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REPORT ON

Inventory and Assessment of Dams in Newfoundland and Labrador Year Two

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REPORT

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Executive Summary

In recent years, many Provincial Governments throughout Canada have been placing a larger emphasis on dam safety in an attempt to limit, and ideally eliminate, the occurrence of dam failures and the risk they can pose to people, infrastructure, and the environment. The Department of Municipal Affairs and Environment, Water Resources Management Division of the Government of Newfoundland and Labrador has continued their initiative to strengthen the province's Dam Safety Program by further updating the provincial dam inventory registry and database with the second year of their Inventory and Assessment of Dams in Newfoundland and Labrador project. Golder assisted with this by providing the Government with a comprehensive and accurate catalogue of all dams within the province. This will help the Government develop the necessary tools to ensure the effective regulation of the province's dams. Golder was retained by the Water Resources Management Division to complete this inventory update for the western and Labrador portions of the province and has provided this report to summarize the process taken, its findings, and recommendations to the Government.

The project was executed in several phases as discussed in detail in this report. The first and largest phase involved verifying that the records presently in the database were current and accurate. This meant contacting every dam owner in the region and requesting that they provide up to date information through the use of a dam inventory form. The information received was then compared with the information in the database and the necessary updates were made. In total, out of the three hundred seventy-seven (377) dams that information was requested for, Golder received updated information for two hundred eighty-two (282) dams from the dam owners. In addition to the forms received, informal notifications (emails) were also received by other owners indicating that eleven (11) dams no longer existed (although only three (3) of these dams were confirmed by the WRMD to be removed from the database). This equates to a 78% response rate on a per dam basis. A total of ninety-five (95) owners were contacted and responses were received from seventy-three (73) of them, whether this was by way of a dam inventory form, indication that a dam no longer existed, or update information provided via email. This equates to a 77% response rate on a per owner basis.

The second phase was similar to the first and involved identifying any new dams not already in the database for the entire province. When receiving responses from dam owners it would sometimes happen that they indicated they owned more dams than just the ones on record for them in the database. Dams were also identified from a KMZ file of potential dams provided by the WRMD. When a new dam was identified, the dam owner was contacted and asked to complete a dam inventory form. In total, twenty-eight (28) new dams were added to the inventory. Of these new dams, indication was provided by the owner for seven (7) of them (25%), by the Water Resources Management Division for five (5) of them (18%), twelve (12) were identified and confirmed from the KMZ file (43%), and four (4) were discovered from the Hidden Newfoundland website (14%). Once indication of these dams was received, information requests were sent to the respective owners. Information was received for fifteen (15) of the new dams, or 54% of them. The new dams for which information was not received for had only their name and owner (if known) added to the database. The owner was unable to be determined for seven (7) of these new dams.

The third phase required collecting any dam breach inundation mapping that had been completed for any dams in the province and digitizing them to a GIS layer. The vast majority of dams in the province do not have any dam breach inundation mapping completed; inundation mapping was only obtained for thirty-two (32) systems/developments, encompassing sixty-eight (68) dam inventory database entries. This is only about 10% of the six hundred ninety-six (696) dams in the inventory (considering additions and subtractions of new and no longer existing dams as of the conclusion of this project). Twenty (20) inundation maps, encompassing twenty-one (21) dams, were provided as hardcopies by the WRMD and were digitized to a GIS layer during this project, as shown in Table 1. An additional five (5) previously digitized maps were also provided by the WRMD at the beginning of the project. The remaining thirty-seven (37) maps are known to exist, but were not obtained during the project.

The fourth phase was to complete risk assessments for all dams in the Western and Labrador regions which had dam safety reviews or other dam safety related documents available. Documents were received for twenty-seven (27) developments, containing a total of one hundred sixty-six (166) dams, and a Dam Owner Annual Dam Safety Report form was completed for each. These forms helped to assign a risk level for each dam. Thirty-three (33) of the dams were assigned a risk level of 1 – Alert (20%), sixty-three (63) were assigned a risk level of 2 – Caution (38%), thirty-seven (37) were assigned a risk level of 3 – Stable (22%), twenty-four (24) were assigned a risk level of 4 – No Concerns (15%), and nine (9) were assigned a risk level of 5 – Effectual (5%).

The fifth phase was to complete consequence assessments on dams that had inundation maps digitized throughout the project. These maps were used in conjunction with the most recent orthorectified imagery along with Google Street View to complete the consequence assessment for the areas identified as being at risk of flooding if one of the dams were to breach. In the areas that fell within dam breach flood inundation zones, the infrastructure likely to be affected was tallied to quantify the potential damage and cost associated with a dam breach, and to determine a likely population that would be at risk of being affected in some way by the flooding. Once infrastructure was counted, a dollar value was assigned that represented the likely cost of repairing the infrastructure to its pre-flood conditions. In some cases, the replacement costs were used. The information collected was summarized into a separate table for each potential dam breach, and the assumed costs were totalled to get a lump sum cost estimate for all the repairs. Because the values for repair costs are highly variable, the total value was translated into an order of magnitude cost assumption that represented the expected cost of damage resulting from a dam breach. The infrastructure costs from a dam breach ranged from millions of dollars to hundreds of millions of dollars. The population at risk in the flood zone was estimated by assuming an average of three (3) persons per household and multiplying by the number of homes affected. The population at risk from a dam breach ranged from zero (0) to four thousand eight hundred ninety-six (4896). A total of twenty-five (25) consequence assessments were completed.

The sixth phase involved creating a prioritized list of dams within the High, Very High, and Extreme classifications that do not currently have dam failure inundation mapping, but which should have it developed. Six (6) priority levels were created and dams were assigned to each. No dams were assigned the highest priority of 1, twelve (12) dams were assigned a priority of 2, sixty-six (66) dams were assigned a priority of 3, nine (9) dams were assigned a priority of 4, fourteen (14) dams were assigned a priority of 5, and twenty-three (23) dams were assigned a priority of 6. This phase also involved identifying methodologies for the derivation of dam break flood inundation mapping. Four (4) different methodologies with varying complexity were identified and were used to predict the downstream effects of a breach in the Deep Bank Dam, which is located in Deer Lake, NL:

- Photo-based topographic mapping method (simplest method, highly conservative);
- SMPDBK modelling (simplified);
- Unsteady, two-dimensional modelling (advanced); and,
- Steady state, one-dimensional modelling (Intermediate).

The seventh phase of the project was to take all of the information gathered in the previous phases and physically update the Government dam registry and database. In total, two hundred eighty-two (282) of the dams already in the database were updated and seven (7) dams were removed. This means that 77% of the three hundred seventy-seven (377) Western and Labrador dams already in the database, prior to the start of this project, were either updated or removed based on information provided by the owners. Pictures were obtained for two hundred ninety-five (295) dams in the Western and Labrador regions, but were only added to one hundred eighty-six (186) dam entries because some of the pictures provided by the WRMD were already included in the Dam Inventory Database. After these additions, there are ninety-six (96) dams in these regions which do not have any pictures attached to their dam inventory entries (including new dams that were added to the database during this project). This means that 76% of the dams in the Western and Labrador regions currently have pictures in the Dam Inventory Database.

This report presents the results of the various surveys and includes recommendations to the Water Resources Management Division on how the dam inventory form, Dam Owner Annual Dam Safety Report form, and Dam Inventory Database can be improved upon. The nature of these recommendations varies, but they were all developed from Golder's experience in using these tools throughout the project. The recommendations mainly focus on the ease of a dam owner to understand the form they are being asked to complete and on the ease of making edits to the Dam Inventory Database.

As previously stated, dam safety is taking on more importance and has become a significant focus for many provinces in Canada. This is very important to ensure that dams are being operated safely and efficiently. Adopting guidelines such as those of the Canadian Dam Association as a dam safety management best practice will help ensure dam owners that their dams are being designed and operated in a safe and effective manner and will significantly limit the risk to people, infrastructure, and the environment. However, there is still much work to be done to raise awareness on dam safety in our province. Currently only about 10% of the dams have inundation mapping, which is an extremely important aspect of a dam safety program. This must increase to better classify dams and to ensure that appropriate emergency preparedness and response plans are in place.

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by the Department of Municipal Affairs and Environment, Water Resources Management Division (WRMD) to conduct an inventory and assessment of all the dams in western Newfoundland (west of the Town of Badger) and Labrador. The purpose of the project was to help strengthen the province's dam safety program by updating the provincial Dam Inventory Database. Having a comprehensive and accurate database will assist Government in developing the necessary regulatory tools to manage dam failure risks in the province. The main objectives of the study included the following:

- Verify information in the current Dam Inventory Database;
- Compile missing information for the existing records;
- Identify new dams and create records for each;
- Digitize the available dam break flood inundation mapping for dams in the entire province;
- Conduct a risk assessment on dams with existing Dam Safety Reviews and/or Dam Safety Inspections;
- Assess the consequences of a potential dam failure for those dams in the province having available dam break flood inundation mapping;
- Identify dams within the entire province where dam break flood inundation mapping should be developed; and,
- Identify methodologies and best practices for the derivation of dam break flood inundation mapping.

This is the second of three phases currently planned. Phase 1 of the project, which covered the dams in the eastern region of the province was completed in 2016 (Golder 2017). The current study began in February 2017 and consisted of compiling available data, requesting information from dam owners, creating records of previously unidentified dams, and verifying and updating the existing information contained within the database. Once these tasks were initiated, the information obtained was used to complete the following: conduct risk assessments on each of the dams where dam safety documents were available, digitize the inundation mapping provided and create a GIS layer for each set of mapping, and complete a consequence assessment for those dams that had the digitized inundation mapping. Lastly, a prioritized list was developed based on Canadian Dam Association (CDA) consequence classifications of dams within the entire province to identify which dams should have flood inundation studies completed, along with four (4) methodologies for the derivation of dam break flood inundation mapping. Each of these tasks are described in further detail in the following sections.

2.0 VERIFICATION AND COMPLETION OF EXISTING RECORDS

This phase of the project consisted of contacting dam owners, compiling received and available information, and verifying and updating existing Dam Inventory Database records. It should be noted that, in general, the accuracy of the information provided by the dam owners was not verified. The only verification that was completed by Golder was with respect to the information provided by each owner and how it compared to the entries in the database.

This phase was the most time-consuming portion of the project. Tasks within this phase were being completed for the majority of the project duration. The starting point was taking the inventory given to Golder by the WRMD and reviewing each entry to verify that the contact information provided was current. To do this, the phone number for the dam owner on file was called and a request was made for an updated email address, phone number, and fax number. Through this action, it was found that most of the contact information listed in the inventory was current and correct, but there were a number of listings with no contact information given, phone numbers that were out of service, or wrong phone numbers. For these cases, a Google search of the owner was completed, Government listings of municipalities and local service districts were checked, and the WRMD was consulted. Most of the remaining contact information was collected by following this process. It is also important to mention that when the owners were contacted by phone they were informed that Golder was calling them in reference to the Government of Newfoundland's Dam Inventory Project and that they would be receiving a brief letter from Golder requesting information on a dam that was listed under their ownership. Within the entire Western and Labrador regions only one (1) dam owner was unable to be contacted; the Aquatic Centre for Research & Education (ACRE) who own dam #899 Hatchery Brook Dam. It should be noted that there is no indication that this organization still exists, and after speaking with several people in western Newfoundland an official owner was not able to be determined.

Once the contact information was gathered, letters were drafted to each owner indicating what information was being requested from them for this project. Attached to Golder's letter was an additional letter to dam owners provided by the WRMD, a map indicating the dams in each region, and the dam inventory form that they were asked to complete and return to Golder. The letter also presented the option for the owner to participate in a conference call with Golder to assist in completing their dam inventory form(s). These letters were sent to the owners via email, or in some cases by fax if the owner did not have an email address. In an attempt to receive the replies in a timely manner, a target date of two (2) weeks from the date the letter was sent was given as the deadline date for the owners to provide their responses. If there was no communication back from the owner within approximately two (2) weeks of the letter being sent, a follow-up phone call was made. If after the follow-up call there was still no reply from the owner, then a further follow-up email was sent.

Of the three hundred seventy-seven (377) dams in the inventory from the Western and Labrador regions as of the start of this project, Golder received updated information for two hundred eighty-two (282) dams, and notification from owners that eleven (11) dams did not exist. Three (3) of these dams were confirmed by the WRMD to be removed from the inventory, the remainder were kept in the inventory until the WRMD could confirm from a site visit that they do not exist. In addition to these, four (4) other dam entries were removed from the inventory based on instruction from the WRMD. These were due to various reasons such as being duplicate or blanket entries, for example. A list of the seven (7) dams that were removed from the database can be seen in **Appendix A**.

At the start of the project there were a total of ninety-five (95) dam owners in the Western and Labrador regions. This number assumes Deer Lake Power and Corner Brook Pulp and Paper Ltd. as one owner; Nalcor Energy, NL Hydro, and Star Lake Hydro Partnership as one owner; and Vale Newfoundland and Labrador Ltd. and Voisey's Bay Nickel Company Ltd. as one owner because for each of these groups a single person/company provided all information for dams listed as being owned by either company within the group. This number ignores the Sir Wilfred Grenfell Society as an owner because this society was listed as owning two (2) dams, but these dams were later discovered to now be owned by the Towns of Cartwright and St. Anthony. It also ignores Richmont Mines as an owner because the dam listed under their ownership was found to be a duplicate entry of a NL Hydro dam; as well as the Town of Great Harbour Deep as an owner because the dam listed under their ownership now belongs to the Department of Transportation and Works. Of the ninety-five (95) dam owners with dams in the database, twenty-two (22) did not provide any response to Golder.

Golder also received one (1) dam inventory form for a dam in the Eastern region. One of these was for dam #742 Water Pond Dam; which was previously listed in the database as Young's Pond Dam, but was updated accordingly.

Along with the dam inventory forms, documentation such as Dam Safety Reviews (DSRs), Dam Safety Inspections (DSIs), Emergency Preparedness Plans (EPPs), Operations, Maintenance and Surveillance (OMS) manuals, construction and design reports, pictures, drawings, and maps were received for various dams. All information received was filed electronically and any hardcopies received were kept as well. The forms received from the owners were first compared with the existing entries in the database to identify any new or updated information, as well as any discrepancies. If any discrepancies were found, the owner was contacted to confirm the correct information. The dam inventory forms received were used to update the WRMD's Dam Inventory Database. To help complete this task, a binder was created that contained an updated dam inventory form for the applicable dams. All the new and updated information on each form was highlighted to flag any updates to be made in the database. This made for a more efficient process when updating the database.

3.0 IDENTIFICATION OF NEW DAMS

This phase of the project included identification of new dams in Newfoundland and Labrador that are not currently in the Dam Inventory Database, based on information provided by the WRMD or from current dam owners about other dams under their ownership that were not previously listed in the database.

At the start of the project Golder was provided with a KMZ file from the WRMD that included the locations of thirty-five (35) dams that the provincial government had identified as potentially existing based on the study of aerial photos and federal dam inventory documents. The first portion of this phase involved analyzing the location of each unverified dam in the KMZ file to determine the closest town or organization that could potentially own the dam or have some information about it. For each of the thirty-five (35) dams listed, an email or phone number was identified for the potential owner, and each was contacted in a similar manner to the previous phase of the project. In cases where an email address was found, an email was sent that provided information about the project, and to help determine if there was a dam in the location identified and if an official owner could be identified by this contact person. Where phone numbers were found, the number was called and the same information was requested. Of the thirty-five (35) dams in the KMZ file, Golder received twenty-six (26) responses either indicating that a dam did or did not exist in the location, or that the contact person was unable to verify the existence of a dam. For eight (8) of the dams listed a contact person could not be found, and one (1) dam was found to already exist within the Eastern region of the dam inventory as part of the Port Union Hydroelectric Generating Facility.

Of the twenty-six (26) responses, six (6) contact persons were unable to confirm the presence of a dam, therefore these dams were left as unconfirmed in the KMZ file. Nine (9) responses indicated that dams do not exist at the locations in question, however after discussing with the WRMD it was decided that four (4) of these should remain as unconfirmed until a site visit could be made, and the other five (5) could be confirmed as not existing. The remaining eleven (11) responses confirmed that a dam did exist at the location in question. Two (2) of these responses indicated that more than one dam existed in the location identified, including five (5) total dams in the Twin Falls area of Labrador and three (3) total dams in the Town of Port au Choix in western Newfoundland. This resulted in a total of seventeen (17) confirmed existing dams.

Although it was indicated that seventeen (17) dams do exist, the WRMD decided that five (5) of these dams should remain as unconfirmed until a site visit can be completed. The remaining twelve (12) dams were added to the inventory, six (6) of which had information available that was compiled into a form, as done in the previous phase. In cases where the contact persons did not have any information regarding the dams, the dams were still added to the inventory, but the only information entered was the dam name, its location, and in some cases the project name and owner information. Of all the dams that a response was received for, a total of fifteen (15) dams were left as unconfirmed.

Based on the updated KMZ file, there were forty-one (41) potential new dams in question, including the additional Twin Falls and Port au Choix dams. One (1) dam was already in the inventory, twelve (12) new dams were added to the inventory, twenty-three (23) were left as unconfirmed, and five (5) were confirmed as not existing. A summary table of information regarding the dams in the KMZ file can be found in **Appendix B**. The original KMZ file was updated with the collected information and returned to the WRMD.

The second portion of this phase involved identifying and creating records for new dams that were identified via current dam owners during phone calls and/or emails as described in Section 2.0; or through additional information provided by the WRMD, such as dams listed on the **Hidden Newfoundland** website. Sixteen (16) additional dams were identified through these correspondences. For these new dams, nine (9) dam inventory forms were completed, while the remaining seven (7) either did not have any information available, or did not receive forms back from the owners. Once again, in these cases the dams were still added to the inventory, but the only information entered was the dam name, its location, and in some cases the project name and owner information.

In total, through this phase twenty-eight (28) previously unidentified dams were discovered and added to the Dam Inventory Database. Golder was unable to determine the owner of seven (7) of these new dams: the Twin Falls Dams TF-1 to TF-5 located west of Churchill Falls, identified from the KMZ file; the Western Bay Waterfall Swimming Area Dam identified from the **Hidden Newfoundland** website; and the Peach Dam found near the abandoned Whalesback Copper Mine site. A summary table of all newly identified dams that were added to the database can be found in **Appendix C**. Similar to the previous phase, all information received was filed electronically and hardcopies of forms, reports, pictures, drawings, etc., received were kept as well.

4.0 DAM FAILURE INUNDATION MAPPING

This phase involved identifying dams within the entire province of Newfoundland and Labrador for which dam break flood inundation mapping has been developed. Inundation studies are known to exist for a total of sixty-three (63) dams throughout thirty-two (32) systems/developments and seven (7) dam owners. This includes mapping of three cascade failures as well. Twenty (20) inundation maps, encompassing twenty-one (21) dams, were provided as hardcopies by the WRMD and were digitized to a GIS layer during this project, as shown in Table 1. An additional five (5) previously digitized maps were also provided by the WRMD at the beginning of the project. The remaining thirty-seven (37) maps are known to exist, but were not obtained during the project.

Table 1: Digitized Inundation Maps for the Year 2 Dam Inventory Assessment

Dam System / Development	Dam Owner	Dam Name & Index Number	Hardcopies Obtained?	GIS Layer Created?
Deer Lake Hydroelectric Generating Station	Deer Lake Power	Main Dam at Grand Lake (#1)	Yes	Yes
Corner Brook Pulp and Paper Limited	Corner Brook Pulp and Paper Limited	Glynmill Pond Dam (#608)	Yes	Yes
		Glynmill Pond Dam (#608) / Three Mile Pond Dam (#629)	Yes	Yes
		Glynmill Pond Dam (#608) / Corner Brook Lake Dam (Twelve Mile Lake Dam) (#628) / Three Mile Pond Dam (#629)	Yes	Yes
Churchill Falls Hydroelectric Development - Orma Lake	Nalcor Energy - Churchill Falls	GR-2 (#1142)	Yes	Yes
		GR-8 (#1148)	Yes	Yes
		GR-9 (#1149)	Yes	Yes
		GR-10 (#1150)	Yes	Yes
Bay d'Espoir Hydroelectric Generating Facility - Long Pond	Newfoundland and Labrador Hydro	LD-1 (Power Canal Embankment) (#46)	Yes	Yes
		LD-2 (North West Cutoff Dam) (#47)	Yes	Yes
		LD-3 (South East Cutoff Dam) (#48)	Yes	Yes
		LD-4 (South West Cutoff Dam) (#49)	Yes	Yes
Snooks Arm and Venams Bight	Newfoundland and Labrador Hydro	SV-1 (Snooks Arm Main Dam) (#77)	Yes	Yes
Star Lake Hydroelectric Generating Station	Newfoundland and Labrador Hydro	Star Lake Main Dam (#9)	Yes	Yes
New Chelsea-Pitman's Pond (NCH / PIT) Hydroelectric Generating Facility	Newfoundland Power Inc.	Seal Cove Pond Dam (NCH Forebay Dam) (#194)	Yes	Yes
		Pitman's Pond Dam (#195)	Yes	Yes
Pierre's Brook Hydroelectric Generating Facility	Newfoundland Power Inc.	Gull Pond Dam (PBK Forebay Dam) (#94) / Big Country Pond Dam (#96)	Yes	Yes
		West Country Pond Dam (#100)	Yes	Yes
Port Union Hydroelectric Generating Facility	Newfoundland Power Inc.	Long Pond Dam (#212)	Yes	Yes
Rose Blanche Brook Hydroelectric Generating Facility	Newfoundland Power Inc.	Rose Blanche Forebay Dam (#240)	Yes	Yes

It should be noted that although it is stated above that the identified inundation mapping includes sixty-three (63) dams, this incorporates sixty-eight (68) Dam Inventory Database entries. This is because some dams are split up into multiple entries in the database. For example, the Muskrat Falls Dam is split up into six (6) entries, but in terms of the inundation mapping they are all lumped together as one dam. The same is true with the inundation maps for the Horse Chops Dam and the Bishop's Falls Dam, which are comprised of two (2) Dam Inventory Database entries each. Also of note is that for three (3) Newfoundland Power owned developments it is known that dam break flood inundation mapping exists, but the specific dams modelled within each are unknown because copies of the mapping were not available. A summary table outlining all dams/developments known to have dam break flood inundation mapping is presented in **Appendix D**.

With almost seven hundred (700) dams in the Dam Inventory Database, only sixty-four (64), or less than 10%, are known to have dam break flood inundation mapping completed. Inundation mapping plays a major role in assigning a consequence classification to a dam, which in turn determines the design requirements of a dam in accordance with CDA guidelines. Ideally, some level of inundation mapping should be completed for every single dam in order to determine an accurate dam classification, although in some very specific cases the inundation zone may be assessed qualitatively. As such, efforts should be made to ensure that inundation studies are being carried out by all dam owners.

5.0 DAM RISK ASSESSMENTS

Risk assessments were completed for each dam where DSRs, DSIs, or other dam safety related documents were available with enough detail to complete an assessment. For each dam with this information, the Dam Owner Annual Dam Safety Report form provided by the WRMD was completed. This form addresses the elements of a dam safety management program that are in place for each dam, the physical condition of the dam, the probability of occurrence of a potential dam failure, and the overall risk level of the dam based on its CDA Dam Classification and the failure probability rating. A copy of the Dam Owner Annual Dam Safety Report has been included in **Appendix E**. Using the Dam Owner Annual Dam Safety Report form and the various reports that were provided to Golder, a preliminary assessment of several of the dams contained within the Western and Labrador regions of the Dam Inventory Database has been completed. In total, there were forty-nine (49) dam safety related documents used to complete risk assessments for one hundred and sixty-six (166) dams. A breakdown of the assessment results is shown in Table 2.

Table 2: Risk Assessment Results Breakdown

Risk Level	# of Dams	Percentage
1 – Very High (Alert)	33	20
2 – High (Caution)	63	38
3 – Moderate (Stable)	37	22
4 – Low (No Concerns)	24	15
5 – Very Low (Effectual)	9	5

There were serval new additions and/or changes made by the WRMD to the Dam Owner Annual Dam Safety Report compared to the previous year's assessment document. One of the most notable changes was that a new bullet was added under the Failure Probability Rating for "Likely" which states "Non-conformance with established dam safety requirements, procedures, systems and instructions". Throughout the review, it was found that most, if not all of the dams assessed, could be considered as having a non-conformance with established dam safety requirements. This could be not having a DSR completed, not having a CDA classification or not having any sort of justifiable CDA classification assessment completed, not having a stability analysis or freeboard analysis completed, or not having the required factor of safety met for a particular analysis, etc. Indicating that a dam had a non-conformance automatically made the failure probability “Likely” as per the general guidelines for allocating failure probability ratings given in the Dam Owner Annual Dam Safety Report. Recognizing that it could be clearly demonstrated that at least one non-conformance existed for most of the dams in the inventory, some professional judgment was exercised when completing the risk assessments, otherwise all dams with a classification of Significant or higher would have been ranked as either Caution (considerable work to do) or Alert (immediate action required). A particular example of the type of judgement exercised when completing the risk assessments is with respect to the requirements to complete a hazard identification and failure modes analysis and to also meet the required factor of safety for the particular analysis completed. For example, if no effort was made by a dam owner to complete a hazard identification and failure modes analysis of any kind, then it was deemed a non-conformance. However, if a hazard identification and failure modes analysis was completed, such as a stability analysis using the design loads, then the owner was given credit for having completed a hazard identification and failure modes analysis, even though other relevant hazards and failure modes may not have been considered. Also, if the factor of safety obtained from the analysis did not meet with the recommendations of the CDA then this was not necessarily considered a non-conformance, unless the factor of safety was grossly deficient or below unity. For example, if the factor of safety was marginal with respect to the required factor of safety then the dam was assigned a Failure Probability Rating of “Probable” based on the guideline statement that “an unacceptable dam deficiency has been confirmed based on CDA guidelines or observed deficiencies that could potentially lead to a dam failure”. It should also be mentioned that a hazard identification and failure modes analyses can be a very intensive and robust process, it involves the identification of hazards and failure modes, as well as assessing the adequacy of risk controls. For the purpose of the risk assessment the very basic requirements of a hazard identification and failure modes analysis were evaluated to determine compliance.

It is important to note that the risk assessments were completed based on information provided by each dam owner as part of this project as well as the information that the WRMD has on file. For example, it is known that some dam owners do actively monitor and complete regular maintenance on their dams. However, without the proper documentation on file and supplied as evidence, the burden of proof has not been met and therefore questions such as “inspection frequency adequate” and “maintenance suitable” where marked off as No on the risk assessment forms.

One final point worth mentioning is that the original methodology that was used to develop the Dam Owner Annual Dam Safety Report provides a provision where the person completing the risk assessment can either upgrade or downgrade the risk level at their discretion. In a few cases this has been done and in those cases additional justification has been provided. For example, if a dam had more than one non-conformance or considerable deficiencies the risk level may have been upgraded to bring attention to the lack of information and deficiencies; such as no CDA classification combined with a lack of failure modes analyses, etc.

6.0 DAM FAILURE CONSEQUENCE ASSESSMENTS

The twenty (20) inundation maps that were digitized throughout the project, and the five (5) previously digitized maps provided by WRMD were used in conjunction with the most recent orthorectified imagery to complete a consequence assessment for the areas identified as being at risk of flooding if one of the dams were to breach. Orthorectified imagery was obtained from the Department of Fisheries and Land Resources, Fish and Wildlife

Enforcement Division (FWED), and was loaded into ArcGIS and overlaid by the digitized inundation layers to see which areas would fall within the flood zones. In any areas where orthorectified imagery wasn't available (Labrador only), community mapping files were obtained from the FWED and used along with the most recently available aerial imagery from Google and Bing maps. Where available, Google Street View was used to determine exactly what each of the buildings in the flood zone were; providing a more accurate assessment.

As discussed in Section 4.0, inundation mapping is known to exist for sixty-three (63) dams in the province. However, not all of these maps were able to be obtained and therefore could not be used to complete a consequence assessment. These dams are as follows:

- #355 Deep Bank Dam – Deer Lake Hydroelectric Generating Station
- #357 West Bank Dam – Deer Lake Hydroelectric Generating Station
- #411 Forebay Dam and Spillway – Deer Lake Hydroelectric Generating Station
- #6 Grand Falls Main Dam – Grand Falls Hydroelectric Generating Station
- #1193 Dam 1 – Buchans Mine Closure
- #682 Dam 4 – Buchans Mine Closure
- #1208 Northwest Dam – Consolidated Rambler Mine (OAM)
- #1201 Gullbridge Tailings Dam – Gullbridge Copper Mine (OAM)
- #392 Main Pine Pond Dam – Hope Brook Gold Mine (OAM)
- #568 New Pine Pond Dam and Spillway and Saddle Dam A – Hope Brook Gold Mine (OAM)
- #569 Main Tailings Pond Dam – Hope Brook Gold Mine (OAM)
- #571 Heap Leach Dam – Hope Brook Gold Mine (OAM)
- #572 Polishing Pond Dam – Hope Brook Gold Mine (OAM)
- #573 Saddle Dam B – Hope Brook Gold Mine (OAM)
- #574 Saddle Dam 1 – Hope Brook Gold Mine (OAM)
- #575 Saddle Dam 2– Hope Brook Gold Mine (OAM)
- #576 Saddle Dam 3– Hope Brook Gold Mine (OAM)
- #740 Minworth Tailings Dam – Minworth Fluorspar Mine (OAM)
- #574 Whalesback Copper Mine Dam – Whalesback Copper Mine (OAM)
- #17 Bishop's Falls Ambursen Dam / #214 Bishop's Falls Earth Dam – Bishop's Falls Hydroelectric Generating Station
- #139 Cape Broyle Forebay Dam – Cape Broyle / Horse Chops (CAB / HCP) Hydroelectric Generating Facility

- #141 Cape Broyle Intake Dam – Cape Broyle / Horse Chops (CAB / HCP) Hydroelectric Generating Facility
- #144 Horse Chops East Dam / #145 Horse Chops West Dam – Cape Broyle / Horse Chops (CAB / HCP) Hydroelectric Generating Facility
- #146 Mount Carmel Pond Dam – Cape Broyle / Horse Chops (CAB / HCP) Hydroelectric Generating Facility
- #229 Sandy Brook Forebay Dam – Sandy Brook Hydroelectric Generating Facility
- #1048 GL-1 – Churchill Falls Hydroelectric Development
- #1076 GL-13 – Churchill Falls Hydroelectric Development
- #1081 GL-18 – Churchill Falls Hydroelectric Development
- #1114 GF-9 – Churchill Falls Hydroelectric Development
- #1115 FF-10A – Churchill Falls Hydroelectric Development
- #1119 FF-12 – Churchill Falls Hydroelectric Development
- #1131 GJ-11A – Churchill Falls Hydroelectric Development
- #1138 GJ-18 – Churchill Falls Hydroelectric Development
- #1162 Ossok Dam 1 – Churchill Falls Hydroelectric Development
- #1176 Gabbro West – Churchill Falls Hydroelectric Development
- Unknown Dam – Petty Harbour Hydroelectric Generating Facility
- Unknown Dam – Seal Cove Hydroelectric Generating Facility
- Unknown Dam – Topsail Hydroelectric Generating Facility

Note: Three (3) dams are unknown. For these dams, it is only known that a dam at the given development has had inundation mapping completed, but not which specific dam.

The full list of dams with inundation mapping known to be completed, along with details of if hardcopies were obtained and if a GIS layer has been created or not, can be seen in **Appendix D**.

The consequence assessments were completed using the worst-case conditions available for each dam, i.e. the digitized inundation layer that shows the largest extent of flooding and in some cases includes the baseline flooding associated with the event leading up to the dam breach. The specific flooding conditions used in each analysis are outlined further in the summary tables provided in the following subsections. In the areas that fell within dam breach flood inundation zones, the infrastructure likely to be affected was tallied to quantify the potential damage and cost associated with a dam breach, and to determine a likely population that would be at risk of being affected in some way by the flooding. The types of infrastructure that were tallied included, but were not limited to, homes, commercial and municipal buildings, recreational areas, roads, transmission lines, bridges, culverts, pipelines, and various other structures that would be likely to sustain damage from flood water. Once infrastructure was counted, research was completed to assign a dollar value that represented the likely cost of repairing the infrastructure to its pre-flood conditions. The information collected was summarized into a separate table for each potential dam breach, and the assumed costs were totalled to get a lump sum cost estimate for all the repairs. Because the values for repair costs are highly variable, the total value was translated into an order of magnitude cost assumption that represented the expected cost of damage resulting from a dam breach. It should be noted that economic losses were extracted from available studies, some dating back to the 1990s. For the current study, an update of these costs has not been performed considering inflation and changes in the land use. In other words, the present values of these costs may be higher than indicated.

In order to determine the population at risk in the flood zone, an average of three (3) persons per household was used to multiply by the number of homes affected. The following general assumptions and limitations were taken into account to reach a finalized consequence assessment:

- In many cases, depth and velocity of flood waters resulting from a breach were not known and therefore could not be factored into the cost of repairing infrastructure.
- Assigned dollar values did not include economic losses associated with the loss of revenue for a company or business whose facilities would be temporarily closed during repairs, or flights that would be cancelled as a result of flooding of an airport and its runway, e.g., loss of tourism, etc.
- The amount of inventory a business may have in their facility was not included in the overall damage repair cost. For example, the value of the cars that may be for sale on a car dealership’s parking lot, or computers that may be damaged in an office building.
- It is likely that some of the structures counted as homes are cabins that only host seasonal, temporary populations, meaning the population at risk estimate may be conservative in some cases.
- The cost assigned for flood repair damages for a particular property only included the costs of the home, with no consideration of additional infrastructure such as a shed in the backyard or a wharf at waterfront properties.
- Commercial infrastructure was assigned to either a large building or small building category. Smaller buildings were those that are similar in size to an average home (e.g., convenience stores or small churches) and therefore would incur a similar cost for damage repair, but would not have a permanent population at risk. Large infrastructure included buildings such as office buildings, warehouses, etc., and had a larger dollar estimate for damage repair. In general, the repair cost of large commercial buildings was assumed to be double that of the small commercial buildings, except for buildings that are several magnitudes larger, such as schools or airports, which were assigned their own repair costs.
- The replacement of the entire section of roadway in the flood zone was not assumed in the cost estimate as it was considered unlikely that a flood would cause all roads to completely wash out. Instead, only areas where the flood water would cross the road perpendicularly were assumed to wash out. In general, the areas of road that were assumed to wash out conveyed water through a culvert or under a bridge, therefore the cost of replacing the culvert or bridge was included along with the associated roadwork.
- The cost value for repairing or replacing most road infrastructure was assigned based on past contracts awarded for similar work in Newfoundland and Labrador, found on the Government of Newfoundland and Labrador’s website, under past awarded contracts, major capital projects documents, or Job Creation Partnerships (JCP) listings. Several costs were looked at for each type of road repair, and an average cost was assumed that was thought to encompass the general road repair work that would need to take place to

repair flood damage. For example, because it would be very difficult to estimate the size of a culvert that would wash out, an average cost for a culvert replacement was assumed based on previous awarded contracts found on the Department of Transportation and Works website.

- Where possible, bridges were categorized by type and assigned a cost per metre that was assigned based on whether they were a concrete, metal, or wooden structure. Those bridges on main roadways were assumed to be concrete, whereas those on smaller access roads were either metal or wooden. The length of the bridges were measured in ArcGIS, and a cost per metre was assigned. The cost assigned was determined based on an average of past government contracts awarded.
- Any infrastructure costs values that were based on past government work (tender documents, major capital projects, JCPs, etc.) are assumed to include the cost of materials, equipment, and labour.
- General debris cleanup in municipalities was not considered in the consequence assessments.
- In the case of hydropower dams, it was assumed that the dam itself would fail and need to undergo major repairs. A cost value was generally assigned based on the kW potential of the hydropower development, and includes the cost of replacing the dam itself, as well as all associated infrastructure such as penstocks, electrical and mechanical equipment, powerhouses, etc. In these cases, this associated infrastructure was not included in other sections of the infrastructure assessment to avoid counting any major infrastructure twice. For example, if the powerhouse for a hydropower dam was in its inundation zone, the building itself was not included in the small or large commercial building tally, as its repair costs are assumed in the repair cost of the dam. In cases where the kW potential was unable to be determined, a different cost assumption was used based on the dam type, such as concrete gravity or earthfill, and its dimensions. It should be recognized that the costs to the dam owner are generally not included as part of the consequence assessment, we have included the owners cost in each analyses as line items and they can be easily subtracted from the total cost if required.
- In order to encompass the worst case conditions, additional dams downstream from the breached dam were assumed to experience cascading failure. If the inundation zone for the breach of the downstream dam was known, all inundation zones were combined to complete an additional consequence assessment of the cascading failure.

Any other assumptions or limitations encountered that were specific to one dam breach are explained in the subsequent sections, along with the tables showing the detailed breakdown of how the consequence assessment was completed for each of the inundation zones. References for the assigned costs are included.

While completing the consequence assessments for each area, Table 3, prepared by Hatch (2011), was used as a secondary check to try and verify the order of magnitude for the total estimated cost of damages that was calculated for each failure scenario. The table relates the CDA dam classification to the economic damages that can be expected as a result of a dam breach. In general, it was found that the consequence assessments completed fit within the guidelines of Table 3, however in some cases, particularly when looking at the “Low” classification dams, the estimated economic losses were more than the estimated $100,000 limit. The higher estimates may indicate that the consequence assessments completed are over-conservative, or that the CDA class assigned to the dam may need to be reviewed to determine if it should be classified as a higher risk structure.

Table 3: Dam Classes and Associated Economic Losses (Hatch, 2011)

CDA Dam Class	Economic Damages ($)
“EXTREME”	>100 million
“VERY HIGH”	>10 million
“HIGH”	>1 million
“SIGNIFICANT”	>$100,000
“LOW”	<$100,000

It should be noted that determining the environmental and cultural losses were not included in the scope of work for this task, however such losses must also be accounted for during a consequence assessment.

The following sections discuss the consequence assessments for twenty five (25) of the dams.

6.1 Rose Blanche Forebay Dam

Inundation maps showing the flood zone resulting from a breach in the Rose Blanche Forebay Dam indicate that the maximum water level during PMF conditions would be up to eight (8) metres in topographically constricted areas. As a result, it was assumed that any infrastructure in the inundation zone could not be repaired and would instead need to be fully replaced.

No homes are located in the inundation zone, therefore there is no permanent population at risk. One building located near the Rose Blanche Brook Dam, which is owned by the town, is in the inundation zone. This is assumed to be a municipal building related to the dam, and was assigned a cost similar to that of a home in the town of Rose Blanche. Given the large volume of water that would travel downstream as a result of the breach, it was also assumed that the Rose Blanche Brook Dam, located close to the outlet of Rose Blanche Brook to the ocean, would also fail and need replacement. The cost of replacing the dam was included in the consequence assessment, however no inundation mapping for the town dam itself exists, so any effects its failure would have downstream could not be included in the consequence assessment.

The following table summarizes all infrastructure in the inundation zone and an estimated cost value for its replacement. The estimated cost of inundation would be in the range of tens of millions of Canadian Dollars (CAD).

Table 4: Rose Blanche Forebay Dam Consequence Assessment

Background Information						
Dam Name:			Rose Blanche Forebay Dam			
Project Name:			Rose Blanche Brook Hydroelectric Development			
Dam Owner:			Newfoundland Power Inc.			
Inventory Number:			240			
Assumed Breach Conditions:			Extreme Flood Dam Failure			
Downstream Communities:			Rose Blanche			
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Small Commercial Buildings	1	building	$ 40,000.00	$ 40,000.00		RE/MAX, 2017

Rose Blanche Forebay Dam	6000	kW capacity	$ 675.00	$ 4,050,000.00		IRENA, 2012
Rose Blanche Brook Dam (#901)	50	metre	$ 75,000.00	$ 3,750,000.00	Concrete Gravity Dam	Nalcor Energy, 2016
Wooden Bridge	20	metre	$ 6,000.00	$ 120,000.00		GPA, 2015a
Wooden Bridge	50	metre	$ 6,000.00	$ 300,000.00		GPA, 2015a
Concrete Bridge	30	metre	$ 98,000.00	$ 2,940,000.00		GPA, 2016b
Culverts	2	culvert	$ 60,000.00	$ 120,000.00		GPA, 2016a
Pipeline	896	metre	$ 350.00	$ 313,600.00		Town of Baie Verte, 2011
Estimated Total Loss ($)					**$ 11,633,600.00**	
Estimated Order of Magnitude of Losses					**Tens of Millions**	
Permanent Population at Risk					**0**	

6.2 Cascading Failure: Corner Brook Lake Dam, Three Mile Pond Dam, Glynmill Pond Dam

The following sections pertaining to the Corner Brook Lake Dam, Three Mile Pond Dam, and Glynmill Pond Dam show that there are no persons at risk should there be a breach in one of the three dams. It should be noted that the population at risk estimate is based on permanent population, i.e. residents who have homes in the area of inundation. In Corner Brook, the area that would be inundated does not have any residential buildings within it, and therefore no permanent population at risk. However, there would be a relatively large temporary population at risk as the area expected to flood is the downtown core, which includes a commercial business park, shopping mall, and the Kruger Paper Mill. Attempting to quantify the temporary population at risk was not carried out as the high level of uncertainty would likely lead to an inaccurate estimate.

Inundation mapping for the dam breach showed that flood water in the major infrastructure areas (downtown core) being approximately three (3) metres, and no flood water velocities were provided. It was assumed that any buildings affected by flooding would sustain damages and not need to be fully replaced, however any bridges or culverts in the flood path were assumed to sustain damages that would render them structurally unsound, requiring replacement. The total estimated cost of damages was in the range of hundreds of millions CAD.

Table 5: Corner Brook Lake Dam Consequence Assessment

Background Information	
Dam Name:	Corner Brook Lake Dam (Twelve Mile Lake Dam), Three Mile Pond Dam, Glynmill Pond Dam (Cascading Failure of Three Mile Pond and Glynmill Pond Dams)
Project Name:	Corner Brook Pulp and Paper Limited
Dam Owner:	Corner Brook Pulp and Paper Limited
Inventory Number:	628, 629, 608
Assumed Breach Conditions:	Probable Maximum Flood breach of Corner Brook Lake Dam with cascading failure of Three Mile Pond Dam and Glynmill Pond Dam
Communities Downstream:	Corner Brook

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Small Commercial Buildings	10	building	$ 16,000.00	$ 160,000.00		Aviva Canada, 2015
Large Commercial Buildings	28	building	$ 32,000.00	$ 896,000.00		Aviva Canada, 2015
Millbrook Mall	1	entire mall	$ 1,500,000.00	$ 1,500,000.00		Mansfield, 2017
Kruger Paper Mill	1	entire site	$ 110,000,000.00	$ 110,000,000.00		Connors, 2014
Water Treatment Plant	1	entire plant	$ 28,200,000.00	$ 28,200,000.00		City of Corner Brook, 2013
Corner Brook Lake Dam	250	metre	$ 2,000.00	$ 500,000.00	Earthfill Dam	Delcan, 2011
Three Mile Pond Dam	9200	kW capacity	$ 675.00	$ 6,210,000.00	9.2 MW hydro development for Watson's Pond industrial park	IRENA, 2012
Bowater Park Dam	1	dam	$ 20,000,000.00	$ 20,000,000.00		Nalcor Energy, 2016
Glynmill Pond Dam	250	kW capacity	$ 675.00	$ 168,750.00		Eaton, 1997
Skate Park	1	entire park	$ 3,500.00	$ 3,500.00		Wells, 2008
Bowater Park Infrastructure	1	entire park	$ 400,000.00	$ 400,000.00		Atlantic Canada Opportunities Agency, 2009
Water Pipeline	734	metre	$ 350.00	$ 256,900.00		Town of Baie Verte, 2011

Background Information						
Culverts	1	culvert	$ 60,000.00	$ 60,000.00		GPA, 2016b
Metal Bridge	35	metre	$ 45,000.00	$ 1,575,000.00		GPA, 2015c
Concrete Bridge	22	metre	$ 98,000.00	$ 2,156,000.00		GPA, 2016b
Concrete Bridge	15	metre	$ 98,000.00	$ 1,470,000.00		GPA, 2016b
Wooden Bridge	10	metre	$ 6,000.00	$ 60,000.00		GPA, 2015a
Wooden Bridge	10	metre	$ 6,000.00	$ 60,000.00		GPA, 2015a
Wooden Bridge	25	metre	$ 6,000.00	$ 150,000.00		GPA, 2015a
Concrete Bridge	10	metre	$ 98,000.00	$ 980,000.00		GPA, 2016b
Metal Bridge	35	metre	$ 45,000.00	$ 1,575,000.00		GPA, 2015c
Metal Bridge	25	metre	$ 45,000.00	$ 1,125,000.00		GPA, 2015c
Wooden Bridge	20	metre	$ 6,000.00	$ 120,000.00		GPA, 2015a
Concrete Bridge	35	metre	$ 98,000.00	$ 3,430,000.00		GPA, 2016b
Concrete Bridge	25	metre	$ 98,000.00	$ 2,450,000.00		GPA, 2016b
Concrete Bridge	25	metre	$ 98,000.00	$ 2,450,000.00		GPA, 2016b
3MP Dam Pump house	1	pump house	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2016
Bowater Park Pump house	1	pump house	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2016
Estimated Total Loss ($)				**$ 186,006,150.00**		
Estimated Order of Magnitude of Losses				**Hundreds of Millions**		
Permanent Population at Risk				**0**		

6.3 Cascading Failure: Three Mile Pond Dam, Glynmill Pond Dam

A breach in the Three Mile Pond Dam followed by the cascading failure of the Glynmill Pond Dam would create flood inundation depths of approximately one (1) to three (3) metres. It was assumed that most infrastructure would require repairs and not replacement, with the exception of bridges and culverts. As previously explained, there is no permanent population living in the area, however a temporary population would be affected by the floodwater but was not quantified for this project. The total estimated cost of damages is in the order of tens of millions CAD.

Table 6: Three Mile Pond Dam Consequence Assessment

Background Information	
Dam Name:	Three Mile Pond Dam, Glynmill Pond Dam (Cascading Failure of Glynmill Pond Dam)
Project Name:	Corner Brook Pulp and Paper Limited
Dam Owner:	Corner Brook Pulp and Paper Limited
Inventory Number:	629, 608
Assumed Breach Conditions:	Fair weather breach of Three Mile Pond Dam with cascading failure of Glynmill Pond Dam
Communities Downstream:	Corner Brook

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Small Commercial Buildings	8	building	$ 16,000.00	$ 128,000.00		Aviva Canada, 2015
Large Commercial Buildings	17	building	$ 32,000.00	$ 544,000.00		Aviva Canada, 2015
Kruger Paper Mill	1	entire site	$ 22,000,000.00	$ 22,000,000.00	Approx. 1/5 the amount inundated as CB lake breach	Connors, 2014
Three Mile Pond Dam	9200	kW capacity	$ 675.00	$ 6,210,000.00	9.2 MW hydro for Watson pond industrial park	IRENA, 2012
Bowater Park Dam	1	dam	$ 20,000,000.00	$ 20,000,000.00		Nalcor Energy, 2016
Glynmill Pond Dam	250	kW capacity	$ 675.00	$ 168,750.00		Eaton, 1997
Skate Park Commercial Street	1	entire park	$ 3,500.00	$ 3,500.00		Wells, 2008
Bowater Park Infrastructure	1	entire park	$ 400,000.00	$ 400,000.00		Atlantic Canada Opportunities Agency, 2009
Water Pipeline	690	metre	$ 350.00	$ 241,500.00		Town of Baie Verte, 2011
Wooden Bridge	10	metre	$ 6,000.00	$ 60,000.00		GPA, 2015a
Wooden Bridge	10	metre	$ 6,000.00	$ 60,000.00		GPA, 2015a
Wooden Bridge	25	metre	$ 6,000.00	$ 150,000.00		GPA, 2015a

Concrete Bridge	10	metre	$ 98,000.00	$ 980,000.00		GPA, 2016b
Metal Bridge	35	metre	$ 45,000.00	$ 1,575,000.00		GPA, 2015c
Metal Bridge	25	metre	$ 45,000.00	$ 1,125,000.00		GPA, 2015c
Wooden Bridge	20	metre	$ 6,000.00	$ 120,000.00		GPA, 2015a
Concrete Bridge	35	metre	$ 98,000.00	$ 3,430,000.00		GPA, 2016b
Concrete Bridge	25	metre	$ 98,000.00	$ 2,450,000.00		GPA, 2016b
Concrete Bridge	25	metre	$ 98,000.00	$ 2,450,000.00		GPA, 2016b
Three Mile Pond Dam pump house	1	pump	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2016
Pump house Bowater park	1	house	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2016
Estimated Total Loss ($)				**$ 62,045,750.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**0**		

6.4 Glynmill Pond Dam

A breach in the Glynmill Pond Dam would create relatively shallow floodwater up to 0.7 metres in depth. The commercial buildings in the downtown core would experience some flooding, but it is assumed not enough to cause entire buildings to need replacement, and it was assumed that any bridges in the flow path could sustain the 0.7 m rise in flood water and would therefore not be affected. As in the previous sections, there is no permanent population at risk, however an unquantified temporary population would be at risk. The total estimated cost of damages is in the range of tens of millions CAD.

Table 7: Glynmill Pond Dam Consequence Assessment

Background Information	
Dam Name:	Glynmill Pond Dam
Project Name:	Corner Brook Pulp and Paper Limited
Dam Owner:	Corner Brook Pulp and Paper Limited
Inventory Number:	608
Assumed Breach Conditions:	1 in 150 year flood event
Communities Downstream:	Corner Brook

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference

Small Commercial Buildings	8	building	$ 16,000.00	$ 128,000.00		Aviva Canada, 2015
Large Commercial Buildings	17	building	$ 32,000.00	$ 544,000.00		Aviva Canada, 2015
Kruger Paper Mill	1	entire site	$ 13,750,000.00	$ 13,750,000.00	Approx. 1/8 the amount inundated as CB lake breach	Connors, 2014
Glynmill Pond Dam	250	kW capacity	$ 675.00	$ 168,750.00	Concrete gravity	Eaton, 1997
Bowater Park Infrastructure	0.1	entire park	$ 400,000.00	$ 40,000.00	Small area of park affected ~10%	Atlantic Canada Opportunities Agency, 2009
Estimated Total Loss ($)				**$ 62,145,750.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**0**		

6.5 Main Dam at Grand Lake

Inundation maps for the Main Dam breach indicate that massive amounts of floodwater would impact a very large portion of Deer Lake, and continue down the Humber River until attenuating into the Bay of Islands. Communities downstream as far as Corner Brook will be impacted by flood water, and it was assumed that all infrastructure in the inundation zone would need to be replaced. Approximately 1112 homes are anticipated to be in the inundation zone, leading to a PAR estimate of approximately 3336 persons. In addition to the homes, other major infrastructure including the Deer Lake International Airport, Humber Valley Resort, the Kruger Paper Mill, and the Corner Brook Port would be affected, leading to an estimated cost of damages in the hundreds of million CAD range, just short of reaching one billion CAD.

Table 8: Main Dam at Grand Lake Consequence Assessment

Background Information	
Dam Name:	Main Dam at Grand Lake
Project Name:	Deer Lake Hydroelectric Generating Station
Dam Owner:	Deer Lake Power
Inventory Number:	1
Assumed Breach Conditions:	Peak Water Level, Dam Failure during Flood Conditions
Communities Downstream:	Deer Lake, Nicholsville, Reidsville, Howley, St. Judes, Pynn's Brook, Taylor Estates, Pasadena, Humber Valley Resort, Humber Village, Little Rapids, Steadybrook, Corner Brook, Irishtown – Summerside

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference

Homes	1112	home	$ 375,000.00	$ 417,000,000.00		RE/MAX, 2017
Small Commercial Buildings	121	building	$500,000.00	$ 60,500,000.00		RE/MAX, 2017
Large Commercial Buildings	38	building	$ 1,000,000.00	$ 38,000,000.00		RE/MAX, 2017
Main Dam at Grand Lake	129000	kW capacity	$ 675.00	$ 87,075,000.00		IRENA, 2012
Culverts	11	culvert	$ 60,000.00	$ 660,000.00		GPA, 2016a
Concrete Bridge	141	metre	$ 98,000.00	$ 98,000.00		GPA, 2016b
Concrete Bridge	62	metre	$ 98,000.00	$ 6,076,000.00		GPA, 2016b
Concrete Bridge	113	metre	$ 98,000.00	$ 11,074,000.00		GPA, 2016b
Wooden Bridge	25	metre	$ 6,000.00	$ 150,000.00		GPA, 2015a
Concrete Bridge	150	metre	$ 98,000.00	$ 14,700,000.00		GPA, 2016b
Wooden Bridge	10	metre	$ 6,000.00	$ 60,000.00		GPA, 2015a
Concrete Bridge	60	metre	$ 98,000.00	$ 5,880,000.00		GPA, 2016b
Concrete Bridge	230	metre	$ 98,000.00	$ 22,540,000.00		GPA, 2016b
Concrete Bridge	160	metre	$ 98,000.00	$ 15,680,000.00		GPA, 2016b
Concrete Bridge	80	metre	$ 98,000.00	$ 7,840,000.00		GPA, 2016b
Concrete Bridge	45	metre	$ 98,000.00	$ 4,410,000.00		GPA, 2016b
Concrete Bridge	90	metre	$ 98,000.00	$ 8,820,000.00		GPA, 2016b
RV Park, 37 spots	37	RV space	$ 8,000.00	$ 296,000.00		Leighty, 2011
RV Park, 50 spots	50	RV space	$ 8,000.00	$ 400,000.00		Leighty, 2011
RV Park, 29 spots	29	RV space	$ 8,000.00	$ 232,000.00		Leighty, 2011
Deer Lake Golf Course	1	entire course	$ 2,000,000.00	$ 2,000,000.00	$1.2M in 1992 converted to 2017 dollars	Government of Newfoundland and Labrador, 1992

Farmland	373	4046 sq. m (1 acre)	$ 2,970.00	$ 1,107,810.00		Statistics Canada, 2017
Deer Lake Airport	1	entire airport	$ 100,000,000.00	$ 100,000,000.00		Deer Lake Regional Airport, 2016
Holiday Inn Express Deer Lake	1	entire hotel	$ 10,500,000.00	$ 10,500,000.00		Government of Newfoundland and Labrador, 2015a
Baseball Field	2	entire field	$ 40,000.00	$ 80,000.00		Government of Newfoundland and Labrador, 2015b
Soccer Field	1	entire field	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015b
Cemetery	1	entire site	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2015b
Recreation Complex	0.5	entire building	$ 40,000,000.00	$ 20,000,000.00		Government of Newfoundland and Labrador, 2017
Humber Valley Resort Golf course	0.33	entire course	$ 4,000,000.00	$ 1,333,333.33	Only 1/3 in inundation zone	Government of Newfoundland and Labrador, 1992
Park	1	entire park	$ 30,000.00	$ 30,000.00		Government of Newfoundland and Labrador, 2015b
Fishing Boat Wharf	1	entire wharf	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015b
Corner Brook Port Wharf	1	entire wharf	$ 300,000.00	$ 300,000.00		Delcan, 2011
Kruger Paper Mill	1	area adjacent to harbour	$ 13,750,000.00	$ 13,750,000.00		Connors, 2014
Barry's Fish Plant Wharf	1	entire wharf	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015c
Oil Boat Wharf	1	entire wharf	$ 20,000.00	$ 20,000.00		Government of Newfoundland

						and Labrador, 2015b
Oil Boat Wharf	1	entire wharf	$ 20,000.00	$ 20,000.00		Government of Newfoundland and Labrador, 2015b
Bay of Islands Marina Wharf	1	entire wharf	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015c
Estimated Total Loss ($)				**$ 850,817,143.33**		
Estimated Order of Magnitude of Losses				**Hundreds of Millions**		
Permanent Population at Risk				**3336**		

6.6 SV-1 (Snooks Arm Main Dam)

Inundation mapping for a breach of the Snooks Arm Main Dam during PMF conditions indicates that flood water levels would reach a maximum depth of 1.7 metres. For this reason, it was assumed that homes would not need to be fully replaced, and would instead incur replacement costs related to drying and repairing the first floor and/or basement. The total estimated cost of damage is expected to be within the range of millions of CAD. The population at risk estimate is 18 persons.

Table 9: Snooks Arm Main Dam Consequence Assessment

Background Information						
Dam Name:	SV-1 (Snooks Arm Main Dam)					
Project Name:	Snooks Arm and Venams Bight					
Dam Owner:	Newfoundland and Labrador Hydro					
Inventory Number:	77					
Assumed Breach Conditions:	Limit of flood due to assumed dam breach. East Pond water surface starting at elevation 87.6m					
Downstream Communities:	Snooks Arm					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	6	home	$ 100,000.00	$ 600,000.00		RE/MAX, 2017
SV-1 Dam	1000	kW capacity	$ 675.00	$ 675,000.00		IRENA, 2012
Culverts	2	culvert	$ 60,000.00	$ 120,000.00		GPA, 2016a
Wooden Bridge	20	metre	$ 6,000.00	$ 120,000.00		GPA, 2015a
Water Pipeline	265	metre	$ 350.00	$ 92,750.00		Town of Baie Verte, 2011
Fishing Shacks	10	shack	$ 30,000.00	$ 300,000.00		RE/MAX, 2017

Estimated Total Loss ($)	**$ 1,907,750.00**
Estimated Order of Magnitude of Losses	**Millions**
Permanent Population at Risk	**18**

6.7 Star Lake Main Dam

Inundation maps related to a breach in the Star Lake Main dam do not provide an indication of the depth or velocity of flood waters. The breach would cause flood water to enter Red Indian Lake, and would travel as far as Buchans Junction. Due to the large size of Red Indian Lake and the large distance of most infrastructure from the dam, it was assumed that by the time flood waters reached areas with infrastructure that would be affected, the water depth would not be at a depth or velocity that would cause the complete replacement of homes and buildings. Based on the consequence assessment, it was assumed that the cost of damages in the inundated area would be in the range of tens of millions of CAD, and the population at risk is approximately 375 persons.

Table 10: Star Lake Main Dam Consequence Assessment

Background Information	
Dam Name:	Star Lake Main Dam
Project Name:	Star Lake Hydroelectric Generating Station
Dam Owner:	Newfoundland and Labrador Hydro
Inventory Number:	9
Assumed Breach Conditions:	Flood Line Extreme Case
Downstream Communities:	Millertown, Buchans Junction, Red Indian Lake Cabin Owners

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	125	home	$ 16,000.00	$ 2,000,000.00		Aviva Canada, 2015
Large Commercial Buildings	3	building	$ 32,000.00	$ 96,000.00		Aviva Canada, 2015
Star Lake Main Dam	18400	kW capacity	$ 675.00	$ 12,420,000.00		IRENA, 2012
Exploits Dam	250	kW capacity	$ 75,000.00	$ 18,750,000.00	Concrete Gravity Dam	Nalcor Energy, 2016
Culverts	4	culvert	$ 60,000.00	$ 240,000.00		GPA, 2016a
Concrete Bridge	17	metre	$ 98,000.00	$ 1,666,000.00		GPA, 2016b
Estimated Total Loss ($)				**$ 35,172,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**375**		

6.8 VD-3 (Victoria Dam)

The inundation maps provided regarding a breach in the Victoria Dam, part of the Bay d'Espoir Hydroelectric Development, do not give an indication of flood water depths or velocities. Given the extensive distance of the inundated area downstream from the dam, and the fact that the majority of infrastructure is located very far downstream in communities like Badger and Bishop's Falls, it was assumed that by the time the floodwater would reach these more populated areas its depth would be fairly low and velocities would have significantly slowed from the levels near the dam at the time of the breach. For this reason, repair costs were used for the homes and buildings in the area, rather than full replacement costs. The costs of fully replacing most culverts and bridges were assumed, however some of the larger bridges located further downstream, such as those along the Trans-Canada Highway between Badger and Bishop's Falls are assumed to be very structurally sound and would likely not breach as a result of the flood water at that location. A tally of the infrastructure in the inundation zone led to a population at risk estimate of approximately 4896 people, with the order of magnitude of repair costs being in the hundreds of millions CAD range.

Table 11: VD-3 (Victoria Dam) Consequence Assessment

Background Information	
Dam Name:	VD-3 (Victoria Dam)
Project Name:	Bay d'Espoir Hydroelectric Generating Facility
Dam Owner:	Newfoundland and Labrador Hydro
Inventory Number:	86
Assumed Breach Conditions:	Overtopping
Communities Downstream:	Millertown, Buchans Junction, Red Indian Lake Cabin Owners, Badger, Red Cliff, Grand Falls, Bishop's Falls

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	1632	per home	$ 16,000.00	$ 26,112,000.00		Aviva Canada, 2015
Small Commercial Buildings	66	building	$ 16,000.00	$ 1,056,000.00		Aviva Canada, 2015
Large Commercial Buildings	17	building	$ 32,000.00	$ 544,000.00		Aviva Canada, 2015
VD-3 Dam	420	metre	$ 2,000.00	$ 840,000.00	Earthfill Dam	Delcan, 2011
Exploits Dam	250	kW	$ 75,000.00	$ 18,750,000.00	Concrete Gravity Dam	Nalcor Energy, 2016
Culverts	14	culvert	$ 60,000.00	$ 840,000.00		GPA, 2016a
Metal Bridge	45	metre	$ 45,000.00	$ 2,025,000.00		GPA, 2015c
Metal Bridge	12	metre	$ 45,000.00	$ 540,000.00		GPA, 2015c
Concrete Bridge	65	metre	$ 98,000.00	$ 6,370,000.00		GPA, 2016b

Background Information

Metal Bridge	10	metre	$ 45,000.00	$ 450,000.00		GPA, 2015c
Metal Bridge	30	metre	$ 45,000.00	$ 1,350,000.00		GPA, 2015c
Metal Bridge	50	metre	$ 45,000.00	$ 2,250,000.00		GPA, 2015c
Metal Bridge	30	metre	$ 45,000.00	$ 1,350,000.00		GPA, 2015c
Concrete Bridge	90	metre	$ 98,000.00	$ 8,820,000.00		GPA, 2016b
Schools	5	per school	$ 1,500,000.00	$ 7,500,000.00		Mansfield, 2017
Recreation Complex	2	entire building	$ 2,000,000.00	$ 4,000,000.00		JAC GovNL
Baseball Field	2	per field	$ 40,000.00	$ 80,000.00		Government of Newfoundland and Labrador, 2015b
Soccer Field	1	per field	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015b
Park	1	Entire park	$ 30,000.00	$ 30,000.00		Government of Newfoundland and Labrador, 2015b
Golf Course	0.50	full course	$ 2,000,000.00	$ 1,000,000.00	$1.2M in 1992 converted to 2017 dollars	Government of Newfoundland and Labrador, 1992
RV Park, 50 spaces	50	per spot	$ 8,000.00	$ 400,000.00		Leighty, 2011
RV Park, 32 Spaces	32	per spot	$ 8,000.00	$ 256,000.00		Leighty, 2011
Lion Max Simms Memorial Camp	1	entire camp	$ 96,000.00	$ 96,000.00	Equivalent to 6 small buildings	Aviva Canada, 2015
Powerhouse Building, Bishop Falls	193	GWh/year	$ 57,475.00	$ 11,076,582.00		Newfoundland Power Inc., 2009
Water Treatment Plant Badger	1	entire facility	$ 15,000,000.00	$ 15,000,000.00		Government of Newfoundland, 1992
Water Treatment Plant Grand Falls	1	entire facility	$ 15,000,000.00	$ 15,000,000.00	$8M to construct in 1992 converted to 2017 dollars	Government of Newfoundland, 1992

Background Information	
Total Loss ($)	**$ 125,775,582.00**
Estimated Order of Magnitude of Losses	**Hundreds of Millions**
Permanent Population at Risk	**4896**

6.9 LD-1 (Power Canal Embankment)

Inundation mapping for the LD-1 dam shows that floodwaters from a dam breach would result in significant floodwater up to nearly 40 metres in peak depth. For this reason, it was assumed that all homes and infrastructure in the inundation area would need to be completely replaced. In addition to infrastructure on land, the area also hosts numerous aquaculture facilities that were assumed to be damaged and would need to be replaced. The total estimated cost of damages is in the range of hundreds of millions CAD, and the population at risk is approximately 618 persons.

Table 12: LD-1 (Power Canal Embankment) Consequence Assessment

Background Information	
Dam Name:	LD-1 (Power Canal Embankment)
Project Name:	Bay d'Espoir Hydroelectric Generating Facility
Dam Owner:	Newfoundland and Labrador Hydro
Inventory Number:	46
Assumed Breach Conditions:	Limit of flood due to an assumed dam breach with long pond water surface elevation at 182.7 m
Communities Downstream:	Conne River, Morrisville, Milltown, Camp Boggy, Saint Veronicas, Saint Joseph's Cove, Head of Bay d'Espoir, Swanger Cove, St. Albans

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	206	per home	$ 180,000.00	$ 37,080,000.00		RE/MAX, 2017
Small Commercial Buildings	19	building	$ 180,000.00	$ 3,420,000.00		RE/MAX, 2017
Large Commercial Buildings	1	building	$ 360,000.00	$ 360,000.00		RE/MAX, 2017
LD-1 Dam	1250	metre	$ 2,000.00	$ 2,500,000.00		Delcan, 2011
Culverts	6	culvert	$ 60,000.00	$ 360,000.00		GPA, 2016a
Metal Bridge	15	metre	$ 45,000.00	$ 675,000.00		GPA, 2015c
Concrete Bridge	95	metre	$ 98,000.00	$ 9,310,000.00		GPA, 2016b
Concrete Bridge	20	metre	$ 98,000.00	$ 1,960,000.00		GPA, 2016b
Concrete Bridge	40	metre	$ 98,000.00	$ 3,920,000.00		GPA, 2016b
Concrete Bridge	12	metre	$ 98,000.00	$ 1,176,000.00		GPA, 2016b
Concrete Bridge	35	metre	$ 98,000.00	$ 3,430,000.00		GPA, 2016b

Baseball Field	3	per field	$ 40,000.00	$ 120,000.00		Government of Newfoundland and Labrador, 2015b
Soccer Field	1	per field	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015b
Conne River Marina	1	entire site	$ 445,000.00	$ 445,000.00		Rutter Hinz Inc., 2009
Conne River Breakwater	1	entire site	$ 475,000.00	$ 475,000.00		Rutter Hinz Inc., 2009
Milltown Marina	1	entire site	$ 600,000.00	$ 600,000.00		Rutter Hinz Inc., 2009
Schools	2	Entire school	$ 1,500,000.00	$ 3,000,000.00		Mansfield, 2017
Cemetery	1	Entire site	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2015b
Bay D'Espoir Hotel	1	Entire hotel	$ 1,500,000.00	$ 1,500,000.00	Assumed similar to school costs	Mansfield, 2017
Newfoundland Aqua Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Long Island Resources Aquaculture Site, St. Albans	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Nordic Salmon's Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Total Loss				**$ 130,396,000.00**		
Estimated Order of Magnitude of Losses				**Hundreds of Millions**		
Permanent Population at Risk				**618**		

6.10 LD-2 (North West Cutoff Dam)

Inundation mapping for the LD-2 dam shows that floodwaters from a dam breach would result in significant floodwater up to nearly 20 metres in peak depth. For this reason, it was assumed that all homes and infrastructure in the inundation area would need to be completely replaced. In addition to infrastructure on land, the area also hosts numerous aquaculture facilities that were assumed to be damaged and would need to be replaced. The total estimated cost of damages is in the range of hundreds of millions CAD, and the population at risk is approximately 618 persons.

Table 13: LD-2 (North West Cutoff Dam) Consequence Assessment

Background Information	
Dam Name:	LD-2 (North West Cutoff Dam)
Project Name:	Bay d'Espoir Hydroelectric Generating Facility
Dam Owner:	Newfoundland and Labrador Hydro
Inventory Number:	47
Assumed Breach Conditions:	Limit of flood due to an assumed dam breach with long pond water surface elevation at 182.7 m
Communities Downstream:	Conne River, Morrisville, Milltown, Camp Boggy, Saint Veronicas, Saint Joseph's Cove, Head of Bay d'Espoir, Swanger Cove, St. Albans

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	206	per home	$ 180,000.00	$ 37,080,000.00		RE/MAX, 2017
Small Commercial Buildings	19	building	$ 180,000.00	$ 3,420,000.00		RE/MAX, 2017
Large Commercial Buildings	1	building	$ 360,000.00	$ 360,000.00		RE/MAX, 2017
LD-2 Dam	650	metre	$ 2,000.00	$ 1,300,000.00		Delcan, 2011
Culverts	6	culvert	$ 60,000.00	$ 360,000.00		GPA, 2016a
Metal Bridge	15	metre	$ 45,000.00	$ 675,000.00		GPA, 2015c
Concrete Bridge	95	metre	$ 98,000.00	$ 9,310,000.00		GPA, 2016b
Concrete Bridge	20	metre	$ 98,000.00	$ 1,960,000.00		GPA, 2016b
Concrete Bridge	40	metre	$ 98,000.00	$ 3,920,000.00		GPA, 2016b
Concrete Bridge	12	metre	$ 98,000.00	$ 1,176,000.00		GPA, 2016b
Concrete Bridge	35	metre	$ 98,000.00	$ 3,430,000.00		GPA, 2016b
Baseball Field	2	per field	$ 40,000.00	$ 80,000.00		Government of Newfoundland and Labrador, 2015b
Soccer Field	1	per field	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015b
Conne River Marina	1	entire site	$ 445,000.00	$ 445,000.00		Rutter Hinz Inc., 2009
Conne River Breakwater	1	entire site	$ 475,000.00	$ 475,000.00		Rutter Hinz Inc., 2009

Milltown Marina	1	entire site	$ 600,000.00	$ 600,000.00		Rutter Hinz Inc., 2009
Baseball Field (town)	1	per field	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015b
Schools	2	entire school	$ 1,500,000.00	$ 3,000,000.00		Mansfield, 2017
Cemetery	1	entire site	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2015b
Bay D'Espoir Hotel	1	entire hotel	$ 1,500,000.00	$ 1,500,000.00	Assumed similar to school	Mansfield, 2017
Newfoundland Aqua Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Long Island Resources Aquaculture Site, St. Albans	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Nordic Salmon's Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Total Loss				**$ 129,196,000.00**		
Estimated Order of Magnitude of Losses				**Hundreds of Millions**		
Population at Risk				**618**		

6.11 LD-3 (South East Cutoff Dam)

Inundation mapping for the LD-4 dam shows that floodwaters from a dam breach would result in significant floodwater up to nearly seven (7) metres in peak depth. For this reason, it was assumed that all homes and infrastructure in the inundation area would need to be completely replaced. In addition to infrastructure on land, the area also hosts numerous aquaculture facilities that were assumed to be damaged and would need to be replaced. The total estimated cost of damages is in the range of tens of millions CAD, and the population at risk is approximately 93 persons.

Table 14: LD-3 (South East Cutoff Dam) Consequence Assessment

Background Information						
Dam Name:	LD-3 (South East Cutoff Dam)					
Project Name:	Bay d'Espoir Hydroelectric Generating Facility					
Dam Owner:	Newfoundland and Labrador Hydro					
Inventory Number:	48					
Assumed Breach Conditions	Limit of flood due to an assumed dam breach with long pond water surface elevation at 182.7 m					
Communities Downstream	St. Albans, Swanger Cove, Conne River (no infrastructure affected)					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	31	per home	$ 180,000.00	$ 5,580,000.00		RE/MAX, 2017
Small Commercial Buildings	1	building	$ 180,000.00	$ 180,000.00		RE/MAX, 2017
LD-3 Dam	385	metre	$ 2,000.00	$ 770,000.00		Delcan, 2011
Concrete Bridge	40	metre	$ 98,000.00	$ 3,920,000.00		GPA, 2016b
St. Alban's Regional Resource Center	1	building	$ 540,000.00	$ 540,000.00	1 large building, 1 small building	RE/MAX, 2017
Small senior's home/apartment building	1	per field	$ 360,000.00	$ 360,000.00		RE/MAX, 2017
Newfoundland Aqua Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Long Island Resources Aquaculture Site, St. Albans	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Nordic Salmon's Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Total Loss				**$ 71,350,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**93**		

6.12 LD-4 (South West Cutoff Dam)

Inundation mapping for the LD-4 dam shows that floodwaters from a dam breach would result in significant floodwater up to nearly five (5) metres in peak depth. For this reason, it was assumed that all homes and infrastructure in the inundation area would need to be completely replaced. In addition to infrastructure on land, the area also hosts numerous aquaculture facilities that were assumed to be damaged and would need to be replaced. The total estimated cost of damages is in the range of tens of millions CAD, and the population at risk is approximately 168 persons.

Table 15: LD-4 (South West Cutoff Dam) Consequence Assessment

Background Information	
Dam Name:	LD-4 (South West Cutoff Dam)
Project Name:	Bay d'Espoir Hydroelectric Generating Facility
Dam Owner:	Newfoundland and Labrador Hydro
Inventory Number:	49
Assumed Breach Conditions:	Limit of flood due to an assumed dam breach with long pond water surface elevation at 182.7 m
Communities Downstream:	St. Albans, Swanger Cove, Conne River (no infrastructure affected)

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	56	per home	$ 180,000.00	$ 10,080,000.00		RE/MAX, 2017
Small Commercial Buildings	3	building	$ 180,000.00	$ 540,000.00		RE/MAX, 2017
LD-4 Dam	390	metre	$ 2,000.00	$ 780,000.00		Delcan, 2011
Concrete Bridge	40	metre	$ 98,000.00	$ 3,920,000.00		GPA, 2016b
Newfoundland Aqua Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Long Island Resources Aquaculture Site, St. Albans	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Nordic Salmon's Aquaculture Site, St. Alban's	1	entire facility	$ 20,000,000.00	$ 20,000,000.00	including wharf and buildings	Government of Newfoundland and Labrador, 2017
Total Loss ($)				**$ 75,320,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**168**		

6.13 Water Supply Dam / Barry Group Reservoir

The inundation map for a breach in the Water Supply Dam / Barry Group Reservoir did not give any indication of the depth or velocity of water that would be experienced in the flood zone. Because of the close proximity of the homes to the dam, and the steep elevation of the assumed flow path the floodwater would take, it was assumed that the peak flood would be large enough and travel quickly enough that the homes in the inundation area would be damaged beyond repair and would need to be replaced. The total cost of damages is anticipated to be in the order of millions of CAD, and the estimated population at risk is approximately 15 persons.

Table 16: Water Supply Dam / Barry Group Reservoir Consequence Assessment

Background Information						
Dam Name:	Water Supply Dam / Barry Group Reservoir					
Project Name:	Barry Group Inc. Fish Plant					
Dam Owner:	Barry Group Inc.					
Inventory Number:	1348					
Assumed Breach Conditions:	Overtopping					
Communities Downstream:	Clarenville					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Repair Cost Per Unit	Total Repair Cost	Comments	Reference
Homes	5	home	$ 300,000.00	$ 1,500,000.00		RE/MAX, 2017
Barry Group Dam	97	metre	$ 2,000.00	$ 194,000.00	Earthfill Dam	Delcan, 2011
Total Loss ($)				**$ 1,694,000.00**		
Estimated Order of Magnitude of Losses				**Million**		
Permanent Population at Risk				**15**		

6.14 Rocky Pond Control Dam and Spillway

The inundation mapping related to a breach in the Rocky Pond Control Dam and Spillway did not indicate flood water depths or velocities. The inundation zone was fairly small and flowed directly into the ocean, therefore it was assumed that infrastructure in the zone would need to be repaired rather than replaced, aside from the two bridges which were assumed to sustain damages that would make them structurally unsound and require replacement. A total of nine (9) homes are located within the inundation zone, leading to a population at risk estimate of 27 persons. The total estimated damages are expected to be in the millions of CAD range.

Table 17: Rocky Pond Control Dam and Spillway Consequence Assessment

Background Information	
Dam Name:	Rocky Pond Control Dam and Spillway
Project Name:	Hearts Content Hydroelectric Development
Dam Owner:	Newfoundland Power Inc.
Inventory Number:	190

Assumed Breach Conditions:	Rainy Day Failure					
Downstream Communities:	Heart's Content					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	9	per home	$ 16,000.00	$ 144,000.00		Aviva Canada, 2015
Small Commercial Buildings	1	building	$ 16,000.00	$ 16,000.00		Aviva Canada, 2015
Rocky Pond Control Dam and Spillway	2700	kW capacity	$ 675.00	$ 1,822,500.00		IRENA, 2012
Concrete Bridge	25	metre	$ 98,000.00	$ 2,450,000.00		GPA, 2016b
Wooden Bridge	20	whole bridge	$ 6,000.00	$ 120,000.00		GPA, 2015a
Wharf	1	entire wharf	$ 40,000.00	$ 40,000.00		Government of Newfoundland and Labrador, 2015
Estimated Total Loss ($)				**$ 4,592,500.00**		
Estimated Order of Magnitude of Losses				**Millions**		
Permanent Population at Risk				**27**		

6.15 Cascading Failure: Pittman's Pond Dam and Seal Cove Pond Dam (NCH Forebay Dam)

The inundation maps for the Pittman's Pond and NCH Forebay Dam do not indicate flood water depths or velocities. It was assumed that homes would need to be repaired rather than replaced as the land is relatively gently sloping and the flood water flows directly to the ocean. The assumed population at risk is approximately 18 people, and the total estimated cost of damages is in the range of millions CAD.

Table 18: Pittman's Pond Dam Consequence Assessment

Background Information	
Dam Name:	Pittman's Pond Dam, Seal Cove Pond Dam (NCH Forebay Dam) (Cascading Failure of Seal Cove Pond Dam)
Project Name:	NCH / PIT Hydroelectric Development
Dam Owner:	Newfoundland Power Inc.
Inventory Number:	195, 194
Assumed Breach Conditions:	PMF Pittman's Pond Dam failure with cascading failure of Seal Cove Pond Dam
Downstream Communities:	New Chelsea

Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	6	per home	$ 16,000.00	$ 96,000.00		Aviva Canada, 2015
Small Commercial Buildings	1	building	$ 16,000.00	$ 16,000.00		Aviva Canada, 2015
Pittman's Pond Dam	625	kW capacity	$ 675.00	$ 421,875.00		IRENA, 2012
NCH Forebay Dam	3700	kW capacity	$ 675.00	$ 2,497,500.00		IRENA, 2012
Estimated Total Loss ($)				**$ 3,031,375.00**		
Estimated Order of Magnitude of Losses				**Millions**		
Permanent Population at Risk				**18**		

6.16 Seal Cove Pond Dam (NCH Forebay Dam)

The inundation map for the NCH Forebay Dam does not indicate flood water depths or velocities. It was assumed that homes would need to be repaired rather than replaced as the land is relatively gently sloping and the flood water flows directly to the ocean. The assumed population at risk is approximately 6 people, and the total estimated cost of damages is in the range of millions of CAD.

Table 19: Seal Cove Pond Dam Consequence Assessment

Background Information	
Dam Name:	Seal Cove Pond Dam (NCH Forebay Dam)
Project Name:	NCH / PIT Hydroelectric Development
Dam Owner:	Newfoundland Power Inc.
Inventory Number:	194
Assumed Breach Conditions:	PMF Seal Cove Pond Dam (NCH Forebay Dam) failure
Communities Downstream:	New Chelsea

Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	2	per home	$ 16,000.00	$ 32,000.00		Aviva Canada, 2015
Small Commercial Buildings	1	building	$ 16,000.00	$ 16,000.00		Aviva Canada, 2015
NCH Forebay Dam	3700	kW capacity	$ 675.00	$ 2,497,500.00		International Renewable Energy Agency, 2012

Total Estimated Loss ($)	**$ 2,545,500.00**
Estimated Order of Magnitude of Losses	**Millions**
Permanent Population at Risk	**6**

6.17 Packs Pond Diversion Dam

The inundation maps for a breach in the Packs Pond Diversion Dam do not indicate flood water depths or velocities. It was assumed that infrastructure would need to be repaired rather than replaced as the land is relatively gently sloping and the inundation zone is quite small, aside from the main roadway bridge which was assumed to sustain damages that would make it structurally unsound and require replacement. The assumed population at risk is approximately 123 people, and the total estimated cost of damages is in the range of millions of CAD.

Table 20: Packs Pond Diversion Dam Consequence Assessment

Background Information						
Dam Name:	Packs Pond Diversion Dam					
Project Name:	Hearts Content Hydroelectric Development					
Dam Owner:	Newfoundland Power Inc.					
Inventory Number:	193					
Assumed Breach Conditions:	Rainy Day Failure					
Downstream Communities:	Victoria					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	41	per home	$ 16,000.00	$ 656,000.00		Aviva Canada, 2015
Small Commercial Buildings	1	building	$ 16,000.00	$ 16,000.00		Aviva Canada, 2015
Pack's Pond Diversion Dam	2700	kW capacity	$ 675.00	$ 1,822,500.00		IRENA, 2012
Concrete Bridge	30	metre	$ 98,000.00	$ 2,940,000.00		GPA, 2016b
Estimated Total Loss ($)				**$ 5,434,500.00**		
Estimated Order of Magnitude of Losses				**Millions**		
Permanent Population at Risk				**123**		

6.18 Long Pond Dam

The inundation maps for a breach in the Long Pond Dam do not indicate flood water depths or velocities. It was assumed that homes would need to be repaired rather than replaced as the inundation zone is very small and the flood water flows directly to the ocean, with the exception of the bridges within the flood path which were assumed to need replacement due to sustained damages rendering them structurally unsound. The assumed population at risk is approximately six (6) people, and the total estimated cost of damages is in the range of millions of CAD.

Table 21: Long Pond Dam Consequence Assessment

Background Information						
Dam Name:	Long Pond Dam					
Project Name:	Port Union Hydroelectric Development					
Dam Owner:	Newfoundland Power Inc.					
Inventory Number:	212					
Assumed Breach Conditions:	PMF					
Downstream Communities:	Port Union					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	2	per home	$ 16,000.00	$ 32,000.00		Aviva Canada, 2015
Long Pond Dam	500	kW capacity	$ 675.00	$ 337,500.00		IRENA, 2012
Concrete Bridge	56	metre	$ 98,000.00	$ 5,488,000.00		GPA, 2016b
Wooden Bridge	10	metre	$ 6,000.00	$ 60,000.00		GPA, 2015a
Pumphouse	1	Pump-house	$ 25,000.00	$ 25,000.00		Government of Newfoundland and Labrador, 2016
Estimated Total Loss ($)				**$ 5,942,500.00**		
Estimated Order of Magnitude of Losses				**Millions**		
Permanent Population at Risk				**6**		

6.19 Cascading Failure: Big Country Pond Dam and Gull Pond Dam (PBK Forebay Dam)

The inundation map for the breach of Big Country Pond Dam and subsequent cascading failure of Gull Pond Dam indicates that flood waters would reach a maximum of approximately 6.18 m at a flow rate of 1233 m^3/s. Because most of the homes in the inundation zone are near the water, it was assumed that most would experience the maximum flood water level of 6.18 m and would therefore be damaged beyond repair. According to the current prices of homes for sale in the Witless Bay area, the average cost of a new home is approximately $400,000. In total, the estimated population at risk would be approximately 33 persons, and the total estimated cost of damages would be in the range of tens of millions of CAD.

Table 22: Big Country Pond Dam Consequence Assessment

Background Information	
Dam Name:	Big Country Pond Dam and Gull Pond Dam (PBK Forebay Dam) (Cascading Failure of Gull Pond Dam)
Project Name:	Pierre's Brook Hydroelectric Development
Dam Owner:	Newfoundland Power Inc.
Inventory Number:	96, 94

Assumed Breach Conditions:	Extreme Flood Dam Failure (1.5 x 1/10,000) with cascading failure of Gull Pond Dam					
Downstream Communities:	Witless Bay					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	11	per home	$ 400,000.00	$ 4,400,000.00		RE/MAX, 2017
Big Country Pond Dam	4300	kW capacity	$ 675.00	$ 2,902,500.00		IRENA, 2012
Gull Pond Dam	4300	kW capacity	$ 675.00	$ 2,902,500.00		IRENA, 2012
Concrete Bridge	28	metre	$ 98,000.00	$ 2,744,000.00		GPA, 2016b
Estimated Total Loss ($)				**$ 12,949,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**33**		

6.20 Cascading Failure: West Country Pond Dam and Gull Pond Dam (PBK Forebay Dam)

The inundation map for the breach of West Country Pond Dam and subsequent cascading failure of Gull Pond Dam indicates that flood waters would reach a maximum of approximately 7.81 m at a flow rate of 774 m^3/s in the area where the majority of homes in the inundation zone are located. Because most of the homes in the inundation zone are near the water, it was assumed that most would experience major flooding leading to damage beyond repair. According to the current prices of homes for sale in the Witless Bay area, the average cost of a new home is approximately $400,000. In total, the estimated population at risk would be approximately 21 persons, and the total estimated cost of damages would be in the range of millions of CAD.

Table 23: West Country Pond Dam Consequence Assessment

Background Information						
Dam Name:	West Country Pond Dam, Gull Pond Dam (PBK Forebay Dam) (Cascading Failure of Gull Pond Dam)					
Project Name:	Pierres Brook Hydroelectric Development					
Dam Owner:	Newfoundland Power Inc.					
Inventory Number:	100, 94					
Assumed Breach Conditions:	Extreme Flood Dam Failure (1.5 x 1/10,000) with cascading failure of Gull Pond Dam					
Downstream Communities:	Witless Bay					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	7	per home	$ 400,000.00	$ 2,800,000.00		RE/MAX, 2017

Small Commercial Buildings	2	building	$ 400,000.00	$ 800,000.00		RE/MAX, 2017
West Country Pond Dam	4300	kW	$ 675.00	$ 2,902,500.00		IRENA, 2012
Concrete Bridge	28	metre	$ 98,000.00	$ 2,744,000.00		GPA, 2016b
Estimated Total Loss ($)				**$ 9,246,500.00**		
Estimated Order of Magnitude of Losses				**Millions**		
Permanent Population at Risk				**21**		

6.21 Muskrat Falls Dam

A breach in the Muskrat Falls Dam would lead to flooding of the downstream communities of Happy-Valley Goose Bay and Mud Lake. While there is no indication of the anticipated depth or velocity of the flood water, the close proximity of the town, size of the dam, and historical flooding in the region indicates that flood damage would be relatively major, and therefore the infrastructure in the flood zone would be damaged beyond repair.

According to current real-estate prices, the average cost of a new home in the area is approximately $350,000.00, while the cost of commercial infrastructure is between $500,000.00 and $1,000,000.00. These estimates lead to an anticipated cost of damages in the hundreds of millions of CAD range, with a population at risk estimate of 1035 persons.

Table 24: Muskrat Falls Dam Consequence Assessment

Background Information	
Dam Name:	Muskrat Falls Dams (South Rockfill Dam, North RCC Dam, North Transition Dam, Gated Spillway, Centre Transition Dam, South Transition Dam)
Project Name:	Lower Churchill Hydroelectric Generation Project
Dam Owner:	Lower Churchill Management Corporation
Inventory Number:	677, 749, 756, 850, 851, 968
Assumed Breach Conditions:	PMF with dam breach
Downstream Communities:	Happy Valley – Goose Bay, Mud Lake

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	345	per home	$ 350,000.00	$ 120,750,000.00		Century 21 Canada Ltd., 2017
Small Commercial Buildings	58	building	$ 500,000.00	$ 29,000,000.00		Century 21 Canada Ltd., 2017
Large Commercial Buildings	2	building	$ 1,000,000.00	$ 2,000,000.00		Century 21 Canada Ltd., 2017
Muskrat Falls Dam	824000	kW	$ 675.00	$556,200,000.00		IRENA, 2012
Culverts	12	culvert	$ 60,000.00	$ 720,000.00		GPA, 2016a

Concrete Bridge	55	metre	$ 98,000.00	$ 5,390,000.00		GPA, 2016b
Concrete Bridge	370	metre	$ 98,000.00	$ 36,260,000.00		GPA, 2016b
Concrete Bridge	112	metre	$ 98,000.00	$ 10,976,000.00		GPA, 2016b
Concrete Bridge	850	metre	$ 98,000.00	$ 83,300,000.00		GPA, 2016b
Concrete Bridge	85	metre	$ 98,000.00	$ 8,330,000.00		GPA, 2016b
Ferry Terminal Wharf	1	wharf	$ 300,000.00	$ 300,000.00		Delcan, 2011
Estimated Total Loss ($)				**$ 853,226,000.00**		
Estimated Order of Magnitude of Losses				**Hundreds of Millions**		
Permanent Population at Risk				**1035**		

6.22 GR-2

Inundation mapping related to the Churchill Falls Dykes gives no indication of maximum flood water depths or velocities. Due to the large size of the Churchill Falls Smallwood reservoir and the extent of flooding it is assumed that a breach in one of the dykes would lead to all infrastructure downstream being damaged beyond repair. Realty prices in North West River and Sheshatshiu were not readily available, therefore the same prices as used in nearby Happy Valley-Goose Bay were used. It was estimated that a breach in the GR-2 dyke would lead to damage costs in the tens of millions of CAD range, with a population of approximately 369 persons being affected.

Table 25: GR-2 Dam Consequence Assessment

Background Information	
Dam Name:	GR-2
Project Name:	Churchill Falls Hydroelectric Development
Dam Owner:	Nalcor Energy – Churchill Falls
Inventory Number:	1142
Assumed Breach Conditions:	PMF Conditions
Downstream Communities:	North West River, Sheshatshiu

Consequence Assessment

Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	123	per home	$ 350,000.00	$ 43,050,000.00		Century 21 Canada Ltd., 2017
Small Commercial Buildings	1	building	$ 500,000.00	$ 500,000.00		Century 21 Canada Ltd., 2017
Large Commercial Buildings	2	building	$ 1,000,000.00	$ 2,000,000.00		Century 21 Canada Ltd., 2017

GR-2 Dam	1699	metre	$ 2,000.00	$ 3,398,000.00		Delcan, 2011
Culverts	1	culvert	$ 50,000.00	$ 50,000.00		GPA, 2016a
Concrete Bridge	175	metre	$ 98,000.00	$ 17,150,000.00		GPA, 2016b
Estimated Total Loss ($)				**$ 66,148,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**369**		

6.23 GR-8

Inundation mapping for the Orma Dykes did not indicate the depth of inundation or flood velocity, however given the amount of water held in the reservoir, and the constricted topography adjacent to the community before the floodwater will reach the ocean, it was assumed that all infrastructure would be highly damaged. It was estimated that a breach in the GR-8 dyke would lead to damage costs in the tens of millions of CAD range, with a population of approximately 171 persons being affected.

Table 26: GR-8 Dam Consequence Assessment

Background Information	
Dam Name:	GR-8
Project Name:	Churchill Falls Hydroelectric Development
Dam Owner:	Nalcor Energy – Churchill Falls
Inventory Number:	1148
Assumed Breach Conditions:	PMF Conditions
Downstream Communities:	North West River, Sheshatshiu

Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	57	per home	$ 350,000.00	$ 19,950,000.00		Century 21 Canada Ltd., 2017
Small Commercial Buildings	1	building	$ 500,000.00	$ 500,000.00	Small hotel	Century 21 Canada Ltd., 2017
Large Commercial Buildings	1	building	$ 1,000,000.00	$ 1,000,000.00		Century 21 Canada Ltd., 2017
GR-8 Dam	263	metre	$ 2,000.00	$ 526,000.00		Delcan, 2011
Concrete Bridge	175	metre	$ 98,000.00	$ 17,150,000.00		GPA, 2016b
Total Estimated Loss ($)				**$ 39,126,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**171**		

6.24 GR-9

Inundation mapping for the Orma Dykes did not indicate the depth of inundation or flood velocity, however given the amount of water held in the reservoir, and the constricted topography adjacent to the community before the floodwater will reach the ocean, it was assumed that all infrastructure would be highly damaged. It was estimated that a breach in the GR-9 dyke would lead to damage costs in the tens of millions of CAD range, with a population of approximately 45 persons being affected.

Table 27: GR-9 Dam Consequence Assessment

Background Information						
Dam Name:	GR-9					
Project Name:	Churchill Falls Hydroelectric Development					
Dam Owner:	Nalcor Energy – Churchill Falls					
Inventory Number:	1149					
Assumed Breach Conditions:	PMF Conditions					
Downstream Communities:	North West River, Sheshatshiu					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	15	per home	$ 350,000.00	$ 5,250,000.00		Century 21 Canada Ltd., 2017
GR-9 Dam	605	metre	$ 2,000.00	$ 1,210,000.00		Delcan, 2011
Concrete Bridge	175	metre	$ 98,000.00	$ 17,150,000.00		GPA, 2016b
Total Estimated Loss ($)				**$ 23,610,000.00**		
Estimated Order of Magnitude of Losses				**Tens of millions**		
Permanent Population at Risk				**45**		

6.25 GR-10

Inundation mapping for the Orma Dykes did not indicate the depth of inundation or flood velocity, however given the amount of water held in the reservoir, and the constricted topography adjacent to the community before the floodwater will reach the ocean, it was assumed that all infrastructure would be highly damaged. It was estimated that a breach in the GR-10 dyke would lead to damage costs in the tens of millions of CAD range, with a population of approximately 54 persons being affected.

Table 28: GR-10 Dam Consequence Assessment

Background Information	
Dam Name:	GR-10
Project Name:	Churchill Falls Hydroelectric Development
Dam Owner:	Nalcor Energy – Churchill Falls
Inventory Number:	1150
Assumed Breach Conditions:	PMF Conditions

Background Information						
Downstream Communities:	North West River, Sheshatshiu					
Consequence Assessment						
Infrastructure Type	Number Affected	Unit	Cost Per Unit	Total Cost	Comments	Reference
Homes	18	per home	$ 350,000.00	$ 6,300,000.00		Century 21 Canada Ltd., 2017
GR-10 Dam	990	metre	$ 2,000.00	$ 1,980,000.00		Delcan, 2011
Concrete Bridge	175	metre	$ 98,000.00	$ 17,150,000.00		GPA, 2016b
Total Estimated Loss ($)				**$ 25,430,000.00**		
Estimated Order of Magnitude of Losses				**Tens of Millions**		
Permanent Population at Risk				**54**		

7.0 FLOOD INUNDATION MAPPING IDENTIFICATION AND METHODOLOGIES

7.1 Identification of Dams without Inundation Mapping

The majority of dams in the province do not currently have flood inundation mapping, which is a key aspect in properly classifying a dam as per the CDA Guidelines. A prioritized list of dams in the dam inventory database with an Extreme, Very High, or High classification that do not currently have dam failure inundation mapping, but should have it developed has been created and is included in **Appendix F**.

The methodology for assigning a priority to a dam was based on its classification. The Loss of Life classification is the most important consideration. Accordingly, a dam with an Extreme Loss of Life classification was given a priority of 1, a Very High Loss of Life classification was priority 2, and a High Loss of Life classification was priority 3 based on the number of fatalities expected; each regardless of what their Environmental & Cultural Values and Infrastructure & Economics classifications were. For the purpose of prioritization, the inundation mapping to be completed the Environmental & Cultural Values and Infrastructure & Economics (E&C/I&E) classifications were assigned a lower priority compared to Loss of Life. For example, a dam with an Extreme classification in either of these two categories, but with a Significant or Low Loss of Life classification was given a lower priority than a dam with an Extreme, Very High, or High Loss of Life classification. A dam with an Extreme E&C/I&E classification and a Low or Significant Loss of Life classification was given a priority of 4, a Very High E&C/I&E classification and a Low or Significant Loss of Life classification was priority 5, and a High E&C/I&E classification and a Low or Significant Loss of Life classification was priority 6.

Each priority level was subsequently divided based on the non-governing classification. For example, a dam with a Loss of Life classification of Very High was given a priority of 2. If its E&C/I&E classification was Extreme it was considered priority 2A, but if its E&C/I&E classification was Very High it was considered priority 2B, and so on. It should be noted that the prioritized list in **Appendix F** begins with a priority of 2 as there were no dams in the database that had an Extreme Loss of Life classification that do not already have inundation mapping completed.

It is important to note that dam classification information was obtained from available information in the database and a check on the accuracy of that information was not carried out as part of the current study. There is potential for dams to have incorrect classifications in the database meaning that some of the dams included in the list may not actually be required (i.e., their classification is actually lower than High) or, more importantly, that some dams are missing from the list (i.e., the classification in the database was lower than High, but in reality, is High or above; or the classification was not given in the database). For these reasons if any future studies are to be completed using this information, a detailed review should be completed first to verify the accuracy of the classifications.

It should also be noted that it is possible that some dam owners may currently be working on developing dam break flood inundation mapping. For example, it is known that Newfoundland and Labrador Hydro is currently in the process of completing a flood study for the Exploits River development and it is expected to be ready later this year. In addition, Deer Lake Power and the Department of Natural Resources are both currently in the process of completing dam break inundation mapping for their developments/sites as well.

7.2 Methodologies for Derivation of Dam Break Flood Inundation Mapping

As a part of Golder's inventory and assessment of dams in Newfoundland and Labrador study, a document summarizing flood inundation mapping methodologies was prepared (Golder, 2017a), which can be found in **Appendix G**. Part of the scope of work for that task was to demonstrate some of these methods using a dam in Newfoundland & Labrador. This section presents the results of this exercise for the Deep Bank Dam upstream of Deer Lake, in Newfoundland.

The Deer Lake Hydroelectric Generating Station has been in operation since 1925. The structures of the generating station include the Main Dam, the Power Canal (which includes the Intake Control Dam, the Long Bank Dam, the Deep Bank Dam and the West Bank Dyke), and the Forebay Dam.

The Deep Bank Dam is located across a deep valley and is approximately 280 m long. The dam has a downstream shell of tipped earthfill and an upstream impervious zone. The crest width of the dam varies from approximately 9 m to 19 m and the downstream and upstream slopes of the dam are approximately 2H:1V and 3H:1V, respectively.

A breach of the Deep Bank Dam would release flow into the old Glide Brook valley, which runs along the eastern edge of Deer Lake and, ultimately discharging into the Upper Humber River. Along the flow path, infrastructure of interest includes the CN Railway Bridge, the Trans-Canada Highway and portions of the Deer Lake Airport.

Four (4) different methodologies with varying complexity were used to predict the downstream effects of a breach in the Deep Bank Dam:

- Photo-based topographic mapping method (simplest method, highly conservative);
- SMPDBK modelling (simplified);
- Unsteady, two-dimensional modelling (advanced); and,
- Steady state, one-dimensional modelling (Intermediate).

The four methodologies are described in the following sections including the process used to create the inundation maps, a description of the level of refinement provided by the methodology, its potential uses, and its limitations. Recommendations on selecting an appropriate methodology for modelling a hypothetical dam breach scenario are provided in Section 7.3. The resulting inundation maps produced through each of the four methodologies can be found in **Appendix H**.

7.2.1 Simplified Photo-Based Topographic Mapping Method

The simplest of the four inundation methodologies performed by Golder is a photo-based topographic mapping method developed by the North Carolina Department of Environment and Natural Resources based on practices outlined by the Association of State Dam Safety Officials (ASDSO). The method is widely used by ASDSO for creating simplified inundation maps (SIMS) for the purpose of developing Emergency Action Plans (EAPs). The method involves performing simple calculations to determine anticipated downstream wave heights based on the height of the dam and distance from the dam downstream. The results of the calculations are then transferred onto aerial photos and/or topographic maps to delineate areas that would likely be susceptible to inundation after a dam breach (North Carolina Department of Environment and Natural Resources, 2015).

SIMS are a quick, inexpensive way of determining whether or not there are any features downstream of a dam that would be considered at risk if a dam breach were to occur, and to determine whether or not further mapping should be considered. Photo-based SIMS are generally applicable only when the dam is small or intermediate in size and has an easily-identified number of downstream structures, and for those small and intermediate size dams for which the resources are not available for in-depth hydrotechnical analysis. Local emergency management must agree that adequate evacuation procedures can be established for the areas identified as at-risk. If and when resources become available, the photo-based maps should be updated with a higher-depth analysis where necessary (Association of Dam Safety Officials, 2009).

For the purposes of this project, the photo-based method was used to map the inundation area from a hypothetical breach involving the Deep Bank Dam. It should be noted that due to the relatively large population immediately downstream from the dam, photo-based SIMS would not be appropriate as the only inundation maps for the Deep Bank Dam. Despite this, the photo-based method was still used for comparison purposes with the more complex methods described in later sections.

7.2.1.1 Photo-Based Mapping Methodology

A Photo-based mapping method may be used as a screening tool to assess dam failure impacts. The first step in performing the photo-based method is to obtain aerial photos to determine whether or not there are any at-risk features downstream from the dam. Next, a topographic or contour map should be obtained and placed overtop the aerial photos. For the purposes of this project, Bing maps were used in combination with ArcGIS software to view the area downstream from the Deep Bank Dam. A contour map for the Deer Lake and surrounding area was created using a combination of topographic information form community mapping and digital elevation model (DEM) points obtained from the Government of Newfoundland and Labrador. This contour map was loaded into ArcGIS over the Bing Maps in order to perform the simplified modelling.

The height of the dam that is hypothetically being breached is the only parameter related to the reservoir that is required for the modelling calculations. In this case, the height of the Deep Bank Dam is 22 m. The next step in the simplified modelling process is to assume that the initial breach wave height just downstream of the dam is about half the height of the dam (North Carolina Department of Environment and Natural Resources, 2015), or

11 m in the case of Deep Bank Dam. From this value, calculations are completed based on the assumption that the height of the breach wave would decrease by half every 16 km (10 miles), downstream. Table 29 outlines the calculations completed for an area up to forty (40) km (25 miles) downstream of the Deep Bank Dam. It should be noted that the rate of flood wave attenuation along the flow path is highly dependent on the terrain and therefore empirical estimates of the flooding impact zone can only be considered a screening tool.

According to the photo-based mapping procedure, as a general guideline, the distance to be analysed downstream from the dam is based on the normal surface area of the reservoir. For reservoirs less than 0.10 sq. km (25 acres), approximately three (3) km (2 miles) should be measured, for reservoirs between 0.10 sq. km and 0.40 sq. km (25 to 100 acres), approximately eight (8) km (5 miles) should be measured, and for reservoirs 0.40 sq. km (100 acres) or more, approximately sixteen (16) km (10 miles) should be measured (North Carolina Department of Environment and Natural Resources, 2015). These distances may need to be modified based on the population density and infrastructure at the end of the recommended distance downstream, or if the breach wave becomes contained within the stream channel limits before reaching the recommended distance for analysis. The Deep Bank Dam reservoir has a surface area of 1.78 sq. km (440.83 acres), meaning a minimum of sixteen (16) km was recommended to be measured downstream. However, at the end of the 16 km the wave height was still over five (5) metres, and since it was known that there are populations further downstream, the distance was extended in order to encompass a larger area. After forty (40) km, the wave height was still 2.06 m, however the inundation map showed that the breach wave was generally contained within the Humber River.

Based on the calculations in Table 29, the next step in creating SIMS is to define the inundation area using both the calculated downstream wave heights and the topographic data for the area. To do this, a scale should be developed that allows the measurement of distances downstream from the dam based on the aerial photos, e.g. 5 cm on an aerial or topographic map is equal to approximately 0.8 km (0.5 mile). Points downstream from the dam should be selected where contours cross the assumed flow-path that the floodwater will take, and a cross section should be drawn perpendicular to the flow-path at each point (Figure 1**)**. It should be noted that for the purposes of this project, mapping was created using ArcGIS software and therefore the above scale method was not utilized, as the distances were simply measured using built-in ArcGIS tools. However, in cases where digital mapping tools are not available, SIMS can be developed just as easily by hand using physical images and an appropriate scale.

Table 29 - Topographic Mapping Methodology Results

Background Information		
Crest Height (m) = 22		
Distance Downstream (miles)	**Distance Downstream (m)**	**Wave Height (m)**
0	0	11.00
0.5	805	10.74
1	1609	10.45
1.5	2414	10.18
2	3219	9.90
3	4828	9.35
4	6437	8.80
5	8047	8.25
6	9656	7.70
7	11265	7.15
8	12875	6.60
9	14484	6.05
10	16093	5.50
11	17703	5.23
25	19312	4.95
13	20921	4.68
14	22531	4.40
15	24140	4.13
16	25749	3.85
17	27359	3.58
18	28968	3.30
19	30577	3.03
20	32187	2.75
21	33796	2.61
22	35405	2.48
23	37015	2.34
24	38624	2.20
25	40234	2.06

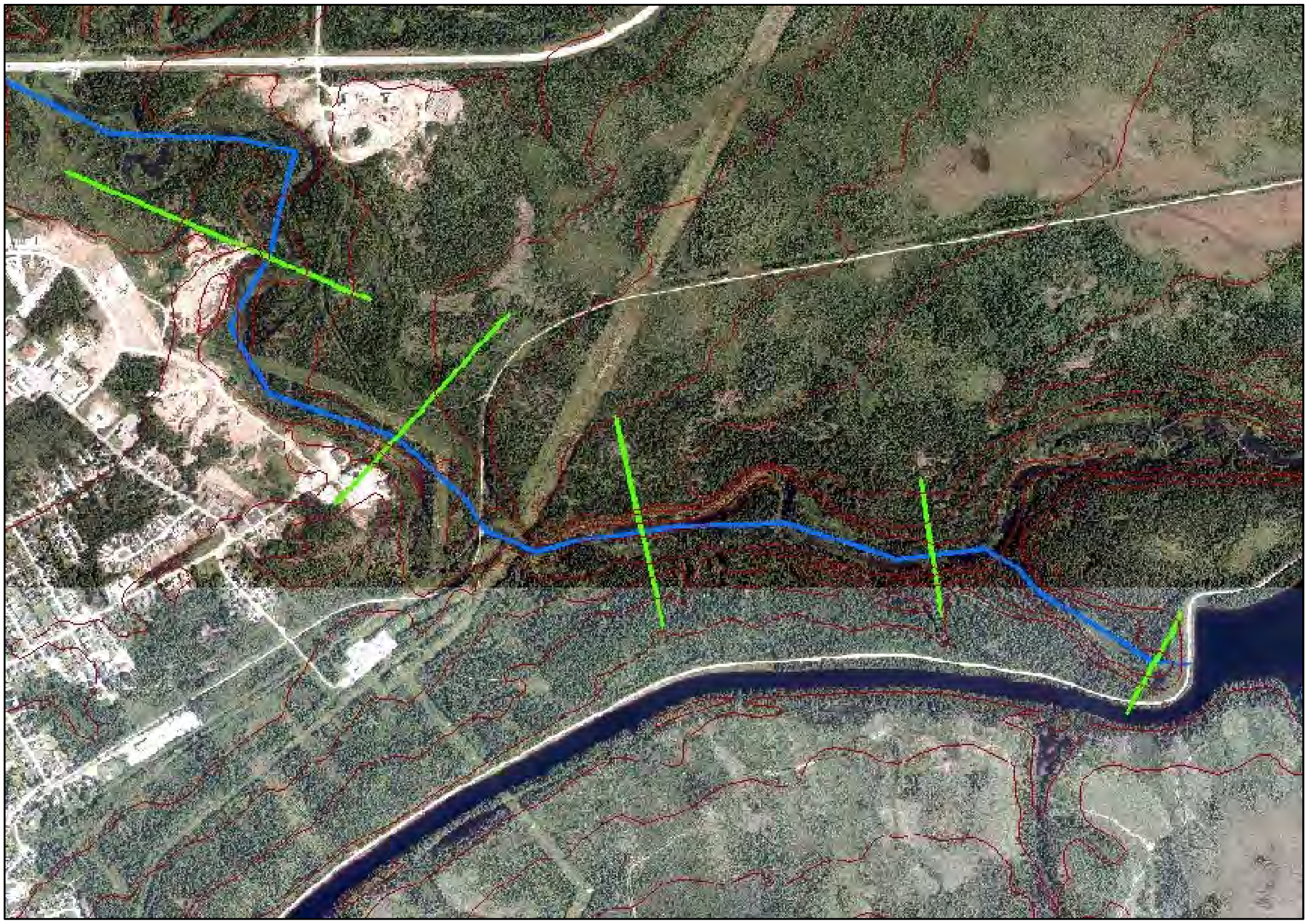

Figure 1: Cross sections (green) along initial portion of assumed flow path (blue) from Deep Bank Dam breach. Elevation contours shown in dark red.

At each cross section, the distance downstream from the dam should be measured and the corresponding breach wave height determined from the calculations in Table 29. The wave height is used to count up from each side of the flow-path to the contour that corresponds with the wave height, where a point should be drawn that represents the floodwater extents at that distance downstream. It should be noted that the more detailed the contour map, the more accurate the inundation boundaries will be. Once completed for each cross section, all boundary points should be joined to form a polygon that delineates the inundation zone, as seen in Figure 2. The full inundation map for the Deep Bank Dam breach scenario is shown in Figure 10 of **Appendix H.** For comparison purposes with the following methods, Figure 11 of **Appendix H** includes a close up view of the resulting inundation area throughout the Town of Deer Lake.

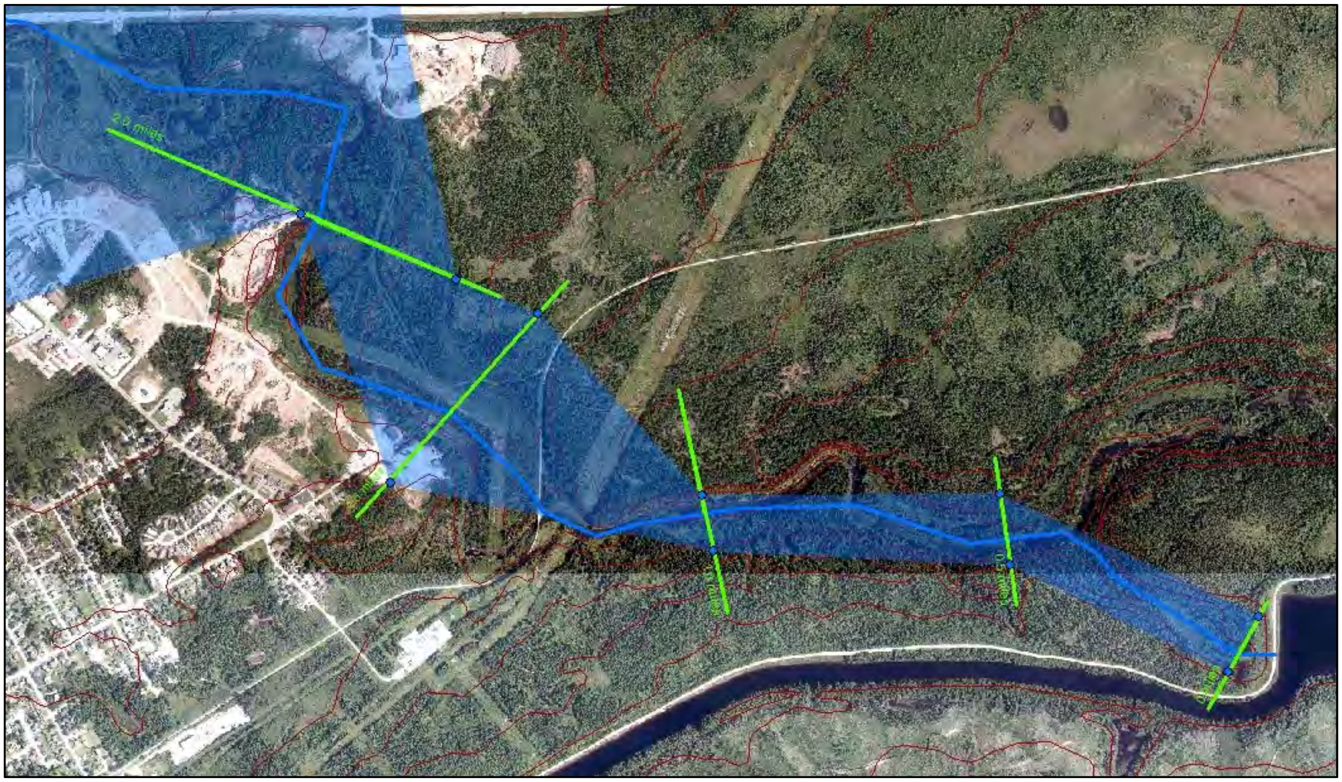

Figure 2: Assumed inundation zone (blue) from a hypothetical Deep Bank dam breach using the photo-based simplified inundation mapping method.

7.2.1.2 Limitations of Photo-Based Inundation Mapping

The photo-based method is one of the simplest forms of inundation analysis that can be completed, and therefore comes with a variety of limitations. Firstly, the topographic method does not take into account any restrictions in topography that may cause floodwaters to backup and inundate in the direction opposite to the direction of flow at an intersecting stream for example. For this reason, the inundation zone shown in Figure 10 of **Appendix H** does not include the area northeast of Deer Lake, extending beyond the airport, into Reidville, and back towards Main Dam. As a result, the method may be considered somewhat over conservative in some cases when it comes to the area shown as being at risk for inundation downstream, as all the floodwater is placed downstream instead of backing up due to topographic restrictions as shown in the higher complexity modeling. This is evident in the photo-based method as the floodwater from the Deep Bank Dam breach extended a great distance down the Humber River towards downstream communities such as Pasadena and Little Rapids, whereas the other, more complex methods showed the floodwater instead backing up towards Reidsville, and not extending as far down the Humber River towards Corner Brook.

The photo-based method is also highly dependent on the number of cross-sections used to develop the map. If cross-sections are only used every few kilometres, the inundation zone will be less precise than if cross-sections were drawn at smaller intervals. An example of the importance of cross-sections can be seen in Figure 2 above, where a section of the assumed flow-path between the 2.4 km (1.5 miles) and 3.2 km (2.0 miles) cross-sections is outside the inundation zone. Because the flow-path has some sharp turns in this area, the section was not accounted for between the 2.4 km and 3.2 km cross-sections. In order to assure that this section would be included, an additional cross-section would have needed to be placed at approximately 2.8 km (1.75 miles) to show how the floodwater would behave in this section.

While the photo-based method does have its limitations, it has proven to be useful in providing a rough idea of the inundation zone. Photo-based SIMS can assist in determining whether or not structures or populations are at risk downstream from a dam that would indicate more detailed inundation mapping should be completed.

It should be noted that SIMS are not appropriate for dams that have a significant or high consequence assessment, or any population downstream. SIMS should be used in instances where a dam safety review has never been completed in order to assess whether or not there are hazards in the potential inundation zone that warrant further, more detailed, flood inundation mapping (Association of Dam Safety Officials, 2009).

7.2.2 Simplified Dam Break Modelling Method using SMPDBK

The second method used by Golder to model a breach in the Deep Bank Dam was another simplified procedure called Simplified Dam Breach (SMPDBK), which is available through RiverMechanics.net. Developed by the US National Weather Service (NWS) in 1983, SMPDBK estimates the outflow hydrograph from a breach and produces information for delineating areas susceptible to inundation from dam-break floodwaters. Unlike other, more complex methods, SMPDBK can quickly be used to calculate inundation with only a limited amount of input data. With minimal information about the breach and reservoir itself, the program predicts the dam-break peak flows, peak flood elevations, and peak travel times at select downstream points (Wetmore et. al., 1991).

It should be noted that SMPDBK only outputs data related to inundation, and cannot actually produce inundation maps within the program itself. For this reason, Golder used a program called Watershed Modeling System (WMS), available from Aquaveo, which has SMPDBK embedded within it. A physical model can be created in the WMS program using basemaps, topography, and streamlines, and is capable of taking the data from SMPDBK and using it to draw the calculated inundation area over top of the input basemap and topography. If WMS is not readily available, the stand-alone version of SMPDBK can be downloaded for free from RiverMechanics.net and used to create inundation maps in ArcGIS. The inundation data generated at each specified cross section in SMPDBK can be used to draw the inundation area in ArcGIS in a similar manner to the previously described photo based method. A contour map and basemap can be loaded into ArcGIS, the same cross sections as specified in SMPDBK can be drawn downstream, and the flood water depth at each of the cross sections, as calculated by SMPDBK, can be drawn in to delineate the inundation area. Numerous cross sections will need to be specified in SMPDBK in order to be able to produce a meaningful map in ArcGIS. The more cross sections that are generated, the more accurate the inundation area will be.

SMPDBK simulations are run by implementing the following three steps (Wetmore et. al., 1991):

- Calculating the peak outflow at the dam using the temporal and geometrical description of the breach and the reservoir volume, which are parameters input by the user;
- The model approximates the downstream channel as a prism, and uses only the effects of peak flow, maximum water surface elevation, and travel time, therefore neglecting factors such as backup from downstream constrictions, such as bridges, culverts, other dams, or topographic constraints; and,
- The model calculates dimensionless peak-flow routing parameters using families of dimensionless routing curves to determine the peak flow at user-specified cross sections downstream from the dam. The dimensionless peak-flow routing curves used were developed by NWS using their more complicated DAMBRK modelling program.

To model the hypothetical Deep Bank Dam breach using WMS, a basemap and elevation data were first obtained through the WMS program to create a digital elevation model (DEM) of the area of interest. Based on the DEM, WMS runs an internal program called TOPAZ which computes flow directions for individual DEM cells and creates streamlines based on these directions. The user then isolates a single stream centerline using the results from TOPAZ, which represents the main flow-path the floodwater would follow from the breach location (Aquaveo, 2015). The final step in setting up the model is to create cross sections along the stream centerline. The cross sections should intersect the stream channel perpendicularly, and while there is no specified minimum number of cross sections that must be drawn, the more cross sections that are included, the more refined the final result of the model will be. For the purposes of this project, the stream centerline isolated was Glide Brook, extending from the location of Deep Bank Dam, and through the northeast portion of Deer Lake until the brook joins the Humber River. Three (3) cross sections were cut through the centerline, as shown in Figure 3**.**

Figure 3: Screenshot from SMPDBK program showing flow-path (blue) and cross sections (light grey).

Parameters regarding the reservoir dimensions and dam breach geometry are then specified in SMPDBK by the user before running the model. In cases where certain parameters may not be known, SMPDBK supplies default values, however these values are not representative of all dam breaches and will lead to less accurate results if used (Wetmore et al, 1991). The parameters used in modelling the Deep Bank Dam breach are shown in Figure 4. Examples of the various equations and relationships used to calculate values for these parameters are described in Golder's document summarizing flood inundation mapping methodologies, which can be found in **Appendix G**. It should be noted that the input parameters were kept constant throughout each of the modeling methodologies to ensure the model results could be accurately compared.

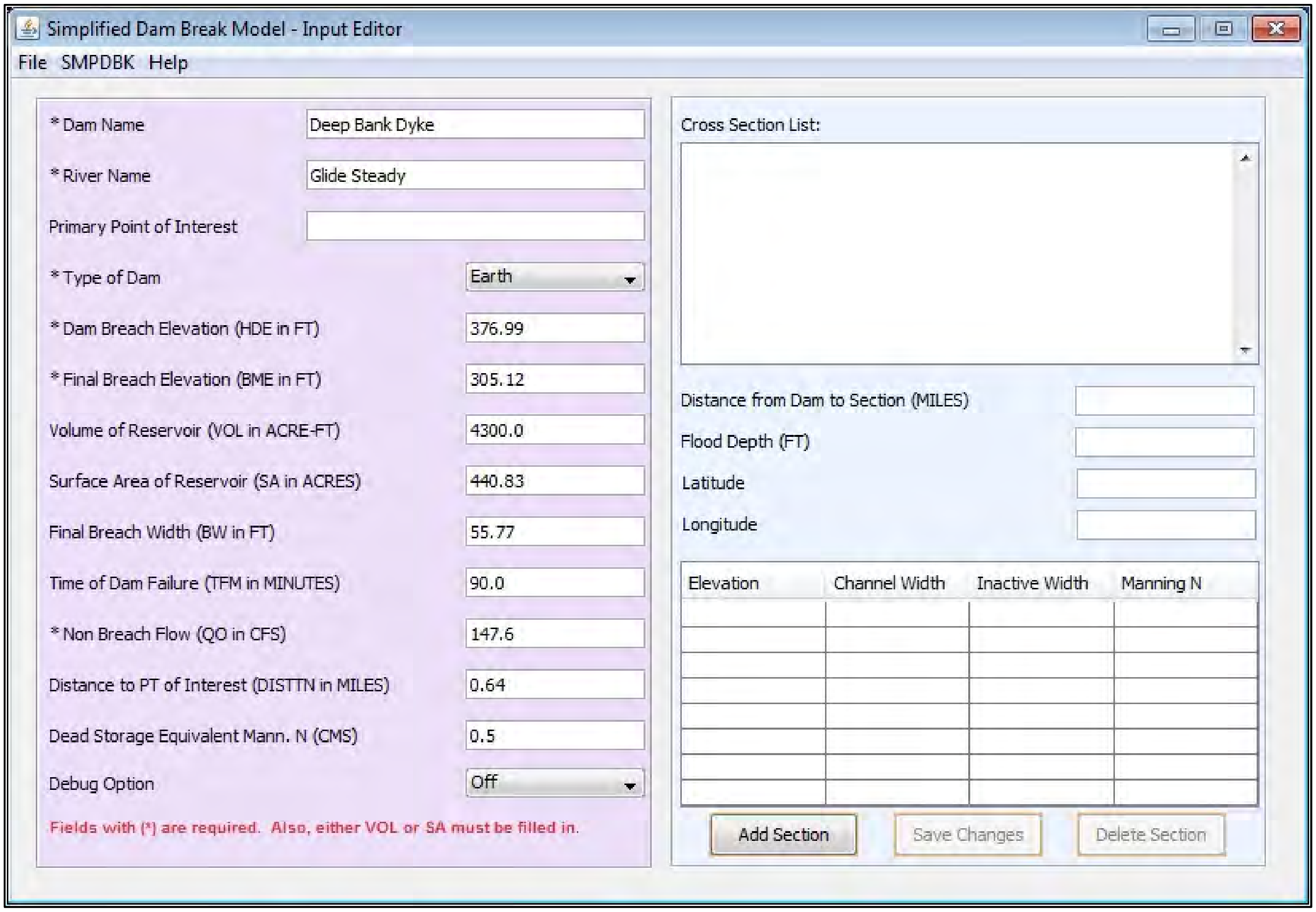

Figure 4: Parameters used for Deep Bank Dam breach SMPDBK model.

Figure 5 shows the area of Deer Lake that that would be subjected to inundation from the Deep Bank Dam breach that was generated using SMPDBK and WMS, based on those parameters specified in Figure 4. A full version of the inundation map can be found in Figure 12 of **Appendix H**, followed by a close up view showing just the inundation affecting the Town of Deer Lake in Figure 13. Table 30 outlines the results of the modelling at the three specified cross sections. While the inundation zone follows the same pattern as those produced with the other methodologies tested, SMPDBK appears to be somewhat conservative compared to the two more complex methods in that a much larger area is expected to succumb to floodwater, particularly the area north of Deer Lake towards Reidsville, as well as a large portion of the downstream Humber River.

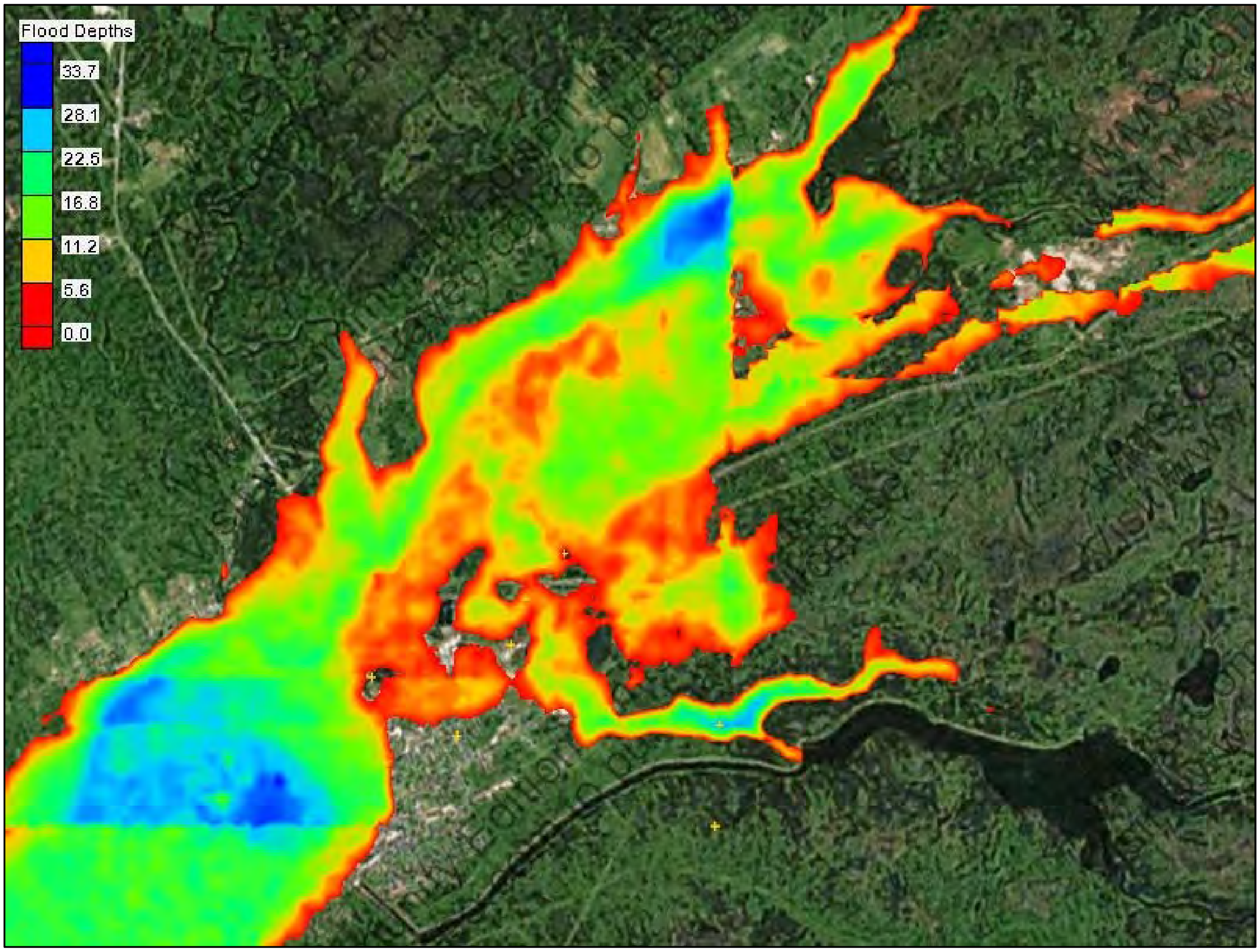

Figure 5: SMPDBK model showing inundation area from Deep Bank Dam Breach

Table 30: Results of SMPDBK Modelling

Cross Section	Distance Downstream (km)	Peak Flow (m^3/s)	Maximum Water Elevation (m)	Maximum Water Depth (m)	Peak Flood Arrival Time (hr)
1	0.00	1742.59	24.67	8.00	1.50
2	2.88	1042.06	6.65	1.85	2.16
3	5.10	691.00	5.85	3.80	3.22

7.2.2.1 SMPDBK Limitations

While SMPDBK is relatively simple to use, it will likely not be effective if the parameters related to the dam breach, such as those shown in Figure 4, are not known for the dam in question. In many cases throughout the province, dams were built many years ago and little to no documentation exists regarding their physical properties, particularly when it comes to those dams acting as water supplies for smaller communities. In cases like these, SMPDBK would likely not be a useful tool, as modelling the dam using the default parameters provided by SMPDBK would not yield accurate results regarding potential inundation.

While the SMPDBK GUI itself is free, in a WMS license costs approximately 3,000 USD, it is not practical for smaller communities to purchase to create inundation maps for just one dam. For larger communities or companies who own several dams, and whose dam characteristics are known, WMS may be a more realistic option for creating inundation maps.

7.2.3 Unsteady-State, Two-Dimensional Approach

The third method analysed was unsteady-state, two-dimensional modelling, and was the most complex of the four methodologies. In this case, the following three steps were used:

- Estimation of dam breach geometry. The breach geometry was defined using the recommendations of Veale and Davison (2013) and Froehlich (2008) as described in Golder (2017b) (**Appendix G**);
- Generation of the dam breach outflow hydrograph. The dam breach outflow hydrograph was generated using HEC-HMS software, developed by the US Army Corps of Engineers; and,
- Simulation of the movement of the peak flood wave along the downstream flow path to determine the inundation area and travel time. The movement of the peak flood wave along the downstream flow path was modelled using HEC-RAS 5.0. (2016) software for two-dimensional modelling.

7.2.3.1 Hydrograph Generation

The HEC-HMS software input parameters used to generate the outflow hydrograph are shown in Table 31.

Table 31: HEC-HMS Deep Bank Dam Breach Analysis Input Parameters

Description		PMF Scenario
Deep Bank Dam Breach Parameters	Deep Bank Dam crest elevation (m)	113.0
	Surface water level (m)	113.0
	Final bottom breach width[2] (m)	17
	Bottom elevation of breach[3] (m)	93.0
	Breach side slope[4] (_V:1H)	0.7
	Breach formation time[3] (hr)	1.5

Notes:
[1] Water volume estimated using elevation-storage relationship
[2] Adjusted to match Froehlich peak flow estimation (Golder, 2017b)
[3] Bottom of old Glide Brook channel
[4] Assumed based on guideline recommendations, Froehlich D.C. (2008)

The resulting outflow hydrograph has a peak discharge of 2,744 m^3/s and is shown in Figure 6.

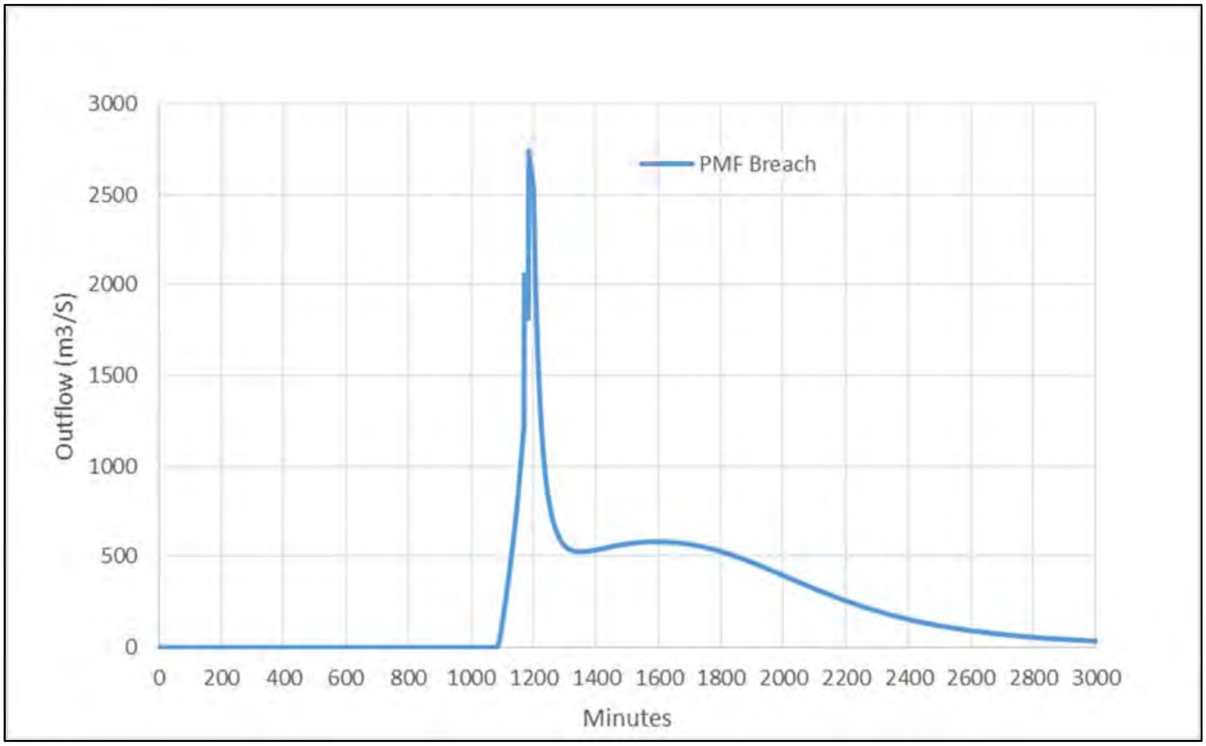

Figure 6: Deep Bank Outflow Hydrograph

7.2.3.2 Flood Routing Simulation

The HEC-RAS software was used to simulate the movement of the peak flood wave in order to define the duration and spatial extent of inundation downstream of the Deep Bank Dam. The geometry model was developed using a combination of the 1 m, 2 m and 5 m contour information obtained from the Department of Fisheries and Land Resources, Fish and Wildlife Enforcement Division.

The following main inputs were required to simulate the peak flood wave using the dam break flood hydrograph:

- Outflow hydrographs from the Deep Bank Dam breach under PMF conditions;
- Boundary conditions:
  - Upstream: inflow hydrographs from Upper Humber River and Grand Lake
  - Downstream: normal depth at Deer Lake; and,
- Roughness (Manning's) coefficient of 0.06.

A screenshot of the geometry file is shown in Figure 7.

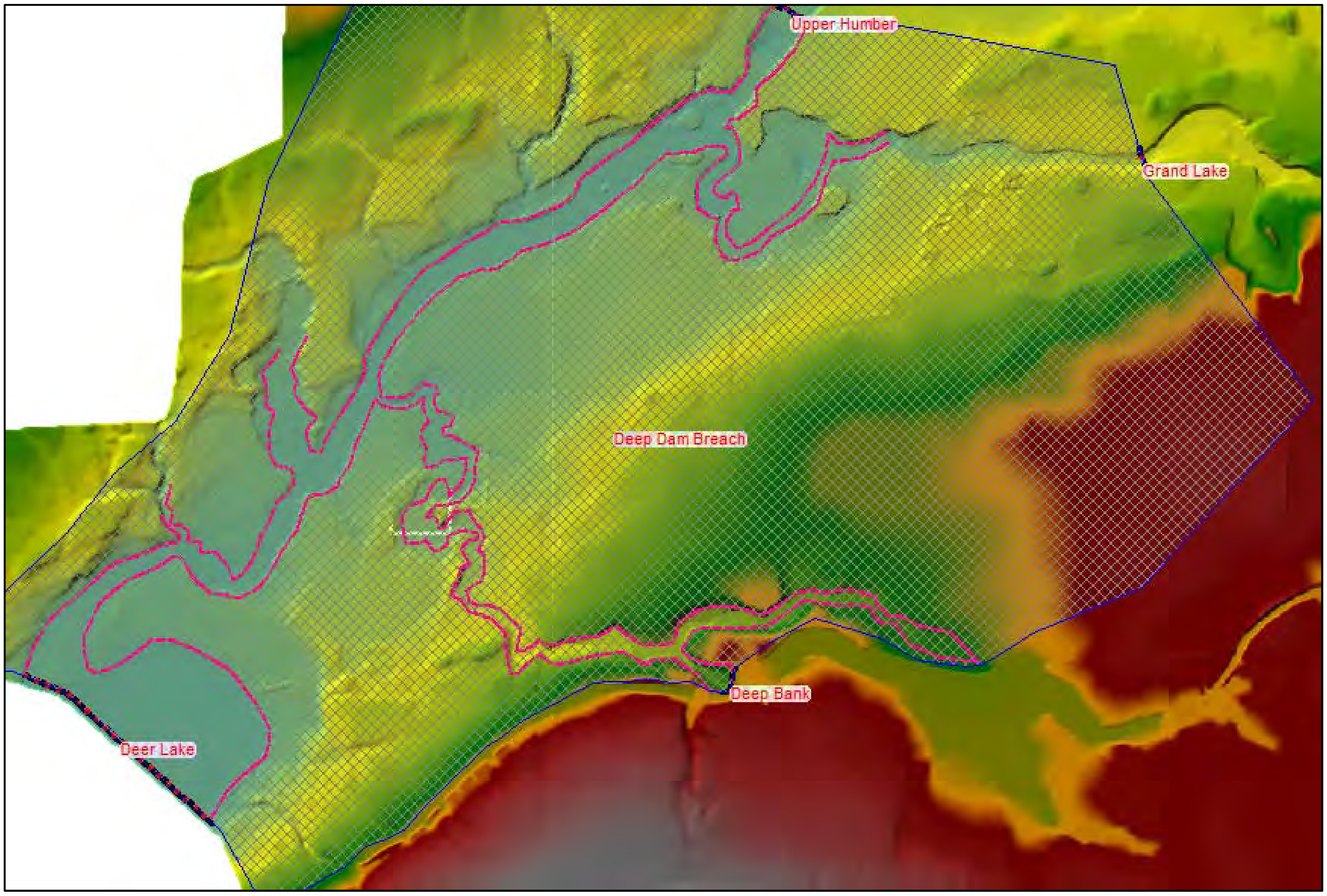

Figure 7: Geometry file for Deep Bank Dam

7.2.3.3 Simulation Results

The passage of the peak flood wave down the Glide Brook valley from a breach at Deep Bank Dam to the Upper Humber River would take place in about 2.4 hrs. The dam breach under PMF conditions is the most critical and would most likely affect the CN Railway Bridge, Trans-Canada Highway and portions of the Deer Lake Airport, which is located about 6.5 km north northwest from the Deep Bank Dam. Table 32 shows the maximum water depth and peak flow velocity at various locations of interest. The inundation map produced can be seen in Figure 14 of **Appendix H**.

Table 32: Unsteady-State - Deep Bank Dam Breach Results

Point of Interest	Distance from Deep Bank Dam (km)	Maximum Water Depth (m)	Peak Flow Velocity (m/s)	Peak Flood Arrival Time Since Breach Started (hr)
Railway Crossing	2.2	5.67	4.96	1.63
HWY bridge crossing	5.3	3.87	4.09	1.73
Airport Area	6.5	5.07	3.08	1.98
Outflow to Upper Humber River	7.0	6.88	3.85	2.41

7.2.4 Steady-State, One-Dimensional Approach

The final method used for the Deep Bank Dam breach was a simplified version of the method previously described in Section 7.2.3. The method followed the same steps for determining breach geometry, and used the same hydrological model generated. However, instead of using the entire outflow hydrograph generated, only the peak flow from the hydrograph was used. Inherent in this assumption is that there is no attenuation of the flood wave, which is conservative. A similar three step approach was involved in the modelling:

- The same breach geometry as in Section 7.2.3 was assumed;
- The peak discharge from the outflow hydrograph generated in the unsteady state case was used throughout the flow path as normal flow; and,
- The maximum inundation level under the peak discharge was modelled using HEC-RAS 5.0. (2016) software for one-dimensional modelling.

7.2.4.1 Hydrograph Generation

The peak PMF discharge from the outflow hydrograph generated in Section 7.2.3.1 was used (2,744 m^3/s).

7.2.4.2 Flood Routing Simulation

The HEC-RAS software was used to simulate the maximum flood depth and spatial extent of inundation downstream of the Deep Bank Dam.

The same contour map used for the unsteady-state modelling was used, with cross sections as shown in Figure 8. The cross sections extend from the downstream of the dam to the flow path discharge into the Upper Humber River.

The following main inputs were required to simulate the peak flood wave using the dam break flood hydrograph:

- Peak discharge from the Deep Bank Dam breach under PMF conditions;
- Boundary conditions:
  - Upstream: normal depth for an upstream slope of 0.03 m/m (upstream slope estimated based on available topography);
  - Downstream: known water surface elevation: 13.89 m. This is the maximum level in the downstream reach (Upper Humber River) under PMF conditions (Golder, 2017b); and,
- Roughness (Manning's) coefficient of 0.06 (same value used for unsteady-state case).

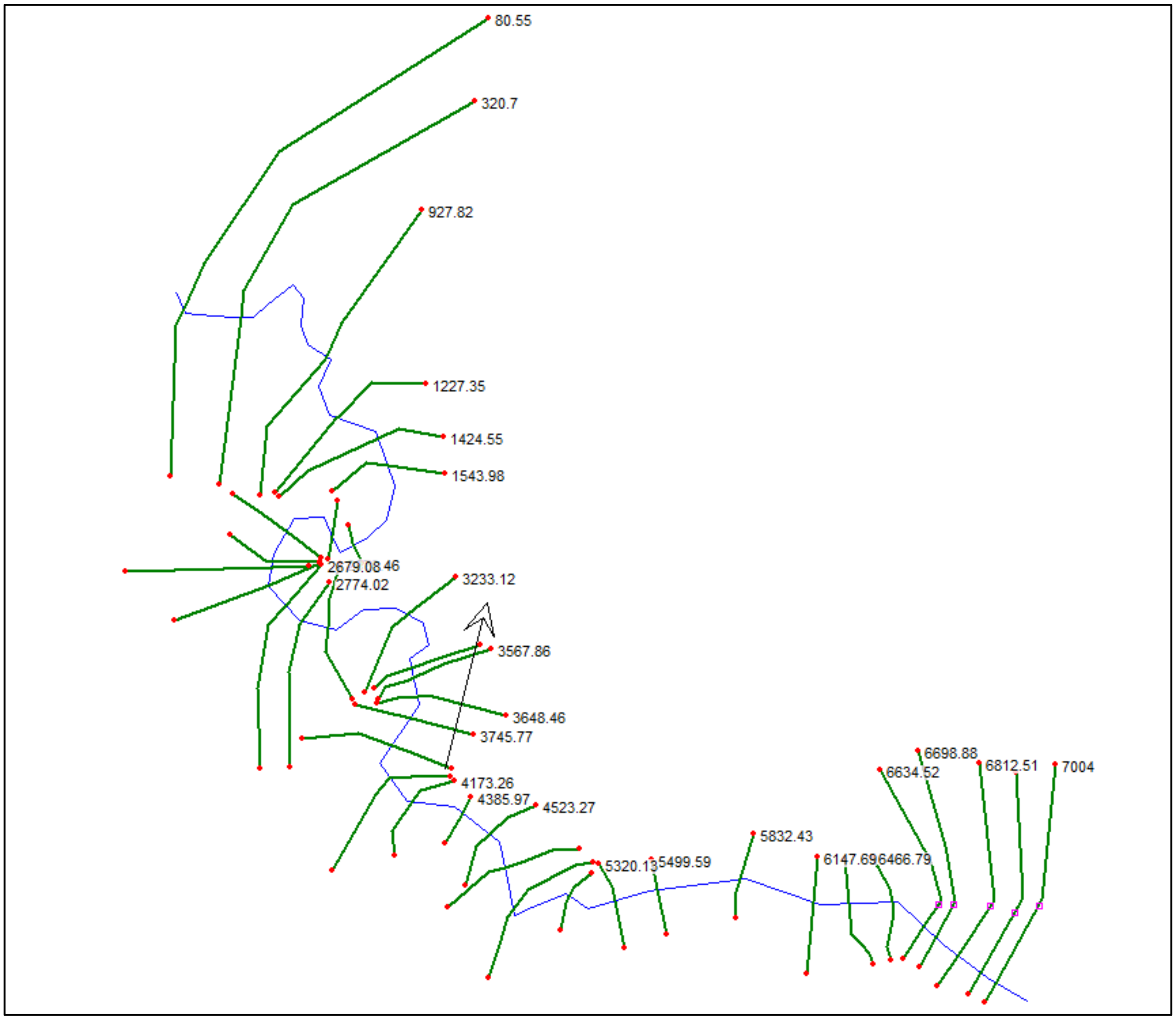

Figure 8: Cross sections for Deep Bank Dam

7.2.4.3 Simulation Results

Table 33 summarizes the results at various points of interest along the flow path under PMF conditions. The inundation map produced can be seen in Figure 15 of **Appendix H**.

Table 33: Steady-State - Deep Bank Dam Breach Results

Point of Interest	Approximate Cross Section Station	Distance from Deep Bank Dam (km)	Maximum Water Depth (m)	Peak Flow Velocity (m/s)
Railway Crossing	4,856.73	2.2	6.8	2.51
HWY bridge crossing	2,496.38	5.3	4.91	2.13
Airport Area	927.82	6.5	5.4	0.69
Outflow to Upper Humber River	80.55	7	6.91	0.55

7.2.4.4 Comparison and Limitations of 1-D and 2-D HEC-RAS Modelling

The steady state, one dimensional approach has the following advantages and disadvantages over the unsteady-state, two-dimensional approach:

Advantages:

- Steady state hydraulic models are easier to set up and run. The instability often encountered when setting up unsteady state models is not present.

Disadvantages:

- Wave travel time and attenuation are not modeled resulting in more conservative estimates of the flood stage.
- Difficult to accurately model flows in flood plains, braided channels, around buildings, etc.

For the Deep Bank Dam breach, a comparison of the model results (Table 34) indicates that, in general, the 1-D steady state model consistently results in a higher inundation depth (from 0.4% to 24% higher at locations of interest along the flow path). In contrast, the peak flow velocities are significantly lower (63% to 150% lower). There are exceptions to this trend that are evident when the inundation maps are super imposed (Figure 9). The yellow circles indicate areas where instabilities in the 2-D model caused short term spikes in water level that artificially raise the maximum water level shown. This is a potential issue with unsteady state models (both one- or two-dimensional). Where possible, instabilities are minimized through modifications of the input files. Where it is not possible to fully eliminate instabilities, model result plots can be used to correctly interpret the results at relevant locations.

Table 34: Comparison of 2-D and 1-D Results

	Maximum Water Depth (m)			Peak Flow Velocity (m/s)		
Point of Interest	**2-D Unsteady State**	**1-D Steady State**	**% Difference**	**2-D Unsteady State**	**1-D Steady State**	**% Difference**
Railway Crossing	5.67	6.80	18	4.96	2.51	66
HWY bridge crossing	3.87	4.91	24	4.09	2.13	63
Airport Area	5.07	5.4	6	3.08	0.69	127
Outflow to Upper Humber River	6.88	6.91	0.4	3.85	0.55	150

In general, the potential impacts of a breach should be used as a guide when selecting between 1-D and 2-D, steady and unsteady state models. Where populations or critical infrastructure, cultural or environmental areas exist downstream of a dam, the extra cost and model complexity of an unsteady state model is justified to accurately predict impacts. Where there is little risk downstream, a simpler steady state model can be considered.

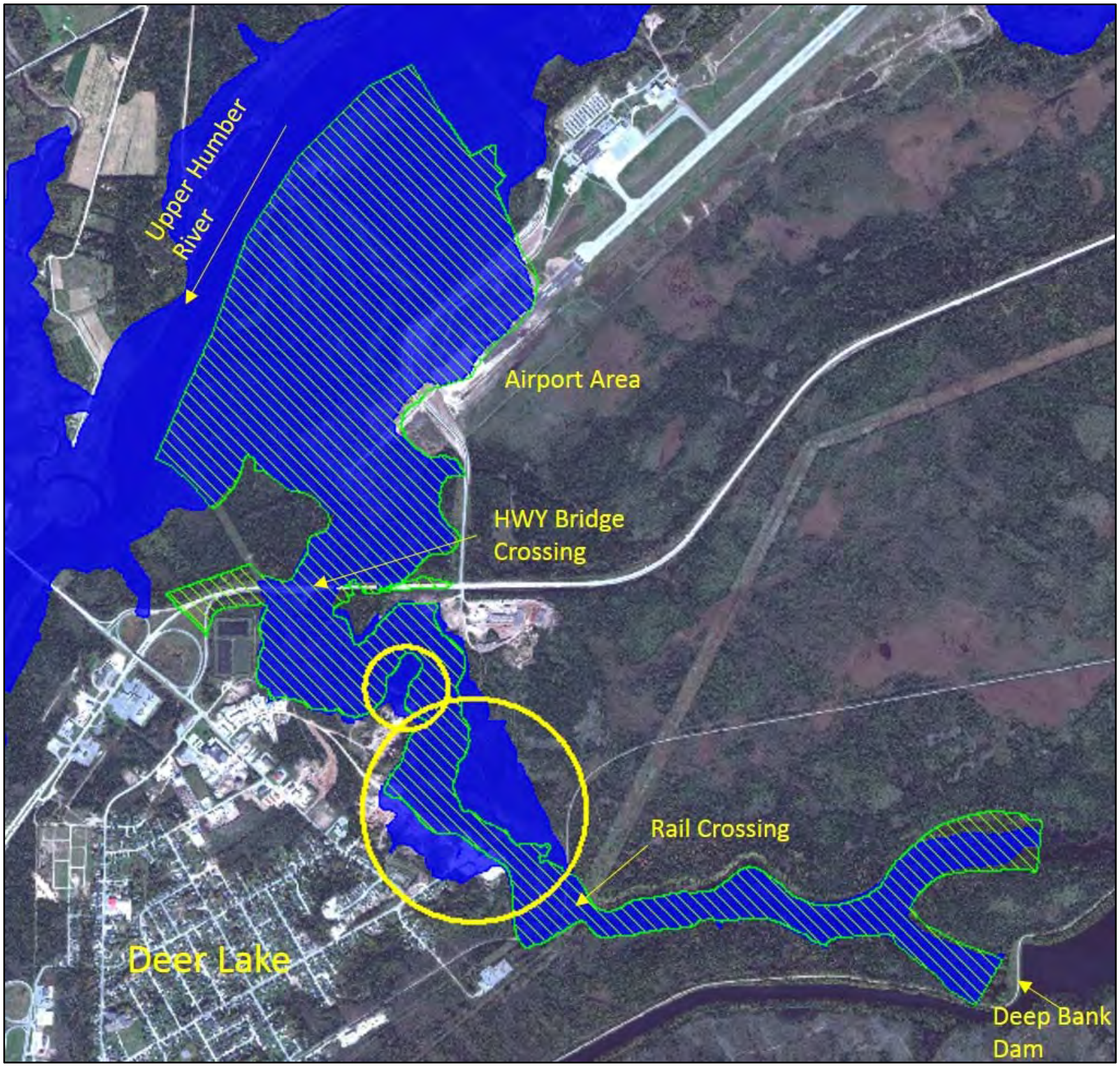

Figure 9: Deep Bank Dam Inundation Map – 2-D, unsteady state model (solid blue), 1-D, steady-state model (hatched green)

7.3 Recommendations for Suitability of Examined Methodologies

The level of effort in carrying out a dam break analysis should be commensurate with the anticipated failure impacts, especially loss associated with the loss of life. CDA Guidelines recommend that simplest and more conservative procedures be applied as a first level approximation for defining the consequence assessment and classification of a dam. If the preliminary analysis shows that there are features downstream that may be at risk of inundation, the complexity and accuracy of mapping methodologies should be increased to confirm the dam classification. These steps allow minimal resources to be required for obviously low-consequence structures where the cost and complexity of larger, more detailed studies is not required (CDA, 2013).

Similarly, FEMA (2013) recommends a tiered approach to determine the appropriate level of complexity in the assessment, modelling, and mapping of a dam failure based on the consequence of failure, and the size and complexity of the downstream area under investigation as shown in Table 35.

Table 35: Recommended Model Types for Various Levels of Dam Breach Modelling

Tier Level	Applicable to	Peak Breach Discharge Prediction	Downstream Routing of Breach Hydrograph
Pre-Screening (non-modeling method) – Photo-based Simplified Inundation Maps (SIMS)	Low-hazard potential and small sized dams with very little infrastructure or population downstream. First level assessment to determine level of detail needed for modeling	SIMS assume initial height of wave at breach is ½ height of dam.	N/A. Water in reservoir routed downstream based on height of the dam. Height of wave decreases by ½ for every 1.6 km (10 miles) downstream.
Tier 1 – Screening and Simple Analysis (basic method)	Low-hazard potential, small size or first-level screening for significant or high-hazard dams	Regression equations, NWS SMPDBK, GeoDam BREACH or TR-66, HEC-HMS or DSAT	GeoDam BREACH, SMPDBK, HEC-RAS steady state, HEC-HMS hydrologic routing or DSAT
Tier 2 - Intermediate	Significant-hazard potential, intermediate-size or high-hazard dams with limited population at risk	HEC-HMS, HEC-RAS Unsteady Model, DSAT or WinDAM	HEC-RAS (steady state or unsteady state modelling) or Two-Dimensional Model for unconfined floodplains
Tier 3 - Advanced	High-hazard potential, large-size dams with sufficient population at risk to justify advance analyses	HEC-HMS, HEC-RAS Unsteady Model, or WinDAM	HEC-RAS Unsteady Model or Two-Dimensional Model

Source: FEMA (2013)

For dams that have an obviously low consequence classification, such as those dams in rural areas with little to no population or infrastructure downstream, a preliminary analysis can be completed using the photo-based method. If it is determined that there may be some related risk downstream, modelling complexity can be increased by using a Tier 1 level study, such as those described in Sections 7.2.2, or 7.2.4. For areas where it is obvious that there is a very high consequence classification, or where preliminary analyses show there may be a significant population or infrastructure in the inundation zone, higher tier methods that have higher accuracy and complexity should be used, such as the Tier 3 methodology outlined in Section 7.2.3. Intermediate Tier 2 level studies may be used for areas where more detailed calculations are justified because of the potential for loss of life. The advanced Tier 3 level may be needed to develop dam breach inundation zone mapping for urbanized areas and for unconfined floodplains (Golder, 2017a).

Of the methodologies investigated by Golder, it is unlikely that 1-D or 2-D modelling using HEC-RAS would be practical for the majority of smaller dams located in rural locations due to the high associated costs and expertise required to develop the models. Often times these smaller dams are owned by the town, which will generally not have the resources available to complete these high-level assessments. Additionally, many of these dams do not contain a large reservoir, and there is a relatively small population, if any, downstream. Therefore, it is recommended to start with a simple analysis, for example the photo-based method, which can be completed without any sort of training. If the results of a photo-based analysis show that the population downstream would be in danger if the dam were to breach, then the resources should be obtained to complete a more accurate analysis. In cases where dams are larger or have a definite population at risk downstream, methods with a higher complexity should be used based on the resources available to complete the mapping and anticipated level of consequences.

When obtaining information from dam owners in the province, it was noted that most dams, particularly smaller dams, do not have any sort of emergency planning in place for a dam breach scenario. In these cases, a photo-based analysis could be used to quickly and simply generate an inundation map that emergency planning can be based on. Although these maps will not be as accurate as those produced with Tier 2 and 3 analyses, they can be distributed to local emergency response teams to help develop an evacuation plan for those people in the inundation area. Again, if initial screening indicates a large population could be at risk, a higher level analysis should be completed to refine the inundation area and develop a precise emergency response plan.

8.0 UPDATING DAM INVENTORY DATABASE

Once Golder received and compiled the information from dam owners, it was possible to update the WRMD's Dam Inventory Database. As previously discussed, this was completed using a binder containing information on the dams that required updating, removal or addition. For dams to be updated, the dam inventory forms within the binder had all the new and updated information highlighted to flag any updates to be made in the database so that it was easily identifiable. A total of two hundred eighty-two (282) dams were updated in the database. A list of these dams can be seen in **Appendix I.**

Any dam entry that was to be removed from the database had its dam inventory number recycled, meaning that all the information for that dam was cleared from that index number and the new dam being added to the database had its information added under that same number. This limited the index numbers in the inventory and avoided adding unnecessary new entries.

The other substantial portion of the inventory update was gathering pictures of each dam and adding them to the respective dam entries in the database. Pictures were collected from the WRMD, dam safety reviews, inspections, and dam owners. Pictures were obtained for two hundred ninety-five (295) dams in the Western and Labrador regions, but were only added to one hundred eighty-six (186) dam entries because it was found that some of the pictures provided by the WRMD were already included in the Dam Inventory Database. After these additions, there are ninety-six (96) dams in these regions which do not have any pictures attached to their dam inventory entries (including new dams that were added to the database during this project). A list of the dams that do not have any pictures associated with them in the database can be found in **Appendix J**. Representative pictures of each dam showing the main dam structure, upstream slope, downstream slope, and any associated structures were selected to be attached to the database entries. The pictures already in the inventory were checked as the new pictures were being added to avoid including any duplicates and to check if any were added to an incorrect dam.

In addition to the Western and Labrador regions, pictures were also obtained and added to the database for six (6) dams in the Eastern Newfoundland region: #742 Water Pond Dam, #2668 Young's Pond Dam, #2669 La Manche Lead Mine Dam, #2673 Red Cliff Radar Station Dam, #2674 Terra Nova Sulphite Mine Co. Mill Dam, and #2676 Western Bay Waterfall Swimming Area Dam.

Additionally, throughout the project if there were any drawings, maps, or reports received for a dam these were saved electronically and any hardcopies received were kept as well. They were then submitted to the WRMD at the conclusion of the project.

The database was only accessible for updating from a Government computer so Golder personnel travelled to the WRMD office and completed the updates there.

9.0 RECOMMENDATIONS

While completing the project, Golder developed a list of recommendations for the WRMD in relation to the Dam and Reservoir Inventory form that was submitted to the dam owners, the Dam Owner Annual Dam Safety Report form used for the dam risk assessments, and the Dam Inventory Database. These recommendations arise from both Golder's own experiences with the project and from speaking with dam owners.

Dam Safety Management

As with the previous year's dam inventory and assessment project it was noted that a large proportion of dam owners do not have inundation mapping completed for their systems. Accordingly, the classification of these dams may not be accurate. The accuracy of a dam classification is very important, as the consequence of a dam failure underlies several of the principles of the CDA dam safety guidelines and inundation mapping is critical for developing an accurate understanding of the consequences of dam failure.

In order to address this deficiency, our first recommendation is that dams that have a conditional CDA dam classification or unconfirmed CDA dam classification (e.g., has not had a classification assigned) should have dam break flood inundation mapping completed immediately to either confirm or assign a CDA dam classification. If dam break inundation mapping is not completed and a classification is assigned, a detailed rational should be provided as to why the inundation mapping is not necessary in order to assign a defendable dam classification.

It is then recommended that the WRMD contact the remaining dam owners based on the prioritized list presented herein and formally request that dam failure inundation mapping be completed for their dams. The timeline for completion should be determined by the WRMD and on a case by case basis.

Dam and Reservoir Inventory Form

The following is a list of updates that Golder recommends being implemented to improve the Dam and Reservoir Inventory form. For the most part, these updates are to benefit the dam owner representatives completing the forms who may not have a technical background in this area and may not be familiar with many of the terms used on the form.

- During the Inventory and Assessment of Dams in Eastern Newfoundland project (Year 1), a pdf form was sent to the dam owners that had to be printed and completed by hand, and was not able to be easily completed electronically. Many owners asked to be sent an editable pdf file of the form because it would be easier, more efficient, and environmentally friendly to electronically fill out the pdf form. For this reason, Golder converted the form into an editable pdf file prior to sending it to dam owners during this Year 2 project. The majority of the dam owners took advantage of this and completed the form electronically, making for a much more efficient process. It is recommended that the WRMD adopt the editable pdf file format of the form for future use.
- During the Inventory and Assessment of Dams in Eastern Newfoundland project (Year 1), it was noticed that many of the dam owners completing the form were not familiar with many of the terms used. This resulted in a large amount of questions being asked to Golder for clarification and guidance, and it decreased the overall

quality and consistency of the information received on the forms. To help mitigate these issues during this Year 2 project, Golder added some attachments to the form which provided helpful information for those completing the form. The information included definitions and images for the various dam types, definitions and a diagram of each requested dimension, definitions and images for the various structures, definitions of design criteria, return period and Probable Maximum Flood (PMF), definitions of freeboard, the definition of catchment area, and the CDA classification table. This extra information was found helpful to dam owners in understanding and completing the information on the form. It is recommended that for future use the WRMD should include attachments with reference information, such as these, with the dam inventory form. Alternately the form can include reference information at the start of each section within.

- Based on experience from the Inventory and Assessment of Dams in Eastern Newfoundland project (Year 1), Golder included questions on the form for this Year 2 project asking if an Emergency Preparedness Plan (EPP) was attached, an Emergency Response Plan (ERP) was completed and attached, a Dam Safety Inspection (DSI) was completed and attached, an Operation and Maintenance (OMS) Manual was completed and attached, inundation mapping was completed and attached, and if a Public Safety Assessment (PSA) was completed or attached. Knowing if these documents were completed or not and having them to review if they were completed was useful in verifying the information provided on the form and determining the accuracy. For this reason, it is recommended that the WRMD includes these questions on the form for future use.
- During the Inventory and Assessment of Dams in Eastern Newfoundland project (Year 1), dam failure information and monitoring equipment information were two significant areas of interest and were requested from dam owners. Although these items were not a focus of this project the value of this information is still clear as it would provide a better understanding of the dam history and the ability to foresee any issues that could result in a failure. It is therefore recommended to include questions on the form asking if a dam failure has ever occurred, with a brief description if so, and if there is any monitoring equipment installed along with details such as the type, location, and operation.
- The quality and accuracy of the information received on the forms during this Year 2 project was improved from that received in the Inventory and Assessment of Dams in Eastern Newfoundland project (Year 1), likely due in part to the extra information given to the owners with the form this time around (as discussed in some of the previous recommendations listed above). However, there was still some information received that either seemed incorrect or was obviously incorrect and proved wrong by other documentation. Since the quality of the information in the database is largely dependent on the information provided in the dam owner's response, it can be seen that a quick QA/QC of any questionable information received would be beneficial. For example, this could be through a follow up call with the dam owner to gauge their level of understanding and verify the information.

Dam Owner Annual Dam Safety Report Form

The following is a list of updates that Golder recommends being implemented to improve the Dam Owner Annual Dam Safety Report form.

- There are some minor content/formatting errors throughout the form. It is recommended that these errors be corrected.
  - On the first page, the text box labelled "Describe Changes to Conditions Downstream of the Dam" is formatted as a single line text box and should be changed to multi-line because if there is a lot of text it does not fit properly and is hard to read.

- The last set of check boxes on the first page for "Reservoir operation as per OMS manual?" is linked to the first set of check boxes on the second page for "IDF inappropriate?". If one of the boxes in the first set is checked and one of the boxes in the second set is subsequently checked, the first set becomes unchecked. The same thing happens if the second set is checked first and then the first set is subsequently checked.
- At the bottom of the first page it states that the form was last updated in May 2016, while the bottom of the second page states the form was last updated in August 2016. These dates should be aligned.
- The set of five check boxes for Dam Failure Consequence Classifications, the set of five check boxes for Condition Assessment, the set of four check boxes for Failure Probability Rating, and the set of five check boxes for Dam Risk Level should all be formatted so that only one of their respective options can be checked at once; such as how the sets of check boxes for Dam Safety Program Elements and Dam Deficiencies are formatted. Being able to select more than one option in each group can cause confusion and errors if this happens to be done by mistake. For example, someone may accidentally check that a dam has a consequence classification of both Very High and Extreme, which would confuse someone else who is reviewing the form.
- In the Risk Level Chart on the fourth page, the dam failure consequence of Low has a [1] next to it indicating that there is a note somewhere related to it. On the preliminary form used in the Inventory and Assessment of Dams in Eastern Newfoundland project (Year 1) there was a note relating to the Low classification, but it was removed in this current form so the [1] should also be removed from the chart.

- It is recommended that a "Follow Up" check box be added to the Dam Safety Program Elements section. The reason for this recommendation is that for some dams the answer to some of the questions was not "yes", "no", or "N/A". An example of this is the "Inspection frequency adequate?" question. The DSR being reviewed may indicate that inspections occur and in some cases, it may also give a frequency, but the problem is that the DSR could be fairly old (e.g., completed ten years ago) and so it cannot be assumed that the same inspection frequency is still carried out. In this situation, it is not acceptable to check "yes" based on what an old DSR says, to check "N/A" because inspections are always applicable, or to check "No" because it cannot be confirmed that the inspection frequency is not adequate without copies of the inspection reports. In this case a "Follow up" option would be the most appropriate option so that the owner could be contacted to provide information, such as inspection reports, to confirm the frequency. Without a "Follow up" option it was deemed that in these situations "No" was the most conservative and best option to select so that this would draw attention to the dam and hopefully some action would be completed to confirm.
- Under dam safety program elements, a question similar to what was included on the Year 1 assessment forms should be added, which asks "Consequence assessment completed?. In many cases there was no justification provided in any of the documents reviewed for a particular dam as to why a particular classification was assigned to a dam. In addition, it was observed in some cases that the classification that had been assigned was done so on a provisional basis and is pending the results of a more in depth classification assessment. Further to this point, dams which do not have at least some level of inundation mapping completed should almost never be given credit for having a consequence assessment completed as the inundation mapping is a critical and necessary component of the classification assessment.
- Under dam safety program elements, we recommend the following edit "Dam break flood inundation study and mapping *completed and submitted*?".

- Under dam safety program elements, the question related to maintenance suitability and the one related to surveillance and monitoring suitability can probably be combined into one question "Maintenance and surveillance suitable?", since, in general, monitoring and surveillance can be considered one in the same.
- Under dam safety program elements, a question related to design for tailings dams should be considered. For example, there are different design requirements for the different stages of mine operation and closure, e.g., operation phase versus closure - passive care phase.
- Under dam safety program elements, we recommend the following edit "Reservoir *or tailings impoundment* operation as per OMS manual?"
- Under dam deficiencies, a question should be added asking if the Environmental Design Flood (EDF) is appropriate. EDFs are specifically related to tailings dams and should be given consideration during design as a management best practice.
- Under dam deficiencies, it is recommended that the "Spillway capacity inadequate?" be reworded to include other structures such as intakes or sluiceways or simplified to read "discharge works". When completing the dam risk assessments, it was noticed that some dams had an intake structure, but not a spillway. In these cases, the question was not answered as "N/A" because there was no spillway, but rather it was answered "Yes", "No", or "Potential" based on the intake structure capacity and a note was made in the comments section saying that there was no spillway, but there was an intake structure and this is what the answer to this question was based on.
- Under dam deficiencies, consideration should be given to moving the "Sliding safety factor inadequate?" below the question related to structural deficiencies so that it is clearer to the person completing the form that the sliding safety factor is related to concrete dams and other similar structures where a sliding stability calculation is required.
- Under dam deficiencies, consideration should be given to adding the words "location" "quantity" and "clarity" in the brackets after the "Seepage observed?" question and removing the rest of the descriptors. Location, quantity and clarity are the key things to considering when describing seepage.

Dam Inventory Database

The following is a list of updates and issues that we would like to bring to the attention of the WRMD for further consideration with respect to the database.

- Currently when adding/updating information in the database the user must click a button to save each section of a dam entry page individually. If the button for a given section is not clicked, that section will not be updated. For example, after entering the information in the General section of the page (project name, dam name, owner name and contact information), the user must click the "Update General Info" button before moving on and updating the Operator section. After entering the Operator information, the user must then click the "Update Operator Info" button before moving on to the next section, and so on. It is easy to forget to click these buttons after every section, as they are located to the left side of the data fields, near the section title, and not below the section's data fields. They would be more easily noticed below the last data field of every section as this is in the line of sight and follows the order of the data entry fields as the user progresses through the database entry. It would be helpful to move these buttons to the end of each section so that they are easily noticed and not accidentally forgotten by the user, or perhaps more preferably, remove these buttons at each section and only have one at the end of the page to update the entire entry.

- It was noticed that some fields only accepted numerical entries and not text. If text was entered into these fields, an error page would be displayed when the "Update" button was pressed. This would result in the user having to reload the database, log back in, and relocate the dam entry they were working on from the drop-down menu in the database. A good example of this issue is the Operation Parameters section. In this section, for water level, surface area, and storage volume the "Normal" field accepted both text and numbers, but the "Minimum" and "Maximum" fields did not accept text. This became problematic when entering water levels because some owners provided water levels as an elevation and some provided them as measured heights. For those given as elevations it was intended to enter these with "EL" before the number to distinguish these from a measurement, but this wasn't possible due to the error. Hence, enabling all data fields to accept both numerical and text entries to avoid future issues with circumstances such as this would be helpful.
- It was found that when text was entered into the "Dam Status – Other" text box after the Dam Status drop down menu it would not save. This issue was noticed and then checked by entering the data, clicking "Update" and then exiting and going back in to view the entry again. This issue should be investigated and corrected.
- The database currently has the 1999 CDA dam classifications in the drop-down menus for both the Life Safety and Socio-Economic classifications in the Dam Safety Review section. It is our understanding that the WRMD is already aware of this and intend on updating the menus with respect to the current 2007 CDA classifications. To include "Significant" and "Extreme" classifications, these were indicated in the "Additional Comments" field of the inventory entry for the time being until the database is updated to the 2007 classifications.
- When entering a year into the "Date of Next Review" field of the Dam Safety Review section, the same error as discussed in the second bullet above would result. It was noticed that in order for the input to work and not get an error message, a full date in the format of DD-MM-YYYY had to be entered instead of just the year. The "Date of Next Update to Emergency Preparedness Plan" field needs the date entered in this format as well, but this is stated next to the data entry field. It is therefore recommended to state the required date format next to the "Date of Next Update to Dam Safety Review" field similar to the EPP field in order to avoid encountering this error.
- When clearing all the information in some entries in order to recycle them it was found that when clearing the dates in the "Date of Next Review" and "Date of Next Update to Emergency Preparedness Plan" fields in the Dam Safety Review section they would revert back to the previously entered values after clicking the "Update" button. This kept happening and there was no way to clear the field. This issue should be investigated and corrected.
- It was noticed that some of the attached photos and documents that had been previously added to the database were attached to the wrong dam entry. There is currently no way for the user to correct one of these mistakes and remove an attached file from an incorrect entry; rather, a list of these cases was made and given to the WRMD to provide to the database administrator who can then delete the files. It would save time if an option to delete incorrect file attachments was added to the database to allow the user to easily correct mistakes such as these. However, we can also appreciate that giving users the ability to delete attachments could prove problematic if the person accessing the database is not fully aware of what they are doing.
- It is recommended to include some additional sections in the database to provide more information on each dam. These sections could include Structural Design, Geotechnical Design, Dam Risk Level, and Dam Monitoring. The first two sections would provide valuable insight on the history of a dam and its initial design. A dam is given a risk level based on its failure consequence and failure probability ratings; it provides a good

high-level view of the status of the dam in terms of if there is any work that needs to be done to reduce its risk of failure and the urgency of the work. Dam monitoring is important in dam safety as it can help to provide a dam operator with a warning of any issues within a dam, such as seepage, which can allow for the operator to complete necessary actions to prevent a breach from occurring. Having an indication in the database of any monitoring equipment that a dam has would be very useful information in terms of dam safety. Any additions to the database would also have to be reflected in the Dam and Reservoir Inventory form.

10.0 CLOSURE

We trust this report meets with your current requirements. Should additional information be required, please do not hesitate to contact the undersigned at your convenience.

Yours truly,

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11.0 REFERENCES

Aquaveo (2015). Hydraulics and Floodplain Modeling – Simplified Dam Break. WMS 10.0 Tutorial.

Association of Dam Safety Officials (2009). Simplified Inundation Maps for Emergency Action Plans. National Dam Safety Review Board Emergency Action Plan Workgroup.

Atlantic Canada Opportunities Agency (2009). Government of Canada Invests in Margaret Bowater Park.

Aviva Canada (2015). Number and cost of residential water damage claims on steady rise, Aviva Canada data shows. Accessed April 2017 at https://www.avivacanada.com/article/number-and-cost-residential-water-damage-claims-steady-rise-aviva-canada-data-shows.

Canadian Dam Association (CDA) (2007) (2013). Dam Safety Guidelines, 2007 (Revised 2013).

Century 21 Canada Ltd (2017). Century 21 Big Land Realty. Accessed July 2017 at http://www.century21.ca/biglandrealty/

City of Corner Brook (2013). City of Corner Brook Water Treatment Project. Prepared for Provincial Clean and Safe Drinking Water Workshop. Gander, Newfoundland and Labrador.

Connors, C (2015). $110M loan finalized for Corner Brook mill. Accessed May 2017 at http://www.cbc.ca/news/canada/newfoundland-labrador/110m-loan-finalized-for-corner-brook-mill-1.2544360

Deer Lake Regional Airport (2016). Airport History. Accessed May 2017 at http://www.deerlakeairport.com/about-us/airport-history/

Delcan (2011). Floodplain Management Strategy Feasibility Plan. Prepared for The City of New Westminster, British Columbia.

Eaton, N (1997). Mini-Hydro Systems Using Induction Generators. Memorial University of Newfoundland, Faculty of Engineering and Applied Science.

FEMA (2013). Federal Guidelines for Inundation Mapping of Flood Risk Associated with Dam Incidents and Failures. First Edition July 2013.

Froehlich, D. C. (2008). Embankment Dam Breach Parameters and Their Uncertainties. Journal of Hydraulic Engineering, Vol. 134, No. 12ASCE. December 1, 2008, p 1708-1721.

Golder (2017a). Dam Break Inundation Mapping Methods; Inventory and Assessment of Dams in Newfoundland and Labrador: Year 2. Technical memorandum No. 1668487 (7000) dated June 1, 2017.

Golder (2017b). Draft Dam Breach Study and Stability Analyses of Deer Lake Structures. Report No. 1656802 (Rev B) dated June 1, 2017.

Government of Newfoundland and Labrador (1992). Inventory of Major Projects. The Economy 1992, Pages 56-64

Government of Newfoundland and Labrador (2015a). Inventory of Major Projects 2017. The Economy 2017, Pages 57 - 70

Government of Newfoundland and Labrador (2017). Inventory of Major Projects 2017. The Economy 2017, Pages 57 - 70

Government of Newfoundland and Labrador (2015b). 2015-2016 Job Creation Partnerships – Approvals. Department of Advanced Education, Skills, and Labour.

Government of Newfoundland and Labrador (2015c). 2015-2016 Job Creation Partnerships – Round 2 Approvals. Department of Advanced Education, Skills, and Labour.

Government of Newfoundland and Labrador (2016). 2016-2017 Job Creation Partnerships – Round 2 Approvals. Department of Advanced Education, Skills, and Labour.

Government Purchasing Agency of the Government of Newfoundland and Labrador (GPA) (2015a). Awarded Tenders 2015 January.

Government Purchasing Agency of the Government of Newfoundland and Labrador (GPA) (2015b). Awarded Tenders 2015 March.

Government Purchasing Agency of the Government of Newfoundland and Labrador (GPA) (2015c). Awarded Tenders 2015 June.

Government Purchasing Agency of the Government of Newfoundland and Labrador (GPA) (2015d). Awarded Tenders 2015 August.

Government Purchasing Agency of the Government of Newfoundland and Labrador (GPA) (2016a). Awarded Tenders 2016 August.

Government Purchasing Agency of the Government of Newfoundland and Labrador (GPA) (2016b). Awarded Tenders 2016 September.

Hatch (2011). Nalcor Energy Exploits River Dam Safety Review. Final Report – February 2011.

International Renewable Energy Agency (IRENA) (2012). Renewable Energy Technologies: Cost Analysis Series. Volume 1: Power Sector, Issue 3/5. Hydropower.

Leighty, J. (2011). How to Value an Underperforming RV Park. Woodall's Campground Management. Accessed May 2017 at http://www.woodallscm.com/2011/06/how-to-value-an-underperforming-rv-park/

Mansfield, G (2017). Flood-damaged Sydney school set to reopen despite incomplete repairs. CBC News.

Nalcor Energy (2016). Exploits Generation: Proposed Grand Falls Main Dam Rehabilitation.

Newfoundland Power Inc. (2009). 2010 Capital Budget Application. Prepared for Newfoundland Board of Commissioners of Public Utilities.

North Carolina Department of Environment and Natural Resources (2015). North Carolina Simplified Inundation Maps for Emergency Action Planning. Accessed July 2017 at https://deq.nc.gov/about/divisions/energy-mineral-land-resources/energy-mineral-land-permits/dam-safety

RE/MAX (2017). NL Real Estate & Homes for Sale. Accessed June 2017 at http://www.remax.ca/nl/

Rutter Hinz Inc. (2009). Marine Infrastructure Study for the Salmonid Aquaculture Industry Bay D'Espoir/Connaigre Peninsula/Fortune Bay Region. Prepared for Department of Fisheries and Aquaculture.

Statistics Canada (2017). Table 002-0003 – Value per acre of farm land and buildings, at July 1. Accessed April 2017 at http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=20003.

Town of Baie Verte (2011). Water System, Phases 3 & 4. Environmental Assessment Act, Registration of an Undertaking. Prepared for Government of Newfoundland and Labrador, Department of Municipal Affairs and Environment.

Veale V. and Davison I., (2013), Estimation of Dam Breach Geometry. NZSOLD/ANCOLD Conference 2013.

Wells, C (2008). Repairs to Skate Park a Kickflip Away. The Western Star

Wetmore, J. N., Fread, D.L., Lewis, J.M., Wiele, S.M. (1991). The NWS Simplified Dam-Break Flood Forecasting Model. National Weather Service.

APPENDIX A

Dams Removed from Dam Inventory Database

Dams Removed from the Dam Inventory Database

Dam Index #	Project Name	Dam Name	Owner
948	Conne River Old Water Supply	Southwest Brook Dam	Conne River
427	Irishtown - Summerside Swimming Hole	Unnamed Dam	Town of Irishtown - Summerside
730	Snooks Arm Earthfilled (potential duplicate)	Fly Pond/Rocky Pond Dam	Richmont Mines Inc.
5	Churchill Falls	Dykes and Dams	Churchill Falls (Labrador) Corp.
1749	Corner Brook Water Supply	Second Pond Dam - Control Structure	City of Corner Brook
1144	Churchill Falls	GR-4	Churchill Falls (Labrador) Corp.
1468	Rambler Metals & Mining Canada Ltd.	Nugget Pond Facility Polishing Pond	Rambler Metals & Mining Canada Ltd.

APPENDIX B

KMZ File Dams Summary

KMZ File Dams Summary

KMZ File Dam #	Location	Contact Person Response	WRMD Response	Final Status
1	South of Gander	Unknown	Unconfirmed	***Unconfirmed***
2	South of Gander	Unknown	Unconfirmed	***Unconfirmed***
7	St. Anthony	Yes	Yes	***Yes***
11/12	Cormack	No	Unconfirmed	***Unconfirmed***
15	Avalon Wilderness Reserve	No contact person found	N/A	***Unconfirmed***
20	Bay Du Nord/Middle Ridge Wilderness Reserve	No contact person found	N/A	***Unconfirmed***
22	Bishop's Falls	No	No	***No***
25	Northern Arm	No contact person found	N/A	***Unconfirmed***
26	Southwest Grand Falls - Windsor	Unknown	Unconfirmed	***Unconfirmed***
27	Southeast Millertown	No	Unconfirmed	***Unconfirmed***
28	Southwest Grand Falls - Windsor	Unknown	Unconfirmed	***Unconfirmed***
31	Paradise	Yes	Unconfirmed	***Unconfirmed***
33	Twin Falls Dams 1	Yes	Yes	***Yes***
33	Twin Falls Dams 2	Yes	Yes	***Yes***
33	Twin Falls Dams 3	Yes	Yes	***Yes***
33	Twin Falls Dams 4	Yes	Yes	***Yes***
33	Twin Falls Dams 5	Yes	Yes	***Yes***
36A	Port au Choix Dams 1	Yes	Yes	***Yes***
36B	Port au Choix Dams 2	Yes	Yes	***Yes***
36C	Port au Choix Dams 3	Yes	Yes	***Yes***
38	Northeast of Birchy Lake area	No contact person found	N/A	***Unconfirmed***
39	Brigus Junction	No contact person found	N/A	***Unconfirmed***
40	Port Union Hydroelectric Generating Facility	Found to already be in the inventory		
42	Along Bay d'Espoir	Yes	Unconfirmed	***Unconfirmed***

KMZ File Dam #	Location	Contact Person Response	WRMD Response	Final Status
	Highway			
43	West of Bay d'Espoir Highway	Yes	Unconfirmed	***Unconfirmed***
44	Mobile	Yes	Yes	***Yes***
47	North of Sop's Arm	No contact person found	N/A	***Unconfirmed***
48	North of Sop's Arm	No contact person found	N/A	***Unconfirmed***
54	South of Millertown	Yes	Unconfirmed	***Unconfirmed***
55	Hare Bay	No	Unconfirmed	***Unconfirmed***
56	Springdale	No	No	***No***
57	South of Badger	Unknown	Unconfirmed	***Unconfirmed***
58	Butterpot Provincial Park	No contact person found	N/A	***Unconfirmed***
59	Between Nippers Harbour and Bobby Cove	No	No	***No***
60	Springdale	Yes	Yes	***Yes***
61	Southeast of Millertown	Unknown	Unconfirmed	***Unconfirmed***
62	Twillingate	Yes	Yes	***Yes***
63	South of Grand Falls - Windsor	Yes	Unconfirmed	***Unconfirmed***
64	Rocky Harbour	No	Unconfirmed	***Unconfirmed***
67	Stephenville	No	No	***No***
68	Burin	No	No	***No***

APPENDIX C

Dams Added to Dam Inventory Database

Dams Added to the Dam Inventory Database

Assigned Dam Index #	Project Name	Dam Name	Owner	Source
730	Springdale Water Supply (Water Transmission Main Intake Gallery)	Sullivan's Pond Intake	Town of Springdale	KMZ File
2588	Port au Choix Water Supply	Beaverhouse Dam	Town of Port au Choix	KMZ File
2589	Port au Choix Water Supply	Middlehouse Dam	Town of Port au Choix	KMZ File
2590	Port au Choix Water Supply	Winterhouse Dam	Town of Port au Choix	KMZ File
2608	St. Anthony Old Water Supply	Frenchman's Pond Dam	Town of St. Anthony	KMZ File
2648*	Twillingate Water Supply	Wild Cove Pond Dam	Town of Twillingate	KMZ File
2670*	MOP/MRP Hydroelectric Generating Facility	Mobile Forebay Dam	Newfoundland Power Inc.	KMZ File
2677	Former Twin Falls Generating Station	TF-1	Unknown Owner	KMZ File
2678	Former Twin Falls Generating Station	TF-2	Unknown Owner	KMZ File
2679	Former Twin Falls Generating Station	TF-3	Unknown Owner	KMZ File
2680	Former Twin Falls Generating Station	TF-4	Unknown Owner	KMZ File
2681	Former Twin Falls Generating Station	TF-5	Unknown Owner	KMZ File
5	Jackson's Arm Old Water Supply	Clay Cove Dam	Town of Jackson's Arm	Owner
948	Channel - Port Aux Basques Water Supply	#3 Reservoir Diversion Pond Dam	Town of Channel - Port Aux Basques	Owner
1144	Teck Duck Pond Operations	Settling Pond Dam	Teck Resources Limited	Owner
1468	Channel - Port Aux Basques Water Supply	#3 Reservoir Dam	Town of Channel - Port Aux Basques	Owner
2609	St. Anthony Water Supply	St. Anthony Pond Dam	Town of St. Anthony	Owner
2628	Humber Arm South Water Supply	Gurges Pond Intake	Town of	Owner

Assigned Dam Index #	Project Name	Dam Name	Owner	Source
		Dam	Humber Arm South	
2671		Noels Pond Dam	Town of Stephenville	Owner
427	Pasadena Old Swimming Pool	Blue Gulch Brook Lower Dam	Town of Pasadena	WRMD
1749*	Swift Current Old Water Supply	Black Duck Pond Brook Dam	Local Service District of Swift Current	WRMD
2668*	Robert's Arm Water Supply	Young's Pond Dam	Town of Robert's Arm	WRMD
2672	Whalesback Copper Mine (OAM)	Peach Dam	Unknown Owner	WRMD
2675	Mainland Old Water Supply	Unknown Dam	Local Service District of Mainland	WRMD
2669*	Former La Manche Lead Mine	La Manche Lead Mine Dam	Government of Newfoundland and Labrador	Hidden NF
2673*	Former Red Cliff Radar Station	Red Cliff Radar Station Dam	Government of Newfoundland and Labrador	Hidden NF
2674*	Former Terra Nova Sulphite Co. Mill	Terra Nova Sulphite Co. Mill Dam	Government of Newfoundland and Labrador	Hidden NF
2676*	Western Bay Waterfall Swimming Area	Western Bay Waterfall Swimming Area Dam	Unknown Owner	Hidden NF

Note: ***Assigned Dam Index #s with a * indicate dams in the Eastern region***

APPENDIX D

Dams with Known Dam Break Flood Inundation Mapping

Dams with Known Dam Break Flood Inundation Mapping

Dam System / Development	Dam Owner	Dam Name & Index Number	Hardcopies Obtained?	GIS Layer Created?
Barry Group Inc. Fish Plant	Barry Group Inc.	Water Supply Dam / Barry Group Reservoir (#1348)	Yes	Yes
Corner Brook Pulp and Paper Limited	Corner Brook Pulp and Paper Limited	Glynmill Pond Dam (#608)	Yes	Yes
		Glynmill Pond Dam (#608) / Three Mile Pond Dam (#629)	Yes	Yes
		Glynmill Pond Dam (#608) / Corner Brook Lake Dam (Twelve Mile Lake Dam) (#628) / Three Mile Pond Dam (#629)	Yes	Yes
Deer Lake Hydroelectric Generating Station	Deer Lake Power	Main Dam at Grand Lake (#1)	Yes	Yes
		Deep Bank Dam (#355)	Yes	Yes
		West Bank Dam (#357)	Yes	Yes
		Forebay Dam and Spillway (#411)	Yes	Yes
Buchans Mine Closure (OAM)	Department of Natural Resources	Dam 1 (#1193)	Yes	Yes
		Dam 4 (#682)	Yes	Yes
Consolidated Rambler Mine (OAM)	Department of Natural Resources	Northwest Dam (#1208)	Yes	Yes
Gullbridge Copper Mine (OAM)	Department of Natural Resources	Gullbridge Tailings Dam (#1201)	Yes	Yes
Hope Brook Gold Mine (OAM)	Department of Natural Resources	Main Pine Pond Dam (#392)	Yes	Yes
		New Pine Pond Spillway and Saddle Dam A (#568) *(*See Saddle Dam 1)*	Yes	Yes
		Main Tailings Pond Dam (#569)	Yes	Yes
		Heap Leach Dam (#571)	Yes	Yes
		Polishing Pond Dam (#572) *(*See Main Tailings Pond Dam)*	Yes	Yes
		Saddle Dam B (#573) *(*See Saddle Dam 2)*	Yes	Yes
		Saddle Dam 1 (#574)	Yes	Yes
		Saddle Dam 2 (#575)	Yes	Yes
		Saddle Dam 3 (#576) *(*See Main Pine Pond Dam)*	Yes	Yes
Minworth Fluorspar Mine	Department of	Minworth Tailings Dam (#740)	Yes	Yes

Dam System / Development	Dam Owner	Dam Name & Index Number	Hardcopies Obtained?	GIS Layer Created?
(OAM)	Natural Resources			
Whalesback Copper Mine (OAM)	Department of Natural Resources	Whalesback Copper Mine Dam (#1204)	Yes	Yes
Churchill Falls Hydroelectric Development - East Forebay Reservoir	Nalcor Energy - Churchill Falls	GF-9 (#1114)	No	No
		FF-10A (#1115)	No	No
		FF-12 (#1119)	No	No
Churchill Falls Hydroelectric Development - West Forebay Reservoir	Nalcor Energy - Churchill Falls	GJ-11A (#1131)	No	No
		GJ-18 (#1138)	No	No
Churchill Falls Hydroelectric Development - Lobstick	Nalcor Energy - Churchill Falls	GL-1 (#1048)	No	No
		GL-13 (#1076)	No	No
		GL-18 (#1081)	No	No
Churchill Falls Hydroelectric Development - Orma Lake	Nalcor Energy - Churchill Falls	GR-2 (#1142)	Yes	Yes
		GR-8 (#1148)	Yes	Yes
		GR-9 (#1149)	Yes	Yes
		GR-10 (#1150)	Yes	Yes
Churchill Falls Hydroelectric Development - Gabbro	Nalcor Energy - Churchill Falls	Gabbro West (#1176)	No	No
Churchill Falls Hydroelectric Development - Ossokmanuan Reservoir	Nalcor Energy - Churchill Falls	Ossok Dam 1 (#1162)	No	No
Bay d'Espoir Hydroelectric Generating Facility - Long Pond	Newfoundland and Labrador Hydro	LD-1 (Power Canal Embankment) (#46)	Yes	Yes
		LD-2 (North West Cutoff Dam) (#47)	Yes	Yes
		LD-3 (South East Cutoff Dam) (#48)	Yes	Yes
		LD-4 (South West Cutoff Dam) (#49)	Yes	Yes
Bay d'Espoir Hydroelectric Generating Facility - Victoria Lake	Newfoundland and Labrador Hydro	VD-3 (Victoria Dam) (#86)	Yes	Yes
Bishop's Falls Hydroelectric Generating Station	Newfoundland and Labrador Hydro	Bishop's Falls Dam - Bishop's Falls Ambursen Dam (#17) - Bishop's Falls Earth Dam (#214)	No	No
Grand Falls Hydroelectric	Newfoundland and Labrador	Grand Falls Main Dam (#6)	No	No

Dam System / Development	Dam Owner	Dam Name & Index Number	Hardcopies Obtained?	GIS Layer Created?
Generating Station	Hydro			
Lower Churchill Hydroelectric Generation Project	Newfoundland and Labrador Hydro	Muskrat Falls Dam - South Rockfill Dam (#677) - North RCC Dam (Overflow Dam) (#749) - North Transition Dam (#756) - Gated Spillway (#850) - Centre Transition Dam (#851) - South Transition Dam (#968)	Yes	Yes
Snooks Arm and Venams Bight	Newfoundland and Labrador Hydro	SV-1 (Snooks Arm Main Dam) (#77)	Yes	Yes
Star Lake Hydroelectric Generating Station	Newfoundland and Labrador Hydro	Star Lake Main Dam (#9)	Yes	Yes
Cape Broyle / Horse Chops (CAB / HCP) Hydroelectric Generating Facility	Newfoundland Power Inc.	Cape Broyle Forebay Dam (#139)	No	No
		Cape Broyle Intake Dam (#141)	No	No
		Horse Chops Dam – Believed to be Horse Chops East Dam (#144) & Horse Chops West Dam (#145)	No	No
		Mount Carmel Pond Dam (#146)	No	No
Hearts Content Hydroelectric Generating Facility	Newfoundland Power Inc.	Rocky Pond Control Dam and Spillway (#190)	Yes	Yes
		Packs Pond Diversion Dam (#193)	Yes	Yes
New Chelsea-Pitman's Pond (NCH / PIT) Hydroelectric Generating Facility	Newfoundland Power Inc.	Seal Cove Pond Dam (NCH Forebay Dam) (#194)	Yes	Yes
		Pitman's Pond Dam (#195)	Yes	Yes
Petty Harbour Hydroelectric Generating Facility	Newfoundland Power Inc.	Unknown	No	No
Pierre's Brook Hydroelectric Generating Facility	Newfoundland Power Inc.	Gull Pond Dam (PBK Forebay Dam) (#94) / Big Country Pond Dam (#96)	Yes	Yes
		West Country Pond Dam (#100)	Yes	Yes
Port Union Hydroelectric Generating Facility	Newfoundland Power Inc.	Long Pond Dam (#212)	Yes	Yes
Rose Blanche Brook Hydroelectric Generating Facility	Newfoundland Power Inc.	Rose Blanche Forebay Dam (#240)	Yes	Yes

Dam System / Development	Dam Owner	Dam Name & Index Number	Hardcopies Obtained?	GIS Layer Created?
Sandy Brook Hydroelectric Generating Facility	Newfoundland Power Inc.	Sandy Brook Forebay Dam (#229)	No	No
Seal Cove Hydroelectric Generating Facility	Newfoundland Power Inc.	Unknown	No	No
Topsail Hydroelectric Generating Facility	Newfoundland Power Inc.	Unknown	No	No

APPENDIX E

Dam Owner Annual Dam Safety Report Form

Dam Owner Annual Dam Safety Report

Newfoundland Labrador

Dam Name: ____

Dam Owner: ______________________________________ Date: ______________

Dam Failure Consequence Classification: ☐ Extreme ☐ Very High ☐ High ☐ Significant ☐ Low

Describe Changes to Conditions Downstream of Dam (increased development, population at risk, etc.):

DAM SAFETY PROGRAM ELEMENTS

	Yes	No	N/A
Any recent alterations to the dam?	☐	☐	☐
Any critical incidents or hazards occurred?	☐	☐	☐
Dam break flood inundation study and mapping available?	☐	☐	☐
Dam owner inspections undertaken?	☐	☐	☐
Inspection frequency adequate?	☐	☐	☐
Dam safety review status acceptable?	☐	☐	☐
OMS plan prepared and submitted?	☐	☐	☐
EPRP prepared and submitted?	☐	☐	☐
EPRP updated (contact information)?	☐	☐	☐
Critical incidents or hazards reported?	☐	☐	☐
Maintenance suitable?	☐	☐	☐
Surveillance and monitoring suitable?	☐	☐	☐
Public safety risk assessment and plan complete?	☐	☐	☐
Public safety measures taken (signs posted)?	☐	☐	☐
Hazard identification and failure mode analysis undertaken?	☐	☐	☐
Outlets, gates and other mechanical components tested?	☐	☐	☐
Reservoir operation as per OMS manual?	☐	☐	☐

General comments and site observations*:

Updated: May 2016

DAM DEFICIENCIES

	Yes	No	Potential	N/A
IDF inappropriate?	☐	☐	☐	☐
Spillway capacity inadequate?	☐	☐	☐	☐
Slope stability inadequate?	☐	☐	☐	☐
Freeboard inadequate?	☐	☐	☐	☐
Sliding safety factor inadequate?	☐	☐	☐	☐
Geotechnical deficiencies observed? (internal erosion, slumping external erosion, sinkhole, settlement, cracks, bulges, lateral movement)	☐	☐	☐	☐
Structural deficiencies observed? (cracks, misalignment, settlement, concrete deterioration, lateral movement)	☐	☐	☐	☐
Rip rap deficiencies observed? (displaced, broken down)	☐	☐	☐	☐
Debris deficiencies observed? (floating debris, spillway blocked)	☐	☐	☐	☐
Animal activity observed? (burrowing, beavers)	☐	☐	☐	☐
Excessive vegetation growth observed? (embankments, spillway)	☐	☐	☐	☐
Seepage observed? (wet areas, ponded water at toe, d/s slope, abutments)	☐	☐	☐	☐

Description of deficiencies*:

Condition Assessment:	Failure Probability Rating:	Dam Risk Level (Corrective Action Level):
**Refer to attached information on pages 3 and 4		
☐ Satisfactory	☐ Likely	☐ 1-Very High (Alert)
☐ Fair	☐ Probable	☐ 2-High (Caution)
☐ Poor	☐ Unlikely	☐ 3-Moderate (Stable)
☐ Unsatisfactory	☐ Very Unlikely	☐ 4-Low (No Concerns)
☐ Not Rated		☐ 5-Very Low (Effectual)

Printed name of Dam Safety Consultant	Signature	Date
Printed name of Dam Owner/Agent	Signature	Date

* Please provide pictures.

Updated: Aug 2016

Condition Assessment (assessment that best describes the condition of the dam based on available information)

1) SATISFACTORY

No existing or potential dam safety deficiencies are recognized. Acceptable performance is expected under all loading conditions (static, hydrologic) in accordance with applicable best management practices.

2) FAIR

No existing dam safety deficiencies are recognized for normal loading conditions. Rare or extreme hydrologic events may result in a dam safety deficiency.

3) POOR

A dam safety deficiency is recognized for loading conditions which may realistically occur. Uncertainties exist as to critical analysis parameters which identify a potential dam safety deficiency. Further investigations and studies are necessary.

4) UNSATISFACTORY

A dam safety deficiency is recognized.

5) NOT RATED

Failure Probability Rating- General Guidelines for Allocating Failure Probability Ratings

(Note: Apply highest failure probability rating, only one bullet required)

Likely

- An unacceptable dam deficiency has been confirmed based on CDA Guidelines or observed deficiencies that could clearly lead to a dam failure.
- Design, construction, structural and/or operational deficiencies remain uncorrected. If the dam owner is actively working on an approved project to correct the deficiency the rating can be reduced to Moderate.
- Non-conformance with established dam safety requirements, procedures, systems and instructions.
- Owner exhibits reluctance to operate dam in a safe and timely manner, or is incapable of doing so.

Probable

- An unacceptable dam deficiency has been confirmed based on CDA Guidelines or observed deficiencies that could potentially lead to a dam failure.
- Design, construction, structural and/or operational deficiencies remain uncorrected.
- Owner exhibits reluctance to undertake and report on annual inspection, or is incapable of doing so.
- Design and operation lacks redundancy (e.g., no back-up power for electrical gates).
- Inadequate/inappropriate dam safety requirements, procedures, systems and instructions.

Unlikely

- An unacceptable dam deficiency might exist, but has not been confirmed.
- Design and/or performance deficiencies may exist, but are actively monitored and are not expected to significantly increase failure potential over the near term.
- Design and operation exhibits redundancy.

Very Unlikely

- Dams that are breached, partially breached, reservoir drained or otherwise safeguarded.

RISK LEVEL CHART

Failure Probability Rating	Dam Failure Consequence Classification				
	Extreme	Very High	High	Significant	Low[1]
Likely	1	1	1	2	3
Probable	2	2	2	3	4
Unlikely	3	3	4	4	5
Very Unlikely	3	4	4	5	5

DAM SAFETY RISK LEVEL & CORRECTIVE ACTION LEVEL

Dam Safety Risk Level	Corrective Action Level	Possible Corrective Actions to Take
1-Very High	Alert (immediate action required)	-Increased site surveillance -Enhanced instrumentation monitoring -Hiring of engineering consultants -Immediate repairs -Restricted reservoir operation -ENVC may request EPRP reviewed at increased frequency -ENVC may issue an Order to lower water levels, empty reservoir, or take other corrective action -Suspend operation of dam
2-High	Caution (considerable work to do)	-Increased site surveillance -Increased instrumentation monitoring -Planning for rehabilitation work in the immediate or near future -Modify reservoir operation -ENVC may request EPRP reviewed at increased frequency -ENVC may request inspection reports at increased frequency -ENVC may request submission of OMS Manual or DSR at increased frequency
3-Moderate	Stable	-Annual inspection reports to ENVC -Monitor operation under peak loading -Rehabilitate hazardous conditions -ENVC may request submission of OMS Manual or DSR at increased frequency
4-Low	No Concerns	-Normal operation -Annual inspection reports to this department
5-Very Low	Effectual (significant and low consequence dams only)	-Normal operation -Annual inspection reports to this department

Glossary

OMS- Operation, Maintenance and Surveillance
EPRP- Emergency Preparedness and Response Plan
IDF- Inflow Design Flood
DSR- Dam Safety Review
d/s- downstream
CDA- Canadian Dam Association
ENVC- Dept of Environment & Conservation

Updated: Aug 2016

APPENDIX F

Dams Requiring Inundation Mapping

High, Very High & Extreme Dams with No Inundation Mapping, but Should Have It Developed

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
1118	Churchill Falls Hydroelectric Development	FF-11	Nalcor Energy - Churchill Falls	Very High	Extreme	2A	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
73	Upper Salmon Hydroelectric Generating Station	SD-2 (North Salmon Dam)	Newfoundland and Labrador Hydro	Very High	Very High	2B	Saint Veronica's, Saint Joseph's Cove, Milltown - Head of Bay d'Espoir, Swanger Cove, Saint Alban's, Conne River
218	Lawn Hydroelectric Generating Facility	Lawn Forebay Dam	Newfoundland Power Inc.	Very High	Very High	2B	Lawn
1163	Churchill Falls Hydroelectric Development	Ossok Dam 2	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1168	Churchill Falls Hydroelectric Development	Ossok Dam 7	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1169	Churchill Falls Hydroelectric Development	Gabbro Dam 1	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1170	Churchill Falls Hydroelectric Development	Gabbro Dam 2	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1173	Churchill Falls Hydroelectric Development	Gabbro - East Dam	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1174	Churchill Falls Hydroelectric Development	Gabbro East	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1175	Churchill Falls Hydroelectric Development	Gabbro - West Dam	Nalcor Energy - Churchill Falls	Very High	Very High	2B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1116	Churchill Falls Hydroelectric Development	FF-10B	Nalcor Energy - Churchill Falls	Very High	High	2C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
91	Petty Harbour Hydroelectric Generating Facility	Bay Bulls Big Pond Dam	Newfoundland Power Inc.	Very High		2D	Goulds, Petty Harbour - Maddox Cove
1113	Churchill Falls Hydroelectric Development	GF-8	Nalcor Energy - Churchill Falls	High	Extreme	3A	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1108	Churchill Falls Hydroelectric Development	GF-2	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1109	Churchill Falls Hydroelectric Development	GF-3	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1120	Churchill Falls Hydroelectric Development	GF-13	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1122	Churchill Falls Hydroelectric Development	GF-15	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1123	Churchill Falls Hydroelectric Development	GF-16	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1127	Churchill Falls Hydroelectric Development	GJ-7	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1128	Churchill Falls Hydroelectric Development	GJ-8	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1132	Churchill Falls Hydroelectric Development	GJ-11B	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1137	Churchill Falls Hydroelectric Development	GJ-17	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1139	Churchill Falls Hydroelectric Development	GJ-19	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
1140	Churchill Falls Hydroelectric Development	GJ-20	Nalcor Energy - Churchill Falls	High	Very High	3B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
4	Deer Lake Hydroelectric Generating Station	Intake Control Dam	Deer Lake Power	High	High	3C	Deer Lake, Pasadena, Steady Brook, Corner Brook, Little Rapids, Humber Village, Humber Valley Resort
53	Bay d'Espoir Hydroelectric Generating Facility	MD-2 (Pudops Dam)	Newfoundland and Labrador Hydro	High	High	3C	Saint Veronica's, Saint Joseph's Cove, Milltown - Head of Bay d'Espoir, Swanger Cove, Saint Alban's, Conne River
107	TCV/ROP Hydroelectric Generating Facility	Tors Cove Pond East Dam	Newfoundland Power Inc.	High	High	3C	Tors Cove, Burnt Cove
108	TCV/ROP Hydroelectric Generating Facility	Tors Cove Pond West Dam	Newfoundland Power Inc.	High	High	3C	Tors Cove, Burnt Cove
128	TCV/ROP Hydroelectric Generating Facility	Cape Pond Dam and Spillway	Newfoundland Power Inc.	High	High	3C	Tors Cove, Burnt Cove
156	CAB / HCP Hydroelectric Generating Facility	Cape Broyle Forebay Spillway	Newfoundland Power Inc.	High	High	3C	Shore's Cove, Cape Broyle
177	Deer Lake Hydroelectric Generating Station	Long Bank Dam	Deer Lake Power	High	High	3C	Deer Lake, Pasadena, Steady Brook, Corner Brook, Little Rapids, Humber Village, Humber Valley Resort
189	Hearts Content Hydroelectric Generating Facility	Southern Cove Pond Dam	Newfoundland Power Inc.	High	High	3C	Heart's Content
191	Hearts Content Hydroelectric Generating Facility	Long Pond Control Dam and Spillway	Newfoundland Power Inc.	High	High	3C	Heart's Content
348	TCV/ROP Hydroelectric Generating Facility	Tors Cove Spillway	Newfoundland Power Inc.	High	High	3C	Tors Cove, Burnt Cove

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
360	CAB / HCP Hydroelectric Generating Facility	Mount Carmel Pond Spillway	Newfoundland Power Inc.	High	High	3C	Cape Broyle
673	Grand Bank Water Supply	Grand Bank Dam	Town of Grand Bank	High	High	3C	Grand Bank
1111	Churchill Falls Hydroelectric Development	GF-6	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1112	Churchill Falls Hydroelectric Development	GF-7	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1124	Churchill Falls Hydroelectric Development	GF-17	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1133	Churchill Falls Hydroelectric Development	GJ-12	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1134	Churchill Falls Hydroelectric Development	GJ-13	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1164	Churchill Falls Hydroelectric Development	Ossok Dam 3	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1165	Churchill Falls Hydroelectric Development	Ossok Dam 4	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1166	Churchill Falls Hydroelectric Development	Ossok Dam 5	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1167	Churchill Falls Hydroelectric Development	Ossok Dam 6	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1171	Churchill Falls Hydroelectric Development	Gabbro Dam 3	Nalcor Energy - Churchill Falls	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1172	Churchill Falls Hydroelectric	Gabbro Dam 4	Nalcor Energy - Churchill	High	High	3C	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
	Development		Falls				River, Sheshatshui
1188	Anaconda Mining Inc. (Pine Cove)	Phase 1 Tailings Dam	Anaconda Mining Inc.	High	High	3C	Anaconda Mining Operation
1192	Beaver Brook Antimony Mine	Old Tailings Pond Dam	Beaver Brook Antimony Mine Inc.	High	High	3C	Glenwood, Appleton
1368	CAB / HCP Hydroelectric Generating Facility	Horse Chops East Spillway	Newfoundland Power Inc.	High	High	3C	Cape Broyle
1408	Beaver Brook Antimony Mine	Southwest Horseshoe Dam	Beaver Brook Antimony Mine Inc.	High	High	3C	Glenwood, Appleton
1789	Voisey's Bay Mine Site	East Diversion Dam	Vale Newfoundland and Labrador Ltd.	High	High	3C	Voisey's Bay Mine Site
1110	Churchill Falls Hydroelectric Development	GF-4	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1117	Churchill Falls Hydroelectric Development	GJ-2	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1121	Churchill Falls Hydroelectric Development	GF-14	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1125	Churchill Falls Hydroelectric Development	GF-18	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1126	Churchill Falls Hydroelectric Development	GJ-5	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1129	Churchill Falls Hydroelectric Development	GJ-9	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1130	Churchill Falls Hydroelectric Development	GJ-10	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1135	Churchill Falls Hydroelectric	GJ-15	Nalcor Energy - Churchill	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay,

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
	Development		Falls				Mud Lake, North West River, Sheshatshui
1136	Churchill Falls Hydroelectric Development	GJ-16	Nalcor Energy - Churchill Falls	High	Significant	3D	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
90	Petty Harbour Hydroelectric Generating Facility	First Pond Dam (PHR Forebay Dam)	Newfoundland Power Inc.	High		3E	Petty Harbour
95	Pierres Brook Hydroelectric Generating Facility	Gull Pond Freeboard Dam	Newfoundland Power Inc.	High		3E	Witless Bay
102	MOP/MRP Hydroelectric Generating Facility	Mobile First Pond Dam	Newfoundland Power Inc.	High		3E	Mobile
103	MOP/MRP Hydroelectric Generating Facility	Mobile Canal Embankment	Newfoundland Power Inc.	High		3E	Mobile
104	MOP/MRP Hydroelectric Generating Facility	Mobile Big Pond Dam	Newfoundland Power Inc.	High		3E	Mobile
172	Topsail Hydroelectric Generating Facility	Topsail Pond (Forebay) Dam	Newfoundland Power Inc.	High		3E	Paradise, Topsail
179	Topsail Hydroelectric Generating Facility	Thomas Pond Dam	Newfoundland Power Inc.	High		3E	Conception Bay South
181	Seal Cove Hydroelectric Generating Facility	Fenelons Pond Dam	Newfoundland Power Inc.	High		3E	Conception Bay South
182	Seal Cove Hydroelectric Generating Facility	Soldiers Pond Dam/Spillway	Newfoundland Power Inc.	High		3E	Conception Bay South
185	Victoria Hydroelectric Generating Facility	Blue Hill Pond Dam (VIC Forebay Dam)	Newfoundland Power Inc.	High		3E	Victoria, Salmon Cove
186	Victoria Hydroelectric	Rocky Pond Dam	Newfoundland Power Inc.	High		3E	Victoria, Salmon Cove

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
	Generating Facility						
213	Port Union Hydroelectric Generating Facility	Wells Pond Dam	Newfoundland Power Inc.	High		3E	Port Union, Catalina
222	Rattling Brook Hydroelectric Generating Facility	Rattling Lake Dam	Newfoundland Power Inc.	High		3E	Rattling Brook
223	Rattling Brook Hydroelectric Generating Facility	Rattling Lake Spillway	Newfoundland Power Inc.	High		3E	Rattling Brook
224	Rattling Brook Hydroelectric Generating Facility	Amy's Lake Dam	Newfoundland Power Inc.	High		3E	Rattling Brook
236	Lookout Brook Hydroelectric Generating Facility	Joe Dennis Pond Dam and Spillway	Newfoundland Power Inc.	High		3E	Flat Bay
239	Lookout Brook Hydroelectric Generating Facility	Cross Pond Spillway	Newfoundland Power Inc.	High		3E	Flat Bay
1050	Churchill Falls Hydroelectric Development	GL-3	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1070	Churchill Falls Hydroelectric Development	GL-7	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1080	Churchill Falls Hydroelectric Development	GL-17	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1082	Churchill Falls Hydroelectric Development	GL-19	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1084	Churchill Falls Hydroelectric Development	GL-21	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1088	Churchill Falls Hydroelectric Development	GL-27	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
							River, Sheshatshui
1091	Churchill Falls Hydroelectric Development	GL-31	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1092	Churchill Falls Hydroelectric Development	GL-32	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1093	Churchill Falls Hydroelectric Development	GL-33	Nalcor Energy - Churchill Falls	Low	Extreme	4	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
738	Voisey's Bay Mine Site	H1 Dam	Vale Newfoundland and Labrador Ltd.	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1051	Churchill Falls Hydroelectric Development	GL-4	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1068	Churchill Falls Hydroelectric Development	GL-5	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1071	Churchill Falls Hydroelectric Development	GL-8	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1073	Churchill Falls Hydroelectric Development	GL-10	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1077	Churchill Falls Hydroelectric Development	GL-14	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1078	Churchill Falls Hydroelectric Development	GL-15	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1079	Churchill Falls Hydroelectric Development	GL-16	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1083	Churchill Falls Hydroelectric Development	GL-20	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
							River, Sheshatshui
1085	Churchill Falls Hydroelectric Development	GL-22	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1086	Churchill Falls Hydroelectric Development	GL-25	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1090	Churchill Falls Hydroelectric Development	GL-30	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1094	Churchill Falls Hydroelectric Development	GL-34	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1097	Churchill Falls Hydroelectric Development	GL-37	Nalcor Energy - Churchill Falls	Low	Very High	5	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
29	Cat Arm Hydroelectric Generating Station	CD-6 (Cat Arm Dam West)	Newfoundland and Labrador Hydro	Significant	High	6A	N/A
30	Cat Arm Hydroelectric Generating Station	CD-7 (Cat Arm Dam East)	Newfoundland and Labrador Hydro	Significant	High	6A	N/A
31	Cat Arm Hydroelectric Generating Station	CD-8 (Cat Arm Dam 8)	Newfoundland and Labrador Hydro	Significant	High	6A	N/A
32	Cat Arm Hydroelectric Generating Station	CD-9 (Cat Arm Dam D)	Newfoundland and Labrador Hydro	Significant	High	6A	N/A
1157	Churchill Falls Hydroelectric Development	GS-1	Nalcor Energy - Churchill Falls	Significant	High	6A	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1158	Churchill Falls Hydroelectric Development	GS-2	Nalcor Energy - Churchill Falls	Significant	High	6A	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
18	Buchans Hydroelectric Generating	Buchans Forebay Dam	Government of Newfoundland and Labrador	Low	High	6B	Buchans

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
	Station						
19	Buchans Hydroelectric Generating Station	Buchans Main Dam	Government of Newfoundland and Labrador	Low	High	6B	Buchans
690	Voisey's Bay Mine Site	South Sedimentation Pond	Vale Newfoundland and Labrador Ltd.	Low	High	6B	Voisey's Bay Mine Site
733	Voisey's Bay Mine Site	H2 Dam	Vale Newfoundland and Labrador Ltd.	Low	High	6B	Voisey's Bay Mine Site
1069	Churchill Falls Hydroelectric Development	GL-6	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1072	Churchill Falls Hydroelectric Development	GL-9	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1075	Churchill Falls Hydroelectric Development	GL-12	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1087	Churchill Falls Hydroelectric Development	GL-26	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1095	Churchill Falls Hydroelectric Development	GL-35	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1096	Churchill Falls Hydroelectric Development	GL-36	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1098	Churchill Falls Hydroelectric Development	GL-38	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1141	Churchill Falls Hydroelectric Development	GR-1	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1146	Churchill Falls Hydroelectric Development	GR-6	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West

Dam Index #	Project Name	Dam Name	Owner	CDA LOL Class	CDA E&C / I&E Class	Priority	Communities Affected Downstream
							River, Sheshatshui
1147	Churchill Falls Hydroelectric Development	GR-7	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1151	Churchill Falls Hydroelectric Development	GR-11	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1152	Churchill Falls Hydroelectric Development	GR-12	Nalcor Energy - Churchill Falls	Low	High	6B	Churchill Falls, Happy Valley - Goose Bay, Mud Lake, North West River, Sheshatshui
1190	Anaconda Mining Inc. (Pine Cove)	Phase 2 Tailings Dam	Anaconda Mining Inc.	Low	High	6B	Anaconda Mining Operation

APPENDIX G

Detailed Analysis of Dam Break Flood Inundation Mapping Methodologies

TECHNICAL MEMORANDUM

DATE August 10, 2017 **PROJECT No.** 1668487

TO Paula Dawe, P. Eng.,
Department of Municipal Affairs and Environment

CC Andrew Peach, P. Geo., EP

FROM Golder Associates Limited **EMAIL** andrew_peach@golder.com

DAM BREAK INUNDATION MAPPING METHODS
INVENTORY AND ASSESSMENT OF DAMS IN NEWFOUNDLAND AND LABRADOR: YEAR 2

1.0 INTRODUCTION

Planning for a dam safety emergency is an integral component of a dam safety management program and is necessary in order to mitigate the impacts of a dam failure; the preparation of inundation maps is a critical component of a dam safety management program. Areas that might be potentially impacted during a dam breach can be identified on the inundation maps and procedures can be established as part of the planning process to deal with the anticipated flooding. The purpose of this document is to present a compilation of dam break inundation methodologies that have been identified during a comprehensive literature review completed by Golder, which focused on peer reviewed journal articles, technical manuals, and common best practices. Available methodologies for estimating breach parameters, generating breach outflow hydrographs, and modelling the downstream inundation zone have been presented herein.

Dam break inundation studies are used for multiple purposes, including:

- Estimating and evaluating the potential for loss of life, environmental and cultural losses, and infrastructure damage/economic losses from a dam break;
- Establishing the consequence classification for a dam, which in turn dictates the design criteria;
- Establishing the appropriate level of surveillance, monitoring, and dam safety reviews/inspections;
- Developing Emergency Response and Preparedness Plans (ERPs/EPPs) and planning exercises associated with dam safety emergencies;
- Developing breach inundation zone mapping for flood warning systems, evacuation procedures, and mitigation; and,
- Communicating to the public the potential impacts of dam failure.

Each application has its own set of unique information requirements and may be used in different manners ranging from mitigation planning by dam safety officials to field-based emergency responders reacting to a developing or imminent dam safety emergency. However, regardless of the unique information requirements, inundation mapping is a common requirement for each application.

This document also presents a brief overview of the different types of dams and their associated mechanisms of failure, followed by a description of different approaches and methods that can be used to complete a dam breach analysis and produce inundation mapping.

2.0 TYPES OF DAMS

Dams may be classified by purpose, type, size, and hazard potential, as discussed below.

2.1 Type of Dam by Purpose

There are two groups of intended purposes for man-made dam structures (FEMA, 2013):

- Water retaining dams such as flood control, diversionary, irrigation and water supply, hydroelectric power generation, and recreational; and,
- Tailings or solids retaining dams.

2.2 Dams by Type of Construction Material

The US National Inventory of Dams (NID) classifies dams by the type of construction material used as either a concrete, embankment, timber or stone dam.

The two common dam types are concrete and embankment dams and are described below. Timber and stone dams were constructed in the past, but are not typically constructed today.

2.2.1 Concrete Dams

There are several types of concrete dams ranging from conventional design styles such as gravity, arch, multi-arch, and buttress dams to newer design approaches such as Roller-Compacted-Concrete (RCC) dams.

Gravity dams typically consist of a solid concrete structure that maintains stability against design loads from the geometric shape, mass and strength of the concrete. Arch dams typically have a much more slender cross section than gravity dams and are designed to transfer the loads to the abutments. Buttress dams have a solid, water retaining upstream face that is structurally supported at intervals on the downstream side by a series of buttresses.

Typically concrete dams are constructed on a straight axis, though they may be slightly angled or curved in an arch shape. Multiple-arch dams are composed of two or more contiguous arches, typically with concrete supporting buttresses.

When concrete dams are built on overburden, greater care is often needed to accurately establish the bearing capacity, deformability characteristics, and in particular the seepage conditions below the dam.

2.2.2 Embankment Dams

Embankment dams represent the most common type of dam and often the most economical. These dams may be constructed with earth materials and rockfill, or other material resistant to erosion. Embankment dams may or may not incorporate a water retaining element, e.g., impervious core. Earthfill dams may be “homogeneous” or “zoned”. Earthfill dams are usually composed of suitable soils obtained from borrow areas that are spread and compacted in layers by mechanical means. It is common to incorporate a filter and drainage layer into the downstream portion of a water retaining, e.g., zoned earthfill dam.

Rockfill dams are primarily constructed with rockfill. The shells of these dams are typically composed of blasted rock fragments. Commonly, internal zoning is provided in the rockfill dams to inhibit seepage and to prevent migration of fines. The impervious zone in a rockfill dam is usually located in the center of the dam or the upstream side.

2.3 Dam Size Classification

There is no universally accepted classification of a dam based on its height and storage volume. Table 1 shows the classification system that was developed in 1979 by the United States Army Corps of Engineers (USACE 1979) for water retaining dams. In this system, the size classification may be determined by the dam height or storage volume (whichever gives the larger size category).

Table 1: USACE Federal Dam Size Classification System

Category	Dam height and impoundment storage volume	
	Height (feet)	Storage (acre-feet)
Small	25 to 40	50 to 1,000
Intermediate	40 to 100	1,000 to 50,000
Large	More than 100	More than 50,000

Source: USACE (1979).

The International Commission on Large Dams (ICOLD) considers large dams to have a height of more than 15 m from lowest point of the foundation to the crest, or a dam between 5 m and 15 m in height impounding more than 3 million cubic metres.

The Canadian Dam Association classifies a dam by the consequence of failure, not by its size (CDA, 2013).

2.4 Dam Consequence Classification

The dam consequence classification presented in Table 2 is provided by the Canadian Dam Association (CDA, 2013) and is based on the population at risk, loss of life, environmental and cultural losses, and infrastructure and economic damage/impacts. It is important to note that these impacts are assessed on an incremental basis, e.g., losses caused by a 1:1,000 year flood compared to the losses caused by a 1:1,000 year flood with a concurrent dam failure. It is for this reason that a sunny day (fair weather) failure, i.e., dam is operating under normal loading conditions prior to failure, should also be assessed. The incremental losses associated with an unexpected, sunny day failure, which in this case would equal the total consequences, can often be higher than those associated with the flooding or rainy day failure.

Table 2: Canadian Dam Association Dam Classification

Dam class	Population at risk (note 1)	Incremental losses		
		Loss of life (note 2)	Environmental and cultural values	Infrastructure and economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of important fish or wildlife habitat	High economic losses affecting infrastructure, public

Dam class	Population at risk (note 1)	Incremental losses		
		Loss of life (note 2)	Environmental and cultural values	Infrastructure and economics
			Restoration or compensation in kind highly possible	transportation and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of critical fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g. highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of critical fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g. hospital, major industrial complex, major storage facilities for dangerous substances)

Source: CDA (2013).

Note 1. Definitions of population at risk:

None – There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary – People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities.

Permanent – The population at risk is ordinarily located in the dam-breach inundation zone (e.g., permanent residents); three consequence classes (high, very high and extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified – The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

3.0 MECHANISMS OF DAM FAILURE

The intent of a dam breach assessment is to identify credible, worst case scenarios, which can lead to a dam failure, and to determine the impact of the failure. The impacts of failure can occur both upstream and downstream of the dam and/or at the dam itself. The breach analyses assume that the modelled dam will fail. For the purpose of impact assessment, a failure is defined as a loss of containment. A failure of the dam could occur either as the result of a defect in the construction, faulty design, improper operation or an extreme natural event (for example, an extreme storm or an earthquake) that exceeds the level for which the structure has been designed to operate. Over time, dam performance could also be influenced by other factors, e.g., internal (drain clogging) or external (animal activity, vegetation).

Depending on the type of dam and site-specific conditions, a dam may be susceptible to failure from multiple causes. Additionally, the breach shape and timing of a dam failure varies depending on the type of dam. For instance, concrete gravity dams tend to have a partial breach, as one or more monolith sections formed during dam construction fail, whereas concrete arch dams tend to fail suddenly and completely (CDA, 2013). In contrast, embankment dams do not usually have a complete or sudden failure. Once a breach is initiated, the discharging water will erode a portion of the dam until the reservoir is depleted or the breached materials resist further erosion.

The most common causes of dam failure are overtopping and piping (internal erosion from seepage). The critical mode of failure is a complete breach of the dam. Overtopping occurs when the inflow to the reservoir or impoundment exceeds the available storage and the capacity of the discharge works, e.g., emergency overflow spillway. Piping is the internal erosion of the embankment material due to the flow of water. While it is primarily a design and construction issue, it can also develop over time due to burrowing animals or decaying root systems below the reservoir level. Both overtopping and piping, if not identified and corrected, could lead to a rapid breach of a dam section - through progressive erosion of the fill materials, resulting in an uncontrolled release of the impounded water. Overtopping and piping are discussed in more detail in the subsequent sections.

A less common cause of dam failure is structural instability. Structural instability and the associated reduction of the safety factor could be caused by several mechanisms such as erosion of the downstream or upstream slope, increased water table (phreatic surface), excessive deformation, seismic events, clogging of filters and drains, compaction deficiencies, foundation treatment deficiencies, and design/construction errors.

For illustration purposes, Table 3 presents the causes of dam failure and a number of events recorded between 1975 and 2011 sourced from the National Policy on Disaster Management (2011).

Table 3: Causes of Dam Failure 1975-2011

Causes of Failure	Number of Dam Failure	Percentage of Dam Failure
Flood or Overtopping	465	70.9%
Piping or Seepage	94	14.3%
Structural	12	1.8%
Human Related	4	0.6%
Animal Activities	7	1.1%
Spillway	11	1.7%
Erosion/Slide/Instability	13	2.0%
Unknown	32	4.9%
Other (Earthquake)	18	2.7%
Total number of dam failure	**656**	100%

Source: National Policy on Disaster Management (NPDM 2011).

It is worth mentioning that the age of a dam also has an influence on the potential for dam failure. There is a greater likelihood of failure just after the first impoundment of the reservoir when unknown defects in the dam are tested. After approximately the first five years following initial impoundment, embankment dams are generally less likely to exhibit potentially serious problems, although slow progressive processes such as internal erosion may be occurring which can manifest themselves many years after impoundment (FEMA, 2013). In addition, flooding events that increase water levels within the impoundment or reservoir to elevations not previously experienced by an embankment or rockfill dam can result in the initiation of internal erosion.

3.1 Overtopping

Although overtopping as a result of flooding has been identified as the most common mode of failure for embankment dams, it is generally considered to be a hydrotechnical storage/discharge capacity adequacy issue. Improper operation of the reservoir and/or loss of spillway conveyance from blockage are common factors that contribute to overtopping. Overtopping can occur along the dam crest, at an abutment, or at a low point along the reservoir rim. Settlement of the dam crest can also be a contributing factor. On rare occasions, seiches, waves caused by earthquakes, or surge waves caused by landslides into the reservoir can also lead to overtopping. Once overtopping occurs, it can cause the dam to breach. The rate at which the breach occurs is dependent on the erodibility of the materials exposed to the overtopping flows.

3.2 Internal Erosion and Piping

Piping is subsurface erosion that most often starts near the downstream toe of the dam and progresses in the upstream direction. Concentrated seepage progressively erodes soil particles leaving large voids in the soil. These voids continue to propagate and work their way upstream under or through the dam until reaching the reservoir. Once the channel reaches the reservoir it can enlarge rapidly causing catastrophic failure of the dam.

Piping failure in dams often occurs without any apparent warning, sometimes many years after the reservoir has been in operation. A key indicator for piping is the existence of muddy or cloudy seepage discharge downstream of the dam, or along the downstream slope or toe.

The most common failure mechanisms associated with internal erosion and piping are (CDA, 2007b):

- Transport of material to the point of seepage.
- Transport of material across the interface between different internal zones of the embankment.
- Transport of core material into coarse natural deposits within the foundation and abutment.
- Transport of materials into or through cracks.
- Development of flow paths in poorly compacted material alongside conduits within the embankment.

4.0 DAM BREACH ANALYSIS STUDY APPROACH

A dam breach analysis is required for all dams that could fail regardless of the likelihood to define the consequences of failure for the purpose of dam classification, and to support emergency planning for such an event. The evaluation should consider two hydrologic conditions (CDA, 2013):

- Sunny-day or fair weather failure – This is a sudden dam failure that occurs during normal operations.
- Flood-induced failure – This is a dam failure resulting from a flood that exceeds the capacity of the dam and its appurtenant control structure(s).

The relevant failure mechanisms applicable to the fair weather conditions are geotechnical slope instability, seismic induced failure, structural instability, piping and failure of the control structure. During an extreme flood event the dam could fail by overtopping, piping, slope instability, structural instability and failure of the control structure. Commonly, the Probable Maximum Flood (PMF) is considered to be the extreme flood event for dam breach modelling. The PMF is defined as the most severe flood that may reasonably be expected to occur at a particular location. It should be noted that the PMF is a credible hydrologic event and therefore must be considered in assessing failure impacts. An assessment should also be made to understanding the failure impacts associated with the flooding event that exceeds the inflow design flood (IDF).

4.1 Dam Breach Methods

There are profound differences in the breaching of a water retaining dam and a dam that impounds tailings with little water. In the former case the impounded water serves to sustain the erosion process until the water storage is completely depleted. In the case of a tailings dam breach, the ability of the tailings to flow from the impoundment is contingent on the availability of water, which provides mobility for the tailings, i.e., the tailings will flow as a slurry. In the absence of water, tailings can only travel a limited distance from the dam breach.

As a non-Newtonian fluid, the flow of slurry is highly complex. However, the dam breach analysis techniques developed for water storage dams may be conservatively applied to the flow of tailings.

The framework for undertaking a dam breach analysis for a water storage dam is reasonably well established. Numerical modelling technologies are available to guide practitioners on a consistent basis for failure impact assessments. Traditionally this has been done through one-dimensional (1D) modelling, but recently the industry has started to move towards two-dimensional (2D) analyses. For a typical tailings dam with free water, saturated tailings and “dry” tailings, there are currently no numerical modelling tools available that can model all three phases simultaneously. Therefore, high-level assumptions and simplifications need to be made in order to make an assessment of the tailings breach inundation zone.

The dam breach methods for water storage dams and tailings storage dams are described below.

4.2 Water Storage Dam

The two primary tasks in the analysis of a potential dam failure are the prediction of the reservoir outflow hydrograph and the routing of that hydrograph through the downstream valley to determine dam failure consequences. The routing of large floods is a well-developed science, although some areas of uncertainty do remain (e.g. changes in channel roughness due to debris effects, sediment deposition modelling). Greater progress is also being made in this field, as geographic information technology and computing resources continue to be developed. However, the greater source of uncertainty in most situations is the prediction of the reservoir outflow hydrograph, especially for embankment dams in which dam failure is usually the end result of the progressive erosion process that is itself very complex and difficult to accurately model.

4.2.1 Modelling Strategies

With the end product of most dam breach analyses being the prediction of flooding conditions and the potential loss of life, the focus of dam breach modelling has traditionally been on the tools to produce the outflow hydrograph.

Three principal strategies for prediction of the outflow hydrograph have emerged since the 1970s:

- The first strategy is to predict the breach outflow hydrograph directly and then use one of the available routing models to route the flood downstream so that flooding consequences could be determined.
- The second approach is to parameterize the breach so that its development over time could be described in mathematical terms. In this approach, breach parameters could be determined by several different means (empirical equations, charts, etc.) external to the flood routing model, but determination of the breach outflow hydrograph takes place in the routing model.
- The third approach is to use a combined model that simulates specific erosion processes and associated hydraulics of flow through the developing breach to yield a breach outflow hydrograph. Early models that took this approach were run separately from flood routing models, with the breach outflow hydrograph provided as input to the routing model. Models which can integrate breach modelling and flood routing capabilities have been recently developed.

The breach modelling strategies described above are summarized in Table 4, with further subdivisions of the various methods shown. This table suggests that there are five different methods that could be used to perform the analysis that leads to the determination of the breach outflow hydrograph.

Table 4: Dam Breach Flood Modelling Strategies

<table>
<tr><th>Methods</th><th>Output</th><th>Application</th></tr>
<tr><td>Regression models for peak flow discharge as a function of dam and reservoir properties</td><td rowspan="2">Approximates breach outflow hydrograph by predicting peak outflow and hydrograph shape directly.</td><td rowspan="5">Route breach outflow hydrograph to determine flooding consequences</td></tr>
<tr><td>Analytical models to predict peak flow discharge with closed-form equations or charts as function of dam and reservoir properties</td></tr>
<tr><td>Regression models for breach parameters as function of dam and reservoir properties</td><td rowspan="2">Provide breach parameters as input to routing model, which determines breach outflow hydrograph through the use of hydraulic equations for flow through the enlarging breach</td></tr>
<tr><td>Apply erosion model to predict breach formation and then approximate breach formation in a parametric way for input into routing models</td></tr>
<tr><td colspan="2">Process-based erosion and hydraulics models that simultaneously determine breach development and resulting outflow hydrograph</td></tr>
</table>

Source: Wahl (2010).

4.2.2 Estimation of Breach Parameters

A key element for calculating a dam breach hydrograph for a specific dam involves estimating the dam breach parameters related to the geometry and timing (e.g., width, depth, shape, and time of failure) of the breach formation.

The greatest uncertainty associated with determining the breach outflow hydrograph lies in the selection of breach parameters for determining the peak outflow/discharge and therefore a careful evaluation and understanding of the associated breach parameters is fundamental.

Many factors should be considered in selecting appropriate breach parameters including type of dam, dam dimensions, and dam construction material. Other pertinent information such as historical records of seepage or foundation problems should also be considered.

A number of methods are available for estimating breach parameters for use in dam breach studies. Since the selection of the breach parameters is specific to each dam, guidance has been provided in the following sections related to selecting common methods that can be used to estimate dam breach parameters.

As discussed in Section 3, dam failure occurs for a wide variety of reasons. A description of the breach formation and determination of breach parameters for the most common dam breach mechanisms (i.e., overtopping and piping) is presented below.

4.2.2.1 Breach Formation – Embankment Dams

4.2.2.1.1 Overtopping Failure

Overtopping failure may occur very differently depending on the composition of the dam. During an overtopping event a small headcut typically forms on the downstream face of an embankment and progresses upstream. The breach is considered to begin when erosion occurs across the width of the dam crest. After the breach initiates at the top of the dam crest, it enlarges rapidly to its ultimate extent. If there is no physical reason to believe that the embankment would fail at a particular location, the breach is typically modelled as initiating along the section of dam with the maximum height. A generalized trapezoidal breach progression is illustrated in Figure 1.

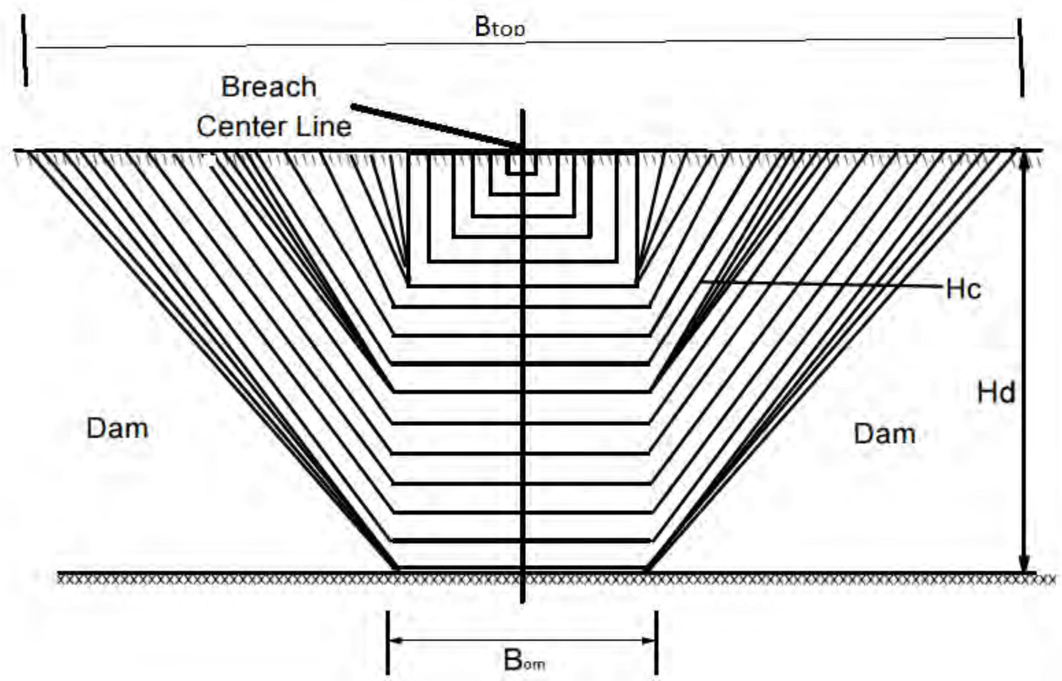

Figure 1: Front view of dam breach formation sequence.

4.2.2.1.2 Piping / Internal Erosion Failure

Piping and internal erosion occurs when concentrated seepage develops within an embankment dam. The seepage slowly erodes the dam, leaving large voids in the soil. Typically, piping begins near the downstream toe of the dam and works its way towards the upper reservoir. As the voids become large accompanied by the increased flow, erosion becomes more rapid. Water flow through the embankment will appear muddy as erosion increases. The piping hole will continue to enlarge and eventually cause the dam crest to collapse.

Piping failures are typically modelled in two phases, before and after the crest collapses. Water flow through the piping hole is modelled as orifice flow before the dam crest collapses and then as weir flow after the dam crest collapses. However, only the second phase is used for estimation of the peak outflow and analysis of the downstream effects.

4.2.2.1.3 Published Breach Parameters Estimation Methods

A variety of methods have been proposed to estimate dam breach parameters associated with embankment dams and the resultant dam breach peak discharge and timing. These methods are summarized below.

- **Predictive Regression Equations –** These equations estimate the dam breach peak discharge empirically based on case study data of peak discharge and hydrograph shape.
- **Parametric Regression Equations –** These equations, developed from case studies, are used to estimate the time-to-failure and ultimate breach geometry.

- **Physically Based Erosion Methods –** These methods predict the development of an embankment breach and the resulting breach outflows using an erosion model based on principles of hydraulics, sediment transport, and soil mechanisms.

Predictive and Parametric Regression Equations

Table 5 provides the most common published parametric and predictive regression equations developed based on information provided in case studies of historic dam failures (mostly from embankment dams). The sources used to populate Table 5 are Wahl (2001), Fread D.L. (2001), Froehlich (2008) and Hu & Zhang (2009). Comments on the application of the equation are summarized in the third column of Table 5. It should be noted that in some instances the input parameters for an empirical equation are only valid for a particular system of measurement, e.g., metric or imperial units. Based on Golder's review of the documents presenting each equation it appears that the input units should be metric for all equations, however, it is strongly recommended that before a particular equation is used, the user obtain a copy of the original study and carefully review the methodology to make sure that the correct inputs into the equation are used and the limitations of the equation are fully understood.

Table 5: Parametric and Predictive Equations for Predicting Breach Parameters in Embankment Dams

Breach Width Equation (Parametric)		Comments
U.S. Bureau of Reclamation (1988)	$B = 3(h_w)$	This equation is not intended to yield accurate predictions of peak breach outflows, but rather intended to produce conservative, upper bound values that will introduce a factor of safety into the hazard classification procedure. Dependent on dam height only.
Von Thun and Gillette (1990)	$B = 2.5h_w + C_b$	Using C_b of 6.1 to represent reservoir size $< 1.23*10^{6}$. This relationship was developed from Froehlich (1987) - subsequently updated by Langridge-Monopolies (1984) - useful mostly as a check for other derived geometries. Does not take specific reservoir volume into account.
Froehlich (1995)	$B = 0.1803K_oV_w^{0.32} H_b^{0.19}$	Dependent on volume and height (overtopping). Where K_o =1.4 for overtopping and K_o =1.0 for other failure modes.
Froehlich (2008)	$B = 0.27K_oV_w^{0.32}H_b^{0.04}$	Equation developed in 2008 based on 74 embankment dam failures, it is an updated version of the 1995 equation. Where dimensionless coefficient K_o =1.3 for overtopping failure and K_o = 1.0 for other failure modes.
Fread D.L. (2001)	$B = 9.5K_o(V_w H_w)^{0.25}$	Dependent on volume and height.
MacDonald/Langridge-Monopolis(1984) – earthfill dam	$V_{er} = 0.0261(V_wh_w)^{0.769}$	Useful as a check of the geometries of other predictions. Based on breach formation factor defined as the product of the volume of breach

		outflow and the depth of water above the breach invert at the time of failure.
MacDonald/Langridge-Monopolis(1984) – rockfill dam	$V_{er} = 0.00348(V_w h_w)^{0.852}$	Non-earthfill (e.g., rockfill).
Breach Formation Time Equations (Parametric)		
U.S. Bureau of Reclamation (1988):	$t_f = 0.011(B)$	This equation is not intended to yield accurate predictions of peak breach outflows, but rather is intended to reduce conservative, upper bound values that will introduce a factor of safety into the hazard classification procedure. Dependent on height only.
Von Thun and Gillette (1990) - highly erodible soils	$t_f = 0.015(h_w)$	It is assumed that embankment is highly erodible, as embankment mostly consists of materials such as coarse rejects. Sands and other small materials also mixed in.
Von Thun and Gillette (1990) - erosion resistant soils	$t_f = 0.020(h_w) + 0.25$	Dependent on height only. More relevant for rockfill, erosion resistant cores, etc.
Von Thun and Gillette (1990) - highly erodible soils	$t_f = B/(4h_w + 61)$	Dependent on height and breach width. However, breach width is not dependent on a specific volume, but rather on a volume range. Equation for embankments with highly erodible material, e.g., coarse rejects, sands and other small materials mixed in.
Von Thun and Gillette (1990) - erosion resistant	$t_f = B/(4h_w)$	Dependent on height and breach width.
Froehlich (1995b)	$t_f = 0.00254(V_w)^{0.53} h_b^{-0.9}$	Dependent on volume and height.
Froehlich (2008)	$t_f = 63.2(V_w / gH_b^2)^{0.5}$	Dependent on volume and height.
Fread D.L. (2001)	$t_f = 0.3\ V_w^{0.53}/H_w^{0.9}$	Dependent on volume and height.
Peak Flow Equations (Predictive)		
Kirkpatrick (1977)	$Q_p = 1.268(h_w + 0.3)^{2.5}$	Dependent on height only. Based on data from 13 embankment failures, and a proposed best-fit relation for peak discharge as a function of depth of water behind the dam at failure.
Soil Conservation Service - SCS (1981)	$Q_p = 16.6(h_w)^{1.85}$	Dependent on height only. Based on envelope curve of same studies cited in Kirkpatrick.

Hagen (1982)	$Q_p = 0.54(S\ h_d)^{0.5}$	Function of storage and height.
U.S. Bureau of Reclamation (1982)	$Q_p = 19.1(h_w)^{1.85}$	This equation is not intended to yield accurate predictions of peak breach outflows, but rather is intended to produce conservative, upper bound values that will introduce a factor of safety into the hazard classification procedure. Dependent on height only.
Singh and Snorrason (1984)	$Q_p = 13.4(h_d)^{1.89}$	Based on height only. Relationship based on the results of eight simulated failures based on DAMBRK and HEC-1 software.
Singh and Snorrason (1984)	$Q_p = 1.776(S)^{0.47}$	Based on storage only. This exhibits a lower standard error than only based on height. Relationship based on the results of eight simulated failures based on DAMBRK and HEC-1 software.
MacDonald/Langridge-Monopolis (1984)	$Q_p = 1.154(V_w h_w)^{0.412}$	Based on breach formation factor defined as the product of the volume of breach outflow and the depth of water above the breach invert at the time of failure. Best-fit curve.
MacDonald/Langridge-Monopolis (1984)	$Q_p = 3.85(V_w h_w)^{0.411}$	Same as above, but envelope curve.
Costa (1985)	$Q_p = 1.122(S)^{0.57}$	Envelope equation based on dam storage only (i.e. no accounting for tails not flowing).
Costa (1985)	$Q_p = 0.981(S\ h_d)^{0.42}$	Based on storage and height parameters.
Costa (1985)	$Q_p = 2.634(S\ h_d)^{0.44}$	Envelope equation based on storage and height parameters.
Evans (1986)	$Q_p = 0.72(V_w\ )^{0.53}$	Based on reservoir volume only.
Froehlich (1995a)	$Q_p = 0.607(V_w^{0.295} h_w^{1.24})$	Best-fit regression equation for prediction of peak discharge based on reservoir volume and head, using data from 22 case studies for which peak discharge data was available.
Hu and Zhang (2009) $Q_p = 0.133(V_w^{1/3}/h_w)^{-1.276}\ e^{C4}\ (gV_w^{5/3})^{0.5}$		Developed as a multi-parameter nonlinear regression analysis based on 182 case studies. C4 is a dimensionless factor depending on mechanisms of dam breach (piping or overtopping), and on dam erodibility degree.

Definition of symbols for equations shown in Table 5 (units of measure may vary by equation):

B = average breach width.
C_b = offset factor in the Von Thun and Gillette breach width equation, varies from 6.1 m to 54.9 m as a function of reservoir storage.
h_b = height of breach.
h_d = height of dam.
h_w = depth of water above breach invert at time of failure.
K_o = overtopping multiplier for Froehlich breach width equation.
Q_p = peak breach outflow.
S = reservoir storage.
t_f = failure time (breach formation time).
V_{er} = volume of embankment material eroded.
V_w = volume of water stored above breach invert at time of failure.

Physically Based Erosion Methods

Since the 1960s there have been numerous developments of physically-based, numerical dam breach models. In 1965, the first breach model was proposed by Cristofano, pioneering the development by others of physically based models: Brown & Rogers BRDAM (1977), Dam Break Forecasting Model (DAMBRK) (1977), Breach Erosion of Earthfill Dams and Flood Routing (BEED) (1985), and BREACH (National Weather Service-NWS, 1988) (FEMA, 2013).

Currently, the NWS BREACH model is a well-known and commonly applied physically based model. The NWS BREACH model was developed to more realistically simulate breaches initiating by overtopping or piping in order to predict the breach characteristics and the discharge hydrograph for an embankment dam. The model was initially developed in 1987 with updates in 1988, 1991, and 2005. The BREACH program is no longer supported by the NWS and is not available on the NWS website. However, it is still used because it is known to more accurately predict breach progression than other available methods and perhaps because it has not yet been replaced by another freely available software that performs the same function.

BREACH couples the conservation of mass of the reservoir inflow, spillway outflow, and breach outflow with the sediment transport capacity of the unsteady uniform flow along an erosion formed breach. The growth of the breach, as shown in Figure 1, is dependent on the dam's material properties and the assumed location of the downstream face of the dam.

This program may be used in conjunction with other programs to simulate downstream dynamic effects using the breach parameters results (i.e., breach width and development time) as input into a separate flood routing model that can determine the breach hydrograph itself (Fread, 1988).

4.2.2.2 Breach Formation - Concrete Dams

Concrete dam failures are typically modelled as structural failures. As such, there are different failure mechanisms dependent on the type of the dam.

Concrete Gravity Dams – Concrete gravity dams are typically constructed from numerous concrete monoliths. For this type of dam, USACE (2007) suggests using an average breach width of multiple monoliths, while the Federal Emergency Commission (FERC, 1988) and Fread (2006) suggest using an average breach width of less than or equal to half of the entire length of the dam. For this type of dam the breach is assumed to have vertical side slopes since monoliths are typically rectangular in shape and therefore are vertical.

Concrete Arch Dam – The most common location for a gravity arch dam is in a deep canyon with steep side walls. For this reason, the breach side slope is assumed to range from vertical to the slope of the valley wall. The suggested breach widths for this type of dam range from 80 percent of the entire length of the dam to the entire length of the dam.

Veale and Davison (2013) performed a study based on 58 historical gravity dam failures and observed that there is a considerable scatter in the ratio of failure (B_F/B_D), refer to Figure 2, and there is no clear relationship between the breach width (B_F) and dam crest length (B_D) as a function of dam type. The relationship (B_F/B_D) varies from 10% to 100% loss of the concrete dam. The ANCOLD (2012) guidance document for an intermediate consequence assessment suggests that for concrete gravity dams, a loss of 30% of the dam monoliths should be considered in the absence of substantial information. Figure 2 suggests that 4 of the 8 observed concrete gravity dam failures meet the criteria of $B_F/B_D > 30\%$.

A study by Veale and Davison (2013) suggested that historical gravity dam failures are highly dependent on site-specific details. Guidance from USACE (1980), reproduced in Table 6, suggests a breach width of two or three monoliths for concrete gravity dams where no site-specific details are available. It is assumed that this would be in the range of 20 m - 60 m for most concrete gravity dams, and this range is shaded in Figure 2 to indicate how this width compares with the failures in the database.

Table 6: Assumed Breach Width and Formation Time (after USACE 1980)

Type	Breach Width	Breach Side Slope	Time to Peak Breach Discharge
Concrete Gravity	Multiple Monoliths	Vertical	0.1 to 0.5 hours
Concrete Arch	Entire dam width	Valley wall slope	Near instantaneous

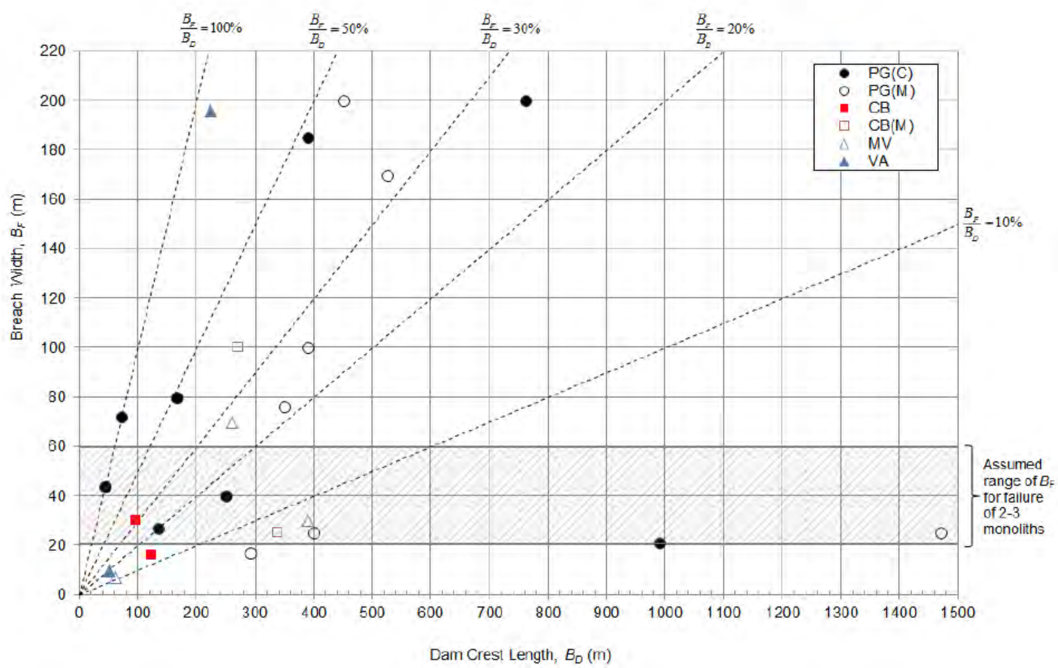

Figure 2: Ratio of dam breach width (B_F) to dam crest length (B_D) for concrete and masonry dams.

Where:

PG(C):	Concrete Gravity	CB(M):	Masonry Buttress
PG(M):	Masonry Gravity	MV:	Concrete Multiple Arch
CB:	Concrete Buttress	VA:	Concrete Arch

Source: Veale and Davison (2013)

4.2.3 Dam Breach Hydrograph and Peak Outflow Generation Models/Tools

It is common practice to first estimate breach parameters using the empirical equations and methods previously described and to then use another model to define the breach hydrograph. The breach hydrograph is then routed downstream using a one-dimensional or two-dimensional hydraulic model. It is also quite common that the model used to generate the breach hydrograph or dam peak discharge outflow does not include the capability of routing the breach hydrograph or peak discharge to the downstream and therefore an additional model must be used to route the flood wave along the flow pathway. The applicability, strength, and limitations of the methods for calculation of the breach hydrograph are summarised in Table 7 (FEMA, 2013).

Table 7: Methods for Breach Hydrograph Generation

Methods	Applicability	Strengths	Limitations
Empirical Equations	Embankment dam failure	-Fast, simple to use -Minimal input data	Large potential for error, suitable for Tier 1 studies (refer to Table 9)
WinDAM B	Embankment dam failure overtopping breach	Physically based model using erosion and sediment transport principals	Limited to homogeneous embankments with simple embankment geometry
NWS-BREACH	Since 2005, the model source code has not been supported by the NWS		
USACE HEC-HMS	Concrete and embankment dam failure	Ease of program use	Level pool routing is not applicable to some reservoirs

Source: FEMA (2013).

4.2.4 Uncertainty of Predicted Dam Breach Results

Progress has been made over the past years in the field of dam failure analysis. The use of sophisticated GIS and computer resources has made it easier to integrate flow information to predict the reservoir outflow hydrograph. However predicting the reservoir outflow hydrograph remains a great source of uncertainty, especially for embankment dams in which dam failure is usually a complex process that is difficult to model (Wahl, 2010). Since the scale of estimated consequences associated with the dam failure can be sensitive to the choice of breach parameters, careful consideration should be given to the selection of the proper method(s) for determining breach parameters and the uncertainty associated, not only with the parameters themselves, but of the overall results of the breach modelling effort (FEMA, 2013).

According to Wahl (2010), the best methods of breach width prediction are empirically derived parametric equations, e.g., USBR (1988); Von Thun & Gillette (1990), and Froehlich (1995a, 2008). These methods have been found to have uncertainties of about ± 1/3 of an order of magnitude.

4.2.5 Hydraulic Routing Models/Tools

Models/tools to perform flood routing downstream of the dam are divided into one-dimensional and two-dimensional models. Hydraulic modelling of a dam breach has traditionally been completed using one-dimensional flow equations. One-dimensional models provide reliable results for many situations; however one-dimensional models in unconfined floodplains do not accurately represent the breach flood wave moving downstream. Two-dimensional models capable of solving two-dimensional shallow water equations currently are more widely used. With recent advancements in the speed of computing capability, the use of two-dimensional models for dam failure studies has grown.

4.2.5.1 One-Dimensional Models

Table 8 lists the most widely used one-dimensional hydraulic models for downstream hydraulic routing of flood waves. Table 8 also provides a summary of the application, strengths and limitations of each model.

Table 8: Summary of One-Dimensional Models

Model	Application	Strengths	Limitations
NWS FLDWAV	Can analyze flows in mixed-flow regime in a system of interconnected waterways	Considers effects of downstream obstructions and resulting backwater effects.	Calibration is time consuming. Not adequate for all complex river conditions.
USACE HEC-RAS	Recommended for detail analysis and routing of the breach hydrograph	Considers effects of downstream obstruction and resulting backwater effects. Output data can be input into GIS to produce inundation maps. Allows dynamic reservoirs routing.	Labor intensive and time consuming. Instability problems may arise.
FEMA GeoDam BREACH Toolset	Simplified method to be used in initial analysis and non-regulatory studies	Simple and quick to use	Only conduct fair weather breach analysis

4.2.5.2 Two-Dimensional Models

Two-dimensional models use full dynamic or simplified forms of one- and two-dimensional shallow water equations and are more appropriate for flat and wide floodplain areas. Several two-dimensional flow models are available for hydraulic modelling and to route dam breach flood waves through the downstream channel and floodplain areas. Currently, the most commonly used two-dimensional software for dam breach studies includes; the DHI MIKE software, FLO-2D and MIKE FLOOD. USACE in 2015 developed the HEC-RAS 2D model, which is expected to become widely used for dam breach modelling in the future.

4.2.6 Recommendations for Selecting Modelling Tools

The level of effort of carrying out a dam break analysis should be commensurate with the anticipated failure impacts, especially loss associated with the loss of life.

FEMA (2013) recommends a tier approach to determine the appropriate level of complexity in the assessment, modelling, and mapping of a dam failure based on the consequence of failure, and the size and complexity of the downstream area under investigation as shown in Table 9.

For dams in rural areas where the potential for loss of life is low, a tier 1 level study using simplified methods may be appropriate. For areas where a potential dam breach can result in the loss of life, an intermediate tier 2 level or advance tier 3 should be performed. The intermediate tier 2 level study may be used for areas where more detailed calculations are justified because of the potential for loss of life. The advance tier 3 level may be needed to develop dam breach inundation zone mapping for urbanized areas and for unconfined floodplains.

Table 9: Recommended Model Types for Various Levels of Dam Breach Modelling

Tier Level	Applicable to	Peak Breach Discharge Prediction	Downstream Routing of Breach Hydrograph
Pre-Screening (non-modeling method)	Low-hazard potential and small sized dams with very little infrastructure or population downstream. First level assessment to determine level of detail needed for modeling	N/A. Initial height of wave at breach assumed to be ½ height of dam.	N/A. Water in reservoir routed downstream based on height of the dam. Height of wave decreases by ½ for every 1.6 km (10 miles) downstream.
Tier 1 – Screening and Simple Analysis (basic method)	Low-hazard potential, small size or first-level screening for significant or high-hazard dams	Regression equations, NWS SMPDBK, GeoDam BREACH or TR-66, HEC-HMS or DSAT	GeoDam BREACH, SMPDBK, HEC-RAS steady state, HEC-HMS hydrologic routing or DSAT
Tier 2 -Intermediate	Significant-hazard potential, intermediate-size or high-hazard dams with limited population at risk	HEC-HMS, HEC-RAS Unsteady Model, DSAT or WinDAM	HEC-RAS (steady state or unsteady state modelling) or Two-Dimensional Model for unconfined floodplains
Tier 3 - Advance	High-hazard potential, large-size dams with sufficient population at risk to justify advance analyses	HEC-HMS, HEC-RAS Unsteady Model, or WinDAM,	HEC-RAS Unsteady Model or Two-Dimensional Model PCSWMM

Source: FEMA (2013).

4.2.7 Dam Breach Inundation Mapping

Although there is guidance for hydrologic and hydraulic procedures for dam breach inundation studies, there is little information on the creation of inundation maps for developing an Emergency Action Plan. Two US agencies USACE and USDOI have developed guidelines for GIS-based mapping standards, however both guidelines involve standards that have been developed for the specific intended use of those agencies.

The most simplified method for producing an inundation map is the topographic photo-based mapping, whereby the water contained in the reservoir is placed downstream based on the assumption that the breach wave is initially half the height of the dam, and that the wave height decreases by half every 10 miles. These assumptions are used to calculate flood water depths at various locations downstream, and identify inundation boundaries that outline at risk areas (North Carolina Department of Environment and Natural Resources, 2015).

Higher level, yet still simplified, computer based methods exist within programs such as HEC-HMS and SMPDBK for computing inundation areas downstream from a dam. The tools use calculated breach parameters known by the user to compute breach hydrographs, and subsequently route the flood downstream to critical locations. Steady-state hydraulic models can be created that accurately predict downstream hydraulic conditions at these critical locations. It should be noted that these methods are relatively conservative when compared to higher-level programs, but can produce inundation maps much more rapidly and at a lower cost. While the calculated parameters are accurate, the maps created are intended more for visual purposes, and higher level mapping should be completed in areas that have a significant or high risk classification (State of Colorado, 2010).

No matter which method is used to create an inundation map, the accuracy of the map will be highly dependent on the basemap and elevation data used. Outdated basemaps may not show the most recent aerial imagery, and therefore key features such as new developments and infrastructure may not be shown in the calculated inundation zone. If the person creating the inundation map is unfamiliar with the area, they may not realize that significant infrastructure lies within the inundation zone, leading to an inaccurate hazard assessment and improper emergency planning. Similarly, it is important to use the most precise elevation data available to create inundation maps. The larger the contour intervals, the less accurate the inundation zone will be, which can again lead to key features being left out of the hazard area, leading to an improper hazard assessment. Up to date, precise elevation data is not always readily available for many locations, however in those locations where it is determined that the inundation hazards downstream may be high, additional efforts should be made to obtain detailed topographic information in order to properly assess the hazards and prepare effective emergency plans.

It is worth noting that in an effort to improve Canada's response to flooding, the federal government has developed the first iteration of the Federal Floodplain Mapping Framework in consultation with provincial and territorial partners and key stakeholders. Although not specifically developed to support dam breach inundation studies, the guidelines will provide details on technical aspects related to floodplain mapping (including map production and geospatial data management) that can be applicable to the preparation of dam breach inundation maps. The various guidelines of the series will be published during 2017 and 2018.

4.2.7.1 Tier 1 Simple Analysis Methods

Oftentimes when dams are small and are considered to pose a low threat to the downstream environment, dam breach analyses are not completed due to lack of resources available to undertake such projects. Tier 1 Screening and/or Simple Analysis can be highly effective in these situations, as they can be completed relatively quickly without any required training, and come at a much lower cost than higher level Tier 2 and 3 assessments.

Tier 1 Screening analyses use conservative methods that can be performed rapidly compared to intermediate and advanced levels, and should be used to determine if further dam breach analysis is required. If initial Tier 1 screening shows that there are potential at-risk features downstream of a dam, this would indicate that a further level assessment should be undertaken, however if the simplified methods indicate that the hazard level is low, no further modelling is generally required (State of Colorado, 2010).

Screening methods ignore dam break hydrographic development and use empirical methods, such as those listed in Table 5, to calculate breach parameters that can be used in further applications, for example as input into the SMPDBK peak discharge equation. From the breach parameters, hydraulic conditions at crucial downstream locations can be determined using empirical routing equations. Further hydraulic conditions at these crucial locations can be determined with normal depth calculations as long as steady, uniform flow is a valid assumption, i.e., there are no significant backwater effects in the vicinity of the section. Should these hydraulic calculations indicate that there may be a certain level of hazard at the critical sections, this could warrant an additional analysis using a less conservative approach (i.e. Tier 2 or Tier 3 analysis) in order to determine the specific hazard classification (State of Colorado, 2010).

Simple methods of analysis are somewhat more complex than screening analysis, as they use empirical methods in conjunction with a hydrologic parametric model to computer a breach hydrograph. This simple level of analysis can be achieved through programs such as HEC-HMS, SMPDBK, or other programs listed in Table 9. These hydraulic tools are used to route the flood downstream to the critical locations, where a steady-state hydraulic model can be used to calculate accurate hydraulic conditions at that point. Simple analysis methods are less conservative than screening methods as the breach hydrograph typically has a smaller peak due to the parametric modeling of the breach formation, and the hydrologic routing typically results in flood wave attenuation by the time it reaches critical locations. The results of the steady-state hydraulic models used in screening methods can be used to create inundation mapping for Emergency Action Plans. The results may provide the necessary conclusions, or may indicate that the intermediate or advanced approaches are warranted if the results produce a borderline situation, i.e. a potentially significant or high classification dam (State of Colorado, 2010).

4.3 Tailings Storage Dam Breach

A tailings dam is a structure that retains mine waste (tailings, water or treatment sludge). The stored materials are unique at each facility and this needs to be considered when conducting a dam break analysis for a tailings dam. The rheological (flow) properties of the tailings behave differently depending on the ore mineralogy, degree of entrenchment during a dam breach, method of deposition, consolidation and densification. The larger the tailings pond, the greater the potential for tailings transport. The extent to which tailings flow from a breach is also a function of the mobility of the tailings, with the maximum flow distance being associated with tailings that become liquefied prior to or during the dam breach. Therefore, undertaking a dam break analysis for a tailings dam is more complex than for a water dam and requires numerous assumptions and simplifications to characterize the flowing tailings.

Due to the complexity of tailings flow from a breach two approaches are currently used to estimate the discharge. Where a tailings pond is present, the outflow is conservatively modelled as water using one of the methods for water retaining dams as discussed in the previous section. When the tailings pond is small relative to the tailings storage, the tailings may be assumed to flow as a liquefied slurry.

4.3.1 Volume of Mobilized Tailings and Runout Distance

During a tailings dam failure with no ponded water only part of the storage is released, Figure 3 shows an idealized geometry of the flowslide based on Lucia, Duncan and Seed (1981) as adopted by Vick (1991). The runout distance can be estimated for a range of residual shear strengths for the liquefied tailings, which is dependent on the vertical effective stress ratio prior to failure (Olson and Mark, 2002). The runout distance is also strongly dependent on the ground inclination downstream of the dam. When the ground slope approaches or exceeds the residual strength of the tailings the runout distance can be very large (Chen and Becker, 2015).

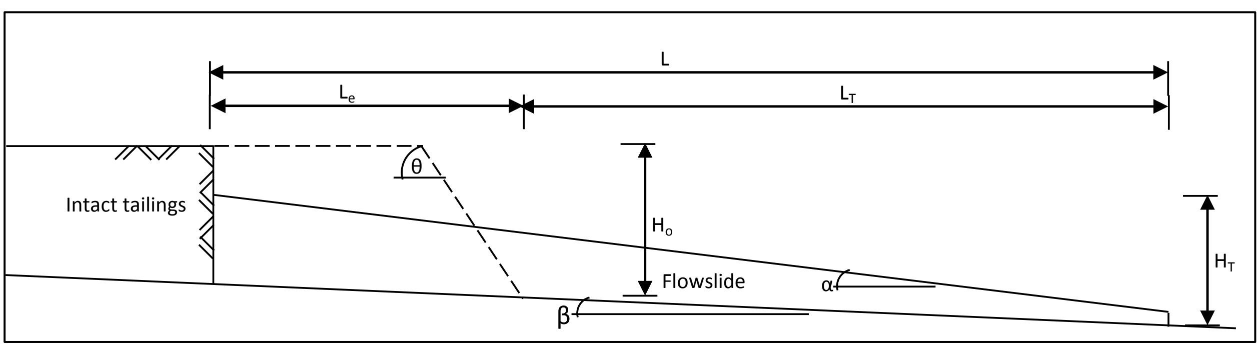

Figure 3: Idealized geometry for force equilibrium analysis.

Where: Initial angle of downstream face of tailings (θ)
Maximum height of tailings prior to failure (H_o)
Ground slope (β)
Flowslide slope (α)
Maximum length of basin (L_e)
Runout distance (L_T)

The quantity of tailings released during a dam breach varies greatly. Documented tailings dam failures have a percentage of total stored tailings released ranging from 5% to 100% (Rico et al., 2008).

An important factor in evaluating the safety and environmental effects of a tailings dam failure is the distance that the flowslide might travel in the event of dam failure. Although, various procedures for estimating this distance have been proposed, a major difficulty in applying them to data has been the inability to reliably determine the necessary input parameters of the tailings properties such as residual undrained shear strength, viscosity and inertial effects.

Rico (2007) compiled information on historical tailings dam failures with the purpose of establishing a correlation between tailings pond geometric parameters (e.g., dam height, tailings volume) and the hydraulic characteristics of floods resulting from the released tailings. His study showed that the tailings outflow volume correlated reasonably well ($r^2 = 0.86$), with the tailings volume stored at the time of failure as shown on Figure 4. The volume of spilled tailings was also correlated with its run-out distance ($r^2 = 0.57$), as shown on Figure 5. On Figures 4 and 5, V_F is the tailings outflow volume and V_T is the tailings stored volume. An envelope curve was drawn encompassing the majority of the data points indicating the potential maximum downstream distance affected by a tailings spill. It should be noted that the data set does not distinguish tailings impoundments with or without a tailings pond. The application of the described regression equation for prediction purposes needs to be treated with caution and with support of on-site measurements and observations.

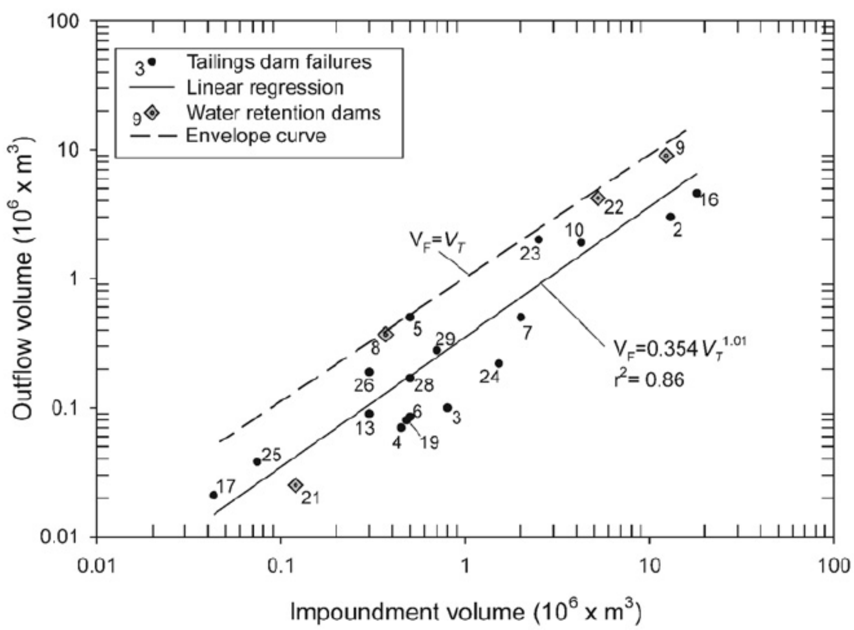

Figure 4: Outflow tailings volume vs. impoundment volume

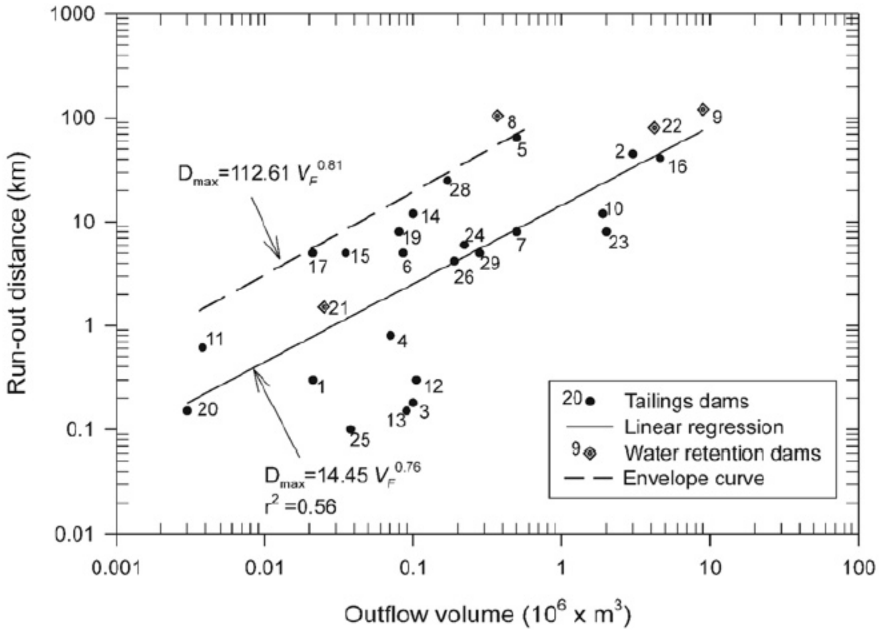

Figure 5: Run-out distance vs. tailings outflow volume.

There is no pre-defined percentage of total tailings that can be applied to all scenarios. Professional judgement is required to select the volume of released tailings. Characteristics such as tailings rheology, degree of saturation, configuration of the tailings facility, and the volume of water stored in the tailings facility at the time of failure are some of the factors that influence the selection of the volume of tailings released during a dam breach.

Advanced numerical modelling of tailings flow with water may be performed. However, such modelling is less common due to the large computational effort involved and the lack of tailings property data required for modelling.

For illustration purposes, Table 10 summarizes the available information on historical tailings dam failures compiled by a number of investigators and provides the number of dam failures, dam height, and the volume of tailings released.

Table 10: Volume of Tailings Released

Source	No. of Dams	Dam Heights	Volume of Tailings Released	
			Range	Average
Lucia (1981)	11	15 m to 46 m	14% to 100%	40%
USCOLD (1995)	31	12 m to 61 m	1% to 100%	26%
Garga and Khan (1995)	19	?	3% to 100%	28%
M. Rico et al. (2007)	28	5 m to 66 m	3% to 100%	33%
Azam and LI (2010)	72	?	?	20%

Source: USSD (2011).

4.3.2 Run-out Assessment Methods

During a tailings dam break, the rheological behaviour of the tailings slurry (i.e., if it's a Newtonian or a non-Newtonian) is dependent on the concentration of solids in the flow discharged from the dam breach. The concentration of solids in the discharge must be estimated by accounting for both pore water and free water from the pond. Figure 6 presents several "typical" regimes used to categorize different flow behaviours. In general, if the sediment concentration (by volume) is less than ~20% then the fluid can be reasonably thought of as a Newtonian fluid. If the sediment concentration (by volume) is between 20%-60% then the fluid can be reasonably thought of as a non-Newtonian fluid. If the sediment concentration (by volume) is above ~60% then the fluid is likely no longer a "fluid" and should be thought of as a granular flow.

	Concentration percent by weight (100% by WT = 1,000,000 ppm)									
	23	40	52	63	72	80	87	93	97	100
	Concentration percent by volume (G. = 2.65)									
Source	10	20	30	40	50	60	70	80	90	100
Beverage and Culbertson (1964)	High	Extreme	Hyperconcentrated				Mud Flow			
Costa (1984)	Water Flood		Hyperconcentrated		Debris Flow					
O'Brien and Julien (1985) using National Research Council (1982)	Water Flood		Mud Flood	Mud Flow		Landslide				
Takahashi (1981)	Fluid Flow		Debris or Grain Flow				Fall, Landslide, Creep, Sturzstrom, Pyroclastic Flow			
Chinese Investigators (Fan And Dou, 1980)	←------------------Hyperconcentrated Flow-------------------→ Sediment Laden		←-----------------Debris or Mud Flow------------------------------→							
Pierson and Costa (1984)	STREAMFLOW Normal: Hyperconcentrated			SLURRY FLOW (Debris Torrent), Debris Mud Flow, Solifluction			GRANULAR FLOW Sturzstrom, Debris Avalanche, Earthflow, Soil Creep			

Figure 6: Flow regime classification by various researchers (adapted from Bradley & McCutcheon, 1985).

A sediment concentration (by volume) of less than ~20% in a flow was often associated with a tailings facility that has ponded water located in the vicinity of the potential breach. Both tailings and water would flow out of the facility upon a breach.

A sediment concentration (by volume) between 20-60% could also be associated with a facility with a tailings pond, but the tailings entrained with the water would control the flow behavior. It could also be associated with a facility without a tailings pond as long as the tailings could liquefy and flow during a breach.

A sediment concentration (by volume) of more than ~60% in a flow was usually associated with a dry stack facility or a facility where the tailings pond would be located sufficiently far away as to not be affected by the breach. The tailings in this case would not be completely saturated and therefore considered non–liquefiable.

The runout assessment can be undertaken qualitatively or using numerical modelling. The following sections describe these two approaches.

4.3.2.1 Qualitative Method for Run-Out Assessment

When using the qualitative method for run-out assessment, the person completing the evaluation must evaluate the potential impacts on the downstream environment following a dam breach in a qualitative manner. This method can be used to assess the run-out for the entire range of sediment concentrations.

Where the tailings pond is substantial and the sediment concentration in the tailings slurry is expected to be 20% or less by volume, the tailings flow should be modelled as a Newtonian fluid. For a tailings slurry with a sediment concentration between 20%-60% by volume, the tailings flow will behaviour like a non-Newtonian fluid. The volumes discharged from the dam breach and the downstream environment's capacity to convey this volume downstream must also be considered in the evaluation. The screening level relationships as proposed by Rico (2008) may be used to provide an estimate of the breach impact. However, the qualitative method doesn't differentiate the flow properties between Newtonian (less than ~20%) and non-Newtonian fluids (between 20%-60%).

For a tailings slurry with a sediment concentration above 60% by volume, the person conducting the evaluation can evaluate the extent of the tailings runout qualitatively by assuming a post-failure surface slope and then performing a cut and fill balance.

4.3.2.2 Numerical Modelling Method for Run-Out Assessment

There are three different methods for numerically modelling the run-out assessment:

- Apparent water flow (Newtonian); sediment concentration (by volume) less than ~20%
- Mud flow (non-Newtonian; tailings slurry); sediment concentration (by volume) between 20%-60%
- Granular flow (tailings slurry); sediment concentration (by volume) above ~60%

Numerical tools to be used for the run-out assessment are not specified since they evolve with improvements in knowledge and technology. The selection remains the responsibility of the person conducting the study and will depend on the approach used, available information, specific site data, study objectives, and the level of detail required in the run-out assessment.

Presently, with the available technologies and costs associated with dam break analyses for a tailings dam, modelling the sedimentation of the tailings flowing out of a dam is not possible. There remains significant uncertainties associated with the properties of the outflowing tailings, cost associated with this type of modelling, and general understanding of the physical process of tailings erosion.

The following sub-sections describe these three different numerical modelling approaches for the run-out assessment.

4.3.2.2.1 Apparent Water Flow

This method is applicable to fluids with a sediment concentration (by volume) of less than ~20%. This would usually be associated with a tailings facility with a tailings pond located in the vicinity of the potential breach. Both tailings and water would flow out of the facility upon a breach.

In this method, the total volume of fluid flowing through the breach is modelled as water using a numerical model and the flow is assumed to be Newtonian. When generating the hydrograph, the volume of mobilized tailings is added to the volume of water flowing through the breach.

Standard water storage dam methods for dam break assessment are used. Modelling can be done in either one dimension (1D) or two dimensions (2D); the latter is recommended when available topographic data is sufficient. The apparent water flow method limitations are the following:

- Viscosity of the tailings is not considered;
- Extent of the flooding is generally overestimated;
- Flood arrival times are generally less than anticipated with a non-Newtonian flow; and,
- Tailings run-out extent in the flood path is not captured.

A similar modelling approach can apply to non-Newtonian fluids, recognizing the limitation of the model results. Apparent water flow can still be used to represent mud flow since the results are more conservative than what is anticipated to occur following a dam breach with a tailings slurry.

4.3.2.2.2 Mud Flow

This method is applicable to fluids with a sediment concentration (by volume) between 20%-60%. This could also be associated with a tailings facility retaining a tailings pond, but the tailings entrained with the water would control the flow behavior. It could also be associated with a facility without a tailings pond provided that the tailings can liquefy and flow upon a breach. As there is much uncertainty in the mechanism of tailings resuspension and erosion, the modelling of this type of problem must be considered very approximate over a range of possible tailings slurry densities.

In this method, the total volume of fluid flowing through the breach can be modelled numerically as a non-Newtonian fluid using one of the following rheological models:

- shear-rate (or strain-rate) dependent viscosity;
- sediment concentration dependent viscosity; and,
- yield stress and plastic viscosity dependent friction slope.

The estimated volume of tailings mobilized by empirical methods is combined with the volume of water and considered here as a homogeneous mixture of tailings and water. Modelling can be performed either in two dimensions (2D) or three dimensions (3D). For this analysis, the rheological properties of the tailings stored in the facility must be obtained, such as the stress-strain relationship, yield stress, plastic viscosity (Bingham) and density. These properties are determined by laboratory testing in order to properly model the non-Newtonian flow numerically. The limitations to this approach are the following:

- Tailings and supernatant are fully mixed at the breach location;
- Without suitable site-specific rheological data, a tailings/water mixture would need to be approximated as a Bingham type non-Newtonian fluid;
- Unless sediment concentration dependent viscosity is used, the percent solids within a numerical domain will not change in either space or time;
- Solids content of the mixture needs to be estimated; and,
- Tailings run-out extent in the flood path is represented, but the extent will depend on the rheological parameters chosen and the representation is limited by the assumption of a homogenous fluid.

4.3.2.2.3 Granular Flow

This method is applicable to fluids with a sediment concentration (by volume) of more than ~60%. This would usually be associated with a dry stack facility or a facility where the tailings pond is located sufficiently far away as to not be affected by the breach. The tailings in this case would not be completely saturated and therefore considered non-liquefiable. This type of analysis can be likened to the analysis of rapid landslides such as debris flows or debris avalanches. The total volume of tailings flowing through the breach is modelled numerically as a landslide of partially saturated granular material capable of entraining additional material along the flow path.

Modelling can be performed either in two dimensions (2D) or three dimensions (3D). This method requires the geotechnical properties of the tailings stored in the facility, such as the shear strength, the internal friction angle and the pore pressure of the materials considered and the their densities. These properties are determined by laboratory tests in order to properly model the granular flow numerically. A range of characteristics representing the in situ tailings can be used to present a range of potential outcomes.

5.0 CONCLUSIONS

Dam break inundation studies are used for multiple purposes such as evaluating and establishing the consequence classification for a dam; estimating and evaluating the potential for loss of life, environmental and cultural losses, and infrastructure damage/economic losses; preparing emergency preparation and response plans, and developing inundation zone mapping.

There is a distinction in the dam breach methodology based on a differentiation between water storage dams and tailings storage dams without a significant amount of impounded water. The dam breach analysis techniques developed for water storage dams may not be appropriate for the direct use with tailings dams, for example, the nature of tailings flow typically shows a different rheological behaviour compared to water.

The framework for undertaking a dam breach analysis for water storage dams is reasonably well established and numerical modelling technologies are available to estimate the downstream inundation impacts. Traditionally this has been done through one-dimensional (1D) flood routing modelling but recently the industry has moved towards two-dimensional (2D) analyses. For a typical tailings storage facility with free water, fluid tailings and solid tailings, there are currently no numerical modelling tools available that can model all three phases simultaneously. Therefore, assumptions and simplifications need to be made in order to make a high level assessment of the tailings dam breach. It is customary to apply water based dam breach models for tailings dams recognizing that some aspects of the results will be conservative.

A compilation of various dam break inundation mapping methods based on a literature review of available technical resources and common best practices has been presented in this document. The compilation included methods to estimate breach formation in embankment dams (earthfill and rockfill dams) and concrete dams, methods to calculate the dam breach hydrograph and peak outflow, models/tools to perform flood routing downstream of the dam, and approaches to estimate the volume of mobilized tailings and run-out distances for tailings storage dams.

6.0 REFERENCES

ANCOLD (2012). Guidelines on the Consequence Categories for Dams. Australia National Committee on Large Dams Inc.

ANCOLD (2013). Estimation of Concrete Dam Geometry, IPENZ Proceedings of Technical Croups 39 (LD).

BC MFLNRO (2001). Estimating Dam Break Downstream Inundation – Dam Safety Program, British Colombia - Ministry of Forests, Lands and Natural Resource Operation (BC MFLNRO) 2001.

Bradley, JB and McCutcheon, SC (1985). The Effects of High Sediment Concentration on Transport Processes and Flow Phenomena. In: International Symposium on Erosion, Debris Flow and Disaster Prevention, Tsukuba, Japan, 3–5 September 1985, 219–225.

CDA (2007a) (2013). “Dam Safety Guidelines, 2007 (Revised 2013)”.

CDA (2007b). “Technical Bulletin: Geotechnical Considerations for Dam Safety”.

CDA (2014a). “Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams, 2014”.

Chen, H.J. and Becker, D.E, (2015). “Dam Breach Tailings Runout Analysis”. H Joanna Chen, Dennis E. Becker. Annual Conference Banff, Alberta 2014.

FEMA (2013). Federal Guidelines for Inundation Mapping of Flood Risk Associated with Dam Incidents and Failures. First Edition July 2013.

Fread, D.L. (1987). DAMBRK: The National Weather Service (NWS)-Dam Break Flood Forecasting Model, Office of Hydrology, NWS, Silver Spring, MD 20910.

Fread, D.L. (1988) (revision 1991). BREACH: An Erosion Model for Earthfill Dams, U.S. Bureau of Reclamation. Denver, Colorado.

Fread, D.L. (2001). Some Existing Capabilities and Future Directions for Dam-Breach Modeling/Flood Routing. Proceedings FEMA workshop on “Issues, Resolution and Research Needs Related to Embankment Dam Failure Analysis”, Oklahoma City, Oklahoma.

Fread, D.L. (2006). ASDSO Advanced Technical Seminar. Dam Failure Analysis.

Froehlich, David C (2008). Embankment Dam Breach Parameters and Their Uncertainties. Journal of Hydraulic Engineering ASCE, vol. 134, No. 12, December 1, 2008.

FERC (1988). USA Federal Regulatory Commission (FERC) – *Notice of Revised Emergency Action Plan Guidelines*.

ICOLD (2003). Tailings Dam Versus a Water Dam, What is the Design Difference? International Committee of Large Dams (ICOLD) Symposium on Mayor Challenges in Tailings Dams, June 2003. Klohm Crippen Berger.

Lucia, P.C., Duncan, J.M. and Seed, H.B. (1981). “Summary of Research on Case Histories of Flow Failures of Mine Tailings Impoundments”, Proceedings; Mine Waste Disposal Technology Transfer Workshop, Denver, Colorado, July 16, 1981.

North Carolina Department of Environment and Natural Resources (2015). North Carolina Simplified Inundation Maps for Emergency Action Planning.

NPDM (2011). National Policy on Disaster Management, Dam Incident Query.

Ralston (1987). Mechanics of Embankment Erosion Overflow. Hydraulic Engineering. Proceedings of the 1987 ASCE National Conference on Hydraulic Engineering. Virginia, p 733-438.

Rico, M. (2007). Floods from Tailings Dam Failures, Research Unit on Geological Hazard and Risks, Instituto Geologico y Mineria de España, Madrid. September 2007.

Rico, M., Benito, G., Diez-Herrero, A. (2008). Floods from Tailings Dam Failures. Journal of Hazard Management. pp. 79-87.

State of Colorado (2010). Guidelines for Dam Breach Analysis. Department of Natural Resources, Division of Water Resources.

USACE (1979). Recommended Guidelines for Safety Inspection of Dams (ER 1110-2-106). Department of the Army. Office of the Chief of Engineers, September 1979.

USACE (1980). Hydraulic Engineering Center, Flood Engineering Plans-Guidelines for Corps Dams, RD 13, June 1980.

USACE (2007). Engineering and Design-Earthquake design and Evaluation of Concrete Hydraulic Structures, EM 1110-2-6051 May 2007.

USSD (US Society on Dams) (2011). Estimation of Tailings Dam Break Discharges. Arvind Dalpatran, USSD Workshop on Dam Break Analysis Applied to Tailings Dams, August 24-26, 2011.

Veale, Bill and Davison, Ian (2013). Estimation of Gravity Dam Breach Geometry, ANCOLD Conference 2013.

Vick S. (1991). Inundation Risk from Tailings Dam Flow Failure. Proc. 9th Panamerican Conf. SW&FE, Viña del Mar, Vol 3, pp 1137-1158.

Wahl, Tony L. (1998). Prediction of embankment Dam Breach Parameters – A Literature Review and Needs Assessment DSO-98-004, Dam Safety Research Report. U.S. Department of the Interior, Bureau of Reclamation Dam Safety Office July 1998.

Wahl, Tony L. (2001). The Uncertainty of Embankment Dam Breach Parameter Predictions Based on Dam Failure Case Studies, USDA/FEMA Workshop on Issues, Resolutions, and Research Needs Related to Dam Failure Analysis. June 26-28, 2001, Oklahoma City.

Wahl, Tony L. (2010). Dam Breach Modeling – An Overview of Analysis Methods. Bureau of Reclamation, Denver, 2nd Joint Federal Interagency Conference, July 2010.

Walder J.S. and O'Connor J.E. (1997). Methods for Predicting Peak Discharge of Floods Caused by Failure of Natural and Constructed Dams. Water Resources Research, vol. 33, No. 10, October 1997, 12 p.

Xu Y. and Zhang L.M. (2009). Breaching Parameters for Earth and Rockfill Dams. Journal of Geotechnical and Geo-environmental Engineering, vol. 135, no. 12, p. 1957-1970.

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o:\active\2016\3 proj\1668487 wrmd year 2 dam inventory nl\3. document management\preparation of deliverables\report\final\appendices\appendix g - rev 0 - 1668487 dam break inundation mapping methods sept 11_la.docx

APPENDIX H

Display of Various Inundation Mapping Methodologies

LEGEND

Inundation Area

Flow Path

KEY MAP

0 1.75 3.5 7

1:100,000 Kilometers

REFERENCE(S)

1. TOPOGRAPHY: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY
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3. PROJECTION: MTMZ2

CLIENT

GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
DEAPRTMENT OF NATURAL RESOURCES

PROJECT

INVENTORY OF DAMS
INUNDATION MAPPING METHODOLOGIES

TITLE

DEEP BANK DAM BREACH FULL INUNDATION EXTENTS
PHOTO-BASED METHODOLOGY

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-18
DESIGNED	LA
PREPARED	LA
REVIEWED	AP
APPROVED	AP

PROJECT NO.	CONTROL	REV.	FIGURE
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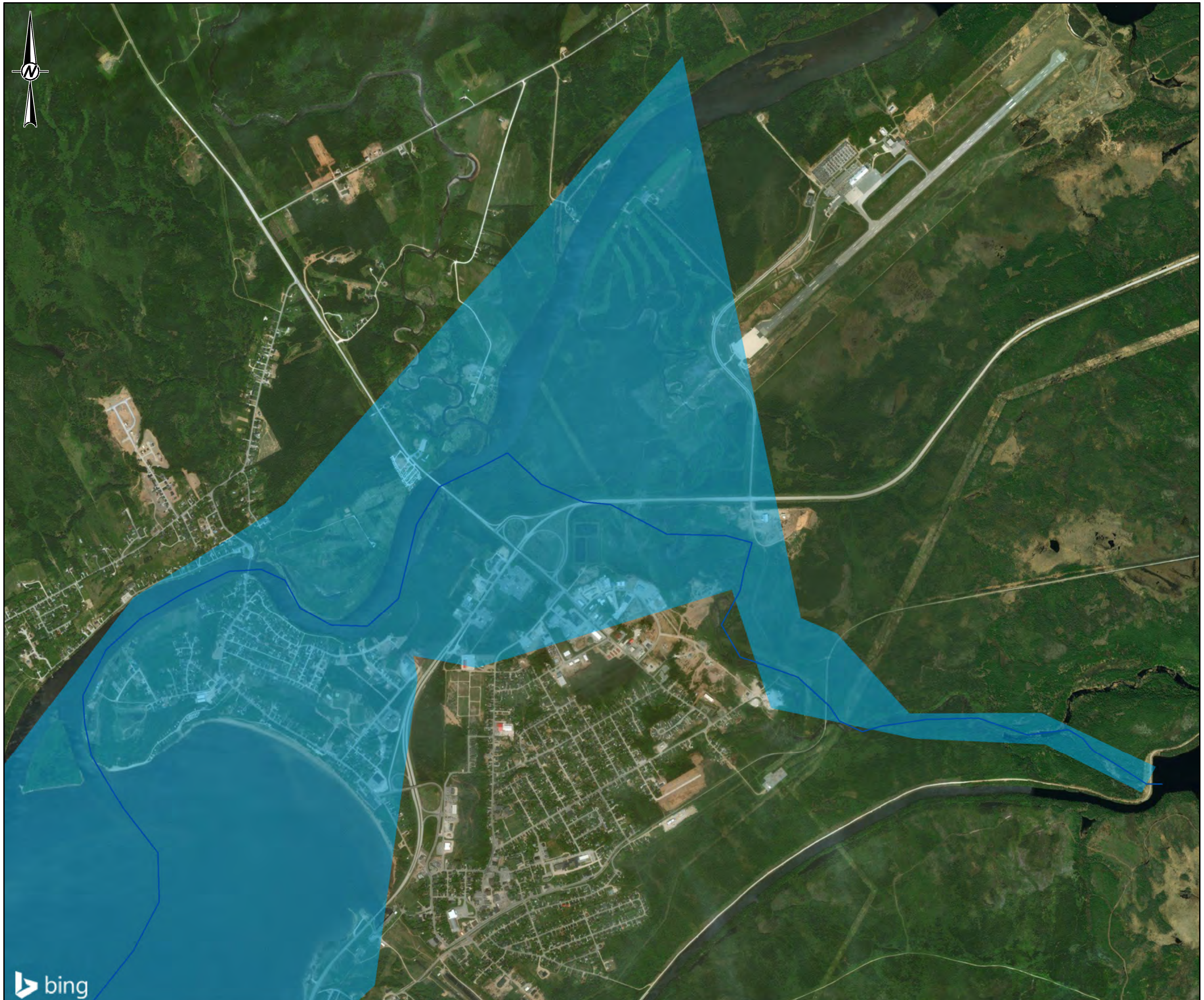
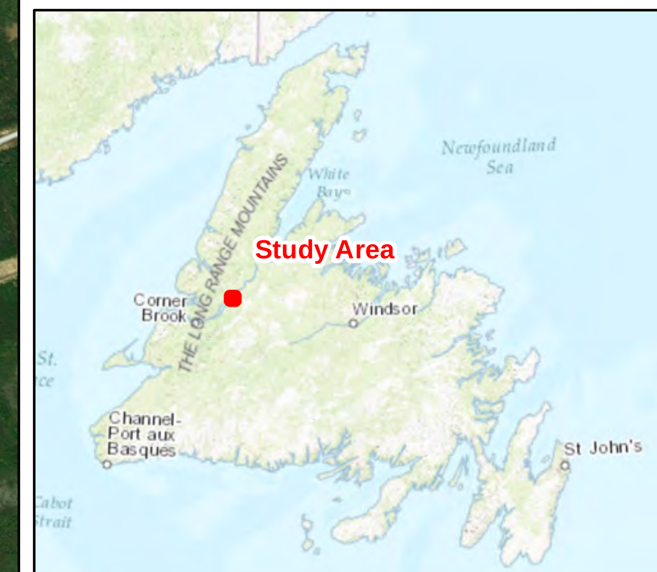


LEGEND

Inundation Area

Flow Path

KEY MAP



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PROJECT

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INUNDATION MAPPING METHODOLOGIES

TITLE

DEER LAKE INUNDATION FROM DEEP BANK DAM BREACH
PHOTO-BASED METHODOLOGY

CONSULTANT

Golder Associates

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REVIEWED	AP
APPROVED	AP

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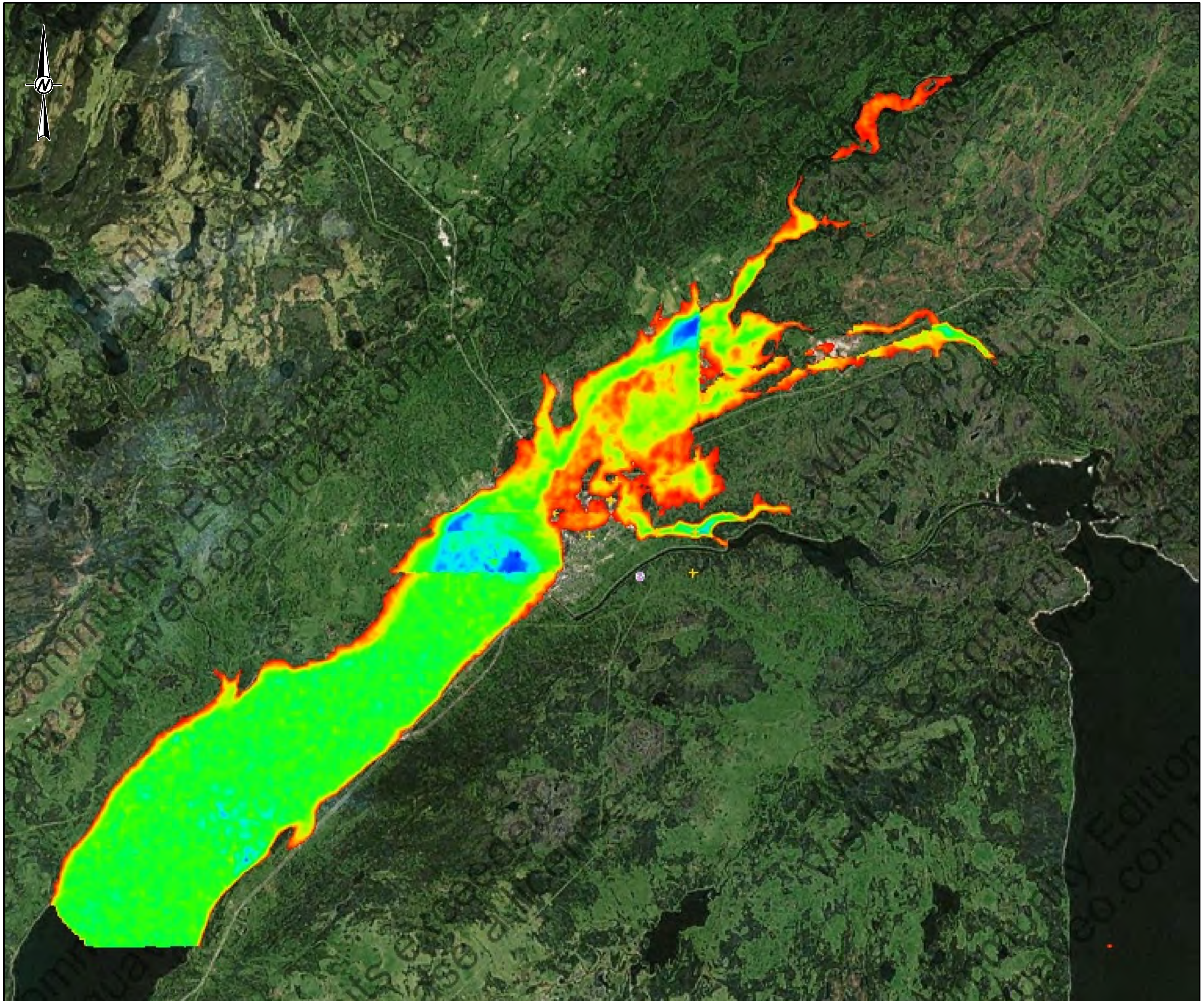

LEGEND

Flood Water Depth (m)

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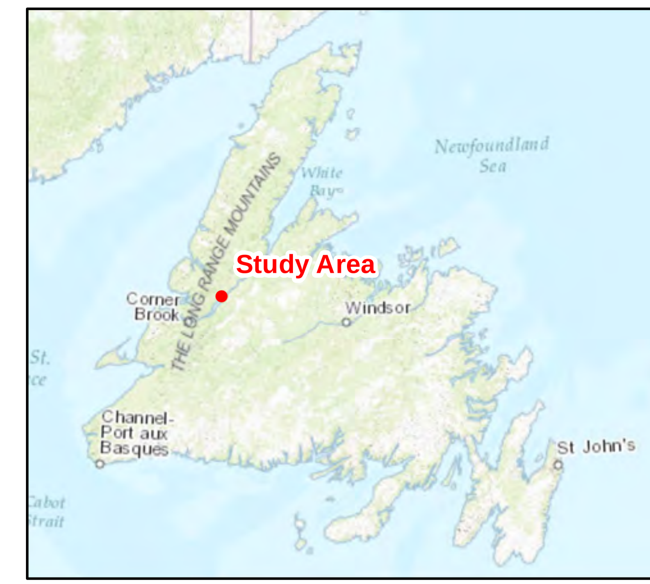
- 26.9
- 20.2
- 13.5
- 6.7
- 0.0

KEY MAP



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3. MAP SCALE NOT AVAILABLE

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INUNDATION MAPPING METHODOLOGIES

TITLE
FULL INUNDATION EXTENTS FROM DEEP BANK DAM BREACH SMPDBK MODELLING

CONSULTANT

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PREPARED	LA
REVIEWED	AP
APPROVED	AP

PROJECT NO.	CONTROL	REV.	FIGURE
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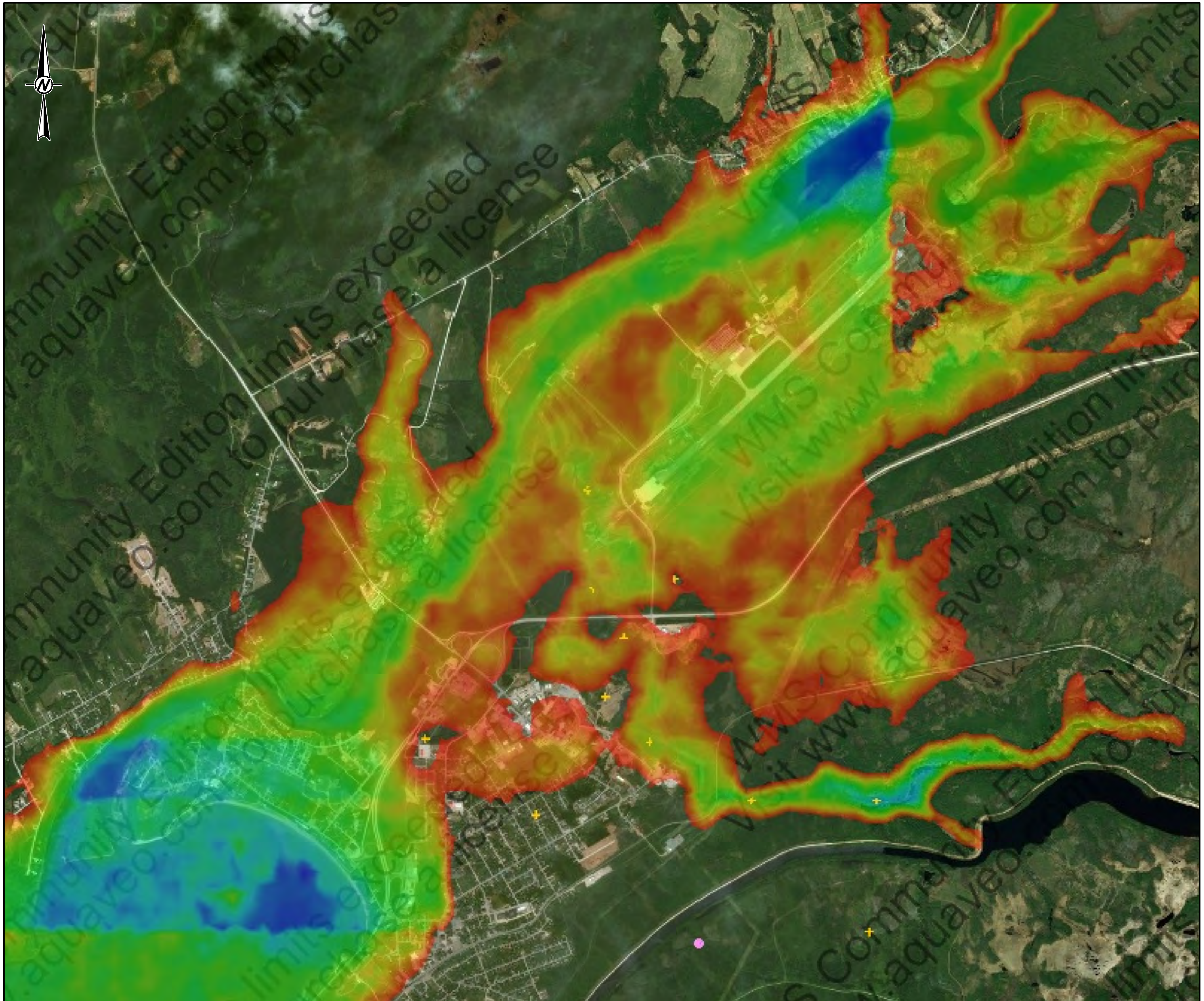

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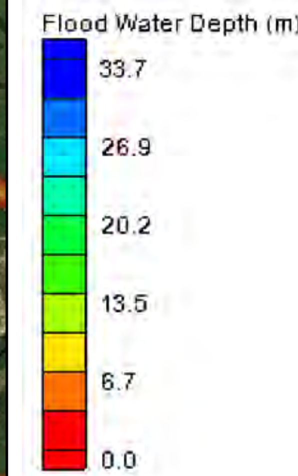

KEY MAP

REFERENCE(S)
1. TOPOGRAPHY: WMS SMPDBK, BING MAPS
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3. MAP SCALE NOT AVAILABLE

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INUNDATION MAPPING METHODOLOGIES

TITLE
DEER LAKE INUNDATION FROM DEEP BANK DAM BREACH SMPDBK MODELLING

CONSULTANT
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APPROVED	AP

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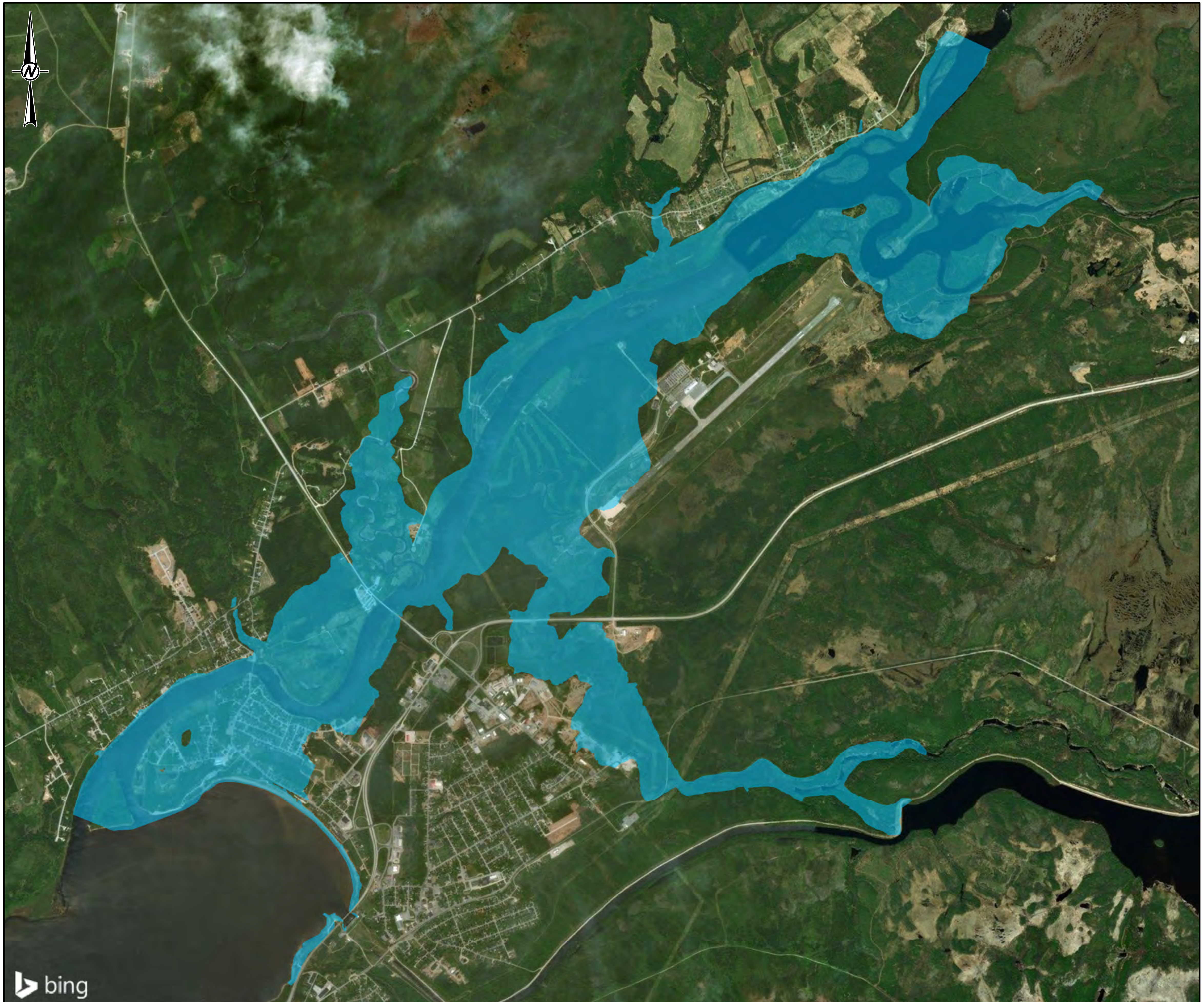

LEGEND

Probable Maximum Flood Breach

KEY MAP

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REFERENCE(S)

1. TOPOGRAPHY: ESRI, HERE, DELORME, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), SWISSTOPO, MAPMYINDIA, © OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY
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INVENTORY OF DAMS
INUNDATION MAPPING METHODOLOGIES

TITLE

DEEP BANK DAM INUNDATION MAP
UNSTEADY-STATE, 2-D MODELLING

CONSULTANT

Golder Associates

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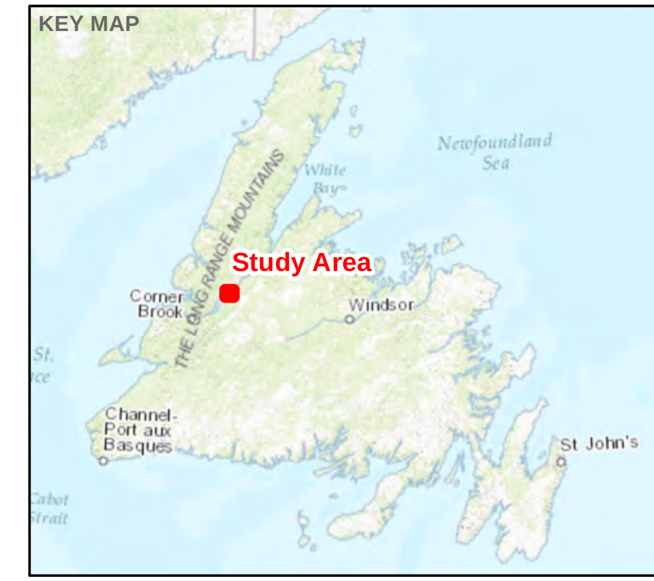
LEGEND

Probable Maximum Flood Breach



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3. PROJECTION: MTMZ2

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DEAPRTMENT OF NATURAL RESOURCES

PROJECT
INVENTORY OF DAMS
INUNDATION MAPPING METHODOLOGIES

TITLE
DEEP BANK DAM INUNDATION MAP
STEADY-STATE, 1-D MODELLING

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-05-18
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PREPARED	LA
REVIEWED	-
APPROVED	-

	CONTROL	REV.	FIGURE
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APPENDIX I

Dams Updated in the Dam Inventory Database

Dams Updated in the Dam Inventory Database

Dam Index #	Project Name	Dam Name	Owner
1	Deer Lake Hydroelectric Generating Station	Main Dam at Grand Lake	Deer Lake Power
4	Deer Lake Hydroelectric Generating Station	Intake Control Dam	Deer Lake Power
9	Star Lake Hydroelectric Generating Station	Star Lake Main Dam	Nalcor Energy
18	Buchan's Hydroelectric Generating Station	Buchans Forebay Dam	Government of Newfoundland and Labrador
19	Buchan's Hydroelectric Generating Station	Buchans Main Dam	Government of Newfoundland and Labrador
20	Grand Falls Hydroelectric Generating Station	Exploits Dam	Government of Newfoundland and Labrador
22	Grand Falls Hydroelectric Generating Station	Long Lake Dam	Government of Newfoundland and Labrador
25	Cat Arm Hydroelectric Generating Station	CD-1 (Cat Arm Dam 1)	Newfoundland and Labrador Hydro
26	Cat Arm Hydroelectric Generating Station	CD-2 (Cat Arm Dam 2)	Newfoundland and Labrador Hydro
27	Cat Arm Hydroelectric Generating Station	CD-4 (Cat Arm Dam 4)	Newfoundland and Labrador Hydro
28	Cat Arm Hydroelectric Generating Station	CD-5 (Cat Arm Dam 5)	Newfoundland and Labrador Hydro
29	Cat Arm Hydroelectric Generating Station	CD-6 (Cat Arm Dam West)	Newfoundland and Labrador Hydro
30	Cat Arm Hydroelectric Generating Station	CD-7 (Cat Arm Dam East)	Newfoundland and Labrador Hydro
31	Cat Arm Hydroelectric Generating Station	CD-8 (Cat Arm Dam 8)	Newfoundland and Labrador Hydro
32	Cat Arm Hydroelectric Generating Station	CD-9 (Cat Arm Dam D)	Newfoundland and Labrador Hydro
33	Cat Arm Hydroelectric Generating Station	CD-10 (Cat Arm Dam E)	Newfoundland and Labrador Hydro
35	Cat Arm Hydroelectric Generating Station	CD-12 (Cat Arm Dam B)	Newfoundland and Labrador Hydro
46	Bay d'Espoir Hydroelectric Generating Facility	LD-1 (Power Canal Embankment)	Newfoundland and Labrador Hydro
47	Bay d'Espoir Hydroelectric Generating Facility	LD-2 (North West Cutoff Dam)	Newfoundland and Labrador Hydro

Dam Index #	Project Name	Dam Name	Owner
48	Bay d'Espoir Hydroelectric Generating Facility	LD-3 (South East Cutoff Dam)	Newfoundland and Labrador Hydro
49	Bay d'Espoir Hydroelectric Generating Facility	LD-4 (South West Cutoff Dam)	Newfoundland and Labrador Hydro
50	Bay d'Espoir Hydroelectric Generating Facility	LD-5 (Salmon River Dam)	Newfoundland and Labrador Hydro
51	Bay d'Espoir Hydroelectric Generating Facility	LD-6 (North Cutoff Saddle Dykes)	Newfoundland and Labrador Hydro
52	Bay d'Espoir Hydroelectric Generating Facility	MD-1A (Ebbegunbaeg Cut-off Dam)	Newfoundland and Labrador Hydro
53	Bay d'Espoir Hydroelectric Generating Facility	MD-2 (Pudops Dam)	Newfoundland and Labrador Hydro
54	Granite Canal Hydroelectric Generating Station	GD-IN (Intake Dyke)	Newfoundland and Labrador Hydro
55	Granite Canal Hydroelectric Generating Station	GD-PC (Power Canal Dyke)	Newfoundland and Labrador Hydro
56	Bay d'Espoir Hydroelectric Generating Facility	MD-3 (Granite Freeboard Dykes)	Newfoundland and Labrador Hydro
57	Bay d'Espoir Hydroelectric Generating Facility	MD-4 (Granite Freeboard Dyke)	Newfoundland and Labrador Hydro
58	Bay d'Espoir Hydroelectric Generating Facility	MD-5 (Granite Freeboard Dykes)	Newfoundland and Labrador Hydro
59	Bay d'Espoir Hydroelectric Generating Facility	MSD-6 (Granite Overflow Spillway)	Newfoundland and Labrador Hydro
60	Bay d'Espoir Hydroelectric Generating Facility	MSD-7 (Granite Overflow Spillway)	Newfoundland and Labrador Hydro
61	Bay d'Espoir Hydroelectric Generating Facility	MSD-8 (Granite Overflow Spillway)	Newfoundland and Labrador Hydro
62	Bay d'Espoir Hydroelectric Generating Facility	MD-9 (Goodyear Dam)	Newfoundland and Labrador Hydro
63	Bay d'Espoir Hydroelectric Generating Facility	MD-10 (Granite Dam)	Newfoundland and Labrador Hydro
64	Bay d'Espoir Hydroelectric Generating Facility	MD-11 (Burnt Dam)	Newfoundland and Labrador Hydro
65	Bay d'Espoir Hydroelectric Generating Facility	MD-12 (Ebbegunbaeg Low Saddle Dyke)	Newfoundland and Labrador Hydro
66	Bay d'Espoir Hydroelectric Generating Facility	MD-BC (Burnt SideHill Canal)	Newfoundland and Labrador Hydro
67	Bay d'Espoir Hydroelectric Generating Facility	MD-FCS (Fisheries Compensation Structure)	Newfoundland and Labrador Hydro
72	Upper Salmon Hydroelectric	SD-1 (West Salmon Dam)	Newfoundland and Labrador

Dam Index #	Project Name	Dam Name	Owner
	Generating Station		Hydro
73	Upper Salmon Hydroelectric Generating Station	SD-2 (North Salmon Dam)	Newfoundland and Labrador Hydro
74	Upper Salmon Hydroelectric Generating Station	SD-IN (Upper Salmon Intake Dyke)	Newfoundland and Labrador Hydro
75	Upper Salmon Hydroelectric Generating Station	SD-PCL (Upper Salmon Power Canal - Left Dyke)	Newfoundland and Labrador Hydro
76	Upper Salmon Hydroelectric Generating Station	SD-PCR (Upper Salmon Power Canal - Right Dyke)	Newfoundland and Labrador Hydro
77	Snooks Arm and Venams Bight	SV-1 (Snooks Arm Main Dam)	Newfoundland and Labrador Hydro
78	Snooks Arm and Venams Bight	SV-2 (Red Cliff Storage Dam) (4 small structures)	Newfoundland and Labrador Hydro
79	Snooks Arm and Venams Bight	SV-3 (Western Pond Storage Dam)	Newfoundland and Labrador Hydro
80	Snooks Arm and Venams Bight	SV-4 (Armchair Pond Storage Dam)	Newfoundland and Labrador Hydro
84	Bay d'Espoir Hydroelectric Generating Facility	VD-1 (Victoria Canal Dyke No. 1)	Newfoundland and Labrador Hydro
85	Bay d'Espoir Hydroelectric Generating Facility	VD-2 (Victoria Canal Dyke No. 2)	Newfoundland and Labrador Hydro
86	Bay d'Espoir Hydroelectric Generating Facility	VD-3 (Victoria Dam)	Newfoundland and Labrador Hydro
87	Bay d'Espoir Hydroelectric Generating Facility	VD-4 (Victoria Spillway Dykes A & B)	Newfoundland and Labrador Hydro
88	Bay d'Espoir Hydroelectric Generating Facility	VD-5 (Victoria Control Dyke)	Newfoundland and Labrador Hydro
89	Bay d'Espoir Hydroelectric Generating Facility	VD-6 (Victoria Control Dyke)	Newfoundland and Labrador Hydro
177	Deer Lake Hydroelectric Generating Station	Long Bank Dam	Deer Lake Power
245	Channel - Port Aux Basques Water Supply	Reservoir #1 Main Dam	Town of Channel - Port Aux Basques
355	Deer Lake Hydroelectric Generating Station	Deep Bank Dam	Deer Lake Power
357	Deer Lake Hydroelectric Generating Station	West Bank Dyke	Deer Lake Power
362	Curling Water Supply	First Pond Dam (Second Pond Dam)	City of Corner Brook
368	Jackson's Arm Water Supply	Lush's Pond Brook Dam	Town of Jackson's Arm

Dam Index #	Project Name	Dam Name	Owner
392	Hope Brook Gold Mine (OAM)	Main Pine Pond Dam	Department of Natural Resources
393	Pasadena Backup Water Supply	Transmission Pond Dam	Town of Pasadena
408	Pasadena Water Supply	Blue Gulch Brook West Dam	Town of Pasadena
409	Hughes Brook Water Supply	Water Supply Dam	Town of Hughes Brook
411	Deer Lake Hydroelectric Generating Station	Forebay Dam	Deer Lake Power
413	Middle Arm Water Supply	Middle Arm Dam	Town of Middle Arm
417	IOC Wabush 3 Development	Pumphouse Pond Fish Barrier	Iron Ore Company of Canada (IOC)
421	Irishtown - Summerside Water Supply	Irishtown Brook Dam	Town of Irishtown - Summerside
424	IOC Tailings System	Western Control Dyke	Iron Ore Company of Canada (IOC)
425	Irishtown - Summerside Water Supply	Pynn's Pond Dam	Town of Irishtown - Summerside
426	Great Harbour Deep Former Water Supply	Great Harbour Deep Dam	Department of Transportation and Works
435	Humber Arm South Water Supply	Dormody's Brook Dam	Town of Humber Arm South
439	St. Anthony (Grenfell) Old Water Supply	Mission Dam	Town of St. Anthony
440	Birchy Basin (DUC Project #6658)	Birchy Basin Dam	Ducks Unlimited Canada
448	Corner Brook Margaret Bowater Park	Margaret Bowater Park Dam	City of Corner Brook
449	Brent's Cove Water Supply	Paddy's Pond Dam	Town of Brent's Cove
450	Glenburnie Water Supply	Croucher's Brook Dam	Town of Glenburnie - Birchy Head - Shoal Brook
452	St. Judes Water Supply	Chute Brook Dam	Local Service District of St. Judes
453	St. Judes Water Supply	Uncle Arthur Brook Dam	Local Service District of St. Judes
468	Cape St. George Water Supply	Rouzes Brook Dam	Town of Cape St. George
469	Agrifoods Division Water Supply	Pynn's Brook Dam	Department of Transportation and Works
488	Labrador City Water Supply	Beverly Lake Dam	Town of Labrador City

Dam Index #	Project Name	Dam Name	Owner
489	Mainland Water Supply	Caribou Brook Dam	Local Service District of Mainland
490	Hermitage - Sandyville Water Supply	Granfer's Pond Dam	Town of Hermitage - Sandyville
491	Port au Port East Water Supply	Unnamed Dam	Town of Port au Port East
508	Westport Water Supply	Western Brook Pond Dam	Town of Westport
511	Cook's Marsh (DUC Project #6411)	Cook's Marsh Water Control Structure	Ducks Unlimited Canada
512	Shoe Cove Water Supply	Shoe Cove Dam	Local Service District of Shoe Cove
540	Daniel's Harbour Backup Water Supply	Andy's Pond Dam	Town of Daniel's Harbour
541	Cox's Cove Water Supply	Cox's Cove Brook Dam	Town of Cox's Cove
545	Codroy Fish Plant Water Supply	Unnamed dam	Unknown Owner
648	McIvers Water Supply	McIvers Reservoir Dam	Town of McIvers
650	Millertown Water Supply	Water Pond Dam	Town of Millertown
652	Ming's Bight Water Supply	Middle Pond Brook Dam	Town of Ming's Bight
653	Morrisville Water Supply	Water System Intake Dam	Town of Morrisville
655	IOC Tailings System	Central Control Dyke	Iron Ore Company of Canada (IOC)
668	Channel - Port Aux Basques	WTP Effluent Control Dam	Town of Channel - Port Aux Basques
671	Baie Verte Advocate Mine	Steam Bath Water Supply Dam	Department of Natural Resources
677	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - South Rockfill Dam	Lower Churchill Management Corporation
681	Humber Arm South Backup Water Supply	Clarkes Brook Dam	Town of Humber Arm South
683	Star Lake Hydroelectric Generating Station	Lake of Hills Dam	Nalcor Energy
689	Hampden Water Supply	Elliot Brook Dam	Town of Hampden
690	Voisey's Bay Mine Site	South Sedimentation Pond	Vale Newfoundland and Labrador Ltd.
693	Curling Water Supply	Second Pond Dam (Third Pond Dam)	City of Corner Brook
708	IOC Wabush 3 Development	Waste Rock Sediment Pond	Iron Ore Company of Canada (IOC)

Dam Index #	Project Name	Dam Name	Owner
709	Burgeo Water Supply	Long Pond Dam	Town of Burgeo
710	Baie Verte Water Supply	Southwest Brook Dam	Town of Baie Verte
711	L'anse au Clair Old Water Supply	Unnamed Dam	Town of L'anse au Clair
713	Rattlebrook Hydroelectric Generating Station	Rattlebrook Dam	Algonquin Power (Rattlebrook) Limited Partnership
719	Pollard's Point Water Supply	Country Cove Pond Dam	Local Service District of Pollard's Point
720	Channel - Port Aux Basques Water Supply	#2 Reservoir Dam	Town of Channel - Port Aux Basques
721	Channel - Port Aux Basques	Unnamed Railway Dam	Government of Newfoundland and Labrador
722	Channel - Port Aux Basques Water Supply	Cut Off Dam	Town of Channel - Port Aux Basques
725	Portland Creek Water Supply	Unnamed Stream Dam	Local Service District of Portland Creek
727	King's Point Water Supply	Bulley's Pond Dam	Town of King's Point
728	Rigolet Water Supply	Rigolet Pond Dam	Rigolet Inuit Community Government
731	Springdale Water Supply	Sullivan's Pond Dam	Town of Springdale
732	St. George's Water Supply	Dribble Brook Dam	Town of St. George's
733	Voisey's Bay Mine Site	H2 Dam	Vale Newfoundland and Labrador Ltd.
738	Voisey's Bay Mine Site	H1 Dam	Vale Newfoundland and Labrador Ltd.
742*	Robert's Arm Water Supply	Water Pond Dam	Town of Robert's Arm
744	Voisey's Bay Mine Site	North Sedimentation Pond	Vale Newfoundland and Labrador Ltd.
746	Voisey's Bay Mine Site	Plant Site Sedimentation Pond A	Vale Newfoundland and Labrador Ltd.
749	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - North RCC Dam (Overflow Dam)	Lower Churchill Management Corporation
756	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - North Transition Dam	Lower Churchill Management Corporation
768	Star Lake Hydroelectric Generating Station	Star Lake Saddle Dam	Nalcor Energy
850	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - Gated Spillway	Lower Churchill Management Corporation
851	Lower Churchill Hydroelectric	Muskrat Falls - Centre	Lower Churchill Management

Dam Index #	Project Name	Dam Name	Owner
	Generation Project	Transition Dam	Corporation
888	Pynn's Brook Water Supply	Pynn's Brook Dam	Local Service District of Pynn's Brook
889	Parsons Pond Water Supply	Cold Spring Dam	Town of Parsons Pond
890	Pasadena Water Supply	Blue Gulch Brook East Dam	Town of Pasadena
891	Eddies Cove West Water Supply	Unnamed Dam	Local Service District of Eddies Cove West
893	Great Brehat Water Supply	Brehat Dam	Local Service District of Great Brehat
895	Daniel's Harbour Water Supply	Perry's Spring Dam	Town of Daniel's Harbour
896	Goose Cove East Water Supply	Jack's Pond Dam	Town of Goose Cove East
897	Jackson's Arm Water Supply	Lush's Pond Dam	Town of Jackson's Arm
898	Beaches Water Supply	Grassy Pond Brook Dam	Local Service District of Beaches
901	Rose Blanche - Harbour le Cou Water Supply	Rose Blanche Brook Dam	Town of Rose Blanche - Harbour le Cou
968	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - South Transition Dam	Lower Churchill Management Corporation
988	Piccadilly Head Water Supply	Unnamed Dam	Local Service District of Piccadilly Head
1008	St. Anthony Bight Water Supply	St. Anthony Bight Dam	Local Service District of St. Anthony Bight
1009	Woody Point Water Supply	Winterhouse Brook Dam	Town of Woody Point
1048	Churchill Falls Hydroelectric Development	GL-1	Nalcor Energy - Churchill Falls
1049	Churchill Falls Hydroelectric Development	GL-2	Nalcor Energy - Churchill Falls
1050	Churchill Falls Hydroelectric Development	GL-3	Nalcor Energy - Churchill Falls
1051	Churchill Falls Hydroelectric Development	GL-4	Nalcor Energy - Churchill Falls
1068	Churchill Falls Hydroelectric Development	GL-5	Nalcor Energy - Churchill Falls
1069	Churchill Falls Hydroelectric Development	GL-6	Nalcor Energy - Churchill Falls
1070	Churchill Falls Hydroelectric Development	GL-7	Nalcor Energy - Churchill Falls

Dam Index #	Project Name	Dam Name	Owner
1071	Churchill Falls Hydroelectric Development	GL-8	Nalcor Energy - Churchill Falls
1072	Churchill Falls Hydroelectric Development	GL-9	Nalcor Energy - Churchill Falls
1073	Churchill Falls Hydroelectric Development	GL-10	Nalcor Energy - Churchill Falls
1074	Churchill Falls Hydroelectric Development	GL-11	Nalcor Energy - Churchill Falls
1075	Churchill Falls Hydroelectric Development	GL-12	Nalcor Energy - Churchill Falls
1076	Churchill Falls Hydroelectric Development	GL-13	Nalcor Energy - Churchill Falls
1077	Churchill Falls Hydroelectric Development	GL-14	Nalcor Energy - Churchill Falls
1078	Churchill Falls Hydroelectric Development	GL-15	Nalcor Energy - Churchill Falls
1079	Churchill Falls Hydroelectric Development	GL-16	Nalcor Energy - Churchill Falls
1080	Churchill Falls Hydroelectric Development	GL-17	Nalcor Energy - Churchill Falls
1081	Churchill Falls Hydroelectric Development	GL-18	Nalcor Energy - Churchill Falls
1082	Churchill Falls Hydroelectric Development	GL-19	Nalcor Energy - Churchill Falls
1083	Churchill Falls Hydroelectric Development	GL-20	Nalcor Energy - Churchill Falls
1084	Churchill Falls Hydroelectric Development	GL-21	Nalcor Energy - Churchill Falls
1085	Churchill Falls Hydroelectric Development	GL-22	Nalcor Energy - Churchill Falls
1086	Churchill Falls Hydroelectric Development	GL-25	Nalcor Energy - Churchill Falls
1087	Churchill Falls Hydroelectric Development	GL-26	Nalcor Energy - Churchill Falls
1088	Churchill Falls Hydroelectric Development	GL-27	Nalcor Energy - Churchill Falls
1089	Churchill Falls Hydroelectric Development	GL-29	Nalcor Energy - Churchill Falls
1090	Churchill Falls Hydroelectric Development	GL-30	Nalcor Energy - Churchill Falls
1091	Churchill Falls Hydroelectric	GL-31	Nalcor Energy - Churchill Falls

Dam Index #	Project Name	Dam Name	Owner
	Development		
1092	Churchill Falls Hydroelectric Development	GL-32	Nalcor Energy - Churchill Falls
1093	Churchill Falls Hydroelectric Development	GL-33	Nalcor Energy - Churchill Falls
1094	Churchill Falls Hydroelectric Development	GL-34	Nalcor Energy - Churchill Falls
1095	Churchill Falls Hydroelectric Development	GL-35	Nalcor Energy - Churchill Falls
1096	Churchill Falls Hydroelectric Development	GL-36	Nalcor Energy - Churchill Falls
1097	Churchill Falls Hydroelectric Development	GL-37	Nalcor Energy - Churchill Falls
1098	Churchill Falls Hydroelectric Development	GL-38	Nalcor Energy - Churchill Falls
1108	Churchill Falls Hydroelectric Development	GF-2	Nalcor Energy - Churchill Falls
1109	Churchill Falls Hydroelectric Development	GF-3	Nalcor Energy - Churchill Falls
1110	Churchill Falls Hydroelectric Development	GF-4	Nalcor Energy - Churchill Falls
1111	Churchill Falls Hydroelectric Development	GF-6	Nalcor Energy - Churchill Falls
1112	Churchill Falls Hydroelectric Development	GF-7	Nalcor Energy - Churchill Falls
1113	Churchill Falls Hydroelectric Development	GF-8	Nalcor Energy - Churchill Falls
1114	Churchill Falls Hydroelectric Development	GF-9	Nalcor Energy - Churchill Falls
1115	Churchill Falls Hydroelectric Development	FF-10A	Nalcor Energy - Churchill Falls
1116	Churchill Falls Hydroelectric Development	FF-10B	Nalcor Energy - Churchill Falls
1117	Churchill Falls Hydroelectric Development	GJ-2	Nalcor Energy - Churchill Falls
1118	Churchill Falls Hydroelectric Development	FF-11	Nalcor Energy - Churchill Falls
1119	Churchill Falls Hydroelectric Development	FF-12	Nalcor Energy - Churchill Falls
1120	Churchill Falls Hydroelectric Development	GF-13	Nalcor Energy - Churchill Falls

Dam Index #	Project Name	Dam Name	Owner
1121	Churchill Falls Hydroelectric Development	GF-14	Nalcor Energy - Churchill Falls
1122	Churchill Falls Hydroelectric Development	GF-15	Nalcor Energy - Churchill Falls
1123	Churchill Falls Hydroelectric Development	GF-16	Nalcor Energy - Churchill Falls
1124	Churchill Falls Hydroelectric Development	GF-17	Nalcor Energy - Churchill Falls
1125	Churchill Falls Hydroelectric Development	GF-18	Nalcor Energy - Churchill Falls
1126	Churchill Falls Hydroelectric Development	GJ-5	Nalcor Energy - Churchill Falls
1127	Churchill Falls Hydroelectric Development	GJ-7	Nalcor Energy - Churchill Falls
1128	Churchill Falls Hydroelectric Development	GJ-8	Nalcor Energy - Churchill Falls
1129	Churchill Falls Hydroelectric Development	GJ-9	Nalcor Energy - Churchill Falls
1130	Churchill Falls Hydroelectric Development	GJ-10	Nalcor Energy - Churchill Falls
1131	Churchill Falls Hydroelectric Development	GJ-11A	Nalcor Energy - Churchill Falls
1132	Churchill Falls Hydroelectric Development	GJ-11B	Nalcor Energy - Churchill Falls
1133	Churchill Falls Hydroelectric Development	GJ-12	Nalcor Energy - Churchill Falls
1134	Churchill Falls Hydroelectric Development	GJ-13	Nalcor Energy - Churchill Falls
1135	Churchill Falls Hydroelectric Development	GJ-15	Nalcor Energy - Churchill Falls
1136	Churchill Falls Hydroelectric Development	GJ-16	Nalcor Energy - Churchill Falls
1137	Churchill Falls Hydroelectric Development	GJ-17	Nalcor Energy - Churchill Falls
1138	Churchill Falls Hydroelectric Development	GJ-18	Nalcor Energy - Churchill Falls
1139	Churchill Falls Hydroelectric Development	GJ-19	Nalcor Energy - Churchill Falls
1140	Churchill Falls Hydroelectric Development	GJ-20	Nalcor Energy - Churchill Falls
1141	Churchill Falls Hydroelectric	GR-1	Nalcor Energy - Churchill Falls

Dam Index #	Project Name	Dam Name	Owner
	Development		
1142	Churchill Falls Hydroelectric Development	GR-2	Nalcor Energy - Churchill Falls
1143	Churchill Falls Hydroelectric Development	GR-3,4	Nalcor Energy - Churchill Falls
1145	Churchill Falls Hydroelectric Development	GR-5	Nalcor Energy - Churchill Falls
1146	Churchill Falls Hydroelectric Development	GR-6	Nalcor Energy - Churchill Falls
1147	Churchill Falls Hydroelectric Development	GR-7	Nalcor Energy - Churchill Falls
1148	Churchill Falls Hydroelectric Development	GR-8	Nalcor Energy - Churchill Falls
1149	Churchill Falls Hydroelectric Development	GR-9	Nalcor Energy - Churchill Falls
1150	Churchill Falls Hydroelectric Development	GR-10	Nalcor Energy - Churchill Falls
1151	Churchill Falls Hydroelectric Development	GR-11	Nalcor Energy - Churchill Falls
1152	Churchill Falls Hydroelectric Development	GR-12	Nalcor Energy - Churchill Falls
1153	Churchill Falls Hydroelectric Development	GR-13	Nalcor Energy - Churchill Falls
1154	Churchill Falls Hydroelectric Development	GR-14	Nalcor Energy - Churchill Falls
1155	Churchill Falls Hydroelectric Development	GR-15	Nalcor Energy - Churchill Falls
1156	Churchill Falls Hydroelectric Development	GR-16	Nalcor Energy - Churchill Falls
1157	Churchill Falls Hydroelectric Development	GS-1	Nalcor Energy - Churchill Falls
1158	Churchill Falls Hydroelectric Development	GS-2	Nalcor Energy - Churchill Falls
1159	Churchill Falls Hydroelectric Development	GS-3	Nalcor Energy - Churchill Falls
1160	Churchill Falls Hydroelectric Development	GS-4	Nalcor Energy - Churchill Falls
1161	Churchill Falls Hydroelectric Development	GS-5	Nalcor Energy - Churchill Falls
1162	Churchill Falls Hydroelectric Development	Ossok Dam 1	Nalcor Energy - Churchill Falls

Dam Index #	Project Name	Dam Name	Owner
1163	Churchill Falls Hydroelectric Development	Ossok Dam 2	Nalcor Energy - Churchill Falls
1164	Churchill Falls Hydroelectric Development	Ossok Dam 3	Nalcor Energy - Churchill Falls
1165	Churchill Falls Hydroelectric Development	Ossok Dam 4	Nalcor Energy - Churchill Falls
1166	Churchill Falls Hydroelectric Development	Ossok Dam 5	Nalcor Energy - Churchill Falls
1167	Churchill Falls Hydroelectric Development	Ossok Dam 6	Nalcor Energy - Churchill Falls
1168	Churchill Falls Hydroelectric Development	Ossok Dam 7	Nalcor Energy - Churchill Falls
1169	Churchill Falls Hydroelectric Development	Gabbro Dam 1	Nalcor Energy - Churchill Falls
1170	Churchill Falls Hydroelectric Development	Gabbro Dam 2	Nalcor Energy - Churchill Falls
1171	Churchill Falls Hydroelectric Development	Gabbro Dam 3	Nalcor Energy - Churchill Falls
1172	Churchill Falls Hydroelectric Development	Gabbro Dam 4	Nalcor Energy - Churchill Falls
1173	Churchill Falls Hydroelectric Development	Gabbro - East Dam	Nalcor Energy - Churchill Falls
1174	Churchill Falls Hydroelectric Development	Gabbro East	Nalcor Energy - Churchill Falls
1175	Churchill Falls Hydroelectric Development	Gabbro - West Dam	Nalcor Energy - Churchill Falls
1176	Churchill Falls Hydroelectric Development	Gabbro West	Nalcor Energy - Churchill Falls
1188	Anaconda Mining Inc. (Pine Cove)	Phase 1 Tailings Dam	Anaconda Mining Inc.
1190	Anaconda Mining Inc. (Pine Cove)	Phase 2 Tailings Dam	Anaconda Mining Inc.
1193	Buchans Mine Closure (OAM)	Dam 1	Department of Natural Resources
1195	Rambler Metals & Mining - Nugget Pond Facility	Dam #1 - Tailings Pond	Rambler Metals & Mining Canada Ltd.
1196	Rambler Metals & Mining - Nugget Pond Facility	Dam #2 (Saddle Dyke) - Tailings Pond	Rambler Metals & Mining Canada Ltd.
1197	Rambler Metals & Mining - Nugget Pond Facility	Dam #3 - Polishing Pond	Rambler Metals & Mining Canada Ltd.
1198	Teck Duck Pond Operations	Dam A - Tailings Pond	Teck Resources Limited

Dam Index #	Project Name	Dam Name	Owner
1199	Teck Duck Pond Operations	Dam B - Tailings Pond	Teck Resources Limited
1200	Teck Duck Pond Operations	Dam C - Polishing Pond	Teck Resources Limited
1228	Forteau Water Supply	Trout River Dam	Town of Forteau
1229	Port Hope Simpson Water Supply	Water Supply Dam	Town of Port Hope Simpson
1248	USAF (former)	Cut Throat Island Dam	Government of Newfoundland and Labrador
1268	IOC Tailings System	Jody's Dyke	Iron Ore Company of Canada (IOC)
1288	Nain Old Water Supply	Nain Brook and Annainaks Pond Dam	Nain Inuit Community Government
1308	Voisey's Bay Mine Site	Plant Site Sediment Pond B	Vale Newfoundland and Labrador Ltd.
1369	Norris Point Water Supply	Neddies Harbour Pond Water Supply Dam	Town of Norris Point
1428	Menihek Generating Station	Margaret Hamilton Dam (MK-3)	Nalcor Energy
1448	Menihek Generating Station	North Bank Dam (MK-1)	Nalcor Energy
1488	Menihek Generating Station	South Bank Dam (MK-2)	Nalcor Energy
1508	Lark Harbour Water Supply	Fairfax Brook Dam	Town of Lark Harbour
1548	Voisey's Bay Mine Site	Port Site Sedimentation Pond	Vale Newfoundland and Labrador Ltd.
1588	Wabush Mines - Flora Lake TMA	Saddle Dike	Cliffs Natural Resources Wabush Mines, Scully Mine Division
1589	Wabush Mines - Flora Lake TMA	North Dike	Cliffs Natural Resources Wabush Mines, Scully Mine Division
1590	Wabush Mines - Flora Lake TMA	South Dike	Cliffs Natural Resources Wabush Mines, Scully Mine Division
1748	Curling Water Supply	Third Pond Dam (Fourth Pond Dam)	City of Corner Brook
1788	Voisey's Bay Mine Site	Mine Water Surge Pond	Vale Newfoundland and Labrador Ltd.
1789	Voisey's Bay Mine Site	East Diversion Dam	Vale Newfoundland and Labrador Ltd.
1828	Anaconda Mining Inc. (Pine Cove)	Phase 2 Polishing Pond Dam	Anaconda Mining Inc.
1868	IOC Wabush 3 Development	Leg Lake Fish Barrier	Iron Ore Company of Canada

Dam Index #	Project Name	Dam Name	Owner
			(IOC)
1908	Norris Point Old Water Supply	Old Water Supply Dam	Town of Norris Point
1928	Cape Makkovik Former US Millitary Site	Cape Makkovik Dam	Government of Newfoundland and Labrador
1948	Bide Arm Former Water Supply	Clay Cove Pond Dam	Town of Roddickton - Bide Arm
2189	Lomond Campground Backup Water Supply	Lomond Dam	Parks Canada Agency / Gros Morne National Park
2208	Bay d'Espoir Hydroelectric Generating Facility	MD-1D (Ebbegunbaeg Cut-off Dam)	Newfoundland and Labrador Hydro
2209	Bay d'Espoir Hydroelectric Generating Facility	MD-1C (Ebbegunbaeg Cut-off Dam)	Newfoundland and Labrador Hydro
2210	Bay d'Espoir Hydroelectric Generating Facility	MD-1B (Ebbegunbaeg Cut-off Dam)	Newfoundland and Labrador Hydro
2288	Mary's Harbour Clinic Former Water Supply	Mary's Harbour Clinic Dam	Labrador Grenfell Health

Dam #742 is in the Eastern region

APPENDIX J

Western and Labrador Dams in Dam Inventory Database without Pictures

Western and Labrador Dams in the Dam Inventory Database with No Pictures

Dam Index #	Project Name	Dam Name	Owner
5	Jackson's Arm Old Water Supply	Clay Cove Dam	Town of Jackson's Arm
22	Grand Falls Hydroelectric Generating Station	Long Lake Dam	Government of Newfoundland and Labrador
51	Bay d'Espoir Hydroelectric Generating Facility	LD-6 (North Cutoff Saddle Dykes)	Newfoundland and Labrador Hydro
64	Bay d'Espoir Hydroelectric Generating Facility	MD-11 (Burnt Dam)	Newfoundland and Labrador Hydro
66	Bay d'Espoir Hydroelectric Generating Facility	MD-BC (Burnt SideHill Canal)	Newfoundland and Labrador Hydro
67	Bay d'Espoir Hydroelectric Generating Facility	MD-FCS (Fisheries Compensation Structure)	Newfoundland and Labrador Hydro
71	Roddickton Hydro Plant	RD-1 (Roddickton Timber Crib Dam)	Newfoundland and Labrador Hydro
76	Upper Salmon Hydroelectric Generating Station	SD-PCR (Upper Salmon Power Canal - Right Dyke)	Newfoundland and Labrador Hydro
236	Lookout Brook Hydroelectric Generating Facility	Joe Dennis Pond Dam and Spillway	Newfoundland Power Inc.
237	Lookout Brook Hydroelectric Generating Facility	Joe Dennis Pond Freeboard Dyke	Newfoundland Power Inc.
238	Lookout Brook Hydroelectric Generating Facility	Cross Pond Outlet	Newfoundland Power Inc.
239	Lookout Brook Hydroelectric Generating Facility	Cross Pond Spillway	Newfoundland Power Inc.
354	Cartwright Water Supply	Burdett's Pond Reservoir Dam	Town of Cartwright
356	Gullbridge Copper Mine (OAM)	Tailings Pond Retaining Dam South	Department of Natural Resources
358	Humber Arm South Old Water Supply	John's Brook Dam	Town of Humber Arm South
363	Gullbridge Copper Mine (OAM)	Tailings Pond Retaining Dam East	Department of Natural Resources
393	Pasadena Backup Water Supply	Transmission Pond Dam	Town of Pasadena
417	IOC Wabush 3 Development	Pumphouse Pond Control Structure	Iron Ore Company of Canada (IOC)
424	IOC Tailings System	West Dyke	Iron Ore Company of Canada (IOC)

Dam Index #	Project Name	Dam Name	Owner
425	Irishtown - Summerside Water Supply	Pynn's Pond Dam	Town of Irishtown - Summerside
426	Great Harbour Deep Former Water Supply	Great Harbour Deep Dam	Department of Transportation and Works
508	Westport Water Supply	Western Brook Pond Dam	Town of Westport
528	Charlottetown Water Supply	Middle Pond Dam	Town of Charlottetown
537	Gaultois Water Supply	Piccaire Pond Dam	Town of Gaultois
540	Daniel's Harbour Backup Water Supply	Andy's Pond Dam	Town of Daniel's Harbour
545	Codroy Fish Plant Water Supply	Unnamed dam	Unknown Owner
652	Ming's Bight Water Supply	Middle Pond Brook Dam	Town of Ming's Bight
655	IOC Tailings System	Central Control Dyke	Iron Ore Company of Canada (IOC)
668	Channel - Port Aux Basques Water Supply	WTP Effluent Control Dam	Town of Channel - Port Aux Basques
675	Consolidated Rambler Mine (OAM)	North Embankment	Department of Natural Resources
677	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - South Rockfill Dam	Lower Churchill Management Corporation
681	Humber Arm South Backup Water Supply	Clarkes Brook Dam	Town of Humber Arm South
682	Buchans Mine Closure (OAM)	Dam 4	Department of Natural Resources
708	IOC Wabush 3 Development	Waste Rock Sedimentation Pond	Iron Ore Company of Canada (IOC)
709	Burgeo Water Supply	Long Pond Dam	Town of Burgeo
711	L'anse au Clair Old Water Supply	Unnamed Dam	Town of L'anse au Clair
712	L'anse au Loup Water Supply	L'anse au Loup River Dam	Town of L'anse au Loup
715	Consolidated Rambler Mine (OAM)	East Dam	Department of Natural Resources
718	Taylor Estates Water Supply	Samm's Brook Dam	Taylor Estates Management Corporation
720	Channel - Port Aux Basques Water Supply	#2 Reservoir Dam	Town of Channel - Port Aux Basques
727	King's Point Water Supply	Bulley's Pond Dam	Town of King's Point
728	Rigolet Water Supply	Rigolet Pond Dam	Rigolet Inuit Community Government

Dam Index #	Project Name	Dam Name	Owner
729	Abitibi Woods Dam	Ambrose Lake-Harpoon Brook Weir	Nalcor Energy
731	Springdale Water Supply	Sullivan's Pond Dam	Town of Springdale
748	Isle aux Mort Water Supply	Burnt Ground Pond Dam	Town of Isle aux Mort
749	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - North RCC Dam (Overflow Dam)	Lower Churchill Management Corporation
756	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - North Transition Dam	Lower Churchill Management Corporation
788	Gillams Water Supply	Meader's Pond Dam #2	Town of Gillams
850	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - Gated Spillway	Lower Churchill Management Corporation
851	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - Centre Transition Dam	Lower Churchill Management Corporation
948	Channel - Port Aux Basques Water Supply	#3 Reservoir Diversion Pond Dam	Town of Channel - Port Aux Basques
968	Lower Churchill Hydroelectric Generation Project	Muskrat Falls - South Transition Dam	Lower Churchill Management Corporation
1085	Churchill Falls Hydroelectric Development	GL-22	Nalcor Energy - Churchill Falls
1087	Churchill Falls Hydroelectric Development	GL-26	Nalcor Energy - Churchill Falls
1172	Churchill Falls Hydroelectric Development	Gabbro Dam 4	Nalcor Energy - Churchill Falls
1188	Anaconda Mining Inc. (Pine Cove)	Phase 1 Tailings Dam	Anaconda Mining Inc.
1189	Anaconda Mining Inc. (Pine Cove)	Diversion Dam	Anaconda Mining Inc.
1190	Anaconda Mining Inc. (Pine Cove)	Phase 2 Tailings Dam	Anaconda Mining Inc.
1202	Gullbridge Copper Mine (OAM)	North Retaining Dam	Department of Natural Resources
1203	Gullbridge Copper Mine (OAM)	Tailings Pond Retaining Dam North	Department of Natural Resources
1228	Forteau Water Supply	Trout River Dam	Town of Forteau
1229	Port Hope Simpson Water Supply	Water Supply Dam	Town of Port Hope Simpson
1248	USAF (former)	Cut Throat Island Dam	Government of Newfoundland and Labrador
1268	IOC Tailings System	Jody's Dyke	Iron Ore Company of Canada (IOC)

Dam Index #	Project Name	Dam Name	Owner
1369	Norris Point Water Supply	Neddies Harbour Pond Water Supply Dam	Town of Norris Point
1428	Menihek Generating Station	Margaret Hamilton Dam (MK-3)	Nalcor Energy
1448	Menihek Generating Station	North Bank Dam (MK-1)	Nalcor Energy
1468	Channel - Port Aux Basques Water Supply	#3 Reservoir Dam	Town of Channel - Port Aux Basques
1488	Menihek Generating Station	South Bank Dam (MK-2)	Nalcor Energy
1728	Lower Cove Quary	Settling Pond #2 Dam	Atlantic Minerals Limited
1748	Curling Water Supply	Third Pond Dam (Fourth Pond Dam)	City of Corner Brook
1749	Swift Current Old Water Supply	Black Duck Pond Brook Dam	Local Service District of Swift Current
1768	Cartwright (Grenfell) Old Water Supply	Grenfell Mission Dam	Sir Wilfred Grenfell Society
1828	Anaconda Mining Inc. (Pine Cove)	Phase 2 Polishing Pond Dam	Anaconda Mining Inc.
1848	IOC Wabush 3 Development	Overburden Stockpile Sedimentation Pond	Iron Ore Company
1868	IOC Wabush 3 Development	Leg Lake Fish Barrier	Iron Ore Company of Canada (IOC)
1908	Norris Point Old Water Supply	Old Water Supply Dam	Town of Norris Point
1928	Cape Makkovik Former US Millitary Site	Cape Makkovik Dam	Government of Newfoundland and Labrador
1948	Bide Arm Former Water Supply	Clay Cove Pond Dam	Town of Roddickton - Bide Arm
2208	Bay d'Espoir Hydroelectric Generating Facility	MD-1D (Ebbegunbaeg Cut-off Dam)	Newfoundland and Labrador Hydro
2209	Bay d'Espoir Hydroelectric Generating Facility	MD-1C (Ebbegunbaeg Cut-off Dam)	Newfoundland and Labrador Hydro
2249	Port Hope Simpson Water Supply	Old Dam	Town of Port Hope Simpson
2288	Mary's Harbour Clinic Former Water Supply	Mary's Harbour Clinic Dam	Labrador Grenfell Health
2588	Port au Choix Water Supply	Beaverhouse Dam	Town of Port au Choix
2589	Port au Choix Water Supply	Middlehouse Dam	Town of Port au Choix
2590	Port au Choix Water Supply	Winterhouse Dam	Town of Port au Choix
2608	St. Anthony Old Water Supply	Frenchman's Pond Dam	Town of St. Anthony
2609	St. Anthony Water Supply	St. Anthony Pond Dam	Town of St. Anthony

Dam Index #	Project Name	Dam Name	Owner
2628	Humber Arm South Water Supply	Gurges Pond Intake Dam	Town of Humber Arm South
2672	Whalesback Copper Mine (OAM)	Peach Dam	Unknown Owner
2675	Mainland Old Water Supply	Unknown Dam	Local Service District of Mainland
2677	Former Twin Falls Generating Station	TF-1	Unknown Owner
2678	Former Twin Falls Generating Station	TF-2	Unknown Owner
2679	Former Twin Falls Generating Station	TF-3	Unknown Owner
2680	Former Twin Falls Generating Station	TF-4	Unknown Owner
2681	Former Twin Falls Generating Station	TF-5	Unknown Owner

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

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