands (SP, SW) (2)	Clayey and silty sands (SC, SM) (1.2)	Well-graded and poorly graded gravels (GW, GP) (1.0); high-plasticity silts (MH) (1.0)	Clayey and silty gravels (GC, GM) (0.8); low-plasticity clays (CL) (0.8)	High-plasticity clays (CH) (0.3)
Core compaction $w_{EF(cc)}$	Appears to be independent of compaction, all compaction types (1.0)	Appears to be independent of compaction, all compaction types (1.0)	Appears to be independent of compaction, all compaction types (1.0)	Appears to be independent of compaction, all compaction types (1.0)	Appears to be independent of compaction, all compaction types (1.0)
Foundation treatment $w_{EF(ft)}$	Untreated vertical faces or overhangs in core foundation (1.5)	Irregularities in foundation or abutment, steep abutments (1.1)		Careful slope modification by cutting, filling with concrete (0.9)	Careful slope modification by cutting, filling with concrete (0.9)
Observations of seepage $w_{EF(obs)}$	Muddy leakage, sudden increases in leakage (up to 10)	Leakage gradually increasing, clear, sinkholes (2)	Leakage steady, clear, or not monitored (1.0)	Minor leakage (0.7)	No or very small leakage measured (0.5)
Monitoring and surveillance $w_{EF(mon)}$	Inspections annually (2)	Inspections monthly (1.2)	Irregular seepage observations, inspections weekly (1.0)	Weekly–monthly seepage monitoring, weekly inspections (0.8)	Daily monitoring of seepage, daily inspections (0.5)

Figure 7-10: Weighting Factors (Values in Parentheses) for Accidents and Failures as a Result of Piping from the Embankment into the Foundation

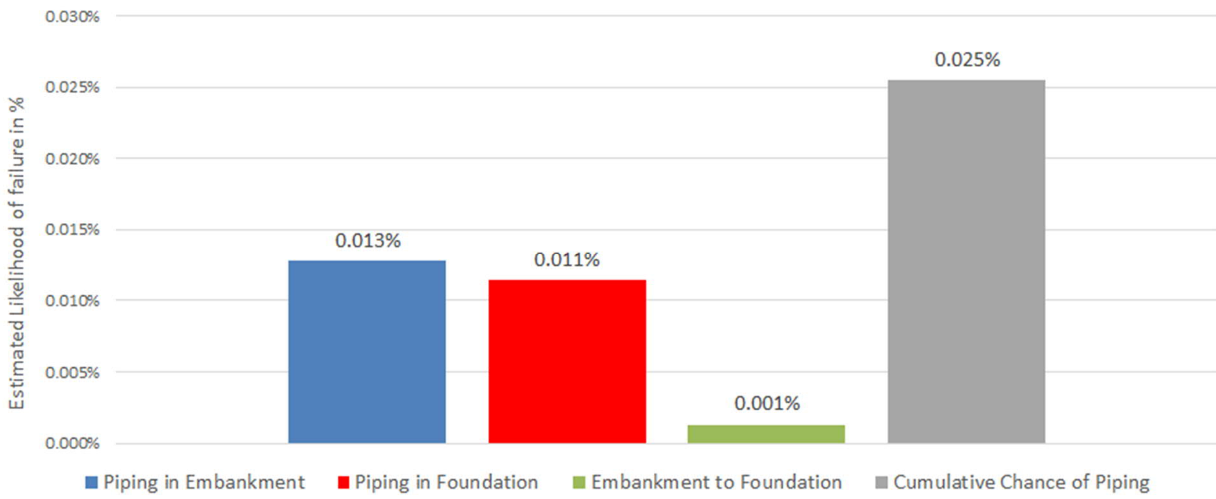

Figure 7-11: Estimated Annual Probability of Failure of the Big Meadow Lake Dam Using Foster and Fell [2000]

According to CDA Guidelines [CDA, 2013a], life safety risk should be consistent with values used in other hazardous industries and with the principle that risks should be made as low as reasonably practicable (ALARP). Using this principal, a better understanding of the piping risks can be obtained by plotting annual exceedance probability against the expected number of persons subjected to a Life Safety Risk. Figure 7-12 outlines the piping risk with regards to life safety risk using the DFCC of “Very High” an assuming a potential for Loss of Life.

The red, yellow, and green bands represent unacceptable, tolerable (as long as the risk is ALARP), and acceptable risk ranges, respectively. ALARP refers to an operating condition where all prudent measures to reduce risk have been undertaken and continuous surveillance is implemented.

In its existing condition, the total probability of piping failure at the Big Meadow Lake Dam appears to be close to unacceptable ranges. However, this potential can be reduced in a number of ways. First, as can be observed in Figure 7-12, the broadly acceptable band is highly influenced by the potential number of people under life safety risk.

The following activities may be undertaken to reduce the piping failure risk at the Big Meadow Lake Dam:

- Provide additional training and instruction to Dam Operators to property identify, sample and respond to seepage turbidity would reduce the piping risk a. Seasonal turbidity laboratory tests could then be conducted on any water samples taken.

- Constructing structural mitigation in terms of piping control measures such as a reverse filter blanket at the toe of dam as assessed and recommended by EBA (2013). (see Table E-4)
- Assess the existing instrumentation information to calculate internal pore water pressure and internal gradients.

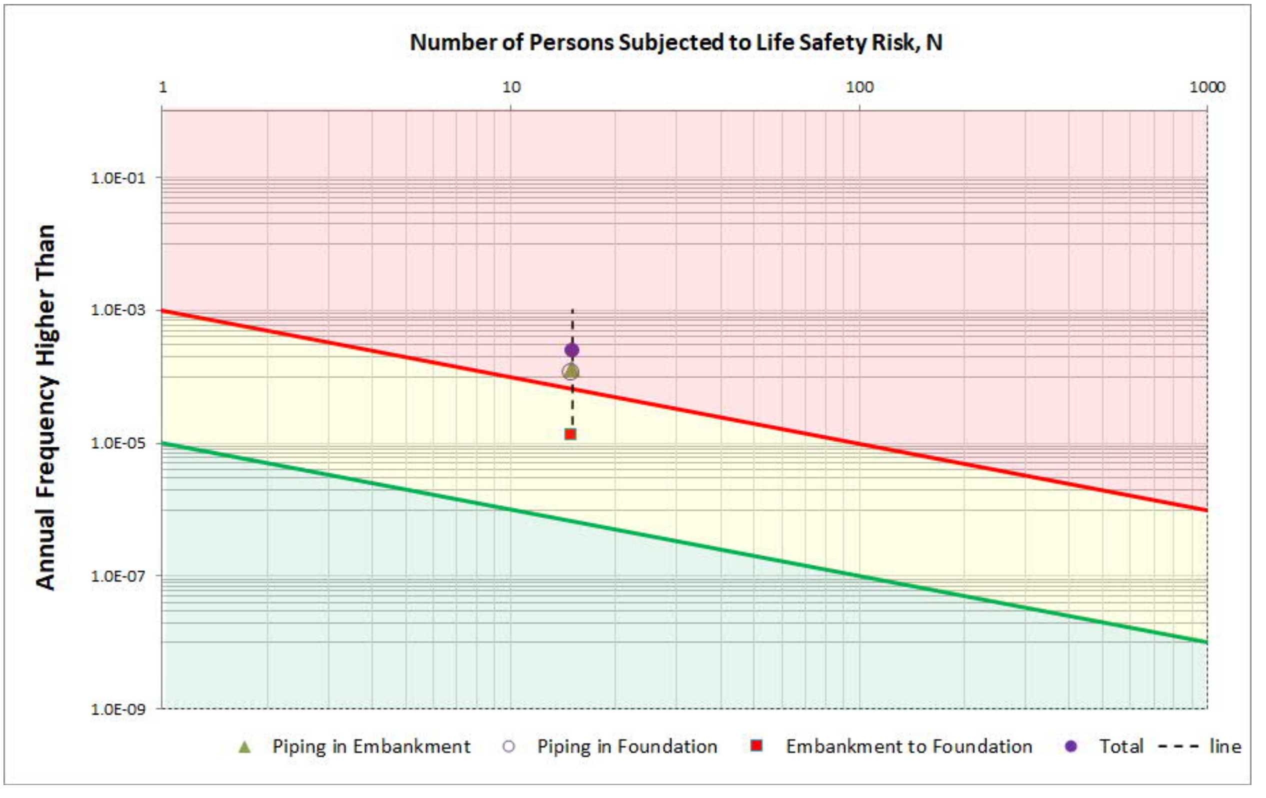

Figure 7-12: Existing Risk Acceptability for Big Meadow Lake Earthfill Dam Considering DFCC of 15

7.4.6 Geotechnical Assessment Conclusions and Recommendations

Geotechnical recommendations arising from the results of the assessment are as follows:

- The risk of piping is greater than the tolerable threshold. This is supported by evidence of seepage and boiling downstream.
- The liquefaction susceptibility and post-seismic instability of the dam are likely even when considering the revised 2020 design earthquake coefficient.
- The improvements recommended by EBA (2013) should be implemented, including a reverse filter blanket at the downstream toe.

- BC Dam Safety Regulations (2016) asks for annual interpretation and analyses of instrumentations at the Big Meadow Dam. Currently this can be carried out for Big Meadow Dam.

7.5 Mechanical Assessment

The only control equipment at the site is the gate on the riparian conduit.

The gate itself is a 0.457 m (18 inch) Armco heavy duty slide gate installed at the upstream/intake end of the concrete encased pipe culvert. The slide gate is connected with a 1-1/2" diameter gate rod and is manually operated via a rotating wheel assembly at the dam deck level. The gate is in generally good condition and is able to provide control for the reservoir as originally intended. This gate is not meant for and generally should not be used for flood control purposes. No further issues concerning dam safety were identified with the gate or mechanism. It should continue to be maintained in good working order and monitored for deterioration and leakage.

8. Public Safety and Security

In 2011, the CDA published guidelines for Public Safety Around Dams [CDA, 2011] and the 2013 revision of the CDA Dam Safety Guidelines [CDA, 2013a] outlines the requirements to address Public Safety and Security in Section 5.4.8. However, public safety and security are not explicitly addressed under the BC Dam Safety Regulation [B.C. Reg 44/2016]. In general, managing public safety and security around dams are important for the dam owner in order to ensure that the presence and normal operation of their structure does not pose an unacceptable risk to the public and to mitigate potential liability should a member of the public become injured at their structure.

8.1 Site Observations

Big Meadow Dam is accessible by either 4x4 vehicles, hiking, snowmobile, motorbikes or off-road recreational vehicles (ATV), and vehicle access is made available via the Arawana Road. ATV trails were present around the dam, indicating the presence of the public on this structure. While this is not an immediate concern, it indicates the type of access the public has to the site and the potential for safety incidents to occur. Additional indicators of public presence include shotgun casings and a shoe.

Currently, there is a sign including contact information for dam safety concerns, including contacts for an emergency, a locked outlet gate preventing public operation of the gate, and a log boom in front of the spillway restricting access to the spillway directly from the lake.

8.2 Public Safety Management Plan Audit

RDOS does not currently have a comprehensive public safety management plan in place for Big Meadow Dam, however, a "Risk Control Survey" has recently been completed by Precise Services in 2019 with the intent of identifying exposures to liability and to assist the risk management and public works staff in managing those exposures. As such, some of the types of control measures recommended within this document are similar to those expected as part of a formal public safety around dams management plan. These include fencing, signage, barriers at the spillway and low flow outlet structure, informative signage, warning signage and gates.

A summary of the findings and recommendations of the report is provided below for each component along with additional comments as applicable. All outstanding recommendations in the Risk Control Survey should be implemented, unless otherwise indicated below.

8.2.1 General

The Risk Control Survey recommends signage to provide information about the dams, water flow, the use of the water in the event of emergency, off-road vehicle restrictions and why, a requirement to pack out what you pack in, ask the public to observe, record and report if they see others vandalizing any aspect of the dam infrastructure.

No signage was present on the dam itself to warn of steep slopes and fall hazards.

8.2.2 *Riparian Conduit Structure*

The Risk Control Survey recommends barriers at the low flow outlet structure as fall protection.

During the site visit it was noted that the riparian conduit wheel is locked and therefore restricted from public operation, however there is no signage warning the public of danger.

No warning signs or buoys are present around the riparian conduit inlet to indicate the presence of a submerged inlet. The inlet is deep enough below FSL that it is unlikely a vortex would form that could affect boaters at the water surface. However, swimmers or other users should be alerted to the presence of potentially dangerous currents in this area of the dam. Although the risk control survey made some good recommendations, it is recommended that a brief supplemental public safety risk analysis and assessment in accordance with CDA Guidelines be undertaken to determine the need and form of signage and safety buoys that may be required in this area.

8.2.3 *Spillway*

The Risk Control Survey generally recommends signage, as indicated above, which could pertain to this area. It also recommends an inspection of the spillway structure by an engineer (which has been completed as part of this DSR), installation of chain link barriers or steel wire mesh around the log structure with warning signage stating, “Keep Out”, “Danger – Stay Back”, and installation of guardrails or barrier along the top of the spillway structure walls. Hatch recommends using caution when installing a chain link fence or steel wire mesh around the log boom within the water, close to the spillway approach. This measure must not obstruct flow to the spillway if debris becomes trapped against it.

The spillway structure is accessible using the gravel access road that crosses the spillway channel downstream of the spillway structure. The main concern would occur when the spillway is activated, and flow is crossing the access road to the dam crest. No warning signage was observed at the approach to the spillway channel at the access road crossing for this purpose.

There is a debris boom at the approach to the spillway inlet. No warning signs were observed in the spillway approach channel to warn boaters or swimmers to stay away from the spillway. No warning signs were present along the approach channel for pedestrian or road access.

It is recommended that a brief supplemental public safety risk analysis and assessment in accordance with CDA Guidelines be undertaken to determine the need and form of signage and safety control measures that may be required in this area.

8.3 Recommendations

We recommend that all outstanding recommendations in the Risk Control Survey be implemented with a high priority. A supplemental public safety risk analysis and assessment should be considered in the future to align with CDA Guidelines [CDA, 2011]. This exercise would ensure that all hazards have been considered and covered off and serve as formal documentation of public safety improvement and reduction of liability for RDOS.

9. Dam Safety Management

The CDA Dam Safety Guidelines state that "The owner is responsible for the safe management of a dam. Dam safety management takes place within the context of public safety reassuring the public and stakeholders that risks to people, property, and the environment are being properly addressed." The Guidelines also state that "A dam safety management system, incorporating policies, responsibilities, plans and procedures, documentation, training, and review and correction of deficiencies and non-conformances, shall be in place." Dam owners can demonstrate a commitment to diligent safety management through the implementation of a formal Dam Safety Management System.

The CDA Dam Safety Guidelines note that the effectiveness of the dam safety management system should be assessed during the course of a DSR. Key elements of the management system are policy development, planning, implementation of procedures, checking, corrective action, and reporting. Indications of effectiveness include the following:

- Roles, responsibilities, and authorities are clearly assigned.
- Key activities are clearly assigned.
- Personnel understand their roles and responsibilities and training is administered.
- Operation, maintenance, and surveillance activities are carried out and documented.
- Safety measures recommended in previous Dam Safety Review reports have been carried out.
- Other supporting documentation (as-built drawings, design calculations, engineering studies, monitoring data, licenses) are readily available.

The RDOS has a dam safety strategy that is in compliance with the B.C. Dam Safety Regulation [B.C. Reg 44/2016] under the Water Sustainability Act, but no formal Dam Safety Management policy document was provided. RDOS has an OMS Manual with documented OMS procedures or activities, and a DEP specific to the dam. Regular surveillance and maintenance activities are conducted. Dam safety training is understood to be completed on the job, although documentation of such is not available.

Recommendations from the previous Dam Safety Review by EBA in 2010, and later 2013 Geotechnical Investigation and Assessment have been partially implemented to date. A number of Dam Safety Concerns are being acted on, as is the case with the construction of downstream toe berm and reverse filter at the Big Meadow Dam.

Pertinent records including drawings, consultant reports and some monitoring records are readily available.

Based on the above, it is evident that RDOS has implemented a number of the elements of an effective Dam Safety Management System with the main shortfalls found in proper documentation of their activities rather than performance of the requirements. RDOS should continue to improve operation, maintenance, and surveillance protocols, improve DEPs as required, and conduct independent dam safety reviews and audits.

RDOS should ensure that its existing dam safety activities are continued in the context of a Dam Safety Management System which provides an overall framework for safety activities, decisions, and supporting processes. This is particularly important to maintain continuity in the event of internal reorganization or changing responsibilities for dam safety. The system should include implementation of the following.

- Dam Safety Policy, defining ultimate accountability and authority for implementation.
- Documented annual reports to management on the state of dam safety activities.
- Keeping of employee training records, inspection records, and DEP testing and training records.
- Public Safety Management Plan.

An overview of the elements of an owner's Dam Safety Management System as described in the CDA Dam Safety Guidelines is shown in Figure 9-1. Additional detail is provided in the following sections.

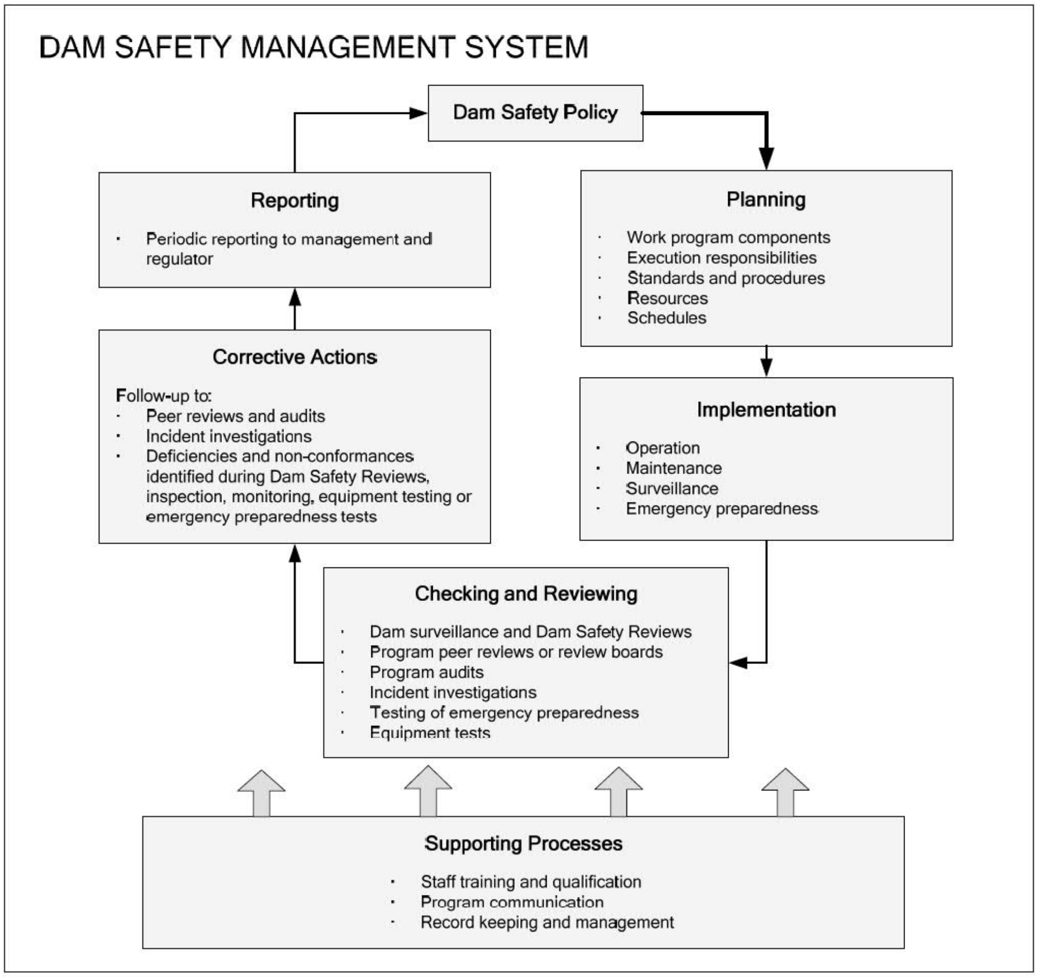

Figure 9-1: Overview of a Dam Safety Management System

9.1 Policy Development

The owner should have a Dam Safety Policy that clearly demonstrates commitment to safety management throughout the complete life cycle of the dam. The Policy should define the following:

- The level of safety that is to be provided, and the safety criteria to be used. Applicable regulations must be met, and industry practice and due diligence must be taken into account.
- Ultimate accountability and authority in the organization for ensuring that the policy is implemented. To ensure that safety objectives are not considered secondary to other objectives, accountability for dam safety should be placed at the highest level of management.

- The delegation of responsibility and authority for all dam safety activities. Key individual positions accountable for dam safety, operation, surveillance and maintenance should be identified, along with their responsibilities for internal and external reporting.
- The process for making decisions related to dam safety. Critical safety decisions with significant societal or financial implications should be made or approved at the highest level.
- We recommend that every dam owner develop a comprehensive policy regarding dam safety so that in an emergency situation the dam managers and operators are empowered to make critical decisions and have clear guidance in making these decisions. This type of policy has been shown to be instrumental in preventing dam safety emergencies from progressing into disasters in numerous situations.

9.2 Planning

Planning involves identifying the items in a dam safety work program, assigning responsibilities for carrying out each item, and ensuring resources are adequate to carry out the work. It is often useful to consider three levels of planning: the strategic or long-range plan (5 to 10 years); the management plan (annual); and operational plans specific to an individual project or task. RDOS currently has a planning process in place that should be more formally documented within their dam safety program.

9.3 Implementation

Ongoing activities associated with dam safety management include operation, maintenance and surveillance, and emergency preparedness. RDOS's regular operations, maintenance and surveillance activities are generally carried out in a structured manner. The results of the current project formalize their DEP and OMS manuals. These should continue to be improved and updated to provide better records of what is planned and what is completed.

9.4 Checking and Reviewing

The Dam Safety Management System should include processes for checking and reviewing dam performance and the management system itself.

Inspections, monitoring and assessment of data, testing of equipment, and emergency exercises are processes to check and review the condition and performance of the dams and their components. Dam Safety Reviews should be performed periodically to provide independent assurance that current safety requirements are met and to make recommendations for improvement.

After any significant dam safety incident, the owner should carry out an investigation to determine root causes, minimize potential for such incidents to happen again, and ensure that lessons learned are incorporated into the system and communicated to staff.

RDOS undertakes periodic reviews of their monitoring and surveillance data. These should be further formalized and documenting as part of their dam safety management program. DSRs are being conducted on a regular basis and should continue to be performed on the required schedule.

9.5 Corrective Actions

The Dam Safety Management System should include a process for timely follow-up and correction whenever safety deficiencies or non-conformance with standards, policies or procedures are identified. This includes prioritizing corrective actions. Prioritizing should take into account the consequences of potential dam failure, the magnitude and significance of the deficiency or issue in question, a risk assessment of the deficiency, applicable regulations and laws, and financial resources.

A strategy for implementing corrective actions and improvements should be implemented and should include priority (the order in which actions should be taken), urgency (how soon the actions should be taken), and progressive improvement (whether the actions can be implemented in stages).

The results of this DSR provide a starting point for dam safety issues tracking and mitigation. This should continue to be formalized and documented in the future.

9.6 Reporting

As a minimum, senior management should be updated annually on the status of the dam safety program. The update should cover:

- Results of the various reviews
- Outstanding issues and deficiencies
- Incidents
- Corrective actions
- Adequacy of policies and procedures (or need for change)
- Program objectives
- Adequacy of resources.

This is one area where RDOS can improve to better document their activities and issues tracking, providing better clarity and understanding for themselves, the BC Dam Safety office and for future DSRs.

9.7 Supporting Processes

9.7.1 Training and Qualification

Supporting processes include adequate training of all individuals with responsibilities for dam safety activities. Training records should be maintained. Training can take the form of internal training, formal courses (held online by bodies such as CDA, USSD, ASDSO, USBR etc.), participation in the BC Dam Safety Office's seminars and self-study of dam safety publications and journals.

9.7.2 Program Communication

It is of utmost importance that the dam safety policy and management commitment be clearly communicated to staff involved in dam safety activities. Dam safety awareness and a culture of continuous improvement should be supported.

Contact with stakeholders (including emergency responders and civic authorities) is necessary during the development, maintenance and testing of plans involving public safety and emergency preparedness.

Once the DEPs are reviewed and accepted a program of regular updates and testing should be implemented to assure the currency of the documents into the future.

9.7.3 Record Keeping and Management

Documentation should be kept up to date so there is a permanent record of (i) the design, construction, operation and performance of the dam; and (ii) the management of its safety. Such documents typically include, but are not limited to:

- An inventory of dams and appurtenant structures in the system
- Permits and licenses
- Design records
- Geotechnical investigation records
- As-built drawings
- Construction completion reports
- Photo and video records of construction activities at various stages
- Instrumentation readings and other technical data
- Inspection and test reports
- Dam Safety Review reports
- Operation and maintenance records
- Closure plans, if any
- Records of dam safety incidents, lessons learned, and follow-up actions

- Records of staff training
- Records of flow control equipment tests
- Records of emergency preparedness tests and follow up actions.

9.8 Recommendations

Based on the above, it is evident that RDOS has implemented a number of the elements of an effective Dam Safety Management System. RDOS should continue to improve operation, maintenance, and surveillance protocols, improve DEPs as required, and conduct independent dam safety reviews and audits. Hatch recommends the following Dam Safety Management actions:

- The RDOS should adopt a formal policy statement on Dam Safety for their program to satisfy the CDA Dam Safety Guidelines. This will demonstrate a commitment to the regulation and provides a reason to perform necessary works. (See Issue No. All-4 in Table 13-1).
- RDOS staff responsible for the DEP should regularly attend BC Dam Safety Dam Management seminars on dam safety and inspections (understood to be provided annually in most areas of BC, including Penticton). Records of attendance at these inspection workshops should be documented along with information on any additional training completed. This could include review of material provided on BC Dam Safety website. (See Issue No. All-7 in Table 13-1).
- Provide documented training to staff in emergency procedures, and carry out and document regular exercises to test the emergency procedures. Follow additional recommendations in proposed new Dam Emergency Plan (DEP) procedure. (See Issue No. All-8 in Table 13-1).

10. Operations, Maintenance and Surveillance

Big Meadow Dam has a DFCC of “Very High”. Under the B.C. Dam Safety Regulation [B.C. Reg 44/2016] and the Water Sustainability Act, a dam under such DFCC requires additional general safety requirements. This includes the preparation of an Operation, Maintenance and Surveillance (OMS) manual and a Dam Emergency Plan (DEP) (see Section 1). The OMS manual must be accepted by the Dam Safety Officer. The CDA Dam Safety Guidelines [CDA, 2013a] recommend that an OMS manual be prepared for each dam project. It should include operating procedures for normal, unusual and emergency conditions. Maintenance procedures should ensure that the dam remains in a safe and operational condition. The surveillance portion of the manual should allow for early identification of issues and allow for timely mitigation of conditions that could affect dam safety.

Hatch has reviewed the combined Operation, Maintenance and Surveillance Plan Emergency Preparedness Plan (OMS EPP) manual prepared by RDOS dated May 2017 [RDOS, 2017], which includes Big Meadow Lake Reservoir and Dam. As part of this project Hatch undertook the separation and update of the OMS and DEP into standalone documents as required by the Dam Safety Regulation. These documents provided some areas that RDOS is required to update and submit to the Dam Safety Office. Into the future, once approved, both of these documents should be reviewed and updated at least annually. Formally, they should be reviewed, revised if necessary, and the revision should be submitted to the DSO every 7 years.

Findings relating to the operation, maintenance, and surveillance of Big Meadow Dam are outlined in the following sections.

10.1 Operation

10.1.1 Normal Operations

The OMS manual produced as part of this project provides adequate information of monitoring and operation of Big Meadow Dam during normal flow conditions. This includes inflow forecasting, the filling schedule and release procedures. RDOS may compare the documented Snow Survey Sites with previous years’ records on file to predict the potential runoff to the storage reservoirs or at the diversion intake. As part of the reservoir filling schedule, Big Meadow Dam, is opened by the end of July. During the summer months the goal is to have a stable drawdown of all of the dams through closely monitored levels and adjustments.

10.1.2 Flood Operations

As the spillway includes a weir with no control gates, there are generally no flood operations associated with the Big Meadow Spillway.

A marking system along the gate hoist stem is available to measure water levels. Regular recording of water levels is noted by RDOS in their Routine Dam Inspection Reports. These are recorded weekly as per regulation during the high-water period.

During times of extreme reservoir inflows, the process for issuing inflow forecasts by comparing the documented Snow Survey Sites with previous years' records on file to predict the potential runoff to the storage reservoirs or at the diversion intake should be outlined. The OMS manual should provide a table with these comparisons, as well as the rating curves for the structures to facilitate calculation of outflows. A rating curve was added to the OMS Manual during this study. Any recommended drawdown in anticipation of large spring runoff events should also be documented.

10.1.3 Emergency Operations

The manual should indicate the policy to be followed should an unusual condition develop at Big Meadow Dam. The OMS has been updated to refer to the Dam Emergency Plan (DEP) in this scenario. The DEP has been updated using the BC Dam Safety "Guide & Template for Preparing a Dam Emergency Plan (DEP) in British Columbia", which fully defines the processes and responsibilities related to emergency management.

The DEP indicates the operating rules to be followed if an unusual condition develops at Big Meadow Dam. The CDA Guidelines [2013a], recommend having flood operating rules that are specific enough that Dam Operators can easily understand and follow them. Additional detail in the Dam Emergency Plan directing Dam Operators on how to identify an emergency condition would be helpful to be included (see Issue No. All-5 in Table 13-1).

Given the steepness of the drainage basin and speed of a runoff even it is unlikely that additional pumping, syphon or drawdown capacity would be useful in managing a single event. However, in the case of a series of rainfall events it may be useful to have the capacity available to help drawdown between events. In addition, emergency drawdown may be required in the case of a potential failure event (i.e., rapid increase in turbid seepage, structural movement of either of the dams or after an earthquake event).

For the Naramata Dam, it has been recommended that RDOS have on hand one (1) or more high volume pumps or a portable syphon in the case that high water levels are observed and assistance in drawdown is required. The capability to rapidly draw down the reservoir may also become necessary at Big Meadow Dam following a seismic event, as post-seismic failure or liquefaction may take place or the central concrete wall and connections to the low level outlet may become damaged. These units could be used at both Naramata and Big Meadow if a need for emergency drawdown ever presents itself. It is recommended that an understanding of the rate of drawdown that can be achieved through this method should be evaluated for operations planning (see Issue No. BM-17 and All-5 in Table 13-1).

10.2 Maintenance

As stated in the CDA Guidelines [CDA, 2013a], the maintenance of equipment and systems is pertinent to ensure safe operations and to upkeep the integrity of the dam. In the BC Dam Safety Regulation [B.C. Reg 44/2016], a "Very High" DFCC dam is expected to have site surveillance conducted on a weekly basis and a formal inspection on an annual basis. Ongoing maintenance checks have been conducted by RDOS staff on a regular basis with annual dam safety inspections and weekly site inspections. The frequency of inspections held since the previous Dam Safety Review is currently adequate and should be continued.

The OMS Manual includes a general discussion on maintenance, followed by maintenance instructions and required frequency for the earthfill dam, outlet works, spillway channel, instrumentation and signage.

10.3 Surveillance

Under Section 3.4.4 of the CDA Guidelines [CDA, 2013a], information related to flow control system operations should be identified and documented. In the BC Dam Safety Regulation, it states that a dam owner must install necessary instruments and maintain or replace the instrumentation to adequately monitor the dam and the surrounding area.

The OMS Manual including Surveillance and Inspection, includes sections and discussion on: Inspection equipment to bring to the inspection and procedure for recordings, Inspection frequencies for components, Routine Surveillance procedures including a Dam Inspection Checklist to be used in conjunction with the provincial Inspection and Maintenance of Dams Manual Appendix F, though a list of key points from this manual are included in the OMS as well; Important Site Specific surveillance conditions; deficiencies; instrumentation; and instruction on when to notify higher authorities.

A review of the annual dam inspection reports shows that in general they conform to the requirements of the BC Dam Safety Regulation. The most recent Formal Annual Inspection forms follow the form provided by the BC Dam Safety Office in their Annual Formal Inspection Form. However, the Routine Dam Inspection Report could be improved by more closely following the form provided by BC Dam Safety Office in their Site Surveillance Form, used for weekly inspections (included in the updated OMS manual). This form can be tailored to the dam itself to include items that are currently documented on the RDOS form and the basic information reused from year to year but in general it provides a more detailed assessment of the dam condition and may reduce the potential of missing an emerging issue.

In addition, though not specifically recommended at this time, should a new geotechnical investigation be undertaken and additional instrumentation installed, these should be monitored on a regular basis to detect changes and trends.

10.4 Recommendations

Hatch recommends the following OMS actions:

- The Routine Dam Inspection report format should be improved by incorporating aspects of the BC Dam Safety Office's Site Surveillance Form (included in the appendices of the updated OMS manual). (See Issue No. All-3 in Table 13-1).
- Install new instrumentation including reinstating/installing the weir downstream of the dam along the low level outlet outflow channels and at the outlet of the drain. The instrumentation monitoring shall include continuous records, plotting, and interpretation of piezometer data and seepage flow quantities against reservoir elevation. An interpretation and analysis of the results should be carried out annually and the results would be gathered in a memorandum (See Issue No. BM-3 and BM-14 in Table 13-1).
- Logs should be kept to show that a review of the OMS is being completed annually, including the documentation of annual training refresher on the OMS Manual and DEP.

11. Dam Emergency Plan

In British Columbia as per Sections 9 and 33 of the Dam Safety Regulation, Water Sustainability Act [B.C. Reg 40/2016], an owner of a dam that has a consequence of failure classification of SIGNIFICANT, HIGH, VERY HIGH or EXTREME must prepare a Dam Emergency Plan (DEP) that includes

- A record describing actions to be taken by the owner if there is an emergency at the dam
- A record containing information for the use of the local emergency authorities for the dam for the purpose of preparing local emergency plans under the Emergency Program Act.

The new regulation still requires dam owners to prepare an emergency plan, but it is now called a Dam Emergency Plan (DEP) and includes some differences including what they contain, what must be done with them, and the date by which they must be prepared and submitted for acceptance by the Dam Safety Officer (DSO). The OMS EPP manual [RDOS, 2017] contains an EPP (Emergency Preparedness Plan) section that generally complies with both the BC Dam Safety Regulation and the CDA guidelines. However, it has previously been noted that some improvements can be made to more fully define the processes and responsibilities related to emergency management. A Guide & Template for Preparing a Dam Emergency Plan (DEP) in British Columbia has been developed to assist dam owners in preparing their DEP. Information in the existing EPP has been brought into this template as part of this study, and any additional relevant information that has come to light during this DSR has been added. This standalone document should be submitted to the DSO for acceptance.

The EPP component of the OMS EPP manual [RDOS, 2017] contains the following sections, which have been brought into the DEP template as appropriate:

- Introduction
- Responsibility
- Emergency Reporting
- Assessment and Categorization of the Emergency
- Emergency Response
- Emergency Materials.

Appendices of information include RDOS Emergency Contacts with a list of contractors and material location, a map of possible affected areas (which can be updated following the "Naramata Dam Breach Assessment and Inundation Mapping" 2020 report), Inundation Properties and Infrastructure Data.

The inundation maps included in the DEP have been updated as part of this study.

11.1 Recommendations

Hatch recommends the following DEP actions:

- Provide documented training to staff in emergency procedures, and carry out and document regular exercises to test the emergency procedures. Follow additional recommendations in proposed new Dam Emergency Plan (DEP) procedure.
- Increase frequency of review of DEP including any necessary revisions and submission to the DSO to every 7 years instead of every 10 years.
- It is recommended that an understanding of the rate of drawdown that can be achieved should be evaluated for operations planning and documented in the DEP. Under the CDA Guidelines [2013a], it is recommended to provide information on staffing requirements and the time required to complete system operations so that an appropriate response can be initiated during an emergency (see Issue No.15 in Table 13-1).
- It is recommended that the RDOS emergency call alert system, CivicReady be setup to allow for public signup in order to receive external text message notifications during an emergency, if possible. The current Emergency Response and Notification does meet the recommendations in the BC Dam Safety Regulation [B.C. Reg 44/2016] CDA Guidelines [CDA, 2013a].
- Use results of the Dam Break analysis to form the Emergency Evacuation Plan.
- Consider using results of Dam Break analysis to prioritize contact list of downstream population to notify in an emergency.

12. Dam Safety Expectations and Deficiencies

12.1 Dam Safety Review Assurance Statement

A Dam Safety Review Assurance Statement was completed by Hatch Ltd. to verify that the DSR was completed in accordance with the APEGBC Guidelines and is included in **Appendix E**.

The definitions of Deficiencies and Non-Conformances used during this DSR are listed in Table 12-1.

Table 12-1: Definition of Deficiencies and Non- Conformances [FLNRO, 2015]

Deficiencies	
An	Actual performance deficiencies under normal loading conditions.
Au	Actual performance deficiencies under unusual loading conditions.
Pn	Potential performance deficiencies under normal loading conditions, expected to be confirmed as actual deficiencies by means of analysis in a dam performance investigation.
Pu	Potential performance deficiencies under unusual loading conditions, expected to be confirmed as actual deficiencies by means of analysis in a dam performance investigation.
Pq	Potential deficiencies under normal or unusual loading conditions, that would lead to dam safety improvements if it could not be readily (quickly) demonstrated that such procedures for activities required for normal or unusual load conditions.
Pd	Potential performance deficiencies under normal or unusual loading conditions, in the following senses: The “Dam” meets minimum performance goals, but additional safety benefits are desirable, practicable and affordable, or, the uncertainties around the concern are such that it is extremely difficult if not impossible to demonstrate that safety improvements are neither required nor desirable.
Non-Conformances	
NCo	Non-Conformance Operational: Established operational procedures, systems and instructions are not being followed, or, they are inadequate or inappropriate and should be revised.
NCm	Non-Conformance Maintenance: Established maintenance procedures, systems and instructions are not being followed, or, they are inadequate or inappropriate and should be revised.
NCs	Non-Conformance Surveillance: Established surveillance procedures, systems and instructions are not being followed, or, they are inadequate or inappropriate and should be revised.
NCi	Non-Conformance Information: There is a deficiency in information required to determine if an actual or potential performance deficiency exists. There is not enough information to determine if an Actual or Potential Deficiency exists.
NCp	Non-Conformance Procedures: Other established procedures, systems and instructions are not being followed, or, they are inadequate or inappropriate and should be revised.

Identified issues have been categorized as non-conformance, actual deficiency or potential deficiency, as outlined in the Dam Safety Expectations table, Table 12-2.

Table 12-2: Dam Safety Expectations

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-conformances	Comments
					Actual	Potential		
1	**Dam Safety Analysis**							
1.1	Records relevant to dam safety are available including design documents, historical instrument readings, inspection and testing reports, operational records and investigation results.			X			NCi	There is insufficient official as-built information, and limited construction records and drawings of the dam were available during this review. Official topographic survey of the dam was carried out in 2012 during a high water level time, therefore the upstream slope is partially surveyed. A detailed geotechnical investigation was carried out in 2012 as well. Likely no further information will be found through document search.
1.2	Hazards external and internal to the dam have been defined	X						Yes, as part of the current DSR.
1.3	The potential failure modes for the dam and the initial conditions downstream from the dam have been identified	X						Potential failure modes for the dam have been identified as part of this study. A full inundation study and downstream consequence classification has been undertaken as part of this study.
1.4	Inundation study adequate to determine consequence classification. Flood and “sunny day” scenarios assessed.	X						A full inundation study and downstream consequence classification has been undertaken as part of this study including the assessment of 5 potential inflow design floods and sunny day scenarios.
1.5	The Dam is classified appropriately in terms of the consequences of failure including life, environmental, cultural and third-party economic losses.	X						Has been assessed as part of this study.
1.6	All components of the water barrier (including retaining walls, saddle dams, spillways, road embankments) are included in the dam safety management process.	X						Yes, all water barrier system components were considered including the dam and its foundations.
1.7	The EDGM selected reflects current seismic understanding	X						Yes, this was assessed as part of the current study. No site specific seismic hazard assessment is deemed necessary.
1.8	The IDF is based on appropriate hydrological analyses	X						Yes, this has been assessed as part of this study.
1.9	The dam is safely capable of passing flows as required for all applicable loading conditions (normal, winter, earthquake, flood)	X						Low level outlet performs as expected. Reservoir is empty or near-empty in winter condition (N/A). The dam is capable of passing its Inflow Design Flood without overtopping. A seismic event is not expected to adversely affect the slopes, spillway channel and path; any distress can be readily fixed.
1.10	The dam has adequate freeboard for all applicable operating conditions (normal, winter, earthquake, flood)			X		Au		Freeboard analysis including wind/wave effects for normal and IDF conditions has been analyzed as part of this DSR and is adequate. Topographical survey of embankment demonstrates some loss of design freeboard at the left abutment due to vehicle activity (taken into account in freeboard assessment). As assessed by EBA (2013), the dam is prone to liquefaction and construction of toe berm with filter is needed.
1.11	The dam safety analyses (stability & hydrological) use current information and standards of practice	X						Yes, as presented in the DSR report. Stability assessments were done based on best practice. A recent geotechnical investigation and assessment is done (EBA, 2013).
1.12	The approach and exit channels of discharge facilities are adequately protected against erosion and free of any obstructions and hazards that could adversely affect the discharge capacity of the facilities			X			NCm	Vegetation was observed in the weir downstream of the low level outlet and on the downstream face. Vegetation and tree growth inhibit detailed inspection of the toe of the dam.
1.13	The dams, abutments and foundations are not subject to unacceptable deformation or overstressing	X						The dam, abutments, and foundation are performing well corresponding to loads, deformation and stress. Slopes are relatively shallow and no sign of distress was observed and expected.

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-conformances	Comments
					Actual	Potential		
1.14	Adequate filter and drainage facilities are provided to intercept and control the maximum anticipated seepage and to prevent internal erosion			X	An, Au			The dam was designed without a filter. Seepage at the toe of the embankment and around the outlet structures has been observed and the previous toe drainage repairs having not permanently resolved this problem. The design of a toe berm incorporating a filter was investigated and recommended.
1.15	Hydraulic gradients in the dams, abutments, foundations and along embedded structures are sufficiently low to prevent piping and instability			X	An, Au			Seepage analyses show that exit gradients at the toe of the embankment are not acceptable. Construction of reverse filter and gravity berm are required.
1.16	Slopes of the embankments have adequate protection against erosion, seepage, traffic, frost and burrowing animals			X			NCm	Dam exhibits erosion from vehicle traffic. No upstream riprap exists on the dam slope. No significant erosion was reported in the past due to wave and surge effects. Seepage on the downstream slope has been observed and reported in the past.
1.17	Stability of reservoir slopes are evaluated under all conditions and any unacceptable risk to public safety, the dam or its appurtenant structures is identified.	X						Reservoir sides slopes are considered suitable therefore present no perceived risk. No sign of distress or concern were raised in the past as well.
1.18	The need for reservoir evacuation or emergency drawdown capability as a dam safety risk control measure has been assessed.			X			NCo	Need for emergency drawdown should be assessed.
2	**Operation, Maintenance and Surveillance**							
2.1	Responsibilities and authorities are clearly delegated within the organization for all dam safety activities	X						Should include a table with positions and associated names describing roles and responsibilities. Added as part of this project.
2.2	Requirements for the safe operation, maintenance and surveillance of the dam are documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure	X						
2.3	The OMS Manual is reviewed and updated periodically when major changes to the structure, flow control equipment, operating conditions or company organizational structure and responsibilities have occurred.	X						Assumed. The OMS EPP was last reviewed in 2017 where updates were made to the filling and release procedures, among others. OMS and DEP have been updated as part of the current study.
2.4	Documented operating procedures for the dam and flow control equipment under normal, unusual and emergency conditions exist, are consistent with the OMS Manual and are followed	X						
	Operation							
2.5	Critical discharge facilities are able to operate under all expected conditions.	X						
a.	Flow control equipment are tested and are capable of operating as required.	X						Flow control equipment is routinely/seasonally operated which satisfies annual testing of mechanical components of the dam.
b.	Normal and standby power sources, as well as local and remote controls, are tested.		X					N/A
c.	Testing is on a defined schedule and test results are documented and reviewed.	X						Flow control equipment is routinely/seasonally operated which satisfies annual testing of mechanical components of the dam.
d.	Management of debris and ice is carried out to ensure operability of discharge facilities	X						Debris boom is present at spill location. It is cleaned as needed.
2.6	Operating procedures take into account:							
a.	Outflow from upstream dams	X						
b.	Reservoir levels and rates of drawdown	X						
c.	Reservoir control and discharge during an emergency	X						
d.	Reliable flood forecasting information	X						

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-conformances	Comments
					Actual	Potential		
e.	Operator safety	X						
	Maintenance							
2.7	The particular maintenance needs of critical components or subsystems, such as flow control systems, power supply, backup power, civil structures, drainage, public safety and security measures and communications and other infrastructure have been identified	X						
2.8	Maintenance procedures are documented and followed to ensure that the dam remains in a safe and operational condition	X						
2.9	Maintenance activities are prioritized and carried out with due consideration to the consequences of failure, public safety and security			X			NCm	Clear evidence that maintenance activities are being carried out in the records. Low dam crest should be compensated in two locations. More consistent and thorough record keeping recommended.
	Surveillance							
2.10	Documented surveillance procedures for the dam and reservoir are followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety	X						
2.11	The surveillance program provides regular monitoring of dam performance, as follows:							
a.	Actual and expected performance are compared to identify deviations			X			NCs	Piezometer was installed as part of the 2013 Geotechnical Assessment (EBA, 2013). The current OMS manual calls for piezometer readings to be taken on a weekly basis between May and November. These readings are found in the weekly routine dam inspection report. No assessment of information was carried out so far. Installation of instrumentation to monitor toe seepage recommended. No record of survey monuments reading could be found. Installation of additional settlement monuments should be considered along the dam crest.
b.	Analysis of changes in performance, deviation from expected performance or the development of hazardous conditions			X			NCs	Piezometer was installed as part of the 2013 Geotechnical Assessment (EBA, 2013). The current OMS manual calls for piezometer readings to be taken on a weekly basis between May and November. These readings are found in the weekly routine dam inspection report. No assessment of information was carried out so far. No instrumentation threshold values are established. Installation of instrumentation to monitor toe seepage recommended.
c.	Reservoir operations are confirmed to be in compliance with dam safety requirements	X						
d.	Confirmation that adequate maintenance is being carried out			X			NCs	Maintenance requirements documented in weekly inspections and some maintenance documentation was provided within these forms as well. Regular recording of maintenance completion would further support that this is being completed.
2.12	The surveillance program has adequate quality assurance to maintain the integrity of data, inspection information, dam safety recommendations, training and response to unusual conditions			X			NCp	Weekly inspections are adequate. Recommend using the BC Dam Safety "Site Surveillance" checklist customized to this dam for weekly inspections to make sure nothing is missed.
2.13	The frequency of inspection and monitoring activities reflects the consequences of failure, dam condition and past performance, rapidity of development of potential failure modes, access constraints due to weather or the season, regulatory requirements and security needs.	X						Dams inspected weekly, weather permitting and documented.
2.14	Special inspections are undertaken following unusual events (if no unusual events then acknowledge that requirement to do so is documented in OMS).	X						

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-conformances	Comments
					Actual	Potential		
2.15	Training is provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively.			X			NCs	No available documentation provided to show if regular dam safety training is provided to the inspector(s). As a minimum RDOS staff responsible for the DEP should regularly attend BC Dam Safety Dam Management seminars on dam safety and inspections (understood to be provided annually in most areas of BC, including Penticton). Records of attendance at these inspection workshops should be documented along with information on any additional training completed. This could include review of material provided on BC Dam Safety website.
2.16	Qualifications and training records of all individuals with responsibilities for dam safety activities are available and maintained			X			NCs	No available documentation provided to show if regular dam safety training is provided to the inspector(s).
2.17	Procedures document how often instruments are read and by whom, where the instrument readings will be stored, how they will be processed, how they will be analyzed, what threshold values or limits are acceptable for triggering follow-up actions, what the follow-up actions should be and what instrument maintenance and calibration are necessary.			X			NCs	Installation of instrumentation (weirs) to monitor toe seepage recommended. Access to the existing weir location should be cleared of trees. The downstream toe of the dam should be kept clear of large trees. Piezometer was installed as part of the 2013 Geotechnical Assessment (EBA, 2013). The current OMS manual calls for piezometer readings to be taken on a weekly basis between May and November. These readings are found in the weekly routine dam inspection report. No assessment of information was carried out so far and threshold levels are not indicated. Procedures should be provided in OMS manual.
3	**Emergency Preparedness**							
3.1	An emergency management process is in place for the dam including emergency response procedures and emergency preparedness plans with a level of detail that is commensurate with the consequences of failure.	X						The existing EPP has been incorporated into the BC Dam Safety DEP template. Dam Breach inundation maps and emergency contact information from downstream landowners has been updated in 2017.
3.2	The emergency response procedures outline the steps that the operations staff is to follow in the event of an emergency at the dam.	X						
3.3	Documentation clearly states, in order of priority, the key roles and responsibilities, as well as the required notifications and contact information.	X						There is an Appendix with an Emergency Contact List for both RDOS and for those located in the potential inundation zone (updated 2017). This information has not been made available to review for privacy purposes, but it has been stated that it exists. With new information on inundation zone, the contact list for downstream inundation could be prioritized.
3.4	The emergency response procedures cover the full range of flood management planning, normal operating procedures and surveillance procedures	X						
3.5	The emergency management process ensures that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.	X						DEP has been prepared. Consider using results of Dam Break analysis to form the Emergency evacuation Plan.
3.6	Roles and responsibilities of the dam owner and response agencies are defined.	X						DEP has been prepared.
3.7	Inundation maps and critical flood information are appropriate and are available to downstream response agencies.	X						Inundation study has been undertaken and inundation maps are to be included in the DEP.
3.8	Exercises are carried out regularly to test the emergency procedures.			X			NCp	No documentation that exercises have been undertaken was provided.
3.9	Staff are adequately trained in the emergency procedures.			X			NCi	No documentation that staff have been undertaken training was provided.
3.10	Emergency plans are updated regularly and updated pages are distributed to all plan holders in a controlled manner.	X						The EPP was prepared in 2010, and updated in 2016 and 2017. DEP has been updated as part of this study.
4	**Dam Safety Review**							
4.1	A safety review of the dam ("Dam Safety Review") is carried out periodically based on the consequences of failure.	X						RDOS commissioned a DSR in 2010 and this dam safety review in 2020. Another Dam Safety Review should be conducted in ten years (2030), however RDOS should endeavor to implement the recommendations of this review before that time.

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-conformances	Comments
					Actual	Potential		
5	**Dam Safety Management System**							
5.1	The dam safety management system for the dam is in place incorporating:							
a.	policies,	X						
b.	responsibilities,	X						
c.	plans and procedures including OMS, public safety and security,			X			NCp	Public safety and security plans not in place. 2019 "Risk Control Survey" has been completed but no evidence of implementation of recommended measures yet.
d.	documentation,	X						
e.	training and review,			X			NCp	No available documentation provided to show if regular dam safety training is provided to the inspector(s).
f.	prioritization and correction of deficiencies and non-conformances,	X						Prioritization and corrections of deficiencies and non-conformances are documented in this Dam Safety Review.
g.	supporting infrastructure		X					
5.2	Deficiencies are documented, reviewed and resolved in a timely manner. Decisions are justified and documented	X						Deficiencies are documented in this Dam Safety Review. Recommendations from the previous Dam Safety Review by EBA in 2010 have been partially implemented to date.
5.3	Applicable regulations are met	X						

13. Conclusions and Recommendations

A systematic Dam Safety Review has been performed for Big Meadow Dam in accordance with the current B.C. Water Sustainability Act and the B.C. Dam Safety Regulation [Reg. 44/2016] and the current Canadian Dam Association Dam Safety Guidelines. This DSR confirms that the reservoir and its water retaining structures are being operated and maintained in a generally safe condition; however, there are some notable dam safety deficiencies that require further investigation and action.

Deficiencies have been identified throughout the document and are tabulated along with their prioritization. The tables of issues and recommendations are provided in Table 13-1.

Recommended actions in the table for each issue are outlined; these represent the controls that can be implemented to mitigate the hazards. The actual and potential deficiencies were given an overall priority rating of the risks, defined as high, medium and low, based upon the potential of the issue leading to a critical failure of the structure. The actual or potential deficiencies are summarized in Table 13-1. The non-conformances were assigned a ranking of low, medium or high based on how they impact dam safety. Priority definitions are as follows:

High: Potential failure mode(s) are judged to present serious risks, either due to a high probability of failure or due to very high potential incremental damages, which justify an urgency in actions to reduce risk.

Medium: Potential failure mode(s) appear to be dam safety deficiencies that appear to indicate a potential concern, and actions are needed to better define risks or to reduce risks. Ensure routine risk management activities are in place. For those actions for which the case has been built to proceed before the next comprehensive review, take appropriate interim measures and schedule other actions as appropriate. Prioritize investigations to support justification for remediation and remediation design, as appropriate.

Low: Potential failure mode(s) at the facility do not appear to present significant risks. Determine whether action can wait until after the next comprehensive review of the dam and appurtenant structures. Continue routine dam safety risk management activities, normal operation, and maintenance.

The various action items are categorized based on areas of responsibility as Minor Improvements (Operations), Minor Capital Works (Engineering), or Major Capital Works (Capital). A budgetary level Class D cost estimate is included with notes on inclusions.

Table 13-1: Summary of Dam Safety Recommendations

Issue No.	Dam	Deficiency/Non-Conformance	Originator	Type	Status	Recommendation	Priority Rating	Cost Estimate - Type	Estimated Cost	Notes
BM-1	Big Meadow	Dam is currently classified as a High consequence facility (EBA, 2010) and dam classification should be updated.	2020 DSR	N/A	New	Classify the Big Meadow Lake Dam as a Very High consequence dam. For the determination of the Inflow Design Flood only, a High classification is recommended, which equates to a flood with annual exceedance probability 1/3 between the 1000 year flood and the PMF. Ensure frequency of review of OMS and DEP is updated for the requirements of revised dam classification.	Medium	N/A	$ -	
BM-2	Big Meadow	Documented history of toe seepage at downstream toe of the dam (EBA, 2010), observed again during the 2020 inspection as wet areas downstream of the low level outlet location.	2010 DSR, 2020 DSR	NCi	Outstanding	Construct a toe berm, filter and drain system at the downstream toe in areas where seepage has been observed. This includes particularly the area of the downstream toe adjacent to the Low Level Outlet. The drain system should be designed to convey seepage flows to the low level outlet.	High	Major Capital Works	$ 300,000.00	
BM-3	Big Meadow	There is currently no ability to measure quantity of seepage in areas where seepage has been observed historically.	EBA, 2013 2020 DSR	NCs	Outstanding	Install or reinstate the weir at the outlet of the drain to allow for quantitative measurement of seepage flows.	Medium	Minor Capital Works	$ 6,000.00	1 weir
BM-4	Big Meadow	Insufficient as-built documents and geotechnical data to conduct a complete geotechnical assessment of the dam	2010 DSR	N/A	Resolved	As recommended in the 2010 DSR, a geotechnical investigation consisting of four boreholes and six CPTs/SCPTs was conducted in June/July 2012 (EBA, 2013). The results of this investigation and subsequent geotechnical analyses were reviewed.	N/A	N/A	$ -	
BM-5	Big Meadow	No performance instrumentation is installed to monitor the performance of the dam. Previous DSR recommended one piezometer at minimum be installed, or a system be developed to quantify seepage.	2010 DSR	N/A	Resolved	Piezometer was installed as part of the 2013 Geotechnical Assessment (EBA, 2013). The current OMS manual calls for piezometer readings to be taken on a weekly basis between May and November. These readings are found in the weekly routine dam inspection report. No assessment of information was carried out so far.	Low	N/A	$ -	
BM-6	Big Meadow	Using updated survey data, the 2020 DSR analysis indicates that the existing dam is able to pass the IDF including wind and wave effects with an available freeboard of 0.31 m to the lowest portion of the dam, which meets CDA requirements. Note that stop log use is no longer implemented.	2010 DSR, Updated 2020	N/A	Resolved		N/A	N/A	$ -	
BM-7	Big Meadow	Topographic survey data from 2012 shows the dam crest elevation is lower than the design elevation of El. 1606.33 (EBA, 2013). However, freeboard requirements are met.	EBA, 2013 Updated 2020 DSR	NCm	Outstanding	Place material to re-grade the crest to the design/typical elevation to provide additional freeboard.	Medium	Minor Capital Works	$ 15,000.00	
BM-8	Big Meadow	Upstream erosion of embankment and woody debris accumulation noted adjacent to the left abutment, should be cleaned out and protected with rip-rap (EBA, 2010)	2010 DSR	N/A	Resolved	The eroded areas as noted by EBA (2010) was repaired.	N/A	N/A	$ -	
BM-9	Big Meadow	Vegetation observed in the weir downstream end of Low Level Outlet and on the downstream face. Vegetation inhibits detailed inspection of the toe of the dam.	2010 DSR 2020 DSR	NCo,s	Outstanding	Increase vegetation clearing at the downstream end of the Low Level Outlet to allow for proper inspection of the seepage/piping areas downstream of the dam.	Medium	Minor Improvements	-	

Issue No.	Dam	Deficiency/Non-Conformance	Originator	Type	Status	Recommendation	Priority Rating	Cost Estimate - Type	Estimated Cost	Notes
BM-10	Big Meadow	Security/access issues leading to damage on dam crest and face from ATV traffic	2010 DSR EBA 2013 2019 Risk Survey 2020 DSR	NCp	Outstanding	Review security protocols and implement appropriate restrictions including those set out in the 2019 Risk Control Survey (Precise Services, 2019) to prevent damage or vandalism.	High	Minor Improvements	$ 10,000.00	
BM-11	Big Meadow	No Operations, Maintenance and Surveillance (OMS) manual was prepared for the dam as of the previous Dam Safety Review.	2010 DSR	NCs	Resolved	An OMS manual has been published since the previous review (RDOS, 2017). The contents of the OMS were reviewed and revised as part of the 2020 review.	N/A	N/A	$ -	
BM-12	Big Meadow	Dam Safety Review schedule	2020 DSR		New	In accordance with the Very High consequence classification, the next Dam Safety Review should be conducted in 2030, and every 10 years subsequently.	Medium	N/A	$ -	
BM-13	Big Meadow	Seismic and post-seismic stability issues were raised by EBA during the 2013 geotechnical assessment report. The assessments need to be implemented.	EBA 2013		New	As shown by EBA (2013), construct a free draining toe berm to mitigate seismic and post-seismic stability concerns.	Medium	Major Capital Works	$ -	See recommendation BM-2
BM-14	Big Meadow	Lack of sufficient instrumentation monitoring for performance assessment of the dam.	2020 DSR	NCs	New	Reinstate the weir downstream of the dam along the tailrace channel. Perform instrumentation monitoring program which should include continuous records, plotting, and interpretation of piezometer data and seepage flow quantities against reservoir elevation.	Medium	N/A	-	
BM-15	Big Meadow	Currently no rip-rap or erosion protection layer on the dam crest or upstream slope.	2020 DSR	NCm	New	Provide appropriately sized armour protection along the upstream face of the dam from the crest to 1 m below the low water level.	Low	Minor Capital Works		
BM-16	Big Meadow	LLO structure is unprotected from vandalism and accidental damage from ATVs or other traffic at dam crest.	2020 DSR	NCm	New	Provide protection to the screw stem by adding bollards or a steel cover to prevent damage from ATV traffic.	Low	Minor Capital Works	$ 10,000.00	
BM-17	Big Meadow	No information is available for the rate of drawdown and the procedures that should be used to accommodate lowering the reservoir for emergency drawdown.	2020 DSR	NCo	New	It is recommended to determine a better understanding of the rate of drawdown that can be achieved for emergency drawdown scenarios such as after a seismic event. A plan to utilize a portable syphon or one or more high volume pumps to provide capacity and emergency drawdown would be a cost effective way to providing required drawdown capacity. This should be evaluated for operations planning as well as potential sources for emergency pumps if needed. Under the CDA guidelines, it is recommended to provide information on staffing requirements and the time required to complete system operations. Add syphon Standard Operating Procedure (SOP) to OMS Manual.	Medium	Minor Capital Works	$50,000.00	Calculations would be small cost. Syphon itself could be less than the $50,000 presented, and could be already accounted for in the Naramata Dam recommendations if it could be used for both locations.
All-1	All Dams	OMS could be improved by including supporting confirmation that highlighted maintenance activities are being completed.	2020 DSR	NCs	New	Regular verification of the completion of maintenance items recorded in the weekly site surveillance form would further support that maintenance items are being completed.	Low	Minor Improvements		
All-2	All Dams	OMS does not have a table with positions and associated names describing roles and responsibilities.	2020 DSR	NCo	New	Update table in OMS to include positions and associated names describing roles and responsibilities.	Medium	Minor Improvements		
All-3	All Dams	Routine Dam Inspection Report format does not contain all aspect of BC Dam Safety Office's Site Surveillance Form for weekly inspections.	2020 DSR	NCp	New	Routine Dam Inspection Report format should be improved to more closely follow the BC Dam Safety Site Surveillance Form for weekly inspections.	Low	Minor Improvements		

Issue No.	Dam	Deficiency/Non-Conformance	Originator	Type	Status	Recommendation	Priority Rating	Cost Estimate - Type	Estimated Cost	Notes
All-4	All Dams	No formal Dam Safety Policy is in place for their dam safety program.	2020 DSR	NCp	New	The RDOS appears to be meeting the intent of a dam safety management system and should continue to improve and develop their system and adopt a formal policy statement on Dam Safety for their program to satisfy the CDA Dam Safety Guidelines. This will demonstrate a commitment to the regulation and provide a reason to perform necessary works.	Medium	Minor Improvements		
All-5	All Dams	OMS could be improved by including more information to assist Dam Safety inspectors in detecting and responding to an emergency situation.	2020 DSR	NCp	New	In the OMS, inflow forecasting should include alarm limits on what scenario of Snow Survey combined with reservoir levels would create a need for action. Actions to be taken should be described. Any recommended drawdown in anticipation of large spring runoff events should also be documented.	Medium	Minor Improvements		
All-6	All Dams	Emergency notification systems to alert the public should be expanded to include a text message template to facilitate public notification in the event of an emergency.	2020 DSR	NCp	New	It is recommended that the RDOS emergency call alert system, CivicReady be setup to allow for public signup in order to receive external text message notifications during an emergency.	Medium	Minor Improvements		
All-7	All Dams	No available documentation provided to show if regular dam safety training is provided to the inspector(s).	2010 DSR, 2020 DSR	NCs	Outstanding	RDOS staff responsible for the DEP should regularly attend BC Dam Safety Dam Management seminars on dam safety and inspections (understood to be provided annually in most areas of BC, including Penticton). Records of attendance at these inspection workshops should be documented along with information on any additional training completed. This could include review of material provided on BC Dam Safety website.	Medium	Minor Improvements		
All-8	All Dams	No available documentation to show that exercises are carried out regularly to test the emergency procedures.	2020 DSR	NCp	New	Provide documented training to staff in emergency procedures, and carry out and document regular exercises to test the emergency procedures. Follow additional recommendations in proposed new Dam Emergency Plan (DEP) procedure.	Medium	Minor Improvements		

Note that Issues No's are categorized as either "BM" (Big Meadow) or "All" (indicating similar OMS related issues that span all of the Naramata Dams).

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Appendix A
Site Visit Photo Report

Photo A1: Big Meadow Lake Dam Upstream Slope, Looking from Right Abutment

Photo A2: Big Meadow Lake Dam Crest, Looking at Right Abutment and Slope

Photo A3: Big Meadow Lake Dam Downstream Slope, Looking from Right Abutment

Photo A4: Big Meadow Lake Dam downstream slope, Looking at Outlet Works Location

Photo A5: Big Meadow Lake Dam Outlet Works

Photo A6: Big Meadow Lake Dam Outlet Works, Seepage from Left Wall Area

Photo A7: Big Meadow Lake Dam Outlet Works, Seepage from Right Wall Area

Photo A8: Big Meadow Lake Dam Downstream Slope and Dam Crest

Photo A9: Big Meadow Lake Dam, Intake Structure and Dam Crest

Photo A10: Big Meadow Lake Dam Spillway Structure

Photo A11: Big Meadow Lake Dam Spillway Downstream Channel and Access Road

Photo A12: Big Meadow Lake Dam Low Crest Area close to Left Abutment

Photo A13: Big Meadow Lake Dam Low Crest Area close to Left Abutment

Photo A14: Big Meadow Lake Dam Upstream Slope close to Left Abutment

Photo A15: Big Meadow Lake Dam, Minor Animal Burrow on Dam Upstream Slope

Photo A16: Big Meadow Lake Dam Debris Boom in Front of Spillway Structure

Photo A17: Big Meadow Lake Dam Intake Gate Operating Wheel Assembly

Photo A18: Big Meadow Lake Dam Spillway Crest Concrete Damage at Mid Span

Photo A19: Big Meadow Lake Dam Spillway Repaired Crack in Left Retaining Wall

Appendix B
Seismic Hazard Characterization

2015 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Site: 49.667N 119.537W **User File Reference:** Naramata Dam Sites 2021-01-06 18:11 UT

Requested by: Tim Tuo, Hatch Ltd.

Probability of exceedance per annum	0.000404	0.001	0.0021	0.01
Probability of exceedance in 50 years	2 %	5 %	10 %	40 %
Sa (0.05)	0.081	0.049	0.032	0.011
Sa (0.1)	0.119	0.071	0.046	0.015
Sa (0.2)	0.151	0.095	0.064	0.025
Sa (0.3)	0.148	0.098	0.069	0.029
Sa (0.5)	0.130	0.089	0.064	0.028
Sa (1.0)	0.097	0.066	0.046	0.020
Sa (2.0)	0.067	0.043	0.030	0.012
Sa (5.0)	0.030	0.017	0.011	0.004
Sa (10.0)	0.010	0.006	0.004	0.002
PGA (g)	0.070	0.044	0.029	0.010
PGV (m/s)	0.124	0.078	0.051	0.020

Notes: Spectral (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are given in units of g (9.81 m/s^2). Peak ground velocity is given in m/s. Values are for "firm ground" (NBCC2015 Site Class C, average shear wave velocity 450 m/s). NBCC2015 and CSAS6-14 values are highlighted in yellow. Three additional periods are provided - their use is discussed in the NBCC2015 Commentary. Only 2 significant figures are to be used. **These values have been interpolated from a 10-km-spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the directly calculated values.**

References

National Building Code of Canada 2015 NRCC no. 56190; Appendix C: Table C-3, Seismic Design Data for Selected Locations in Canada

Structural Commentaries (User's Guide - NBC 2015: Part 4 of Division B)
Commentary J: Design for Seismic Effects

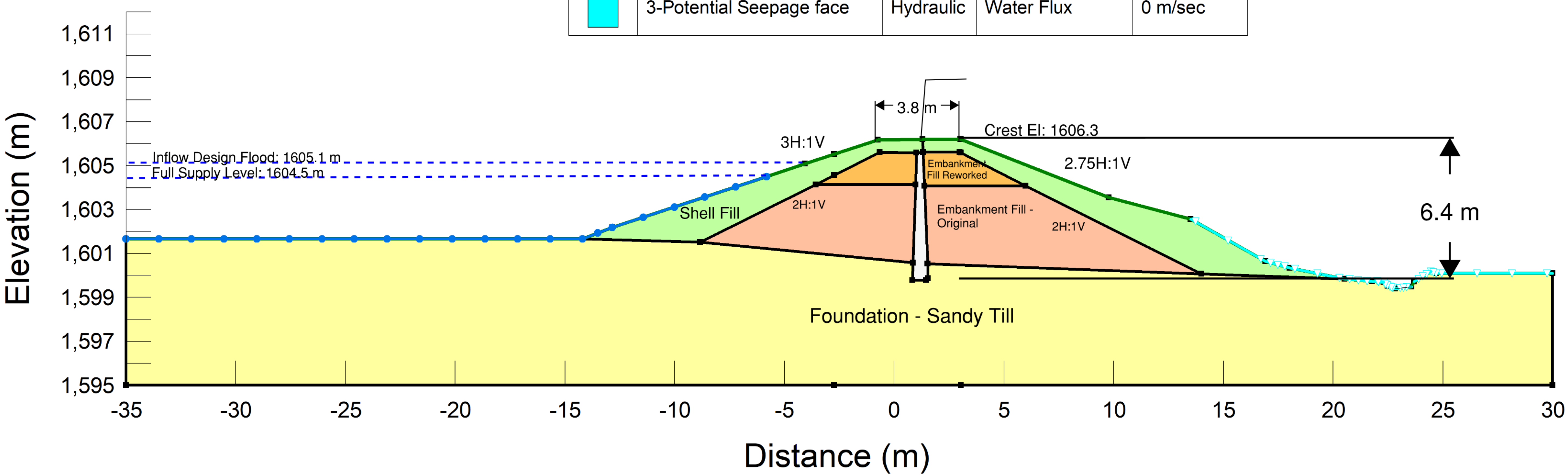
Geological Survey of Canada Open File 7893 Fifth Generation Seismic Hazard Model for Canada: Grid values of mean hazard to be used with the 2015 National Building Code of Canada

See the websites www.EarthquakesCanada.ca and www.nationalcodes.ca for more information

Appendix C
Seepage Analysis Results

Color	Name	Model
	Foundation - Sandy Till	Saturated / Unsaturated
	Sandy Embankment Fill (Original)	Saturated / Unsaturated
	Sandy Embankment Material (Re-worked)	Saturated / Unsaturated
	Shell Fill	Saturated / Unsaturated

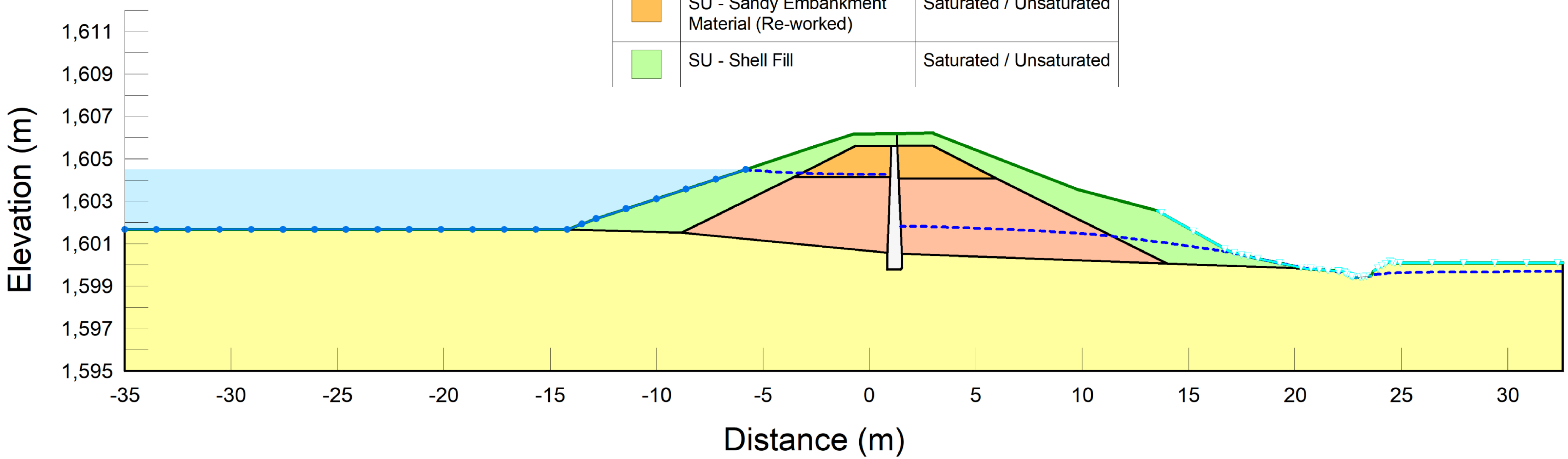
Color	Name	Category	Kind	Parameters
	1- US Head : FSL 1604.5 m	Hydraulic	Water Total Head	1,604.5 m
	3-Potential Seepage face	Hydraulic	Water Flux	0 m/sec



HATCH	Project	Big Meadow Lake Dam – Dam Safety Review	
	Analysis Description	Seepage Analysis – Model Geometry	
	Analysis By T. Tuo	Output	Model Geometry
	Date 11/01/2021	Report No.	H362819

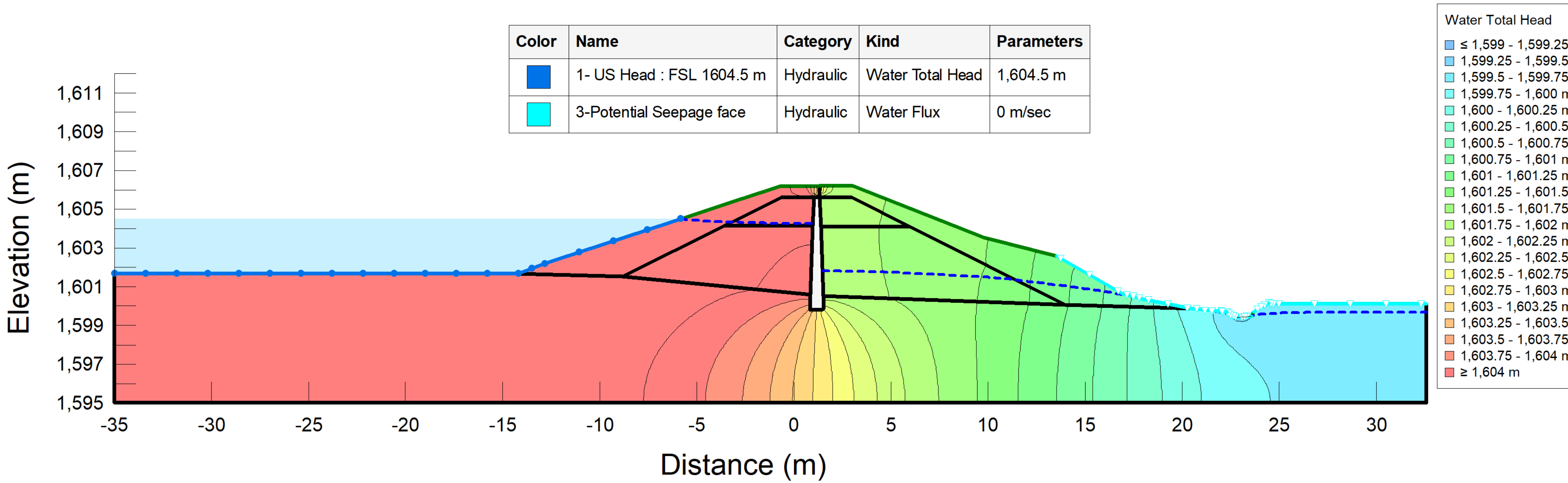
Color	Name	Category	Kind	Parameters
	1- US Head : FSL 1604.5 m	Hydraulic	Water Total Head	1,604.5 m
	3-Potential Seepage face	Hydraulic	Water Flux	0 m/sec

Color	Name	Model
	SU - Foundation - Sandy Till	Saturated / Unsaturated
	SU - Sandy Embankment Fill (Original)	Saturated / Unsaturated
	SU - Sandy Embankment Material (Re-worked)	Saturated / Unsaturated
	SU - Shell Fill	Saturated / Unsaturated



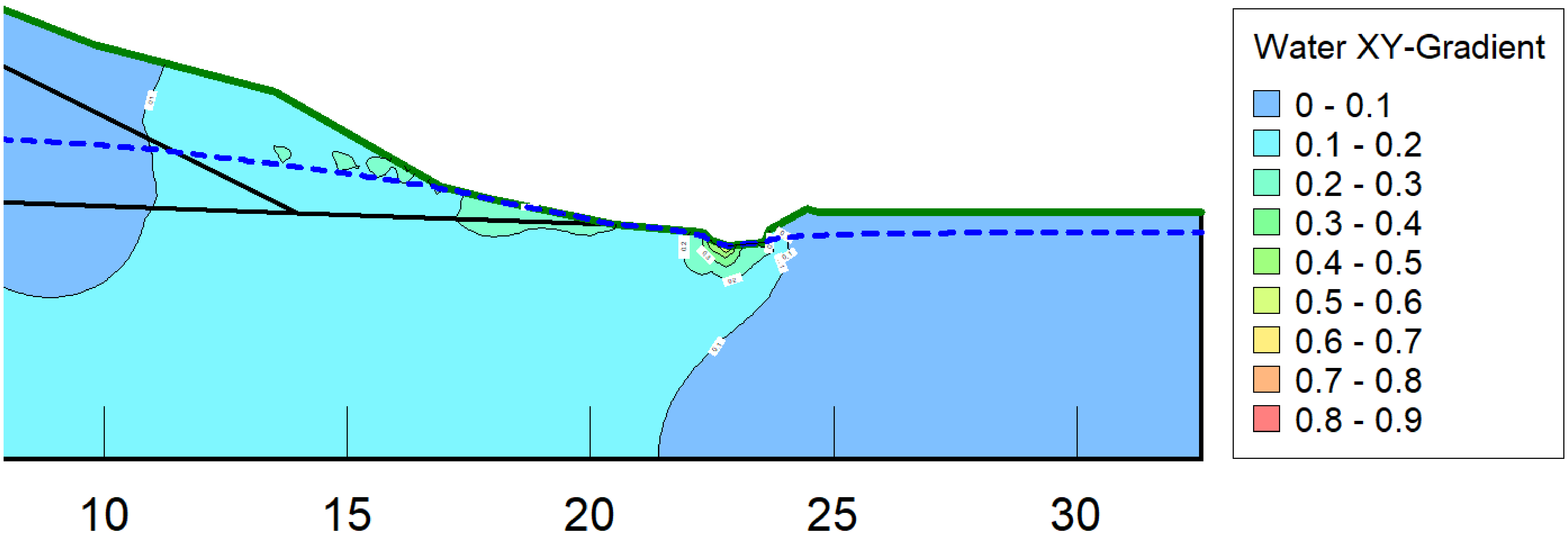
HATCH

Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Seepage Analysis: Steady State Condition – Full Supply Level		
Analysis By	T. Tuo	Output	Steady State Phreatic Surface
Date	11/01/2021	Report No.	H362819



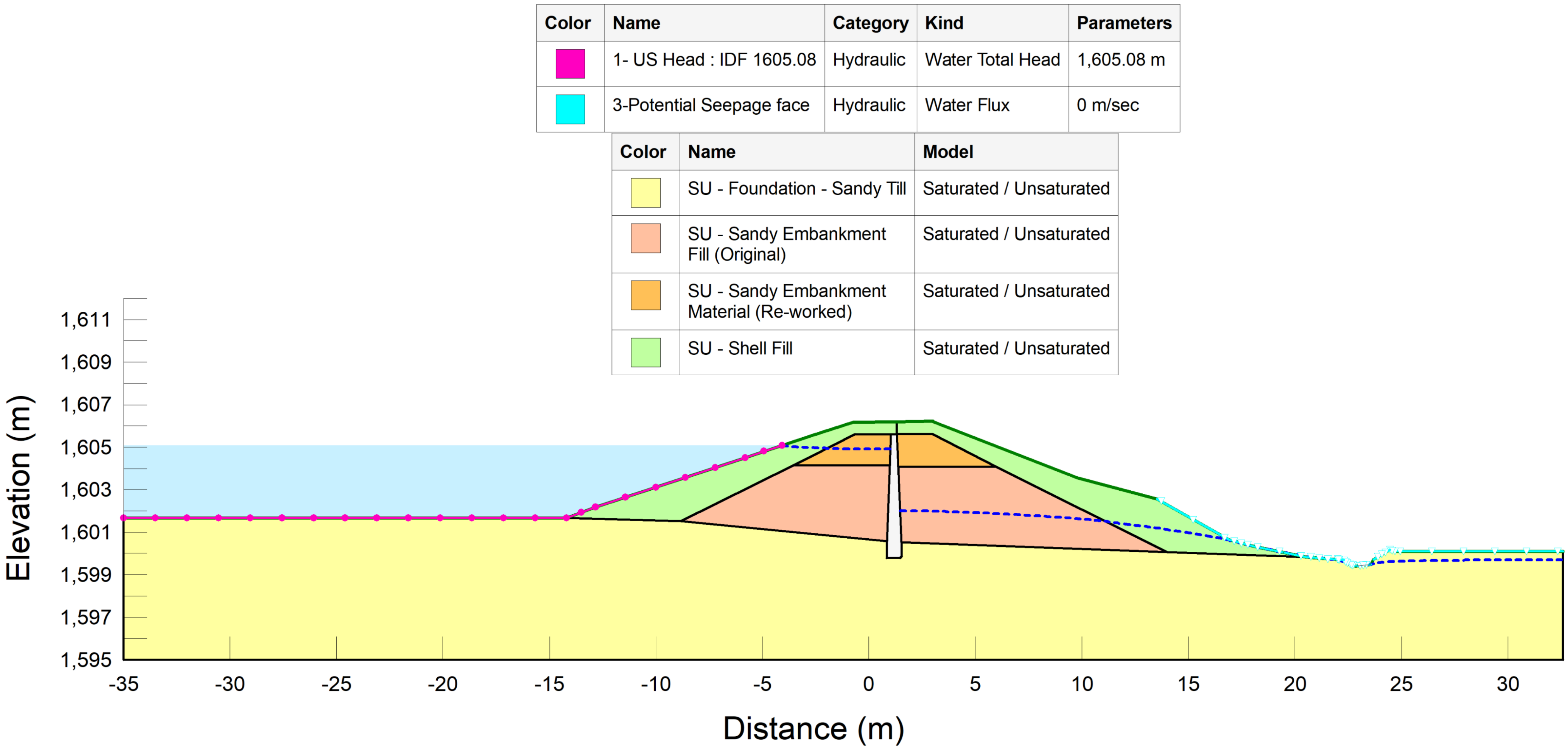
HATCH

Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Seepage Analysis: Steady State Condition – Full Supply Level		
Analysis By	T. Tuo	Output	Water Total Head (m)
Date	11/01/2021	Report No.	H362819

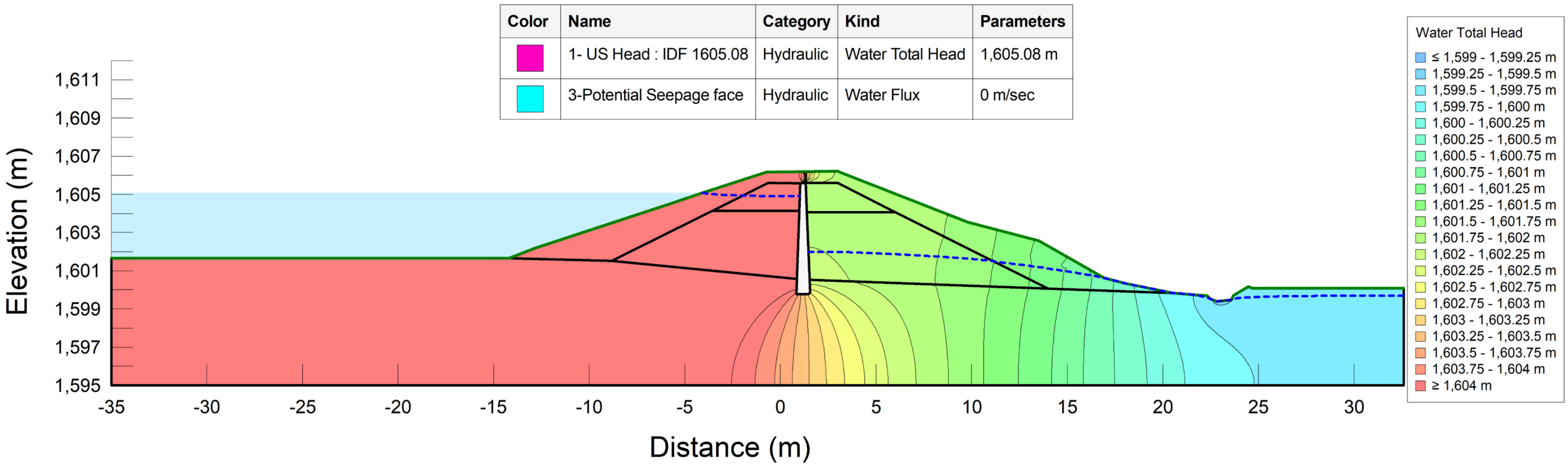


HATCH

Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Seepage Analysis: Steady State Condition – Full Supply Level		
Analysis By	T. Tuo	Output	Toe Exit Gradients
Date	11/01/2021	Report No.	H362819

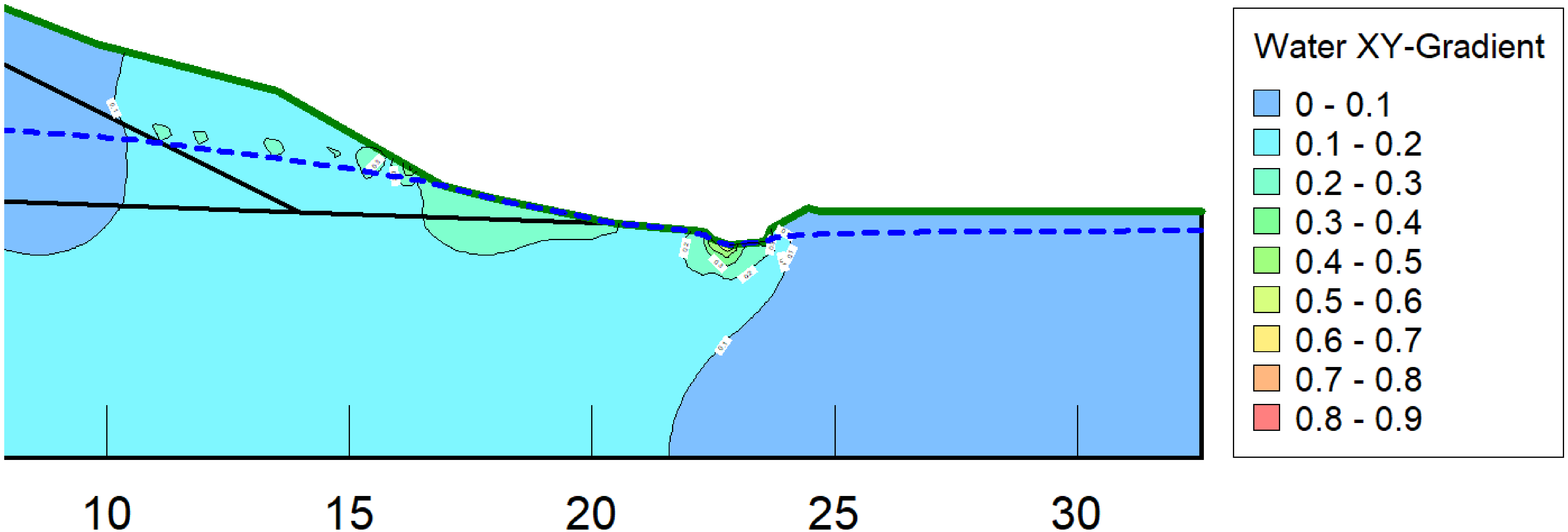


HATCH	Project	Big Meadow Lake Dam – Dam Safety Review	
	Analysis Description	Seepage Analysis: Steady State Condition – Inflow Design Flood	
	Analysis By T. Tuo	Output	Steady State Phreatic Surface
	Date 11/01/2021	Report No.	H362819



HATCH

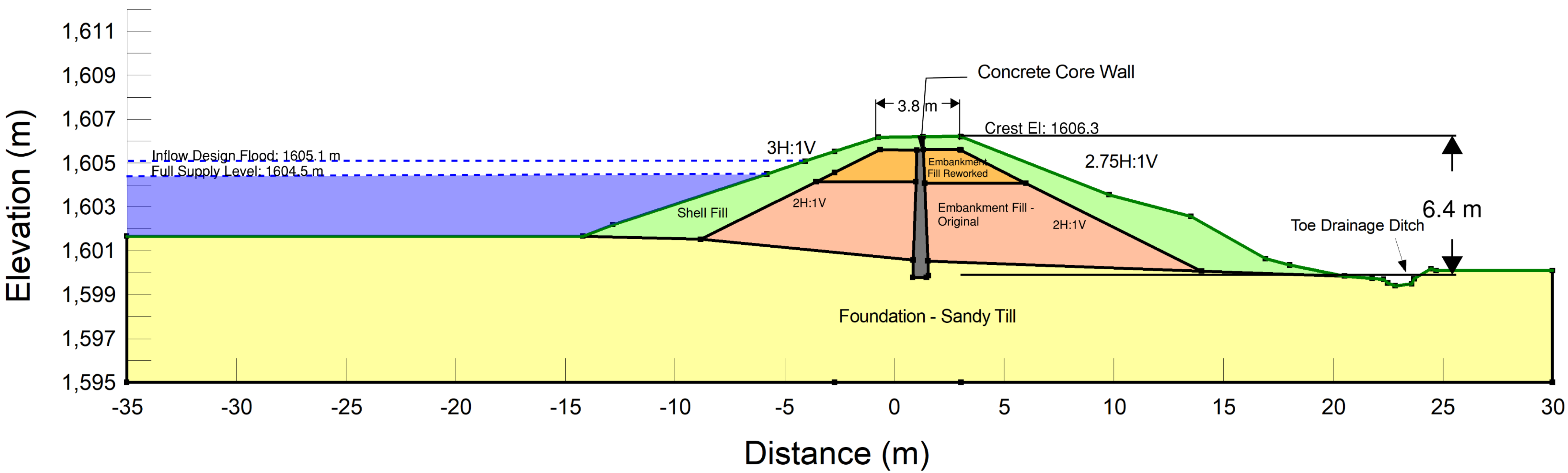
Project	**Big Meadow Lake Dam – Dam Safety Review**		
Analysis Description	**Seepage Analysis: Steady State Condition – Inflow Design Flood**		
Analysis By	T. Tuo	Output	Water Total Head (m)
Date	11/01/2021	Report No.	H362819



Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Seepage Analysis: Steady State Condition – Inflow Design Flood		
Analysis By T. Tuo		Output	Toe Exit Gradients
Date 11/01/2021		Report No.	H362819

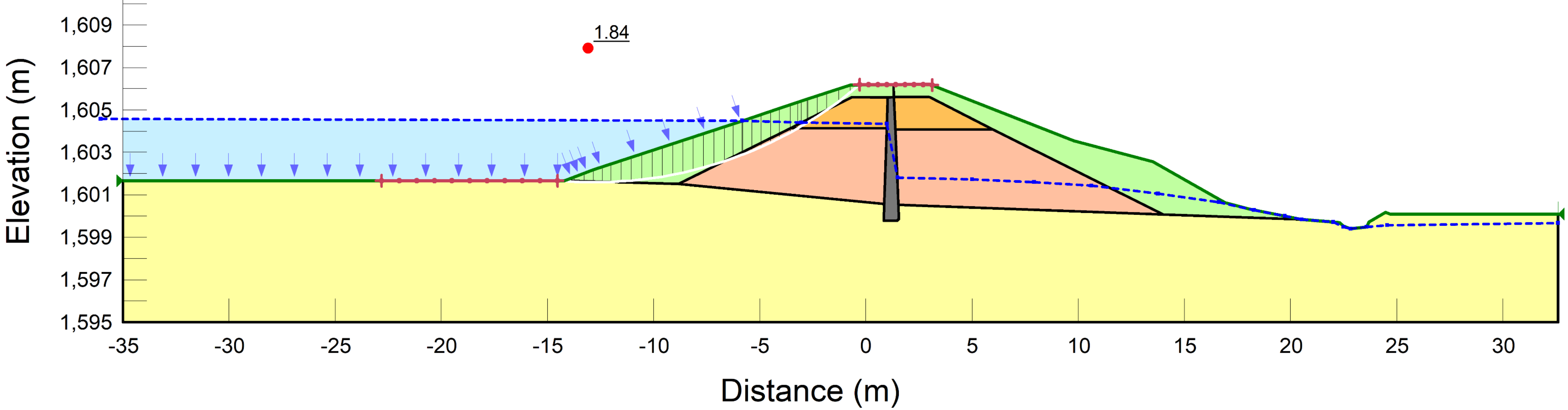
Appendix D
Slope Stability Analysis Results

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
(grey)	Concrete Core Wall	High Strength	22		
(pale yellow)	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
(salmon)	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
(orange)	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
(light green)	Shell Fill	Mohr-Coulomb	20	0	32



HATCH	Project	Big Meadow Lake Dam – Dam Safety Review	
	Analysis Description	Slope Stability Analysis – Model Geometry	
	Analysis By T. Tuo	Output	Model Geometry
	Date 11/01/2021	Report No.	H362819

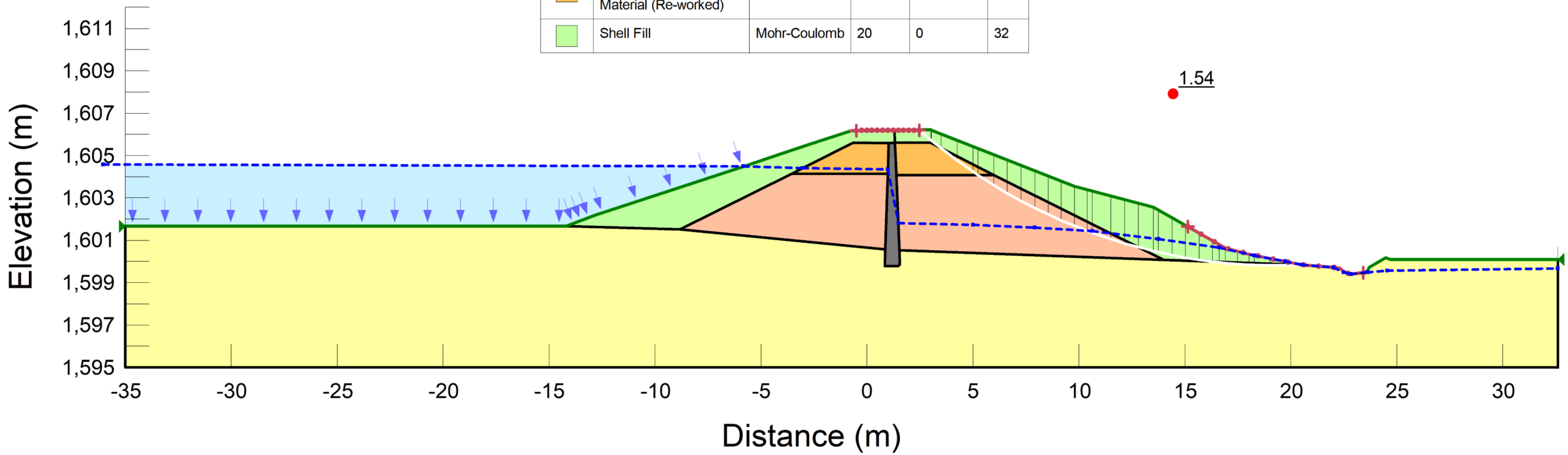
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
Dark grey	Concrete Core Wall	High Strength	22		
Light yellow	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
Peach	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
Orange	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
Light green	Shell Fill	Mohr-Coulomb	20	0	32



HATCH

Project	Big Meadow Lake Dam – Dam Safety Review
Analysis Description	Slope Stability Analysis: LC-1 – Normal Load Condition – Full Supply Level
Analysis By T. Tuo	Slope: Upstream
Date 11/01/2021	Report No. H362819

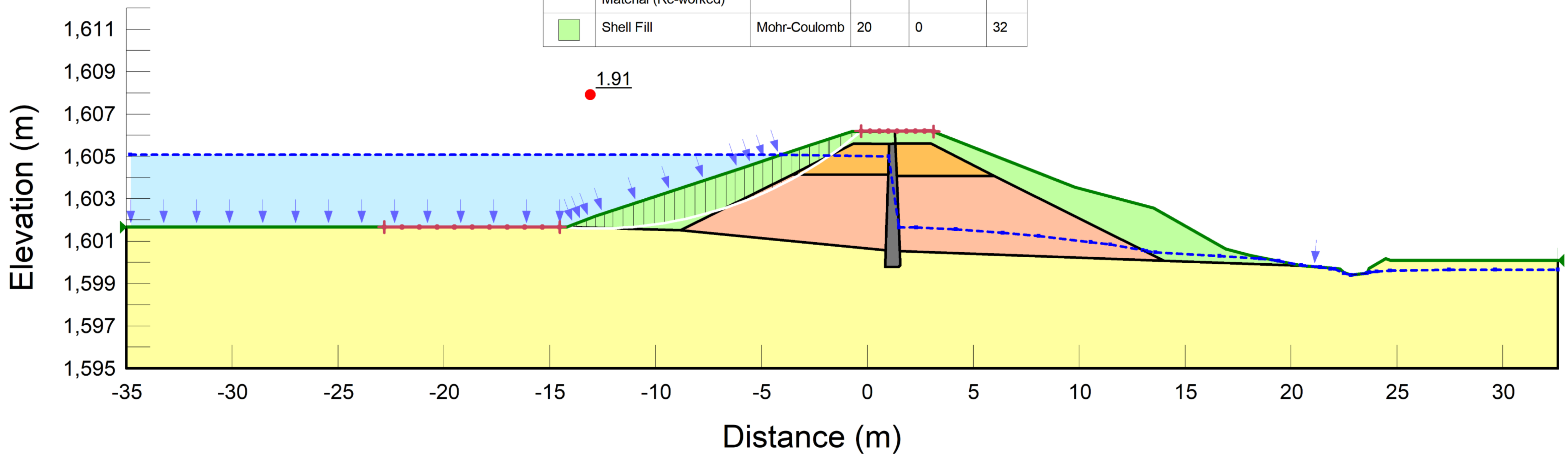
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Concrete Core Wall	High Strength	22		
	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
	Shell Fill	Mohr-Coulomb	20	0	32



HATCH

Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Slope Stability Analysis: LC-1 – Normal Load Condition – Full Supply Level		
Analysis By	T. Tuo	Slope	Downstream
Date	11/01/2021	Report No.	H362819

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
(dark grey)	Concrete Core Wall	High Strength	22		
(yellow)	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
(light orange)	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
(orange)	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
(light green)	Shell Fill	Mohr-Coulomb	20	0	32



HATCH

Project: **Big Meadow Lake Dam – Dam Safety Review**

Analysis Description: **Slope Stability Analysis: LC-2 – Flood Load Condition – Inflow Design Flood**

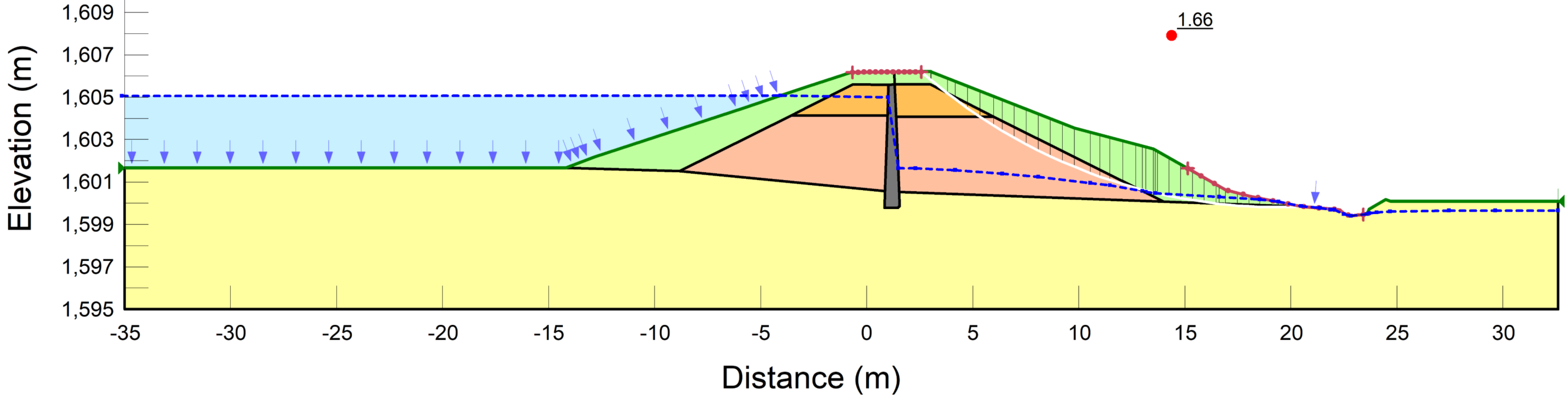
Analysis By: T. Tuo

Slope: Upstream

Date: 11/01/2021

Report No.: H362819

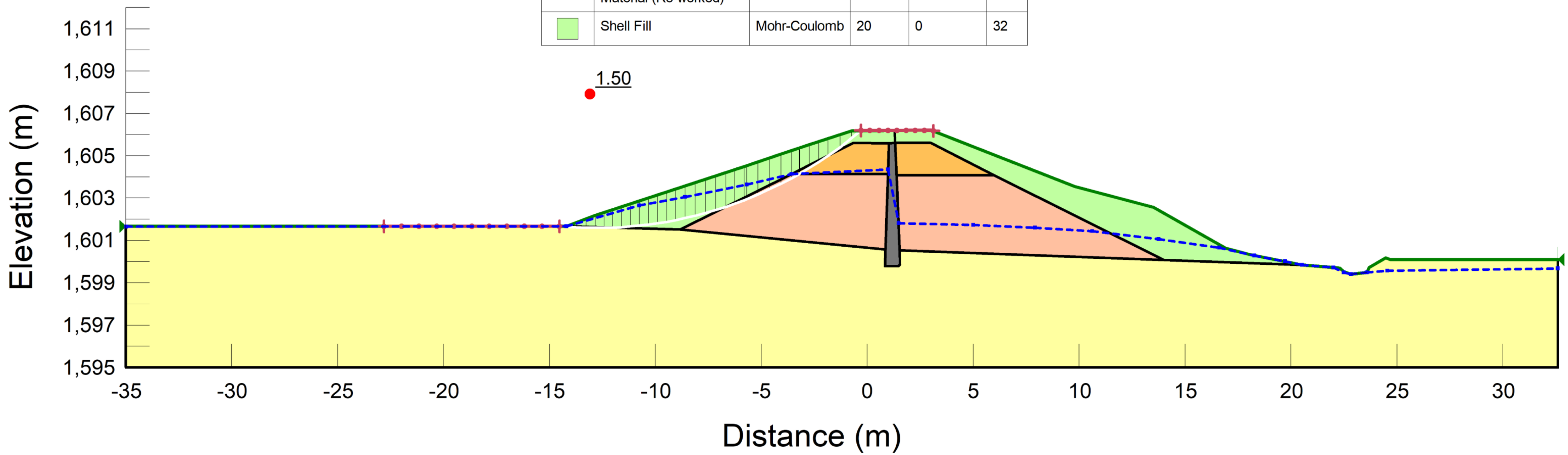
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Concrete Core Wall	High Strength	22		
	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
	Shell Fill	Mohr-Coulomb	20	0	32



HATCH

Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Slope Stability Analysis: LC-2 – Flood Load Condition – Inflow Design Flood		
Analysis By	T. Tuo	Slope	Downstream
Date	11/01/2021	Report No.	H362819

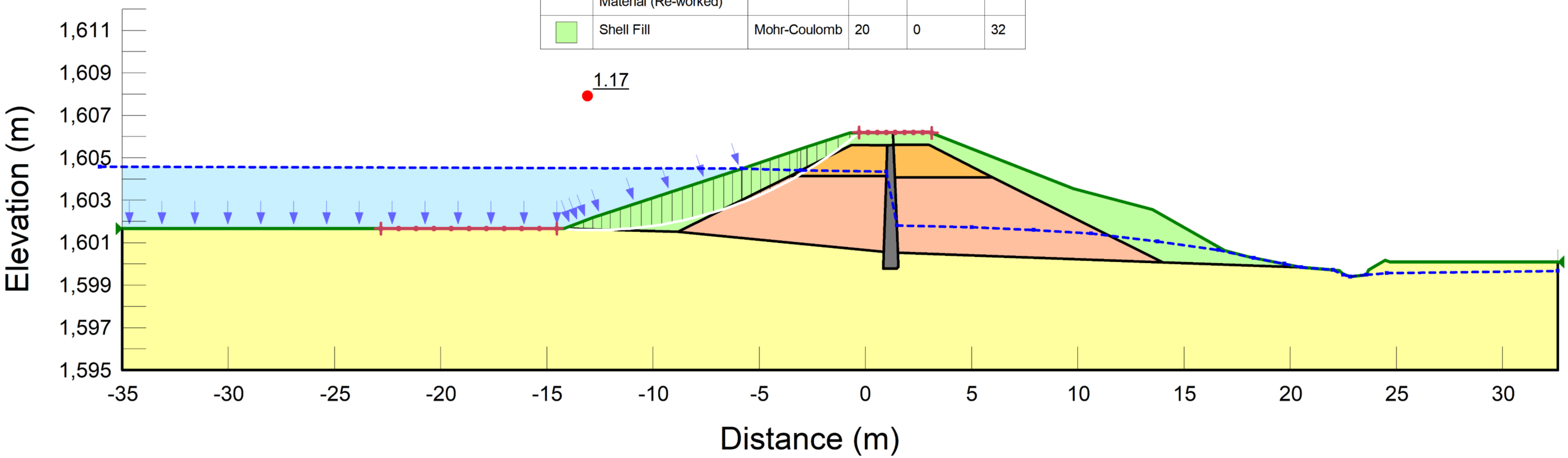
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Concrete Core Wall	High Strength	22		
	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
	Shell Fill	Mohr-Coulomb	20	0	32



HATCH

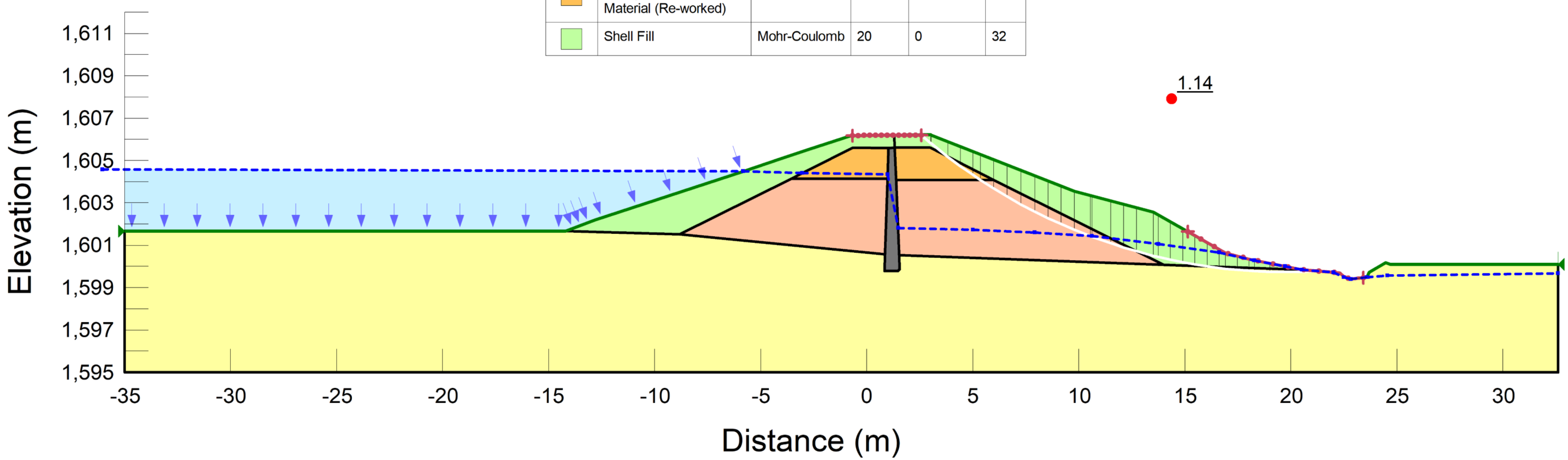
Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Slope Stability Analysis: LC-3 – Rapid Draw Down – From Full Supply Level		
Analysis By	T Singh	Slope	Upstream
Date	11/01/2021	Report No.	H362819

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Concrete Core Wall	High Strength	22		
	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
	Shell Fill	Mohr-Coulomb	20	0	32



HATCH

Project	Big Meadow Lake Dam – Dam Safety Review		
Analysis Description	Slope Stability Analysis: LC-4 – Seismic Condition – Full Supply Level		
Analysis By	T Singh	Slope	Upstream
Date	11/01/2021	Report No.	H362819



Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Concrete Core Wall	High Strength	22		
	Foundation - Sandy Till	Mohr-Coulomb	21	0	37
	Sandy Embankment Fill (Original)	Mohr-Coulomb	19	0	30
	Sandy Embankment Material (Re-worked)	Mohr-Coulomb	19.5	0	35
	Shell Fill	Mohr-Coulomb	20	0	32

HATCH

Project: **Big Meadow Lake Dam – Dam Safety Review**

Analysis Description: **Slope Stability Analysis: LC-4 – Seismic Condition – Full Supply Level**

Analysis By: T. Tuo

Slope: Downstream

Date: 11/01/2021

Report No.: H362819

Appendix E
Dam Safety Review Assurance Statement

Dam Safety Review Assurance Statement

Note: This statement is to be read and completed in conjunction with the current APEGBC Professional Practice Guidelines – Legislated Dam Safety Reviews in British Columbia, ("APEGBC Guidelines") and is to be provided for dam safety review reports for the purposes of the Dam Safety Regulation, BC Reg. 40/2016 as amended. Italicized words are defined in the APEGBC Guidelines.

To: The *Owner(s)* Date: February 25, 2021

Regional District of Okanagan-Similkameen

Name

101 Martin Street, Penticton, BC, V2A 5J9

Address

With reference to the Dam Safety Regulation, B.C. Reg. 40/2016 as amended.

For the dam:

UTM (Location):	Big Meadow Lake Dam:49.6794 North, 119.4652 West
Located at (Description):	Near the headwaters of the Chute Creek catchment, approximately 13 km to the northeast of the Naramata Township.
Name of dam or description:	Big Meadow Lake Dam
Provincial dam number:	Big Meadow Lake Dam:
Dam function:	Maintaining essential creek flows, emergency backup supply of water and supplying irrigation water to agricultural lands
Owned by: (the "Dam")	Regional District of Okanagan-Similkameen

Current Dam classification is:
Check one

- ☐ Low
- ☐ Significant
- ☐ High
- ☑ Very High
- ☐ Extreme

The undersigned hereby gives assurance that he/she is a Qualified Professional Engineer.

I have signed, sealed and dated the attached dam safety review report on the Dam in accordance with the APEGBC Guidelines. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items (see Guideline Section 3.2):

✓ 1. Collected and reviewed available and relevant background information, documentation and data.
✓ 2. Understood the current classification for the Dam, including performance expectations.
✓ 3. Undertaken an initial facility review.
✓ 4. Reviewed and assessed the Dam safety management obligations and procedures.
✓ 5. Reviewed the condition of the Dam, reservoir and relevant upstream and downstream portions of the river.
✓ 6. Interviewed operations and maintenance personnel.
✓ 7. Reviewed available maintenance records, the Operations, Maintenance and Surveillance (OMS) Manual and the Dam Emergency Plan (DEP).
✓ 8. Confirmed proper functioning of flow control equipment.
✓ 9. After the above, reassess the consequence classification, including the identification of required dam safety criteria.
✓ 10. Carried out a dam safety analysis based on the classification in 9. Above.
✓ 11. Evaluated facility performance.
✓ 12. Identified, characterized and determined the severity of deficiencies in the safe operation of the Dam and non-conformances in dam safety management system.
✓ 13. Recommended and prioritized actions to be taken in relation to deficiencies and non-conformances.
✓ 14. Prepared a dam safety review report for submittal to the Regulatory Authority by the Owner and reviewed the report with the Owner.
✓ 15. The dam safety review report has been reviewed in meeting the intent of APEGBC Bylaw 14(b)(2).

Based on my dam safety review, the current dam classification is:
Check one

☑ Appropriate
☐ Should be reviewed and amended

I undertook the following type of dam safety review:

Check one

☐ Audit
☑ Comprehensive
☐ Detailed design-based multi-disciplinary
☐ Comprehensive, detailed design and performance

I hereby give my assurance that, based on the attached dam safety review report, at this point in time:

Check one

☐ The Dam is reasonably safe in that the dam safety review did not reveal any unsafe or unacceptable conditions in relation to the design, construction, maintenance and operation of the Dam as set out in the attached dam safety review report

☐ The Dam is reasonably safe but the dam safety review did reveal non-conformances with the Dam Safety Regulation as set out in section~~(s)~~ ___ of the attached dam safety review report.

☑ The Dam is reasonably safe but the dam safety review did reveal deficiencies and non-conformances as set out in section(s) __12__ of the attached dam safety review report.

☐ The Dam is not safe in that the dam safety review did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ____ of the attached dam safety review report.

Name: David Bonin P.Eng. (Dam Safety/Hydrotechnical)
Shayla Murphy P.Eng. (Hydrotechnical)
Parham Ashayer P.Eng. (Geotechnical)
Amit Pashan P.Eng. (Structural)

Date: February 25, 2021

Signatures: ____________________
____
____
____

Shayla Murphy
Feb. 26, 2021

PROFESSIONAL PROVINCE OF D. V. BONIN # 42966 BRITISH COLUMBIA ENGINEER
2021-02-26

PROFESSIONAL PROVINCE OF S. J. MURPHY # 48322 BRITISH COLUMBIA ENGINEER

PROFESSIONAL PROVINCE OF A. PASHAN # 33146 BRITISH COLUMBIA ENGINEER
2021-02-26

PROFESSIONAL PROVINCE OF P. ASHAYER # 43014 BRITISH COLUMBIA ENGINEER
2021-02-26

Address: 1066 W Hastings St., Suite 400,
Vancouver, BC, V6E 3X2

Telephone: (604) 689-5767

(Affix Professional Seals here)

If the Qualified Professional Engineer is a member of a firm, complete the following:

I am a member of the firm Hatch Ltd.
(Print name of firm)
and I sign this letter on behalf of the firm.