NHC Reference 3008511
January 10, 2024

Regional District of Nanaimo
6300 Hammond Bay Road
Nanaimo, BC
V9T 6N2

Attention: Jordan Vander Klok, Parks Planner
Via email: jvanderklok@rdn.bc.com

Re: **Coats Marsh Weir Decommissioning**
Beaver Dam Risk Assessment Final Report, Rev. 0

Dear Mr. Vander Klok:

SUMMARY

The Regional District of Nanaimo (RDN) retained Northwest Hydraulic Consultants (NHC) to design the removal of a small dam located at the outlet of Coats Marsh on Gabriola Island. Within Coats Marsh, there is a beaver dam upstream of the man-made dam that holds back most of the water in the marsh (approximately 30 Olympic-sized swimming pools when full). The purpose of this report is to evaluate the risk of leaving the beaver dam in place when the man-made dam is removed, specifically the potential downstream effects if the beaver dam were to fail in the future.

To evaluate the effects of a breach, NHC developed a computer model of the Coats Marsh and Hoggan Lake area, which simulated what would happen if:

- the marsh experiences a 200-year rainstorm without a beaver dam breach (base case scenario)
- the marsh experiences a 200-year rainstorm and the beaver dam breaches
- the beaver dam breaches on a sunny day, without a storm occurring

The model showed that some downstream properties will experience flooding in the event of a 200-year storm or breach. Flooding would mainly occur on lawns and forested portions of private property. The only buildings found to be affected by flooding were a log cabin (guesthouse) at 1040 Coats Drive and a shed at 1034 Coats Drive. The surge of water from a beaver dam breach would cause water to overtop South Road and would likely damage the roadway, potentially creating a hazardous condition for motorists and other road users. Road overtopping would also occur during the 200-year storm by itself but is much more severe during a beaver dam breach.

The likelihood and consequence of a beaver dam breach are expected to increase if the beaver builds the dam any higher or if the beaver abandons the dam. Any future development near Coats Creek could also increase consequences of a breach. Additionally, the likelihood of a beaver dam failure is expected to increase over time due to climate change.

Based on the risks associated with the Coats Marsh beaver dam, NHC proposed a list of ways to mitigate risk, which focus on monitoring and emergency preparedness measures, consequence reduction, and possible future interventions to the beaver dam itself.

1 INTRODUCTION

The Regional District of Nanaimo (RDN) retained Northwest Hydraulic Consultants Ltd. (NHC) to prepare a decommissioning plan for the man-made dam located at the outlet of Coats Marsh, on Gabriola Island, BC. Upstream of the man-made dam there is a beaver dam that the RDN proposes to leave in place. RDN requested that NHC carry out a risk assessment of the beaver dam, with the following objectives:

- Evaluate potential beaver dam failure modes
- Complete a dam breach assessment to evaluate potential consequences of a future beaver dam failure, assuming the existing man-made dam and berm are removed and the proposed outlet grade control structure is constructed
- Develop conceptual mitigation strategies

This report describes the beaver dam risk assessment and includes the following sections:

Section 2: Hydraulic Model Development

Section 3: Hydraulic Model Results

Section 4: Risk Interpretation

Section 5: Mitigation Concepts

2 HYDRAULIC MODEL DEVELOPMENT

NHC prepared the beaver dam breach assessment using the Hydrologic Engineering Center's River Analysis System (HEC-RAS). HEC-RAS is a computer program developed by the US Army Corps of Engineers to simulate flood conditions and calculate flood profiles. HEC-RAS is widely used by practitioners throughout BC for hydraulic analysis and floodplain mapping. Version 6.4.1 was released in July 2023 and was used for this study. The program is designed to perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for a full network of channels under steady or unsteady flow conditions. For this project, a 2D model was used with unsteady flow conditions. The model also made use of HEC-RAS's dam breach analysis feature to simulate breaches of the beaver dam.

2.1 Model Geometry

The model geometry was configured as follows:

- Coats Marsh was represented as a storage area (SA) with an assigned storage-elevation curve based on previous bathymetry analysis prepared by NHC (2023).
- The beaver dam was represented as a SA/2D Connection embankment with a breach. For simplicity, a consistent top elevation of the beaver dam was selected from survey elevation as 97.7 m.

- The downstream reach was represented as a 2D flow area extending from the beaver dam to 175 m downstream of Hoggan Lake's outlet. The reach between Coats Marsh and Hoggan Lake is approximately 1.3 km long, referred to in this report as Coats Creek. The following should be noted about the 2D flow area:
    - No bathymetric data existed for Hoggan Lake; the terrain elevation was set equal to the water surface elevation at the time of 2019 LiDAR data acquisition.
    - A dam exists along Hoggan Lake's outlet channel, 150 m downstream of the lake outlet. This dam was not explicitly incorporated into the model terrain. As such, the geometry and hydraulic characteristics of this channel are uncertain; the outlet channel was included to better represent the lake levels in Hoggan Lake, not to understand the hydraulics of the channel itself.
- The 1 m resolution digital elevation model (DEM) was prepared to represent the model terrain. Figure 2.1 shows the full terrain used in the HEC-RAS model, which was compiled using the following data sources:
    - 2022 NHC survey, covering the weir area and limited marsh bathymetry between the marsh and the beaver dam.
    - 2019 British Columbia LiDAR data, covering terrestrial areas and the water surface of Hoggan Lake
- Terrain modifications were applied within HEC-RAS to remove the existing man-made dam (including the weir and berm), remove the section of beaver dam that was to be breached, and to adjust the weir outlet channel to conform with the preliminary decommissioning design. Figure 2.2 shows a detailed view of the terrain modifications applied in and around the marsh.
- The 2D mesh was developed iteratively based on the Courant criteria, with final cell dimensions of 1 m within the weir pool, 3 m within Coats Creek and overbank, 3 m in Hoggan Lake, and 50 m on the floodplain outside of the immediate overbank. The model mesh and configuration are represented in Figure 2.3
- Manning's roughness coefficients (n) were assigned to the model domain based on the different types of land cover within the model area using values informed by the HEC-RAS 2D User Manual, which corresponds with the National Land Cover Database (USACE, n.d.). Notably, the bedrock channel bed of Coats Creek was not represented by its own roughness coefficient, given that its width relative to the terrain resolution did not merit this level of detail. Table 2.1 presents the Manning's n values used in the model.
- Coats Creek flows through a culvert where it intersects with South Road. Based on observations from an NHC site visit in 2023, this culvert is a 1.2 m corrugated steel pipe. Site photos show the culvert constructed such that it protrudes from the roadway fill. The culvert was added to the model within the 2D flow area. Another culvert exists at the intersection of Coats Creek and an RDN path 400 m downstream of the marsh. Based on preliminary model runs, this culvert had a negligeable effect on results, and it was therefore omitted from the model. Other structures such as timber footbridges and rock weirs on private property were not included in the model due to a lack of survey information and the relatively coarse resolution of the model terrain in those areas.

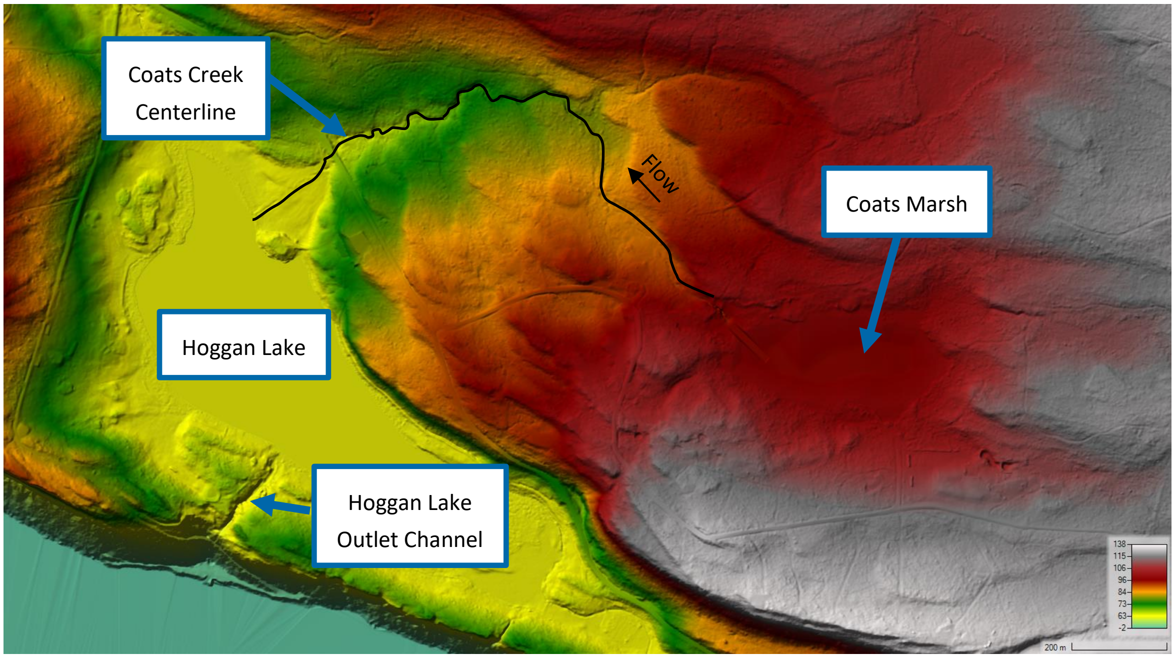

Figure 2.1 Model DEM

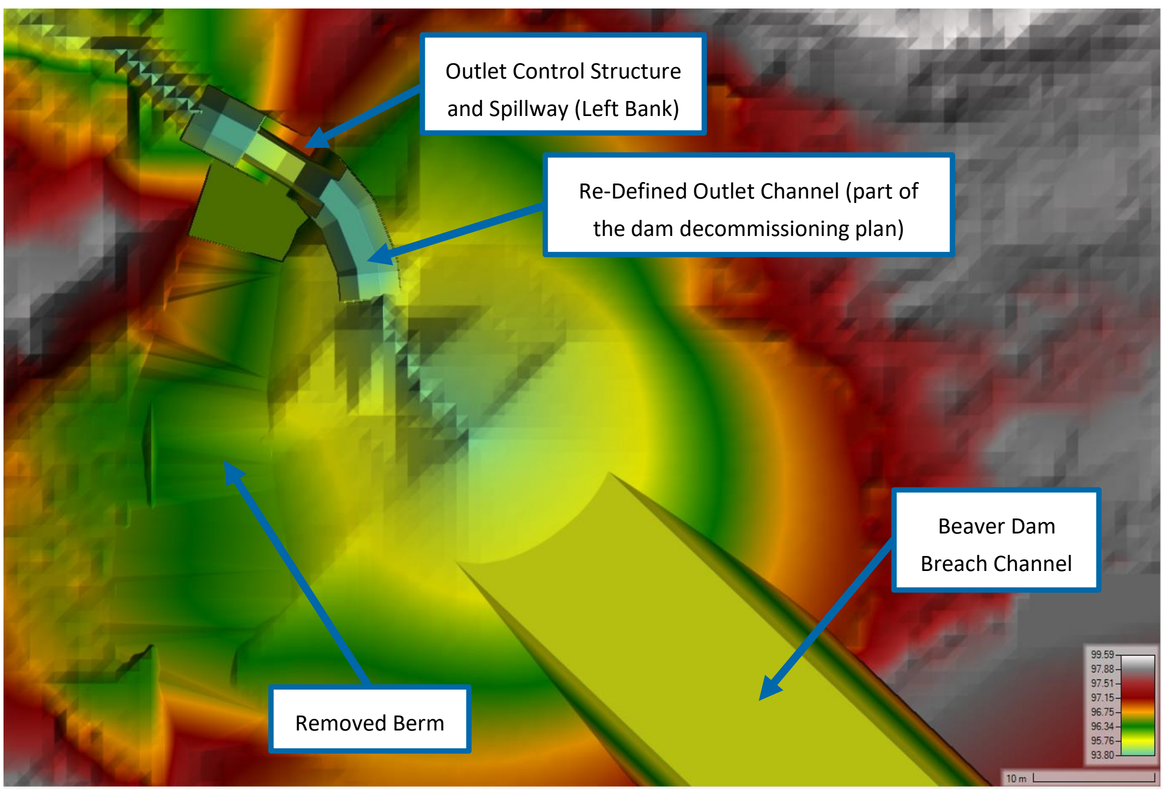

Figure 2.2 Terrain modifications in and around Coats Marsh associated with the decommissioning of the man-made dam and the breach of the beaver dam.

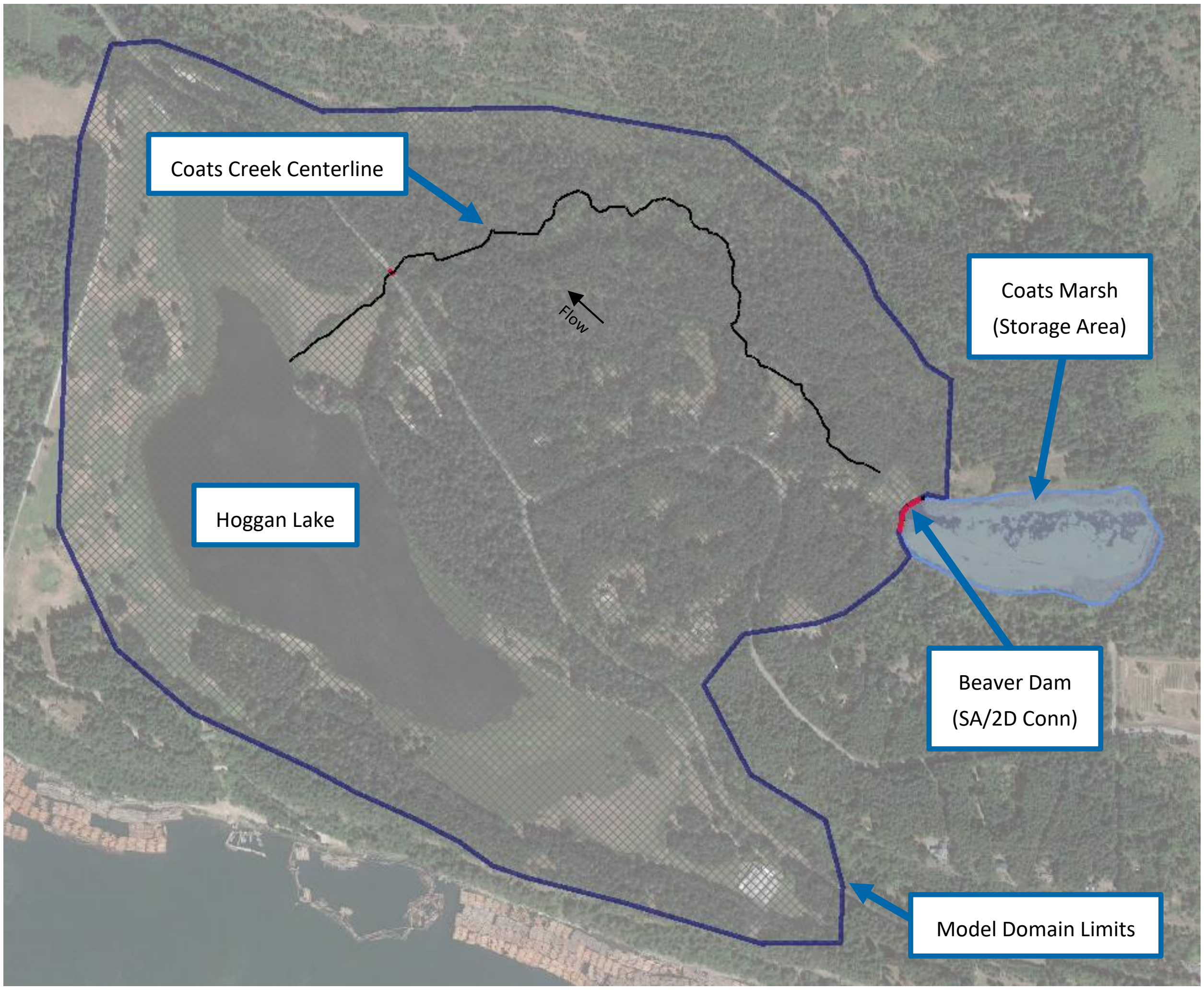

Figure 2.3 HEC-RAS Model Domain. Dark blue line shows extents of 2D flow area, light blue area represents the Coats Marsh storage area, and red line shows the beaver dam. SA/2D is the storage area to two-dimensional model connection.

Table 2.1 Manning's n Values

Land Cover Classification	Manning's n Value
Open Water	0.024
Rural/Agricultural Open Space	0.040
Marsh	0.065
Mixed Forest	0.080

2.2 Flood Scenarios

The Canadian Dam Association Dam Safety Guidelines (2013) recommend assessing dam breaches using two scenarios:

2. A flood-induced failure scenario: This situation is where the dam fails during a significant flood event, typically due to overtopping. In the case of a 200-year design flood, which is typically used for regulatory floodplain mapping in BC, the *incremental consequences* associated with the failure are determined by calculating the difference between:
    a. The flood impacts during a 200-year flood, assuming the dam fails; and
    b. The flood impacts during a 200-year flood, assuming the dam does not fail.
3. A sunny day scenario: This is a situation where the dam is at full supply level and fails due to reasons other than flooding, such as seepage, structural deterioration, or a seismic event. In this case, the consequences of failure can be solely attributed to the breach.

NHC has evaluated both flood-induced failure and sunny-day failure impacts associated with the beaver dam. For the flood-induced failure, NHC developed 200-year inflow hydrographs using peak flows from previous hydrologic analyses (NHC, 2023). The hydrograph shape was assumed as triangular, based on the Modified Rational Method (Ministry of Environment, 1991). The hydrograph lasts 5.2 hours and has peak discharge occurring at the watershed's time of concentration (2.6 hours).

Initial conditions for both the flood-induced and sunny day failures assume a baseflow of 0.2 m^3/s in the creek. The value was chosen as a conservative estimate based on streamflow observations made by local resident N. Doe (Doe, 2023). The model was run over a 22-hour period, with 12 hours of baseflow running through the model before the storm hydrograph begins (for the 200-yr storm scenario). The dam breach was assumed to occur at the peak marsh level, at 2 hours 45 minutes into the storm hydrograph (9 minutes after the hydrograph peak). The model run ends 2 hours after a steady state baseflow is re-established following the breach release.

The two flow scenarios are summarized in Table 2.2.

Table 2.2 Model inflow scenarios

Flow Condition	Peak Marsh Inflow	Baseflow	Storm Duration
Sunny Day	0.2 m^3/s	0.2 m^3/s	N/A
200-year storm	4.54 m^3/s	0.2 m^3/s	5.2 hours

2.3 Beaver Dam Failure Modes and Model Breach Parameters

To model the dam breach, NHC utilized the simplified breach module in HEC-RAS, which assumes that the breach develops to a specified geometry over a set time. The dam breach user input parameters required in HEC-RAS include:

- Elevation at bottom of breach
- Bottom width of breach
- Side slopes of breach
- Breach formation time

Beaver dams are composite structures and their potential breach characteristics are expected to vary greatly between sites, and even over the life of the dam as it deteriorates or is modified by beavers. To the authors' knowledge, there are no guidelines available for developing breach parameters for beaver dams. Instead, NHC has developed the breach parameters using a combination of literature review, empirical formulas applicable to embankment dams, and professional judgement.

2.3.1 Beaver Dam Characteristics

The beaver dam is located 50 m upstream of the man-made dam and has existed since approximately 2013. Field observations by RDN staff indicate that the beavers on site are highly active, both at the beaver dam and at the outlet of the man-made dam. The following summarizes key characteristics of the beaver dam based on field observations by NHC:

- Height: 2.0 m to 2.5 m, with a crest elevation of approximately 97.7 m
- Length: 55 m, with abutments consisting of native soil at high ground points
- Material composition: logs, brush, and mud where visible above the water surface
- Upstream storage volume: approximately 77,000 m^3 at a water level of 97.7 m

To the authors knowledge, no large-scale beaver dam failures have occurred at the site since 2013. Observations by local resident N. Doe indicate that the beaver dam has sustained localized damage during large floods, but that the beavers quickly repaired damaged areas to their previous condition (Doe, 2023).

2.3.2 Literature Review

The failure modes and breach characteristics of man-made dams are well described in the literature. However, less information is available regarding beaver dams. NHC has reviewed readily available literature to characterize the potential hazards and failure modes of relevance to the Coats Marsh site, summarized as follows (Butler, 1989; Case et al., 2003; Doe, 2023; Hillman, 1998; Puttock, 2019; Ronnquist, 2021; Ronnquist and Westbrook, 2021; Welsh, 2012):

- Beaver dams can fail in several ways: overtopping, leakage through the dam itself (through flow), and breaches at the dam interfaces (under flow).
- *Catastrophic* beaver dam failure events are characterized by a near-instantaneous water release and typically occur from overtopping under high flow conditions. It is common for this type of breach to wash away a complete section of the dam, but a failure of the entire dam is unlikely.
- Typically, beavers will maintain their dams and repair minor failures in quick order. Vegetation growth can also increase the strength and integrity of a maintained beaver dam over time.

However, beavers can abandon their dams if food sources deplete, if their dam fails past the threshold of repair, or if they perish. Without a beaver's regular maintenance, beaver dams can deteriorate and erode quickly, increasing the likelihood of catastrophic failures under high flows.

- Other mammals such as muskrats and otters can tunnel through beaver dams and decrease dam integrity. It should be noted that observations made by local resident N. Doe (2023) have not included sightings of such mammals.

Considering the foregoing, the most likely failure modes are anticipated to be:

1. A gradual breach of the dam, resulting from a void forming and enlarging within the dam body, base, or contact surface with adjacent ground. In our opinion, the likelihood of this failure mode appears relatively low, so long as the beaver continues to actively maintain the dam as in previous years. A reduction in beaver activity, or increased rates of wood deterioration, would increase the likelihood of this failure mode.
2. A rapid breach of the dam, resulting from a significant flood event. In our opinion, failure of the entire dam structure is unlikely. A more likely scenario would involve a discrete section of dam failing, either through displacement of a log element or overtopping erosion at the contact surface with adjacent ground. Based on previous project experience and professional judgement, a breach width between 5 and 10 m is reasonable for this site.

2.3.3 Empirical Breach Parameter Estimation

Several empirical equations are available in the literature to calculate dam breach parameters. Generally, the equations seek to estimate breach geometries and failure times based on a dataset of observed real-world failures, using inputs such as dam height, erodibility, and upstream storage volume. There is limited applicability of these equations to a beaver dam; however, they provide an order-of-magnitude indication of the potential breach geometries and failure times. Two dam breach equations were evaluated for the flood-induced failure scenario (Brunner, 2014):

1. The Froehlich (2008) equations, which are applicable to earthen embankment dams. This equation considers dam height and volume, but not erodibility of the dam material. For a flood-induced overtopping failure, the breach width and failure time were calculated as 13.6 m and 24 minutes, respectively.
2. The Von Thun and Gillette equations (1990), which are applicable to earthen embankment dams. This equation considers dam height, reservoir size, and erodibility of the dam material. For a flood-induced overtopping failure, the breach width and failure time were calculated as 15.1 m and 66 minutes, respectively.

Considering NHC's literature review (see Section 2.3.2), it appears unlikely that a breach would develop to the widths predicted by these equations. However, failure could occur more suddenly than predicted by the equations if a section of dam were to displace.

For comparison, concrete gravity dams often are assumed to fail in 6 to 30 minutes, and concrete arch dams nearly instantaneously (Brunner, 2014; NHC, 2021). Given the nature and strength of a beaver dam's material relative to concrete, the failure times calculated by the empirical equations are not sensible for a catastrophic beaver dam breach; a more rapid failure time should be assumed for this site.

2.3.4 Design Breach Parameters

Considering the empirical calculations, literature review, and site-specific judgement, the values presented in Table 2.3 were selected for the dam breach model.

Table 2.3 Model Breach Parameters

Bottom Width	Bottom Elevation[1]	Side Slopes	Failure Time
8 m	95.5 m	1H:1V	1 minute (0.017 hr)

1. NHC assumes that the dam would fail down to the marsh bottom elevation.

2.4 Model Verification

Given that there is no previous dam breach or storm data for the study area, the model was not able to be calibrated. In absence of calibration, several model verification methods were applied where possible.

2.4.1 Peak Flow Attenuation

Investigating flow peaking at various cross sections along Coats Creek, it was observed that the peak flowrate of the breach surge attenuated between the outlet control structure and South Road by 42% for the sunny day breach and by 37% for the 200-year breach. Considering the timescale and volume of the breach, these attenuation magnitudes appear reasonable for a creek with this channel length, floodplain vegetation, and valley topography. Hydrograph attenuation curves available from the province (BC MFLNRO, 2016) indicate that peak flow attenuation in the range of 30% to 50% could be expected for a creek with this geometry and upstream storage volume.

2.4.2 Culvert Hydraulics

The hydraulic conditions through the South Road culvert were checked against an Inlet Control Headwater Depth nomograph in the Handbook of Steel Drainage & Highway Construction Products (CSPI, 2007). Modelling results were analysed at the timestep immediately before the South Road overtops to capture the maximum flow scenario at which all flow is still being conveyed through the culvert. The model's headwater depth of 1.63 m was within 6% of the calculated inlet control headwater depth of 1.74 for a 1,200 mm culvert projecting from fill. As such, NHC deemed that the modelled culvert was conveying flow in a reasonable manner. It should be noted however, that these magnitudes of headwater depth suggest that the existing South Road culvert is undersized relative to the design flows.

2.4.3 Sensitivity Analysis

A sensitivity analysis was performed for the breach width and failure time parameters, comparing flood extents and South Road overtopping flow conditions under varying breach conditions. This was run under 200-year storm flow conditions.

Table 2.4 Breach Parameter Sensitivity Analysis Setup

Breach	Bottom Width	Bottom Elevation	Side Slopes	Failure Time
Lower Bound Breach	5 m	95.5 m	1H:1V	0.433 hr[1]
Baseline Breach	8 m	95.5 m	1H:1V	0.017 hr
Higher Bound Breach	13.55 m[1]	95.5 m	1H:1V	0.01 hr

1. Value from Froehlich (2008) equation calculations.

Analysing the difference in results between the lower and higher bound breaches, horizontal flood extents differed by a maximum of 4 m around the weir pool and did not differ substantially in any other areas of the model. By the time the breach surge reaches South Road, the difference in the peak discharge and maximum depth over South Road is 3.2 m^3/s and 0.05 m, respectively. These findings indicate that model results are not overly sensitive to the breach parameters.

A sensitivity analysis was also performed to determine the increased risk introduced if the beaver continues to raise the height of the dam. A dam height increase of 0.5 m was implemented under the 200-year storm scenario with the baseline breach. This height increase was shown to have a substantial impact on results, with flooding extents increasing by as much as 40 m for the nearest property downstream of the weir and by approximately 3 to 4 m for most of Coats Creek. Maximum flow and height over South Road also increased by 18.6 m^3/s and 25 cm, respectively. These sensitivity results were considered in the risk interpretation section of this report (Section 4).

2.5 Model Limitations and Assumptions

The following summarizes key assumptions and limitations applicable to the model development and outputs:

- There is limited (1 m) terrain resolution and LiDAR density in the Coats Creek channel and overbanks, increasing the uncertainty of modeled flood extents and the marsh's volume-elevation curve.
- The culvert along the RDN path and other in-channel structures on private property were not incorporated into the model, adding uncertainty to the hydraulics in those channel reaches. The culvert at South Road could become obstructed by debris during a flood, further increasing the severity of road overtopping.
- There are other streams entering Hoggan Lake whose flows have not been included in the model.
- There is a lack of industry knowledge and observations regarding beaver dam breach mechanisms and characteristics; in our opinion, the breach parameters used for modeling are conservative but remain subject to substantial uncertainty.
- Without detailed hydrometric records, the 200-year storm was developed using the rational method, which uses an empirical relationship to relate rainfall to peak discharge. In our opinion, the input parameters used to develop the hydrology were reasonably conservative, but there is limited to no field data available to validate these parameters or results.

- The beaver dam geometry and height are not fixed and could evolve over time in ways not captured by the 0.5 m height increase incorporated into the sensitivity analysis.
- The hydraulics at and around marsh outlet channel are complex, involving 3D flow behaviour and non-uniform flow that aren't well represented by 2D models. This adds uncertainty in the flood extents and depths around the weir pool and outlet channel.
- Hydraulic conditions in the Hoggan Lake outlet channel are uncertain because the dam that exists in this creek was not incorporated into the model. This outlet channel was included in the model to better understand the effect of beaver dam breaches on the water levels within Hoggan Lake, and not for the intent of understanding the conditions in the outlet channel itself.
- There is no data or historical events against which to calibrate the model, which introduces further uncertainty to all aspects of the model. Without the ability to check results against known conditions, the model relies more heavily on engineering judgement and theoretical hydraulics.
- Hydraulic models are approximate representations of real-world conditions. They approximate conditions to the extent that site information is available and should be interpreted in a way that considers the level of information available and the amount of uncertainty that is inherent in those approximations.

3 HYDRAULIC MODEL RESULTS

Following model development, the model was run under the three scenarios recommended by the Canadian Dam Association Dam Safety Guidelines: 200-year storm, 200-year storm with a breach, and sunny day breach. The model results are summarized in this section.

3.1 Flood Extents

In all modelled scenarios, the inundated properties include:

- 1050 Coats Drive (PID 001300415)[1]
- 1040 Coats Drive (PID 001300466)
- 1034 Coats Drive (PID 001300474)
- Lands within Coats Marsh Regional Park (PID 009735828)
- Agricultural Land Reserve lands around Hoggan Lake and South Road (PID 009740741)

Property inundation was analyzed using publicly available satellite imagery. Features such as primary residences, lawns, and forested areas were interpreted from this imagery. Without more detailed property information, specific site features such as septic tanks and fields were not considered in this flooding analysis.

[1] Property identifiers (PID) derived from RDN GIS data, available at: https://webmap.rdn.bc.ca/Html5Viewer/?viewer=Public.

3.1.1 1050 Coats Drive

In both breaches, only a small, forested portion of the northeast corner of this property was inundated. Under the 200-year storm, flooding did not reach this property.

3.1.2 1040 Coats Drive

Coats Creek's alignment intersects this property, flowing northwest. During flooding and breaches, flow overtops the creek banks and spills onto forested portions of the property. The primary residence on this property is not shown to be affected, however this property contains a log cabin that is inundated under all model scenarios. The severity of inundation is greatest during the flood-induced dam breach, when water depths are approximately 0.6 m around the cabin. Property owners have stated that this cabin is occasionally used as a guesthouse (NHC, 2023). It should also be noted that an unlicensed in-channel rock weir exists adjacent to the cabin and likely contributes to localized flooding.

3.1.3 1034 Coats Drive

Coats Creek's alignment intersects this property's north end, flowing northwest. A free-standing shed located 38 m northeast of the property's main house experiences inundation under the two breach scenarios. Otherwise, flooding only extends onto the property's north forested portions and a section of the lawn.

3.1.4 Hoggan Lake Levels

Table 3.1 presents the modelled Hoggan lake levels.

Table 3.1 Hoggan Lake Levels

Model Run	Change in Hoggan Lake Level[1]	Maximum Hoggan Lake Elevation
Sunny day breach	+0.39 m	59.70 m
200-year storm	+0.24 m	59.55 m
200-year storm with breach	+0.53 m	59.84 m

1. Assumes an initial lake elevation of 59.31 m, based on 2019 BC LiDAR.

The property on the east edge of Hoggan Lake, south of where Coats Creek enters the lake, sits on an elevated platform (64.8 m elevation), and remains unaffected by raised lake levels.

The flood extents under all model scenarios are presented in Appendix A.

3.2 South Road Overtopping

The model results indicate overtopping of South Road for all the flow scenarios assessed. Table 3.2 summarizes the conditions modelled at South Road.

Table 3.2 South Road Model Conditions

Model Scenario	Peak flow rate[1]	Peak flow arrival time after breach	Duration of overtopping flow	Maximum overtopping flow depth
Sunny Day Breach	12.7 m^3/s	28 minutes	180 minutes (3h)	0.43 m
200-yr Storm	4.0 m^3/s	N/A	107 minutes (1h 47m)	0.23 m
200-yr Storm with Breach	21.5 m^3/s	20 minutes	224 minutes (3h 44m)	0.61 m

1. Includes overtopping flow and flow through the culvert.

Figure 3.1 provides a cross section visualization of South Road with maximum water levels for each model scenario.

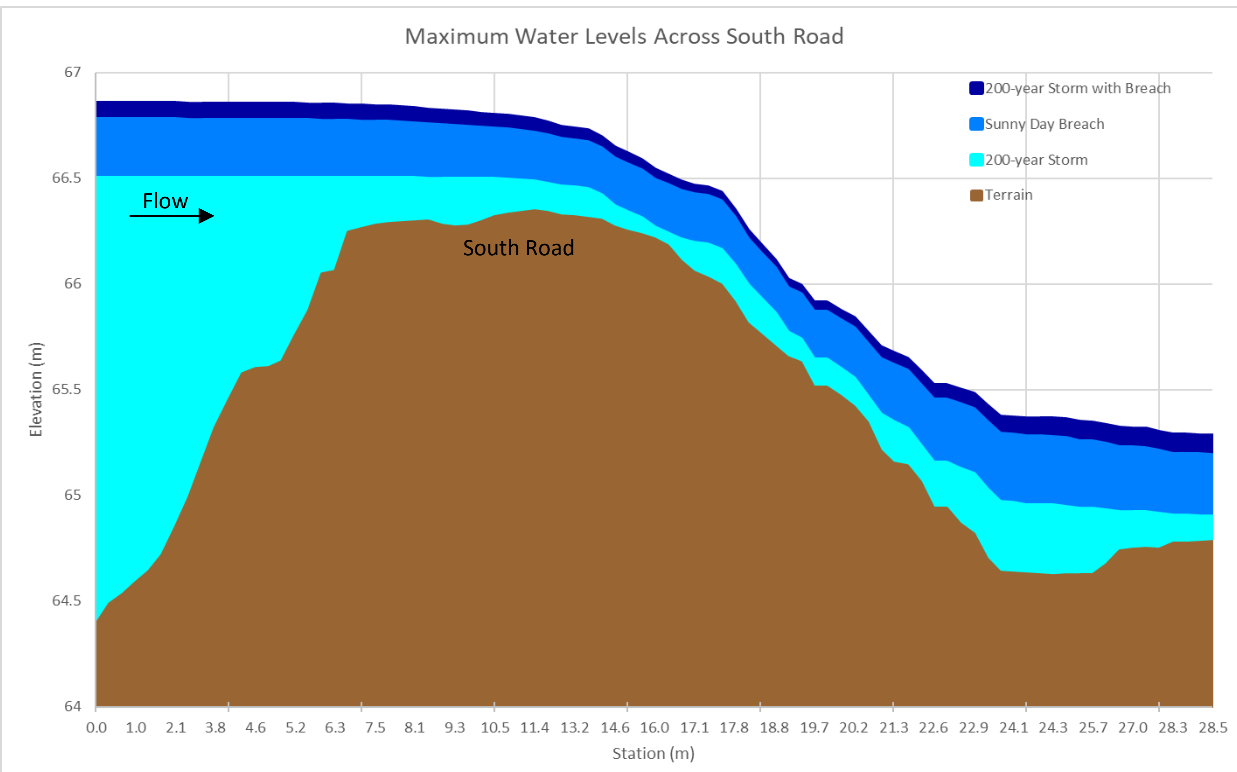

Figure 3.1 Maximum Water Levels Across South Road

3.3 Effect of Weir Decommissioning

The hydraulic model and associated results discussed in this section assume that the existing concrete weir and earth embankment are removed and that the proposed outlet grade control structure is constructed. If the concrete weir and berm were to remain in place, flood extents and depths for all modelled scenarios would change from those shown. NHC has not completed additional modeling to evaluate beaver dam breach risks with the weir and berm in place; however, we have prepared the following qualitative discussion based on available information and site knowledge:

- It is possible that the concrete weir could fail due to additional hydraulic loads imposed by the beaver dam breach outflows. If the concrete weir fails near the peak beaver dam breach outflow, there will be a secondary weir breach outflow and it is likely that downstream hydraulic effects would be similar to those modeled.
- If the concrete weir does not fail, the beaver dam breach opening will be backwatered by the concrete weir and peak breach outflows will be reduced. In this case, it is likely that downstream hydraulic effects would be less severe than those modeled.
- The effect of the existing berm on beaver dam breach hydraulics is uncertain. For a small magnitude breach, the berm is expected to concentrate flow in the outlet channel. Flooding of yard areas at 1034 and 1040 Coats Drive would be reduced, but peak flows in Coats Creek would increase. During a large magnitude breach, it is likely that the berm would overtop and yard areas at 1034 and 1040 Coats Drive would be flooded.

4 RISK INTERPRETATION

In general, risk is defined as a function of likelihood and consequence. The risk associated with the Coats Marsh beaver dam is therefore interpreted as being the product of the likelihood that the beaver dam breaches catastrophically and the consequences of such a breach.

4.1 Likelihood of Failure

In Section 2.3, the most likely dam failure mode was identified as a breach of a discrete section of the dam under a significant flood event, due to erosion or log displacement. As mentioned in the same section, the likelihood of erosion and failures of the dam structure would be expected to substantially increase if the beaver were to vacate the area or perish. The likelihood of structural failure is also expected to increase if the beaver continues to increase the height of the dam.

Under global climate change, the frequency and likelihood of significant flood events is expected to increase, and with it the likelihood of a breach event.

4.2 Consequences of Failure

Consequences of failure can be quantified in terms of exposed assets, including people, infrastructure, the environment, and cultural values.

4.2.1 Populations at Risk

Based on model results, populations that could be exposed to a breach include those staying in the log cabin at 1040 Coats Drive, those travelling on South Road, and those who happen to be within the inundation zone on private property at the time of flooding. It is important to note that there would be very limited warning time between the time of breach and the arrival of the flood surge, especially to those in the immediate downstream properties.

Notably, similar populations are exposed under a 200-year storm without a breach as with a breach, but to a lesser extent and without the fast-moving surge created by the breach. Therefore, populations at risk are not unique to the breach scenarios, but the hazard levels increase as a result of the breach.

4.2.2 Infrastructure

The key infrastructure exposed to flooding includes:

- South Road
- Cabin at 1040 Coats Drive
- Shed at 1034 Coats Drive
- Culverts and footbridges on private property along Coats Creek
- Hoggan Lake dam

For the 200-year flood, all infrastructure except the shed at 1034 Coats Drive is exposed under both breach and no breach storm conditions, but with differing hazard levels. South Road, for example, overtops under all scenarios but with significant variance in peak flow rate, time of overtopping, and maximum overtopping depth, as shown in Section 3.2. It appears likely that a sunny day breach or flood-induced breach would result in damage to one or both traveling lanes. For Hoggan Lake dam, it appears unlikely that a dam breach and associated lake level changes will impact the dam, however these impacts were not specifically assessed as part of this study.

4.2.3 Environment

The consequences of a dam breach to the environment include the loss of wetland habitat within Coats Marsh, the erosion of potential trout spawning habitat upstream of Hoggan Lake, sediment and nutrient loading to Hoggan lake, and environmental contamination due to flooding of septic tanks and septic fields located on private property. The latter three effects are also factors under a 200-year storm without a breach, but to a lesser degree. The effect of different marsh levels on habitat within Coats Marsh was assessed in detail in the previous phase of this project (EDI, 2023). Spawning habitat loss and sediment and nutrient loading were not evaluated as part of this study. Septic system effects were also not assessed, as their locations and elevations within the inundated properties were unknown.

4.2.4 Cultural Values

There are no known archeological assets in the inundation zone (NHC, 2023).

4.2.5 Future Considerations

As shown in the Section 2.4, the beaver dam height influences the severity of flooding during a dam breach. If the beaver increases the height of the dam sometime in the future, the consequence to each of the identified assets is expected to increase incrementally as the storage capacity of the marsh increases.

Future development in the floodplain must also be considered. Coats Marsh and Coats Creek are under riparian area regulations, which prohibits the construction of structures within 30 m of water bodies without special approval. The reach of Coats Creek that extends from 75 m upstream of South Road to Hoggan Lake was shown to have flooding that extends further than 30 m from the creek. Any future construction that occurs in that area, or which is granted special approval within 30 m of any part of the creek, would result in increased consequence from a beaver dam breach.

5 MITIGATION CONCEPTS

The risk assessment results indicate that there are potential downstream consequences in the event of a beaver dam failure. The likelihood of a failure may increase over time as the dam materials deteriorate, or if the beaver abandons or reduces its maintenance activities at the dam (see Section 2.3.)

Eliminating beaver dam risk would require partial or full removal of the dam, as well as long-term monitoring and site interventions (e.g., beaver trapping) to ensure that the dam is not rebuilt. Partial removal would, at a minimum, require an engineered breach that prevents the dam from retaining water during flooding events and is wide enough to deter a beaver from repairing the breach. However, we understand that RDN wishes to keep the beaver dam in place to maintain the marsh's ecological values. NHC has instead prepared a series of mitigation concepts that could be implemented to reduce, but not eliminate, flood risks. We note the following limitations regarding the mitigation concepts:

- NHC is not qualified to comment on the legal liability aspects of a beaver dam breach; we recommend that RDN consult with its insurer or legal counsel regarding this topic.
- Despite mitigation, a breach could still occur. If a breach results in damages, NHC does not warrant or guarantee that implementation of the mitigation concepts would absolve RDN of legal liability. The mitigation concepts are intended to reduce, but not eliminate, the likelihood or consequences of a breach.

The following sections summarize the mitigation concepts for RDN's consideration.

5.1 Monitoring and Emergency Preparedness

- Informing stakeholders of the potential risks associated with a failure. These include downstream landowners, the Gabriola Fire Department, and the BC MOTI. Land use regulation could be considered to limit development within the potential inundation zone, though this would have to be coordinated through the Islands Trust.

- Develop an emergency protocol in the event of a dam failure. This could include emergency callouts to stakeholders. Local closure of South Road could be considered in coordination with BC MOTI. Post-breach site inspections are recommended to be carried out by qualified engineering and/or environmental professionals. A site restoration protocol could be developed to stabilize exposed soils and promote vegetation establishment.
- Developing and implementing a monitoring program for the beaver dam. Monitoring should focus on identifying signs of beaver dam deterioration, instability, or changes in geometry (e.g., increase in height). Monitoring could be conducted monthly and during any substantial rainfall events where there is an increased likelihood of dam failure. Note that NHC is not aware of any professional standards or of any engineering professionals in the region with experience or qualifications to assess the stability of beaver dams.

5.2 Consequence Reduction

- Removal or relocation of the cabin on private property at 1040 Coats Drive, or removal of the unlicensed rock weir on the property.
- Installing signage along South Road to indicate no parking within the potential breach inundation area. Similar work was recently implemented for the Mallett Creek Dam along Descanso Bay Road on Gabriola Island.

5.3 Beaver Dam Interventions

- We recommend removal of beaver dam debris from the marsh outlet if its height exceeds the elevation of the overflow channel. The overflow channel is intended to maintain the outlet’s discharge capacity, mitigating flooding of private property at 1040 and 1050 Coats Drive during a breach.
- If monitoring activities identify a potential stability concern at the beaver dam, the existing siphon system (and/or pumps) could be used to draw down the upstream reservoir and reduce pressure on the dam. The siphon system should be maintained and tested annually to ensure it can be used if needed. In our opinion, continued seasonal use of the siphons may be unnecessary, as they are not designed to convey peak flows during storms and can result in undesirable water level fluctuations. RDN could consider installing a high-capacity siphon system, Clemson pond leveler, or similar apparatus, particularly if the beaver continues to increase the elevation of the dam over time. However, we note that a high-capacity pond leveler or siphon would be costly to install if were sized to accommodate a large flood (e.g., a 2-year peak flow).
- If beavers abandon the dam or it deteriorates substantially, we recommend draining the upstream reservoir and pre-emptively breaching or removing the dam.
- The site of the proposed grade control structure should be regularly monitored for signs of beaver activity. Any evidence of beaver dam construction in this area should be removed immediately.

- Any construction activities at the beaver dam would involve in-stream work and require environmental permits to proceed. These would likely include Fisheries and Oceans Canada notifications or reviews, as well as provincial approvals under Section 11 of the *Water Sustainability Act*.

6 CLOSURE

We trust this report meets your needs. If you have any questions or requests, please feel free to contact the undersigned at (250) 754-6425.

Sincerely,

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DISCLAIMER

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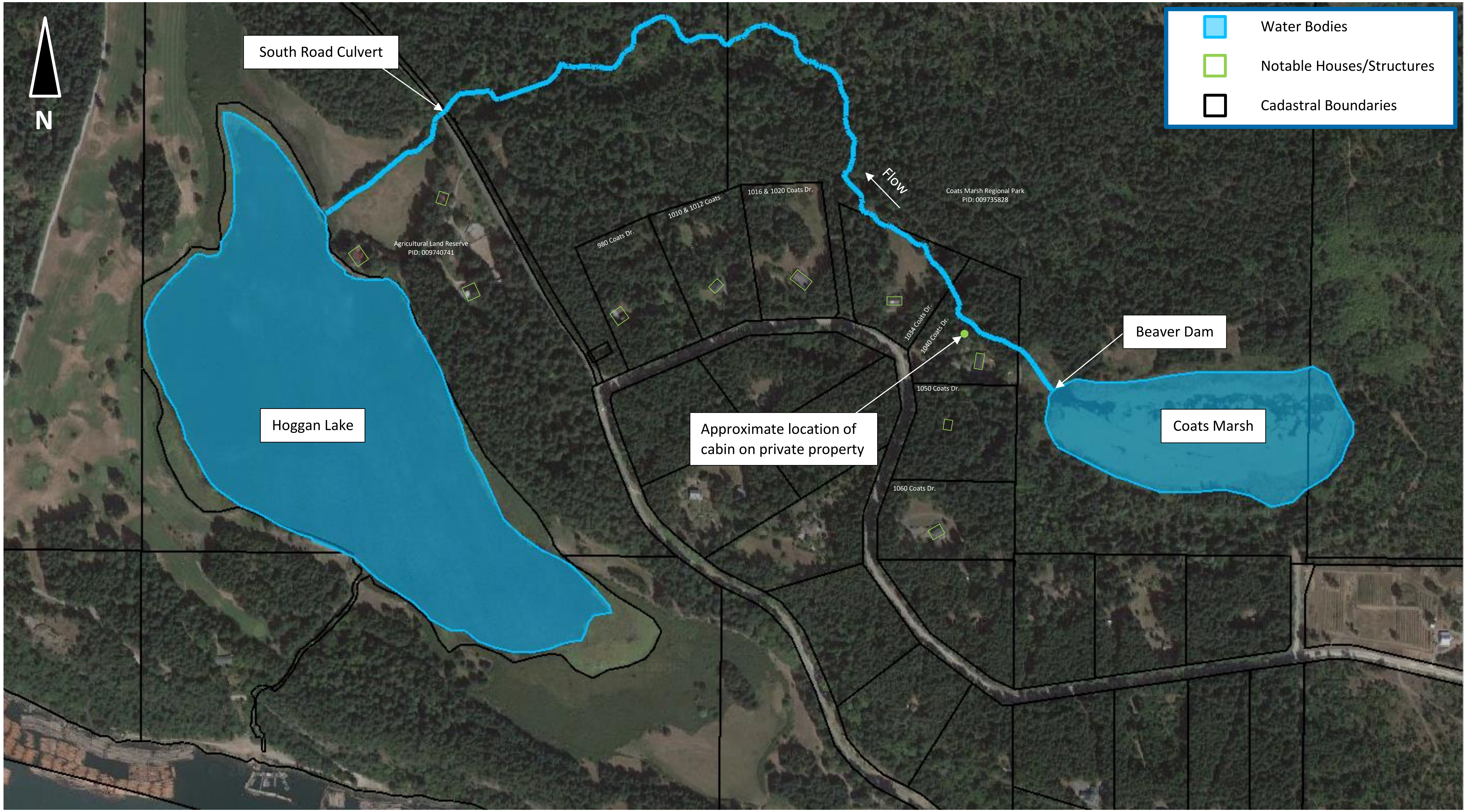
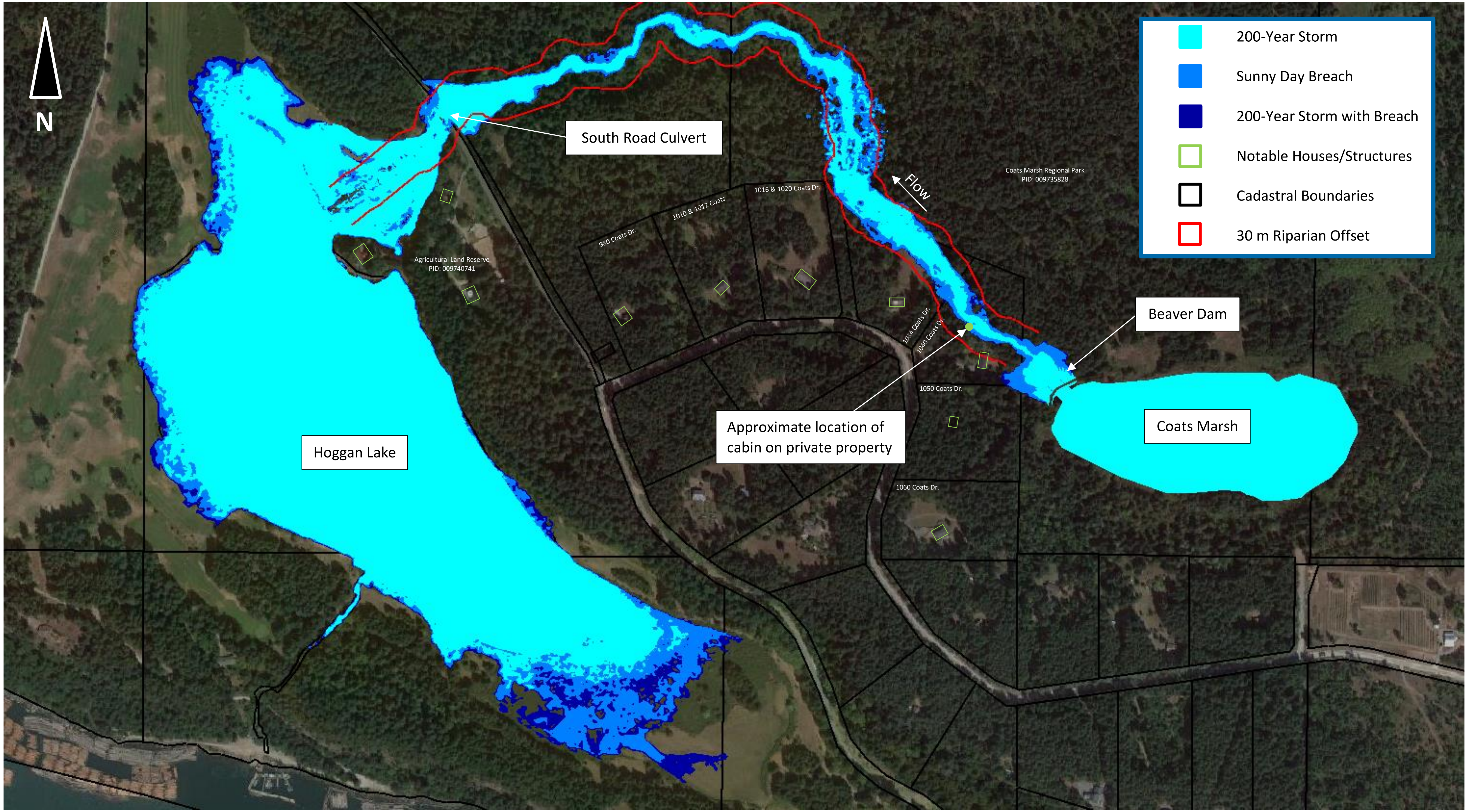
APPENDIX A

SITE AND RESULT MAPS



C.1 Map of existing site conditions[2].

[2] Background orthophotography generated by HEC-RAS using publicly available web imagery, and cadastral boundaries from ParcelMap BC, available at: https://catalogue.data.gov.bc.ca/dataset/parcelmap-bc-parcel-fabric.



C.2 Map of flood extents, with 200-year storm in cyan, sunny day breach in light blue, and 200-year storm with breach in dark blue[3].

[3] Background orthophotography generated by HEC-RAS using publicly available web imagery, and cadastral boundaries from ParcelMap BC, available at: https://catalogue.data.gov.bc.ca/dataset/parcelmap-bc-parcel-fabric.