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Skeena River and Bulkley River Flood Study

Floodplain Mitigation Plan Report

Prepared for:

The Village of Hazelton

April 13, 2021

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Signature Page

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Executive Summary

As requested, SNC-Lavalin Inc. (SNC-Lavalin) has conducted a Skeena River and Bulkley River Flood Study and prepared this Floodplain Mitigation Plan report for the Village of Hazelton (Village) and Gitanmaax Band (Band). This work was completed under an agreement with the Village and was executed July 23, 2020.

The purpose of this report is to map potential flood hazards potentially experienced in the event the Skeena River and Bulkley River experience coincident 200-year water levels with an allowance for climate change and identify as well as rank assets at risk within the inundation boundary. The purpose is also to provide non-structural and structural options to mitigate these flood risks.

This work was completed through a quantitative assessment of flood hazards and qualitative assessment of flood risks. The 200-year flood (with allowance for climate change) depths and velocities from the 2-dimensional model (developed in the Floodplain Mapping report, SNC-Lavalin 2021) were multiplied. The product of depth and velocity were ranked from ‘Very Low’ to ‘Very High’ based on the USA 3 x 3 principle (Ontario MNR and Watershed Science Centre 2001) and UK formula (APEGBC 2017). The resulting hazards were mainly ‘Very High’, therefore the scale was extended to ‘Very High 1’ through ‘Very High 5’.

The flood hazard map was overlain on an orthophoto and assets at risk were identified. Flood hazard areas with similar assets at risk were divided into zones (six zones total) and ranked on their subjective importance using a risk matrix. Green spaces and roadways were given relatively low importance while buildings and essential services (e.g., fire hall) were given higher importance. The assets at risk were ranked based on the resulting risk number as follows:

Rank	Zone	Asset(s)	Hazard Class	Risk Rank Number
1	Zone 5	‘Ksan administration buildings	Very High 5	22
2	Zone 4	Cunningham Street residences	Very High 5	22
3	Zone 2	Residences, fire hall, community buildings	Very High 2	20.4
4	Zone 4	River Road residences	High	16
5	Zone 3	Pump Station, school field	High	12
6	Zone 6	‘Ksan Historical Village	Moderate	12
7	Zone 1	Government Street, park, yards	Moderate	6

Mitigation options were developed for all zones, as the risk rankings were all relatively high.

Four non-structural options were suggested for the Village and Band to consider including:

- Flood emergency response plan (including demountable / temporary flood wall deployment);
- Public education (online access for updated flood inundation and flood hazard maps, information session);
- Flood forecasting using BC River Forecast Centre (BC 2019); and
- Land use management (update Zoning Bylaw No. 478).

Non-structural options complement the structural options; the level of effort to develop these depends on structural options implemented.

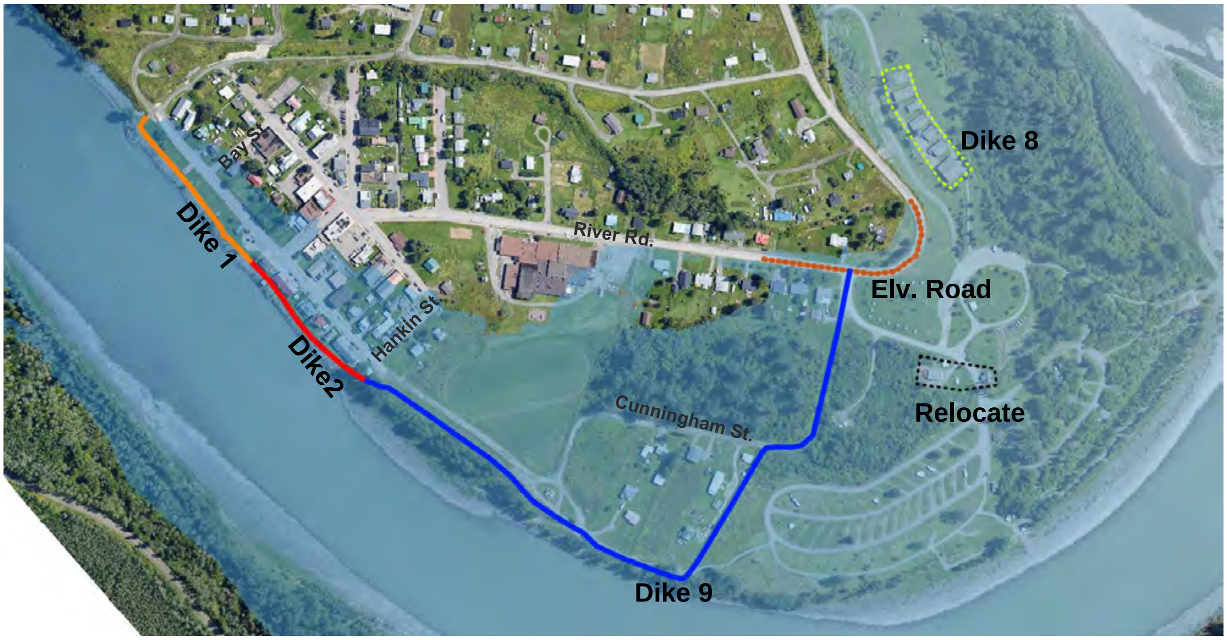
Structural mitigation options considered in the study included:

- Earthen berm;
- Retaining wall;
- Demountable / temporary flood walls;
- Wet building floodproofing; and
- Building elevation / relocation.

Several different structural options were developed for every zone. Some options could be implemented independently (protecting individual zones) and some options could be combined to protect multiple zones simultaneously. Preliminary cost estimates were also provided for each structural option. The feasibility of preferred structural options must be assessed with further studies (e.g., hydrotechnical analysis, geotechnical investigations, land availability).

Structural recommendations were given for the protection of all zones, as summarized below:

- Relocate 'Ksan administration buildings;
- Build Dike 1, Dike 2, and Dike 9 to protect Hankin Street to Bay Street buildings, pump station, Cunningham Street residences, and River Road residences;
- Build earthen berm for Dike 1;
- Acquire and build demountable flood wall for Dike 2;
- Build earthen berm for Dike 9 and raise River Road elevation; and
- Acquire temporary flood wall (Dike 8) for 'Ksan historical village buildings.



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1 Introduction

SNC-Lavalin Inc. (SNC-Lavalin) is pleased to provide this Skeena River and Bulkley River Flood Study - Flood Mitigation Plan report to the Village of Hazelton (Village) and Gitanmaax Band (Band) as proposed in our request for proposal response entitled *Request for Proposal: Flood Risk Assessment, Flood Mapping, and Flood Mitigation Plan 2019-01, Issue Date: October 15, 2019,* and submitted November 15, 2019.

The village of Hazelton, Gitanmaax, and surrounding areas have experienced significant flood events, including most recently in June 2007 when several communities had to evacuate the area. As a result, the Village and Band have set a priority to assess the nature of future floods due to climate change to understand the potential impacts. Both organizations are stakeholders and are keen to be informed of flood risks to the community in order to assist decision makers on flood mitigation matters. To succeed in their mandate, the Village and Band require a flood hazard and risk assessment and flood mitigation plan.

This report includes a flood hazard assessment, qualitative risk assessment, and proposed mitigation options (both non-structural and structural) for the 200-year climate change affected flooding on the Skeena River and Bulkley River. As such, this report should be reviewed in conjunction with our *Skeena River and Bulkley River Flood Study – Floodplain Inundation Mapping Report* (SNC-Lavalin 2021), which is provided under separate cover and includes a flood inundation mapping for Skeena River and Bulkley River that flow adjacent to the village of Hazelton and Gitanmaax lands.

2 Project Description

2.1 Objective

This report aims to describe the flood hazard assessment approach, present the flood hazard mapping results, perform a qualitative risk assessment to identify higher risk areas, and propose mitigation measures for the higher risk areas identified. Both structural and non-structural mitigation measures are suggested, with preliminary cost estimates included for structural measures. The assessment was undertaken for the 200-year flood event.

2.2 Flood Inundation Mapping Summary

The floodplain mapping report outlines the methodology and results of the flood assessment for the Skeena River and Bulkley River 200-year flood events using two-dimensional (2D) modelling. The flood inundation boundaries were mapped in the study area: 3 km upstream on the Skeena River from the confluence, 2 km upstream on the Bulkley River from the confluence, and 2 km downstream of the confluence. This area encompassed the Village of Hazelton limits and most of the Gitanmaax Band limits.

2.3 Guidelines

This study was guided by the publicly available reference documents that include but are not limited to the following:

- Association of Professional Engineers and Geoscientists of British Columbia [APEGBC] Professional Practice Guidelines – Flood Mapping in BC (2017); and
- BC Ministry of Water, Land, and Air Protection [MWLAP] – Flood Hazard Area Land Use Management Guidelines (2018).

3 Flood Hazard Assessment

To prioritize estimated qualitative risk and develop a mitigation plan, hazards first needed to be identified. Open water flood hazards were assessed quantitatively in the study area for the 200-year flood with allowance for climate change, namely water depth and water velocity. Note that the hazard assessment did not include the 0.6 m of freeboard as shown on the flood inundation maps (SNC 2021) as there were no associated velocities modelled. However, structural mitigation options (Section 5.2.7) did include the 0.6 m of freeboard in the preliminary cost estimates.

Very fast shallow water is just as dangerous as moderately flowing deep water; therefore, a combination of depth and velocity was considered. A flood hazard class was developed using the “3 x 3 rule” from the United States (Ontario MNR and Watershed Science Centre 2002). This rule suggests that people become vulnerable to floodwaters when the product of water depth and water velocity is greater than 9 ft^2/s (or the product of 3 ft depth and 3 ft/s velocity) which equates to 0.8 m^2/s. The “3 x 3” rule is similar to the safety factors followed by the Water Survey of Canada Hydrometric Technician guidelines (Environment Canada 1999). The guide states that for safe wading conditions, the product of depth and velocity should be less than 1.0 m^2/s.

A flood hazard class matrix was developed using the flood depth (from 0.0 m to 1.5 m) on one axis and the flood velocity (from 0.0 m to 1.5 m/s) on the other axis. The matrix to determine the flood hazard class is presented in Table 3-1. The product of depth and velocity was divided into five hazard classes: ‘Very Low’, ‘Low’, ‘Moderate’, ‘High’, and ‘Very High’.

The 200-year flood (with climate change) depth x velocity was an output from the 2D hydraulic model at each mesh node. The product of these two parameters was used to preliminarily assess the flood hazard class values in the floodplain. The resulting preliminary hazard map is shown in Figure 3-1. Most of the modelled depth and velocity products on the overbanks were higher than 1.44 m^2/s (i.e., classified as a ‘Very High’ flood hazard zone).

The UK formula for hazard rating suggested by APEGBC (2017) is: Hazard Rating = depth (m) x (velocity (m/s) + 0.5) + debris factor (0, 0.5, 1 depending on probability that debris will lead to a significantly greater hazard). Assuming debris doesn’t create a greater hazard (i.e., debris factor = 0), the results of the UK formula were very similar to the results of the flood hazard class matrix developed using the 3 x 3 rule, as shown in Figure 3-2 The UK formula only has four categories, so the majority of areas were classified as ‘Danger for All’ which is similar to ‘Very High’.

In the interest of prioritizing flood hazards, the ‘Very High’ category was further subdivided, however, the ‘Very High’ categories would still be a danger for all during the flood event. A ‘Very High’ flood hazard class matrix was developed using the flood depth (from 1.2 m – 2.0 m) on one axis and the flood velocity (from 1.2 m – 2.0 m/s) on the other axis. The matrix to determine the ‘Very High’ flood hazard class is presented in Table 3-2.

The 200-year flood (with climate change) depth x velocity hazard maps are shown in Figure 3-3.

Table 3-1: Matrix for Flood Hazard Classes

Hazard Class	Flood Depth (m)	0 – 0.3	>0.3 – 0.6	>0.6 – 0.9	>0.9 – 1.2	>1.2 – 1.5
Flood Velocity (m/s)	Score	A	B	C	D	E
0 – 0.3	1	0.09	0.18	0.27	0.36	0.45
>0.3 – 0.6	2	0.18	0.36	0.54	0.72	0.9
>0.6 – 0.9	3	0.27	0.54	0.81	1.08	1.35
>0.9 – 1.2	4	0.36	0.72	1.08	1.44	1.8
>1.2 – 1.5	5	0.45	0.9	1.35	1.8	2.25

Very Low
Low
Moderate
High
Very High

Figure 3-1: Preliminary Flood Hazard Map for 200-year Flow (with Climate Change) – Mostly 'Very High'

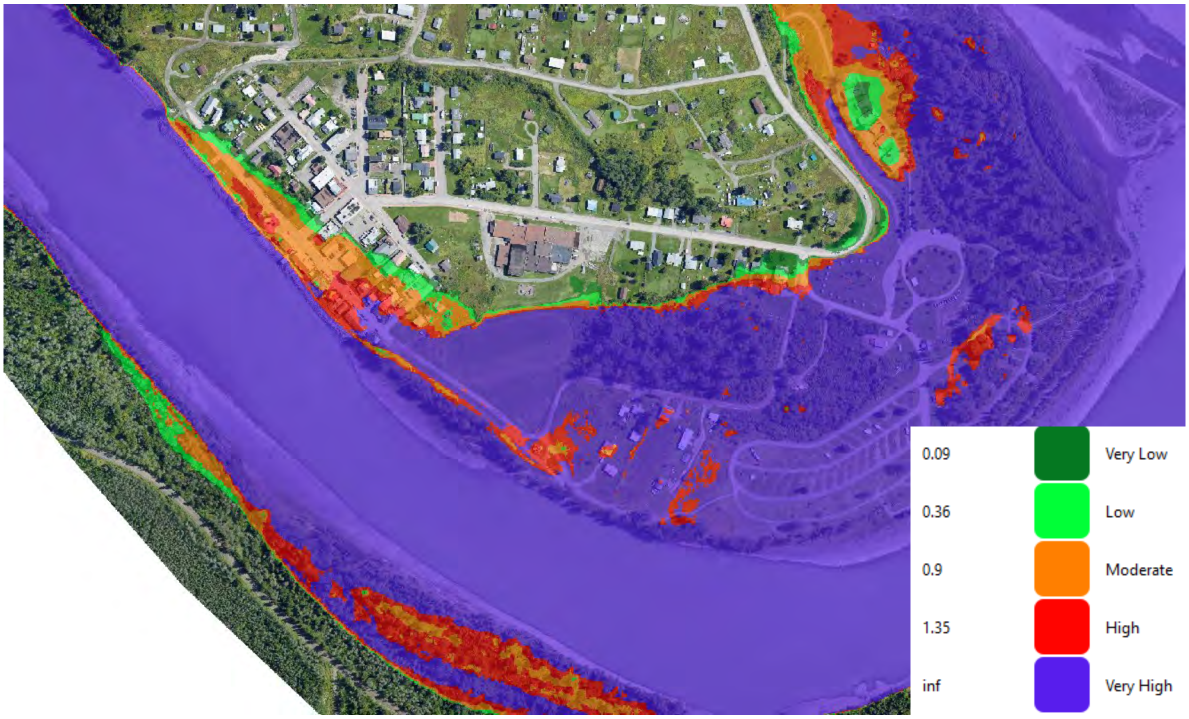


Figure 3-2: Preliminary UK Formula Flood Hazard Map for 200-year Flow (with climate change)

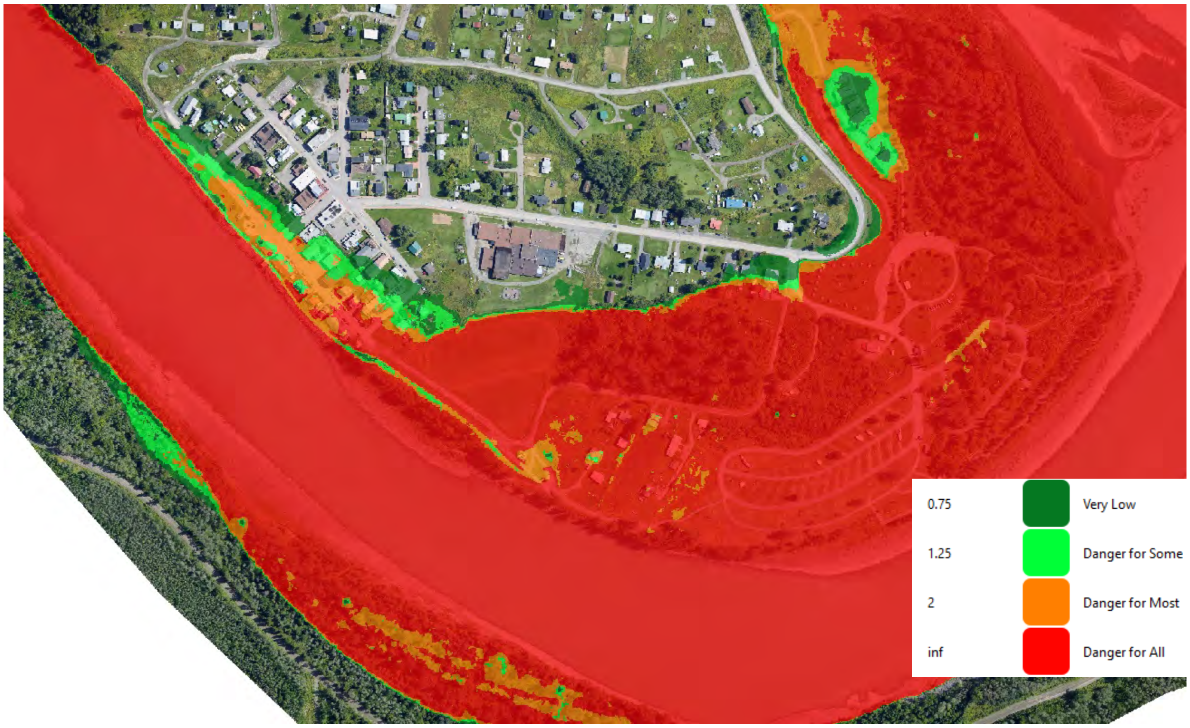
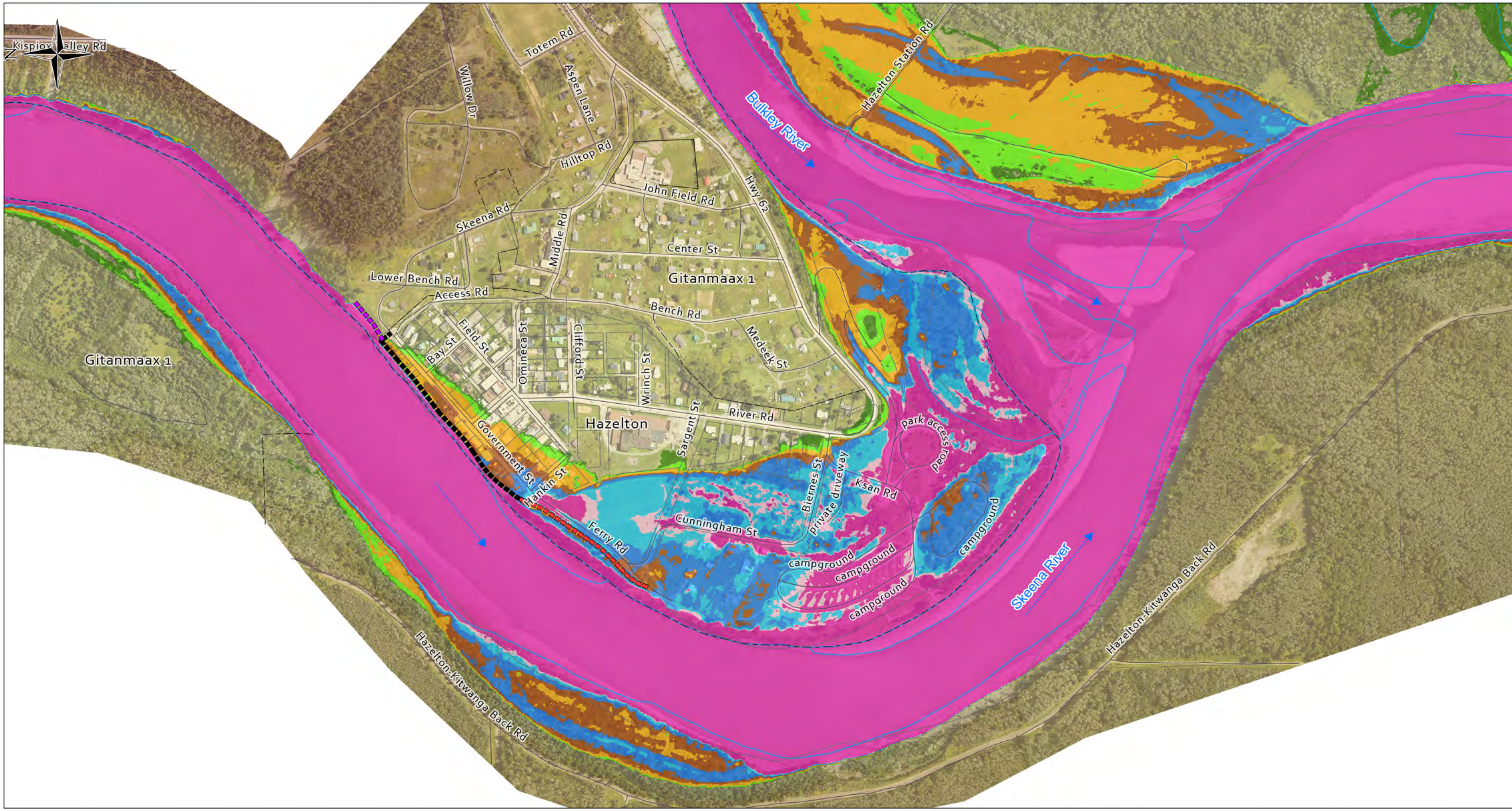


Table 3-2: Matrix for 'Very High' Flood Hazard Classes

Hazard Class	Flood Depth (m)	>1 – 1.2	>1.2 – 1.4	>1.4 – 1.6	>1.6 – 1.8	>1.8 – 2
Flood Velocity (m/s)	Score	F	G	H	I	J
>1 – 1.2	6	1.44	1.68	1.92	2.16	2.4
>1.2 – 1.4	7	1.68	1.96	2.24	2.52	2.8
>1.4 – 1.6	8	1.92	2.24	2.56	2.88	3.2
>1.6 – 1.8	9	2.16	2.52	2.88	3.24	3.6
>1.8 – 2	10	2.4	2.8	3.2	3.6	4

Very High
Very High 2
Very High 3
Very High 4
Very High 5

The entire main channel of the Skeena River and Bulkley River have a 'Very High 5' hazard class due to fast and deep flow. Residences along Government Street have various hazard classes, mainly 'Medium' and 'High'. A 'Very High 3' and 'Very High 4' hazard class dominates the school playing field and the gully between River Road and Cunningham Street. Residences west of Cunningham Street (on the riverward side) have a 'Very High 2' hazard rating; velocities are generally around 1 m/s, with deeper flows (2 m – 3 m). A large portion of 'Ksan campground (including two administration buildings) have a 'Very High 5' hazard class, mainly due to the deep flow (+3 m). The 'Ksan Historical Village generally has a 'Low' to 'Medium' hazard class because it is in an elevated area (e.g., lower depths).



LEGEND

- Local Government Boundaries
- Parcels
- Roads

Flood and Erosion Protection Works (Approximate Locations)

- Dike
- Dike and Riverbank Protection
- Riverbank Protection

- River or Stream - Definite
- River or Stream - Dry
- River or Stream - Definite

Flood Hazard

- Very Low
- Low
- Medium
- High
- Very High 1
- Very High 2
- Very High 3
- Very High 4
- Very High 5

REFERENCES

0 45 90 180 270 360 Meters

1. This map is based on the 2021 Skeena River and Bulkley River Flood Study - Floodplain Mitigation Plan Report prepared for the Village of Hazelton by SNC-Lavalin Inc. and should be consulted when utilizing this map.
2. This map delineates potential depth x velocity hazards from simultaneous Skeena River and Bulkley River 200-year return period events with an allowance for climate change.

Data Sources

1. Flood depths and velocities based on 2D hydraulic modelling by SNC-Lavalin Inc.
2. Model bathymetry based on LiDAR data flown August 2019 and survey data collected August 2020.
3. Survey data coordinates were derived from static GPS observations at control points 101 and 102. They are referred to NAD83, Zone 9.

Point 101 - 583839.35 m E, 6123806.24 m N, Elv. 215.49 m Point 102 - 583839.35 m E, 6123806.26 m N, Elv. 215.48 m

4. Orthophoto background from August 2019.
5. Local government boundaries, parcels, and roads based on DataBC.

Limitations

1. Current industry best practices were used to develop the flood hazard map. Acutal flood depths and velocities may vary; SNC-Lavalin Inc., Village of Hazelton, and Gitanmaax Band do not assume any liability for such variations.
2. Maps do not indicate erosion, scour, channel migration hazards. A Qualified Professional must be consulted to determine site-specific hazards.

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CLIENT NAME: Village of Hazelton

PROJECT LOCATION: Hazelton and Gitanmaax, BC

Figure 3-3: 200-year Flood Hazard Map for Skeena River and Bulkley River

BY: ECH	SCALE: 1:7,000	DATE: 2021-04-01	REF No: 675878-008	REV: 0
CHK'D: BR	PROJ COORD SYS: UTM Zone 9N NAD83			

MXD Path: \\Sli2606\projects\Current Projects\Village of Hazelton\675878\40_Execution\45_GIS_Dwgs\GIS\675878_Pro_2\675878_Pro_2.aprx

4 Qualitative Risk Assessment

A comprehensive flood risk assessment involves a technical and systematic process to determine the adverse consequences that may arise as a product of exposure and vulnerability (consequence and probability) to different flood scenarios. SNC-Lavalin understands that a comprehensive risk assessment including financial, environmental, and social losses is well beyond the scope of this study. Valuable risk information, however, can be obtained by combining the resulting flood hazard map with an overlay map of the assets at risk, such as green spaces, roadway or utility infrastructure, buildings, and other essential assets to indicate potential loss or damage.

A risk matrix approach was utilized to categorize risk where assets were within the inundation and flood hazard areas to qualitatively assess a risk rank number. The subjective level of asset importance versus the flood hazard class was used to develop the risk matrix shown in Table 4-1.

The flood hazard map was overlaid on the orthophotos. Elements at risk were identified and ranked in order of subjective importance. For discussion, the assets at risk were divided into six (6) different zones, as shown in Figure 4-1.

Zone 1 extends northeast from about Omineca Street to the end of Government Street. This zone consists of a park area, Government Street, and residential yards. The ‘Moderate’ hazard along Government Street results in a risk rank number of six.

Zone 2 extends northeast from about Hankin Street to about Omineca Street. This zone consists of several riverfront buildings (including the Hazelton Pioneer Museum, Hazelton Public Library, Gitxsan Child and Family Services building, and residences) and several setback buildings (including the Hazelton Fire Hall and residences). The Fire Hall is considered an essential building, so it was given the highest ranking of importance. Given the ‘Moderate’ hazard class, a risk rank number of 15 was calculated. However, the buildings further southwest had a ‘Very High’ hazard class which resulted in a risk rank number of 20.4. This maximum risk rank number was assigned to Zone 2.

Zone 3 extends southwest from about Hankin Street to the sewer lift station. This zone consists mainly of a school field, Ferry Road, and the sewer lift station. The sewer lift station has a ‘High’ hazard class and is considered of medium importance (utility). Therefore, the risk rank number assigned to Zone 3 was 12.

Zone 4 extends along the length of Cunningham Street. This zone consists of several residences west of Cunningham Street (riverward) and several residences west of River Road (riverward). Residential buildings are given the second highest rank of importance. For mitigation options, a risk rank number was assigned to the residences separately. A ‘Very High 5’ and ‘High’ hazard class were found for Cunningham Street Residences and River Road Residences, respectively. This resulted in risk rank numbers of 22 and 16, respectively.

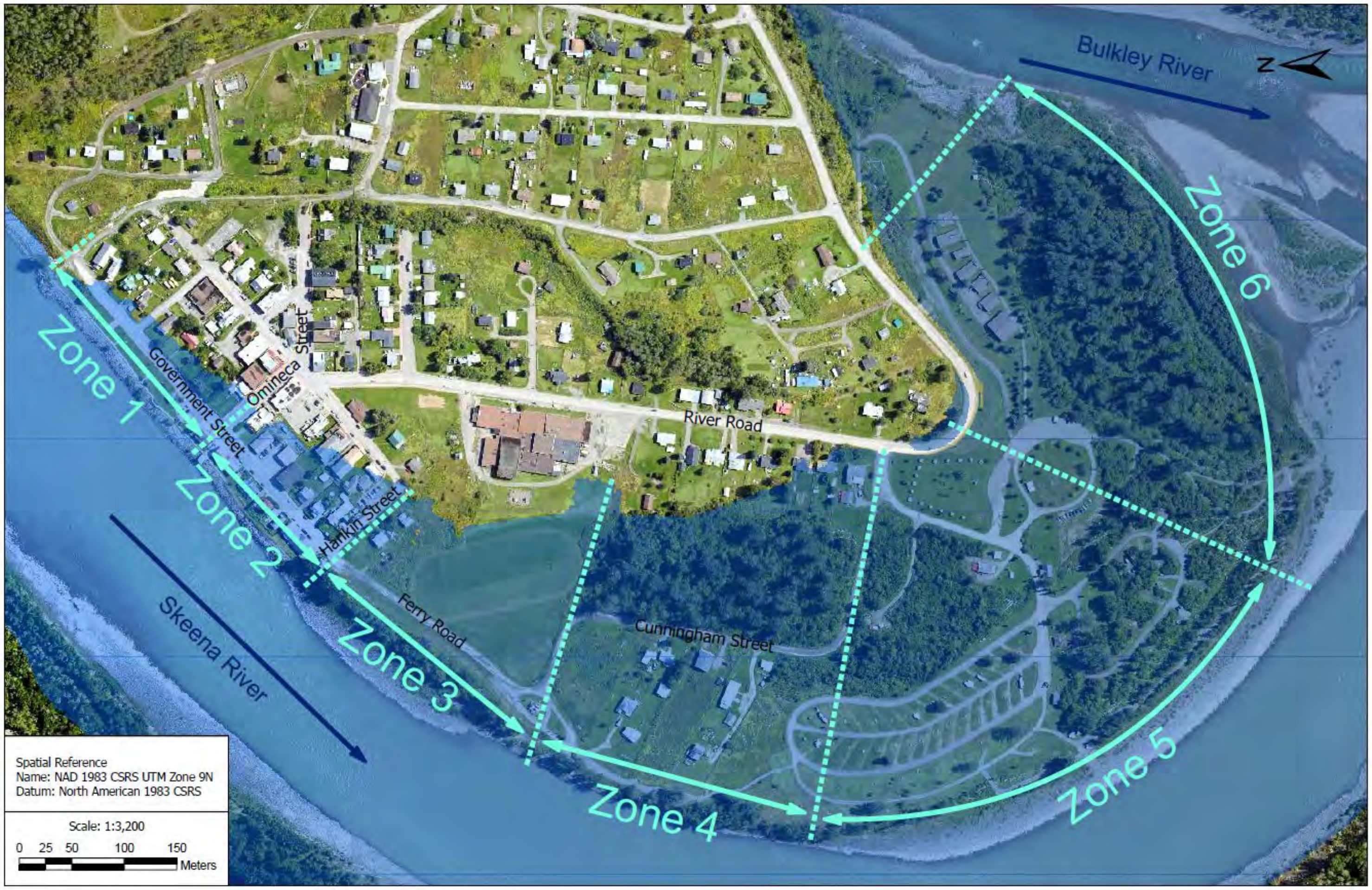
Zone 5 includes the ‘Ksan Campground area. This zone consists of seasonal campground stalls and administration buildings. A hazard class of ‘Very High 5’ for the buildings results in a risk rank number of 22.

Zone 6 includes the ‘Ksan Historical Village. This zone contains several historic buildings and artifacts. A hazard class of ‘Moderate’ results in a risk rank number of 12.

Table 4-1: Matrix for Qualitative Risk Assessment of Assets in Flood Hazard Areas

Risk Rank Number		Hazard Class									
	Score	Very Low	Low	Moderate	High	Very High	Very High 1	Very High 2	Very High 3	Very High 4	Very High 5
Assets within Flood Hazard Areas	Less Important – parks, green spaces	1	2	3	4	5	5.1	5.2	5.3	5.4	5.5
	Roadways	2	4	6	8	10	10.2	10.4	10.6	10.8	11
	Utilities	3	6	9	12	15	15.3	15.6	15.9	16.2	16.5
	Private/Public Buildings	4	8	12	16	20	20.4	20.8	21.2	21.6	22
	Very Important – Essential Buildings (fire and police stations, hospital, airport)	5	10	15	20	25	25.5	26	26.5	27	27.5

Figure 4-1: Zones for Assets at Risk



A summary, in order of the relative risk rankings (then maximum hazard value) of identified assets is provided in Table 4-2.

Table 4-2: Qualitative Relative Risk Rankings of Assets in 200-Year Flood Inundation Zone

Rank	Zone	Asset(s)	Max Hazard Value (D x V)	Hazard Class	Risk Rank Number
1	Zone 5	'Ksan administration buildings	2	Very High 5	22
2	Zone 4	Cunningham Street residences	1.7	Very High 5	22
3	Zone 2	Residences, fire hall, community buildings	1.5	Very High 2	20.4
4	Zone 4	River Road residences	1.2	High	16
5	Zone 3	Pump Station, school field	1.3	High	12
6	Zone 6	'Ksan Historical Village	1.2	Moderate	12
7	Zone 1	Government Street, park, yards	1.2	Moderate	6

Zone 1 has the lowest relative risk ranking. However, if structural mitigation (e.g., dike) were to be implemented, Zone 1 and Zone 2 would have to be completed together, in order to tie into high ground. All other Zones could be mitigated independently (e.g., ring dike), but there would be cost savings in combining the structural mitigation options. This is discussed further in Section 5.2.

5 Proposed Mitigation Measures

Historically, structural measures (e.g., dikes) are used more frequently for flood protection, however, it is known these options alone are not always effective and large floods still have resulted in catastrophic damages. There has been a shift towards complementing structural options with more non-structural options and effective flood mitigation considers both.

Conceptual non-structural mitigation measures were developed for the village of Hazelton and Gitanmaax communities. As well, conceptual structural mitigation measures were developed for all six zones, so that they can be developed in conjunction with one another or independently. These proposed mitigation measures are presented in the following sections.

5.1 Non-Structural

Non-structural flood mitigation measures are a method of reducing flooding risks without influencing or impinging on the actual flood waters. Various non-structural measures include (but are not limited to):

› Emergency response planning;

› Provide information on floods and flood risk areas to the public;

› Efficient flood forecast warning system; and

› Regulations for building in a floodplain.

Details of each of these measures are outlined in the following sections.

5.1.1 Flood Emergency Response Planning

An emergency response plan is an important tool in reducing the risk of the residences in the event of a flood related emergency. The emergency response plan for the village of Hazelton and Gitanmaax could include closing down potentially affected streets and evacuating potentially affected residences and businesses. High grounds and evacuation routes should be established and clearly identified. The effectiveness of this option is dependent on early enough warning from a flood warning system (i.e., sufficient lead time) as well as comprehensive public education to inform residences in the affected areas of their risk and ensure they understand what to do in case of an emergency, and which areas they should be evacuating to for safety.

If a demountable or temporary flood wall is used as a structural mitigation measure (see Section 5.2), the emergency response plan should provide details regarding deployment of the flood wall. This would include the delegation of tasks such transportation and mounting of the flood wall and ensure emergency response teams are provided with adequate training and safety equipment. An early warning system would also be developed to increase the warning time for emergency response team to carry out the deployment.

5.1.2 Public Education

Education can help the public understand the potential flood hazards and risks, and better prepare community members for flood events. An informational meeting could be held periodically for the village of Hazelton and Gitanmaax communities and pamphlets could be handed out to residences and businesses affected to communicate the following information:

- Access to information on flood hazards, flood preparation, and emergency response plan;
- Location of real-time forecast of discharge, water level, and how it relates to flood hazards;
- Presentation of flood hazard mapping as 2D visual presentations of extent and severity of potential flood hazards (i.e., inundation depth and extent, flow velocity, hazard maps);
- Increase awareness of flood seasons, appropriate preparation, and proper response procedures; and
- Location and identification of nearest high ground and evacuate routes.

Flood hazard maps and the emergency response plan should be made accessible through the Village of Hazelton website to allow quick access through computers and smart phones in the case of an emergency. The 2021 floodplain map provides an updated 200-year flooding extent (see SNC-Lavalin 2021), and the 2021 flood hazard map provides classes (e.g., 'Low', 'High', 'Very High') (see Figure 3-1). Residents should be encouraged to review the updated floodplain maps and flood hazard map, as areas previously assessed to be safe may now be designated as at risk. It should also be communicated that an area or property unaffected by previously recorded floods does not imply it's safe from future flooding, and residents and businesses should refer to the 2021 flood hazard map to evaluate their level of risk.

5.1.3 Flood Forecasting and Warning System

A flood forecasting system can be developed using existing Water Survey of Canada hydrometric stations located along the Skeena River and Bulkley River upstream of their confluence. Several of these stations were examined in the flood inundation mapping for each river (SNC-Lavalin 2021). Stations located further away upstream could be used to establish an early flood warning system so that sufficient warning time is available for residents and businesses to carry out the emergency response plan.

Real-time discharge readings (where available) could be input into the 2-dimensional hydraulic model to provide forecast in terms of the inundation extent which can help identify areas at risk and need to be evacuated. A flood forecasting system could integrate elements from the BC River Forecast Centre (BC 2019), which provides information on the current and forecasted streamflow conditions, flood advisories and flood warnings (available here: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/river-forecast-centre).

Based on the flood forecasting system, a flood warning system could be developed that may consist of a system of sirens, flashing lights, and automated short message service (SMS) text transmission.

5.1.4 Land Use Management

Land use management involves zoning bylaws that designate specific areas for residential, commercial, and natural use. This should be informed by the flood hazard map presented in the flood hazard assessment (see Figure 3-1. In general, intensive capital investment and future development should be avoided in high hazard zones, while assets already present in the high hazard zones should be covered by flood insurance and additional mitigation measures such as flood proofing buildings should be promoted.

The Village of Hazelton Zoning Bylaw No.478 (2015) should be amended to reflect the latest flood mapping study. Flood Plain Development Permit Areas presented in Schedule A should be updated using the 200-year inundation boundary plus freeboard. Flood Plain Development Permit Area Guidelines in Schedule B should require structural mitigation measures (such as flood proofing buildings outlined in this report) for any existing and future development below the 200-year inundation boundary.

5.2 Structural

Structural flood mitigation measures are a method of reducing flooding risks by preventing, eliminating, or reducing the influence of flood waters through construction. Different types of structural measures considered for this study include:

- Earthen dike;
- Retaining wall systems;
- Demountable flood walls;
- Temporary flood walls;
- Dry/Wet building flood proofing; and
- Building elevation or relocation.

The first four options retain the flood waters to prevent the inundation of the floodplain (and assets within it). Constricting the flood waters from the floodplain could result in high-water elevations and faster water velocities. All these options need to consider the impact of the structure on the design flow condition. These types of structural flood mitigation measures are constructed to prevent the flooding of land, which classifies the structure as a dike and would need to be regulated. As defined in the BC Dike Maintenance Act (British Columbia 1996): “a dike means an embankment, wall, fill, piling, pump, gate, floodbox, pipe, sluice, culvert, canal, ditch, drain, or any other thing that is constructed, assembled or installed to prevent the flooding of land”. The applicable Provincial responsibilities include:

- Administering the flood protection structures under the Dike Maintenance Act;
- Setting dike design and maintenance standards and other criteria;
- Promoting dike management best practices;
- Monitoring and auditing management of works by local diking authorities;
- Approving changes to existing dikes and construction of new dikes; and
- Providing technical expertise for high risk diking issues.

The design and construction of any such flood protection measures must comply with industry accepted design standards and codes and maintained in accordance with the BC Dike Maintenance Act.

The last two options eliminate or reduce the influence of flood waters on individual assets by modifying or moving them.

A short description of each structural option is provided in the following sections.

5.2.1 Earthen Dike

The village of Hazelton currently has an approximately 625 m long earthen dike along the Skeena River (see Photograph 5-1), however, the dike does not have sufficient elevation for the 200-year climate change affected flow. The 2D hydraulic model created for flood inundation mapping (SNC-Lavalin 2021) predicted that the dike would overtop around the 50-year event (with no allowance for climate change).

Photograph 5-1: Earthen Dike along Skeena River in Hazelton (August 27, 2020)

Earthen dikes are applicable when there is a good availability of land adjacent to the riverbank and there is minimal interaction with existing structures. Design requires the consideration of slope stability (both internally and existing stream banks), seepage control (internal and through foundation), and settlement of materials (both dike and underlying).

5.2.2 Retaining Wall System

Retaining wall systems can be effective if there are areas with limited space or when near structures/slopes that are sensitive to movement and loading. Retaining wall systems come in various forms, such as rock baskets, gabions, lock blocks, bin walls, concrete gravity or cantilever walls, and segmental walls. This option can be potentially expensive, depending on the system, and could require some in-stream work.

5.2.3 Demountable Flood Walls

Demountable flood walls are barriers that are erected onto permanent foundation structures when flooding is anticipated (see Photograph 5-2).

Photograph 5-2: Demountable Flood Wall Foundation (Left) and Erected Barriers (Right) along the Ottawa River (photo from Flood Control Canada)

This measure can be used in locations where construction of permanent walls is not feasible, which may be the case for riverfront properties that wish to maintain views during non-flooding times. This measure requires advance notice of flooding and a proactive emergency management response plan. As well, additional costs are incurred for storage of the detachable barriers and deployment of the barriers prior to possible flood events.

5.2.4 Temporary Flood Walls

Temporary flood walls are barriers that are erected when flooding is anticipated, but they do not require permanent foundations (see Photograph 5-3. This measure is similar to demountable flood walls, but temporary flood walls typically cannot hold back as much water height. There are a variety of temporary flood wall products available, including sandbags, plastic block walls (e.g. Muscle Wall), metal flood barriers (e.g., INERO), and inflatable bladder dams (e.g., AquaBarrier). The choice of temporary flood wall should consider:

- Deployment time: sandbags are typically inexpensive up-front costs, but time and labour required for construction can be significant;
- Stream hazards: if the flood wall is to be directly adjacent to a stream, it can experience significant velocity and debris hazards (e.g., puncture hazards make inflatable bladder dams unsuitable for certain applications); and
- Required height: different temporary flood walls have different limits in the height of water they can protect against.

This method of flood mitigation requires advance notice of flooding, and additional costs include storage and deployment.

Photograph 5-3: Temporary Flood Walls (INERO) (photo from Flood Control Canada)

5.2.5 Dry/Wet Building Flood Proofing

Dry flood proofing includes materials applied to a building that prevent floodwater from entering. This includes methods such as waterproof wall coatings and permanent or removable door/window shields. An important design consideration with dry flood proofing is the hydrostatic pressure from flood water; typically, this is not a feasible option for water heights greater than 1.0 m (Aerts 2018). An alternative is wet flood proofing, which allows floodwater to enter the building but strategically places damageable components (e.g., utilities, electrical sockets) above the high-water level (Aerts 2018).

5.2.6 Building Elevation or Relocation

Buildings that are located in the flood inundation zone can be elevated above the high-water level. The cost and feasibility of this measure is dependent on factors such as house condition, electrical and plumbing adjustments required, grading for access requirements, permits, elevation increase required etc. (Aerts 2018). Buildings can also be relocated to an area not in the flood inundation zone. Cost and feasibility of this option depend on factors such as house dimensions, travel distance, road obstacles, new foundation costs etc. (Aerts 2018).

5.2.7 Structural Mitigation Options

The suitability of different structural mitigation options is influenced by various factors and design elements. For this study, the mitigation options were developed in consideration of factors such as:

- Availability of land and right-of-way or easements;
- Proximity of buildings to river's edge;
- Proximity of high ground for tie-ins;
- Design elevations required (e.g., 200-year water elevation plus allowance for climate change and 0.6 m of freeboard);
- Stakeholder requirements (e.g., assets at risk);
- Potential environmental impacts (e.g., higher river water levels);
- Cost – both construction and maintenance costs; and
- Maintenance requirements.

SNC-Lavalin has developed structural mitigation options for Zone 1 through Zone 6. These are conceptual structural mitigation options and their suitability is subject to further geotechnical investigation, hydrotechnical study, and design. A summary of the different mitigation options considered for each zone is provided in Table 5-1.

Table 5-1: Summary of Structural Mitigation Options for Zone 1 through Zone 6.

Zone	Asset(s)	Earthen Berm	Retaining Wall	Demountable Flood Wall	Temporary Flood Wall	Wet Flood Proofing	Elevate/ Relocate
Zone 1	Government Street, park, yards	Y	Y	Y	Y	Y	Y
Zone 2	Residences, fire hall, community buildings	Y*	Y	Y	Y	Y	Y*
Zone 3	Pump station, school field	Y	Y	Y	-	-	Y
Zone 4	Cunningham Street and River Road Residences	Y	Y	Y	-	-	Y
Zone 5	'Ksan campground admin buildings	Y	Y	Y	-	-	Y
Zone 6	'Ksan historical village	Y	Y	Y	Y	-	Y
*Earthen berm must be done in conjunction with relocation.							

A variety of structural flood mitigation option combinations can be used to protect all the zones; some are shown in Figure 5-1, Figure 5-2, and Figure 5-3. The proposed dikes have been numbered for discussion purposes. A more detailed description of options for each zone is presented in the following sections.

Figure 5-1: Combination One of Dikes to Protect all Zones

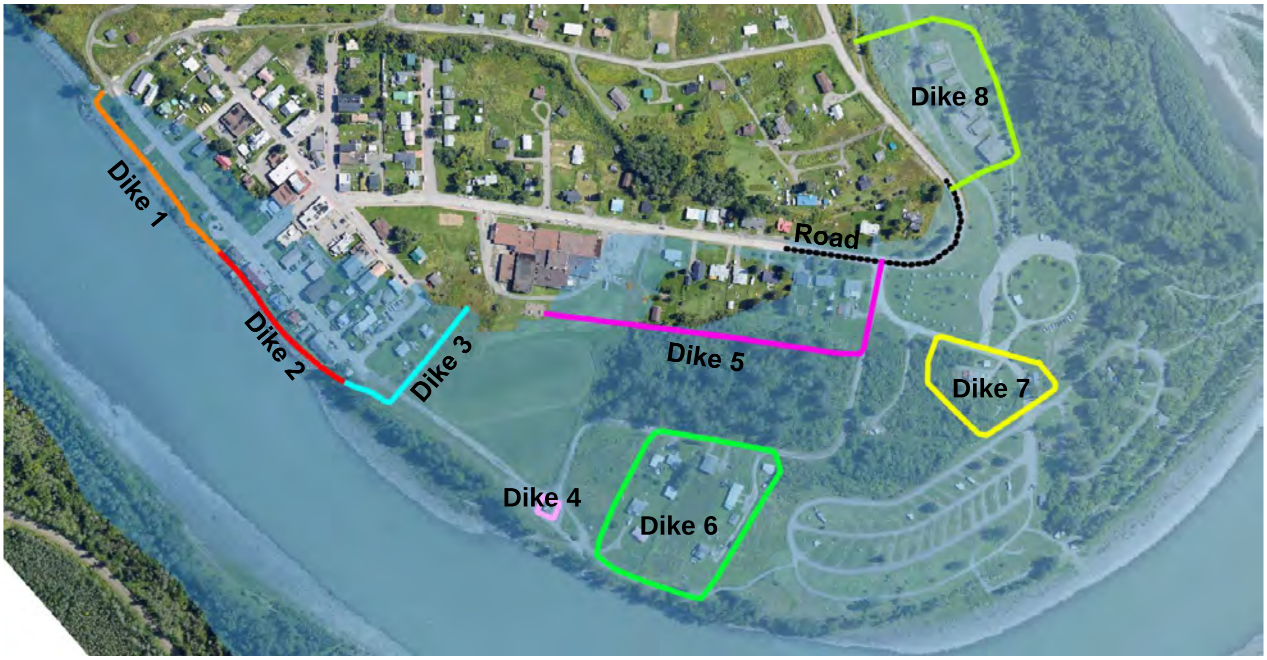


Figure 5-2: Combination Two of Dikes to Protect all Zones

Figure 5-3: Combination Three of Dikes to Protect all Zones

The average height to retain the design flood elevations (with climate change and 0.6 m freeboard) was calculated using the existing topography and modelling results. An additional 0.3 m of freeboard was included in the height (as recommended by the BC Dike Design and Construction Guide (2003) for instantaneous maximum flood levels). A summary of conceptual dike parameters that were used for proposed options and cost estimates is provided in Table 5-2.

Table 5-2; Conceptual Dike Parameters

Zone	Dike Name	Average Height (m)	Length (m)
Zone 1	Dike 1	1.5	205
Zone 2	Dike 2	1.9	180
	Dike 3	1.9	175
Zone 3	Dike 4	2.6	70
Zone 4	Dike 5	2.9	415
	Dike 6	3.1	550
Zone 5	Dike 7a	3.7	350 (earthen, retaining wall)
	Dike 7b	3.7	240 (demountable flood wall)
Zone 6	Dike 8a	2.4 (earthen, retaining wall)	320 (earthen, retaining wall)
	Dike 8b	1.3 (demountable, temporary flood wall)	325(demountable, temporary flood wall)
Zone 3, 4	Dike 9	2.6	845
Zone 3, 4, 5	Dike 10	2.6 (Zone 3, 4) and 3.5 (Zone 5)	570 (Zone 3, 4) and 500 (Zone 5)

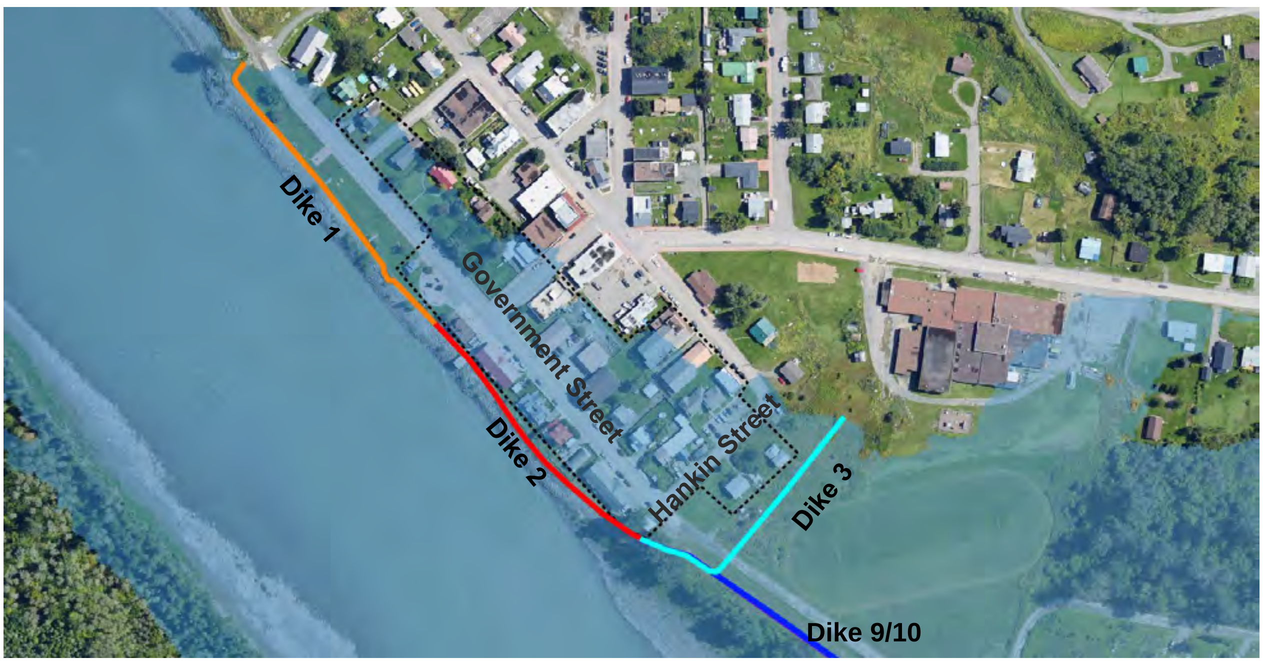
Note: Differences in height / length for (a) earthen / retaining wall and (b) demountable / temporary flood walls due to proximity to asset.

5.2.7.1 Zone 1 and Zone 2

As mentioned previously (Section 4), structural flood mitigation options for Zone 1 and Zone 2 need to be developed together. Retaining flood water options (e.g., Dike 1 and Dike 2) would require a tie-in to high ground at the upstream end (near the end of Government Street) and downstream end; downstream tie-in could be a tie-in near Hankin Street (e.g., Dike 3) or a continuation of the dike (e.g., Dike 9 or Dike 10). These dikes are shown in Figure 5-4 for reference.

Eliminating or reducing the influence of flood waters on individual assets (e.g., flood proofing or elevating) would require modification to every building located in the inundated areas (see dashed black line in Figure 5-4).

Figure 5-4: Dike Options Considered and Approximate Buildings in Inundated Area (Dashed Black Line) for Zone 1 and Zone 2



The riverfront in Zone 1 is a community park and has space available for structural mitigation structures. This zone is about 205 m long and requires an average of 1.5 m of height (including 0.3 m freeboard above flood inundation level). The riverfront in Zone 2 has several buildings adjacent to the river's edge. This zone is about 180 m long and requires an average of 1.9 m of height (including 0.3 m freeboard above flood inundation level). Zone 1 and 2 both have several buildings that would potentially be inundated by flood waters (approximately 4 buildings and 20 buildings, respectively). The flood water depth ranges from about 1.4 m to 2.3 m from Bay Street to Hankin Street.

The structural mitigation options considered for Zone 1 and Zone 2 are summarized in Table 5-3 and Table 5-4. The tie-in option at Hankin Street (Dike 3) is summarized in Table 5-5. The details of how all structural mitigation option costs were estimated is provided in Section 5.3

Table 5-3: Zone 1 Structural Mitigation Options

Option		Comments	Cost Estimate
1-1	Earthen berm (Dike 1)	• adds on to existing earthen dike at this location (currently too low). • incorporates earthen dike with surrounding park. • constructed on Village land. • largest dike footprint due to 3:1 slope required.	$731,000
1-2	Lock block retaining wall (Dike 1)	• assumed lock block retaining wall with 2:1 backslope. • adds on to existing earthen dike at this location (currently too low). • incorporates structure with surrounding park. • constructed on Village land. • safety concern with vertical drop on riverward side.	$620,000
1-3	Demountable flood wall (Dike 1)	• deploy when advanced notice of flooding. • incorporates concrete base onto existing earthen dike at this location (currently too low). • constructed on Village land. • type of wall needs to be selected based on flood velocities, depths, and potential floating debris hazards. • smallest dike footprint (vertical). • requires flood warning system and emergency response plan. • requires storing of product and deployment training.	$726,000
1-4	Temporary flood wall (Dike 1)	• deploy when advanced notice of flooding. • type of wall needs to be selected based on flood velocities, depths, and potential floating debris hazards. • requires flood warning system and emergency response plan. • requires storing of product and deployment training. • approximately 50-year life span.	$446,000
1-5	Wet flood proofing	• not suitable for all buildings such as primary living spaces situated below flood level. • flood velocities and potential floating debris hazards could damage properties. • approximately 30-year life span.	$120,000
1-6	Elevate	• not suitable for all buildings due to age / integrity of existing buildings and utilities / infrastructure adjustments. • would need adjustments to access, utility, and possibly roadway elevations (these costs not accounted for). • foundations may require protection from velocity and debris hazards (not accounted for in cost).	$600,000
1-7	Relocate	• acceptable relocation area required (not currently identified).	$2,000,000

Table 5-4: Zone 2 Structural Mitigation Options

Option		Comments	Cost Estimate
2-1	Earthen berm (Dike 2) with relocate riverfront properties	› adds on to existing earthen dike at this location (currently too low). › would need to remove buildings on riverfront to have space for earthen dike (relocation accounted for in cost). › constructed on Village land and private property, land use needs to be negotiated (cost not accounted for). › largest dike footprint due to 3:1 slope required. › would lose central location of community buildings (e.g., museum, library, Gitxsan Child and Family Services).	$3,884,000
2-2	Lock block retaining wall (Dike 2)	› assumed lock block retaining wall with 2:1 backslope. › adds on to existing earthen dike at this location (currently too low). › blocks view of river for riverfront properties. › constructed on Village land and private property, land use needs to be negotiated (cost not accounted for). › safety concern with vertical drop on riverward side. › potentially more expensive retaining wall required due to limited space (e.g., cantilever wall).	$666,000
2-3	Demountable flood wall (Dike 2)	› deploy when there is advance notice of flooding. › incorporates concrete base onto existing earthen like at this location (currently too low). › constructed on Village land (existing dike). › don't lose centrally located community buildings. › maintains view. › type of wall needs to be selected based on flood velocities, depths, and potential debris hazards. › smallest dike footprint (vertical). › requires flood warning system and emergency response plan. › requires storing of product and deployment training.	$700,000
2-4	Temporary flood wall (Dike 2)	› deploy when advance notice of flooding. › don't lose centrally located community buildings. › maintains view. › type of wall needs to be selected based on flood velocities, depths, and potential floating debris hazards. › requires flood warning system and emergency response plan. › requires storing of product and deployment training. › approximately 50-year life span.	$392,000
2-5	Wet flood proofing	› not suitable for all buildings such as primary living spaces situated below flood level. › don't lose centrally located community buildings. › maintains view. › residences potentially isolated in houses during flooding. › flood velocities and potential floating debris hazards could damage properties. › approximately 30-year life span.	$750,000

Table 5-4 (Cont'd): Zone 2 Structural Mitigation Options

Option		Comments	Cost Estimate
2-6	Elevate	› not suitable for all buildings due to age / integrity of existing buildings and utilities / infrastructure adjustments. › would need adjustments to access, utility, and possibly roadway elevations (these costs not accounted for). › don't lose centrally located community buildings. › maintains view. › residences potentially isolated in houses during flooding. › foundations may require protection from velocity and debris hazards (not accounted for in cost).	$3,750,000
2-7	Relocate	› acceptable relocation area required (not currently identified). › would lose central location of community buildings (e.g., museum, library, Gitxsan Child and Family Services).	$12,500,000

Table 5-5: Tie-in for Zone 1 and Zone 2

Option	Comments	Cost Estimate
Earthen Berm (Dike 3)	› downstream tie-in if Dike 9 or Dike 10 not being built (i.e., construction of Zone 1 and 2 dikes done independently).	$555,000

The options for Zone 1 and Zone 2 could be constructed with different combinations of dikes. A matrix of possible combinations is provided in Table 5-6. All dike option cost estimates assumed Dike 3 was used as a tie-in.

Table 5-6: Zone 1 and Zone 2 Flood Mitigation Combined Dike Option Costs

		Zone 1 (Dike 1)				Zone 1		
Zone 2 (Dike 2)	Option	1-1 Earthen Berm	1-2 Retaining Wall	1-3 Demountable Flood Wall	1-4 Temporary Flood Wall	1-5 Wet Flood Proofing	1-6 Elevate	1-7 Relocate
	2-1 Earthen Berm & Relocate Properties	$5.17 M	$5.06 M	$5.17 M	$4.89 M	-	-	-
	2-2 Retaining Wall	$1.95 M	$1.84 M	$1.95 M	$1.67 M	-	-	-
	2-3 Demountable Flood Wall	$1.99 M	$1.88 M	$1.98 M	$1.70 M	-	-	-

Table 5-6 (Cont'd): Zone 1 and Zone 2 Flood Mitigation Combined Dike Option Costs

		Zone 1 (Dike 1)				Zone 1		
Zone 2 (Dike 2)	2-4 Temporary Flood Wall	$1.68 M	$1.57 M	$1.67 M	$1.39 M	-	-	-
	2-5 Wet Flood Proofing	-	-	-	-	$0.87 M	$1.35 M	$2.75 M
	2-6 Elevate	-	-	-	-	$3.87 M	$4.35 M	$5.75 M
	2-7 Relocate	-	-	-	-	$12.62 M	$13.1 M	$14.5 M

5.2.7.2 Zone 3 and Zone 4

Zone 3 and Zone 4 could be protected independently (e.g., Dike 4, Dike 5, and Dike 6 or elevate/relocate pump station and Cunningham Street/River Road residences) or protected together (e.g., Dike 9 or Dike 10).

Dike 9 or Dike 10 would require a tie-in to high ground at the upstream end and downstream end. The upstream end tie-in could be a continuation from Dike 1 and Dike 2 or a tie-in near Hankin Street (e.g., Dike 3). The downstream end tie-in is proposed to be at the intersection of River Road and Cunningham Street. However, a portion of this road is too low for the design flood elevation and would need to be elevated approximately 0.4 m for a length of approximately 250 m (see 'Road' in Figure 5-5.

Eliminating or reducing the influence of flood waters on individual assets (e.g., relocating or elevating) would require modification to every building located in the inundated areas (see dashed black line in Figure 5-5).

Figure 5-5: Dike Options Considered and Approximate Buildings in Inundated Area (Dashed Black Line) for Zone 3 and Zone 4.

The riverfront in Zone 3 contains a school field, Ferry Road, and a pump station. There is some space available for mitigation structures. However, for Dike 4, earthen berms and retaining walls were not considered economical because of the length of dike would increase substantially for 3:1 and 2:1 slope requirement. Zone 4 has several buildings in the floodplain and space for mitigation structures. Zone 3 and Zone 4 require a structure an average of 2.6 m of height (including 0.3 m freeboard above flood inundation level). Zone 3 has a pump station and Zone 4 has 16 buildings that would potentially be inundated by flood waters. The flood water depth ranges from about 0.7 m to 2.3 m from River Road to Cunningham Street.

The structural mitigation independent options considered for Zone 3 and Zone 4 are summarized in Table 5-7 and Table 5-8. The tie-in option at River Road is summarized in Table 5-9. The details of how all structural mitigation option costs were estimated is provided in Section 5.3.

Table 5-7: Zone 3 Independent Structural Flood Mitigation Options

Option		Comments	Cost Estimate
3-1	Demountable flood wall (Dike 4)	› deploy when there is advance notice of flooding. › constructed on Village land. › type of wall needs to be selected based on flood velocities, depths, and potential floating debris hazards. › cannot access pump station during flood event. › requires flood warning system and emergency response plan. › requires storing of product and deployment training.	$672,000

Table 5-7 (Cont'd): Zone 3 Independent Structural Flood Mitigation Options

Option		Comments	Cost Estimate
3-2	Elevate	› would need to tie-in pump station infrastructure with 2.6 m elevation gain (cost estimated from similar projects). › difficult to access pump station during flood event, possible by boat.	$1,290,000

Table 5-8: Zone 4 Independent Structural Flood Mitigation Options

Option		Comments	Cost Estimate
4-1	Earthen berm (Dike 5)	› constructed on Gitanmaax land and private property, land use needs to be negotiated (cost not accounted for). › largest dike footprint due to 3:1 slope required. › Cunningham St. residences would be isolated during flood. › drainage from inside ring dike needs to be incorporated (cost not accounted for).	$3,249,000
	Earthen berm ring dike (Dike 6)		$5,291,000
4-2	Lock block retaining wall (Dike 5)	› assumed lock block retaining wall with 2:1 backslope. › constructed on Gitanmaax land and private property, land use needs to be negotiated (cost not accounted for). › Cunningham St. residences would be isolated during flood. › drainage from inside ring retaining wall needs to be incorporated (cost not accounted for).	$2,608,000
	Lock block ring retaining wall (Dike 6)		$4,028,000
4-3	Demountable flood wall (Dike 5)	› deploy when there is advance notice of flooding. › constructed on Gitanmaax land and private property, land use needs to be negotiated (cost not accounted for). › smallest dike footprint (vertical). › type of wall needs to be selected based on flood velocities, depths, and potential debris hazards. › possible ground levelling required to build concrete foundations (cost not accounted for). › requires flood warning system and emergency response plan. › requires storing of product and deployment training. › Cunningham St. residences would be isolated during flood.	$4,139,000
	Demountable flood wall (Dike 6)		$5,630,000
4-4	Elevate River Road residences	› not suitable for all buildings due to age / integrity of existing buildings and utilities / infrastructure adjustments. › would need adjustments to access, utility, and roadway elevations (these costs not accounted for). › foundations may require protection from velocity and debris hazards (not accounted for in costs). › residents potentially isolated in houses during flood event.	$750,000
	Elevate Cunningham Street residences		$1,500,000
4-5	Relocate River Road residences	› acceptable relocation area required (not currently identified).	$2,500,000
	Relocate Cunningham Street residences		$5,000,000

Table 5-9: River Road Increased Elevation for Tie-in

Option	Comments	Cost Estimate
River Road Elevated (Road)	› downstream tie-in for Dike 5, Dike 9, or Dike 10.	$710,000

The individual options for Zone 3 and Zone 4 could be constructed with different combinations of dikes. A matrix of possible combinations is provided in Table 5-10. All dike option cost estimates included the section of River Road had been elevated. As well, it was assumed an upstream tie-in was present in Zone 2 (e.g., Dike 2 or Dike 3) and not accounted for in these costs.

Table 5-10: Zone 3 and Zone 4 Flood Mitigation Combined Dike Option Costs

		Zone 3 (Dike 4)	Zone 3
	Option	**3-1 Demountable Flood Wall**	**3-2 Elevate**
Zone 4 (Dike 5 and Dike 6)	**4-1 Earthen Berm**	$9.92 M	$10.54 M
	4-2 Lock Block Retaining Wall	$8.02 M	$8.64 M
	4-3 Demountable Flood Wall	$11.15 M	$11.77 M
Zone 4	**4-4 Elevate**	$3.63 M	$4.25 M
	4-5 Relocate	$8.88 M	$9.50 M

Zone 3 and Zone 4 can also be protected by a riverfront dike that ties into River Road. This dike can protect only Zone 3 and Zone 4 (Dike 9) or can be extended to protect Zone 5 as well (Dike 10). The structural mitigation combined options considered for Zone 3, Zone 4, and Zone 5 are summarized in Table 5-11. The details of how all structural mitigation option costs were estimated is provided in Section 5.3. The downstream tie-in at River Road was included in these costs. As well, it was assumed an upstream tie-in was present in Zone 2 (e.g., Dike 2 or Dike 3) and not accounted for in these costs.

Table 5-11: Zone 3 and Zone 4 Combined Structural Flood Mitigation Option

Option		Comments	Cost Estimate
34-1	Earthen berm (Dike 9)	› encompasses Zone 3 and Zone 4. › adds on to existing earthen dike along Ferry Road (currently too low). › uses part of Cunningham Street as dike (roadway finishing and tie-ins required). › ties-in to River Road; River Road needs to be elevated (not accounted for in cost estimate). › constructed on Village land, Gitanmaax land, and private property, land use needs to be negotiated (cost not accounted for). › largest dike footprint due to 3:1 slope required.	$5,242,000

Table 5-11 (Cont'd): Zone 3 and Zone 4 Combined Structural Flood Mitigation Option

Option		Comments	Cost Estimate
34-2	Lock block retaining wall (Dike 9)	› encompasses Zone 3 and Zone 4. › assumed lock block retaining wall with 2:1 backslope. › adds on to existing earthen dike along Ferry Road (currently too low). › safety concern with vertical drop on riverward side. › uses part of Cunningham Street as dike (roadway finishing and tie-ins required). › ties-in to River Road; River Road needs to be elevated (not accounted for in cost estimate). › constructed on Village land, Gitanmaax land, and private property, land use needs to be negotiated (cost not accounted for).	$5,221,000
345-3	Earthen berm (Dike 10)	› encompasses Zone 3, Zone 4, and Zone 5. › see 34-1.	$10,165,000
345-4	Lock block retaining wall (Dike 10)	› encompasses Zone 3, Zone 4, and Zone 5. › see 34-2.	$7,902,000

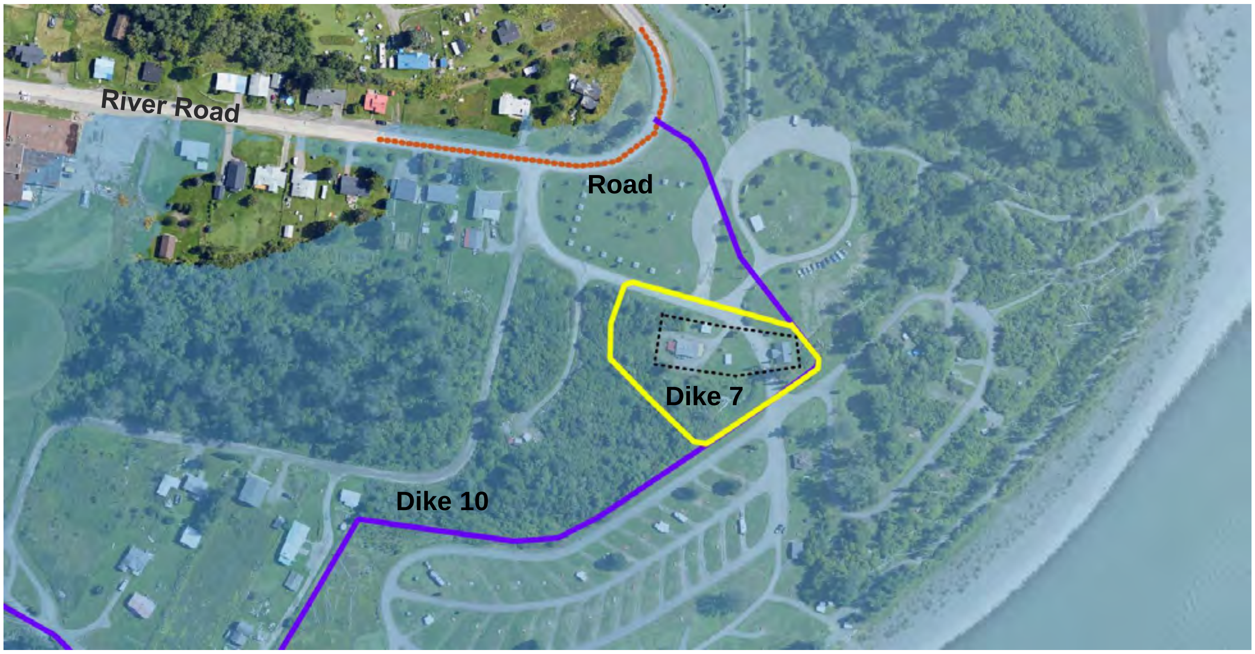
5.2.7.3 Zone 5

Zone 5 could be protected independently (e.g., Dike 7 or elevate/relocate 'Ksan administration buildings) or protected with Zones 3 and 4 (e.g., Dike 10).

Dike 10 would require a tie-in to high ground at the upstream end and downstream end. The upstream end tie-in could be a continuation from Dike 1 and Dike 2 or a tie-in near Hankin Street (e.g., Dike 3). The downstream end tie-in is proposed to be along River Road (see Figure 5-6). However, a portion of this road is too low for the design flood elevation and would need to be elevated approximately 0.4 m for a length of approximately 250 m (see 'Road' in Figure 5-6).

Eliminating or reducing the influence of flood waters on individual assets (e.g., relocating or elevating) would require modification to every building located in the inundated areas (see dashed black line in Figure 5-6).

Figure 5-6: Dike Options Considered and Approximate Buildings in Inundated Area (Dashed Black Line) for Zone 5



The riverfront in Zone 5 is mainly 'Ksan Campground; there is space available for mitigation structures, but it does require significant fill of the treed gully. Dike 7 and Dike 10 require several roadway tie-ins at significant heights (+3m). These dikes require an average of 3.6 m of height (including 0.3 m freeboard above flood inundation level). Zone 5 has three buildings that would potentially be inundated by flood waters (campground administration offices). The flood water depth ranges from about 2.8 m to 3.5 m to m at these two buildings.

The independent structural mitigation options considered for Zone 5 are summarized in Table 5-12. The cost for the tie-in option at River Road was included in the costs (option summarized in Table 5-9). The details of how all structural mitigation option costs were estimated is provided in Section 5.3.

The combined structural mitigation option for Zone 5 (i.e., Dike 10) was presented in Table 5-10.

Table 5-12: Zone 5 Independent and Combined Structural Flood Mitigation Options

Option		Comments	Cost Estimate
5-1	Earthen berm (Dike 7a)	› constructed on Gitanmaax land, land use needs to be negotiated (cost not accounted for). › largest dike footprint due to 3:1 slope required. › administration offices will be isolated during flood events. › drainage from inside ring dike needs to be incorporated (cost not accounted for). › will obstruct surrounding view from offices (3+ m required).	$4,657,000

Table 5-12: Zone 5 Independent and Combined Structural Flood Mitigation Options

Option		Comments	Cost Estimate
5-2	Lock block retaining wall (Dike 7a)	› assumed lock block retaining wall with 2:1 backslopes. › constructed on Gitanmaax land, land use needs to be negotiated (cost not accounted for). › administration offices will be isolated during flood events. › drainage from inside ring dike needs to be incorporated (cost not accounted for). › will obstruct surrounding view from offices (3+ m required).	$4,164,000
5-3	Demountable flood wall (Dike 7b)	› deploy when there is advance notice of flooding. › constructed on Gitanmaax land, land use needs to be negotiated (cost not accounted for). › smallest dike footprint (vertical). › type of wall needs to be selected based on flood velocities, depths, and potential debris hazards. › possible ground levelling required to build concrete foundations (cost not accounted for). › requires flood warning system and emergency response plan. › requires storing of product and deployment training. › administration offices will be isolated during flood event.	$2,932,000
5-4	Elevate Buildings	› not suitable for all buildings due to age / integrity of existing buildings and utilities / infrastructure adjustments. › would need adjustments to access, utilities, and roadway elevations (these costs not accounted for). › lower velocity zone; foundations likely won't need significant protection (cost not accounted for). › administration offices will be isolated during flood event.	$2,180,000
5-5	Relocate Buildings	› acceptable relocation area near campground required (not currently identified).	$1,500,000

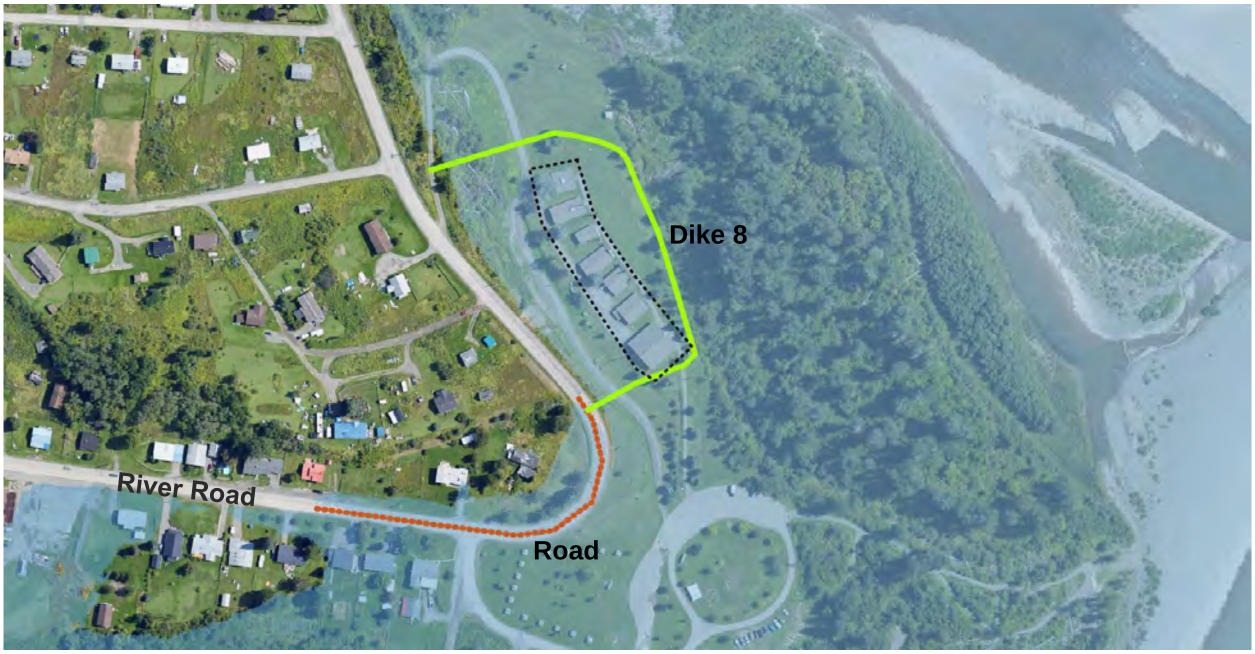
5.2.7.4 Zone 6

Zone 6 can be protected independently (e.g., Dike 8 or elevate/relocate).

Dike 8 may require a tie-in to high ground at the upstream end and downstream end; both tie-ins could both be along River Road. However, a portion of this road is too low for the design flood elevation and would need to be elevated approximately 0.4 m for a length of approximately 250 m (see 'Road' in Figure 5-7).

Eliminating or reducing the influence of flood waters on individual assets (e.g., elevating or relocating) would require modification to every building located in the inundated areas (see dashed black line in Figure 5-7).

Figure 5-7: Dike Option Considered and Approximate Buildings in Inundated Area (Dashed Black Line) for Zone 6



Zone 6 is the ’Ksan Historical Village buildings, which are already elevated. There is space available for mitigation structures. Permanent structure concepts (earthen berm, retaining wall) were assumed set back from buildings to provide accessibility, resulting in a length of about 320 m and height of 2.4 m (including 0.3 m freeboard above flood inundation level). Flood wall concepts (demountable, temporary) were assumed close to the buildings, resulting in a length of about 325 m and height of 1.3 m (including 0.3 m freeboard above flood inundation level). Zone 6 has 7 buildings that would potentially be inundated by flood waters (historical village buildings). The flood water is an average of 1.3 m at the building locations.

The structural mitigation options considered for Zone 6 are summarized in Table 5-13. The details of how all structural mitigation option costs were estimated is provided in Section 5.3.

Table 5-13: Zone 6 Independent Structural Flood Mitigation Options

Option		Comments	Cost Estimate
6-1	Earthen berm (Dike 8a)	› constructed on Gitanmaax land, land use needs to be negotiated (cost not accounted for). › largest dike footprint due to 3:1 slope required. › will obstruct surrounding view from historical village (2+ m required).	$2,410,000

Table 5-13: Zone 6 Independent Structural Flood Mitigation Options

Option		Comments	Cost Estimate
6-2	Lock block retaining wall (Dike 8a)	› assumed lock block retaining wall with 2:1 backslope. › constructed on Gitanmaax land, land use needs to be negotiated (cost not accounted for). › safety concern with vertical drop on riverward side. › will obstruct surrounding view from historical village (2+ m required).	$1,526,000
6-3	Demountable flood wall (Dike 8b)	› deploy when there is advance notice of flooding. › constructed on Gitanmaax land, land use needs to be negotiated (cost not accounted for). › type of wall needs to be selected based on flood velocities, depths, and potential debris hazards. › smallest dike footprint (vertical). › requires flood warning system and emergency response plan. › requires storing of product and deployment training. › buildings would be isolated during flood event. › concrete pad detracts from historic village aesthetic.	$1,132,000
6-4	Temporary flood wall (Dike 8b)	› deploy when there is advance notice of flooding. › type of wall needs to be selected based on flood velocities, depths, and potential debris hazards. › requires flood warning system and emergency response plan. › requires storing of product and deployment training. › approximately 50-year life span.	$696,000
6-5	Elevate	› not suitable for all buildings due to age / integrity. › builds up existing elevated area (currently too low). › adjustments to pathway elevations needed (costs not accounted for).	$1,050,000
6-6	Relocate	› undesirable since this is a well-known tourist location. › no suitable relocation area near historical village currently identified.	$3,500,000

5.2.8 Recommendations

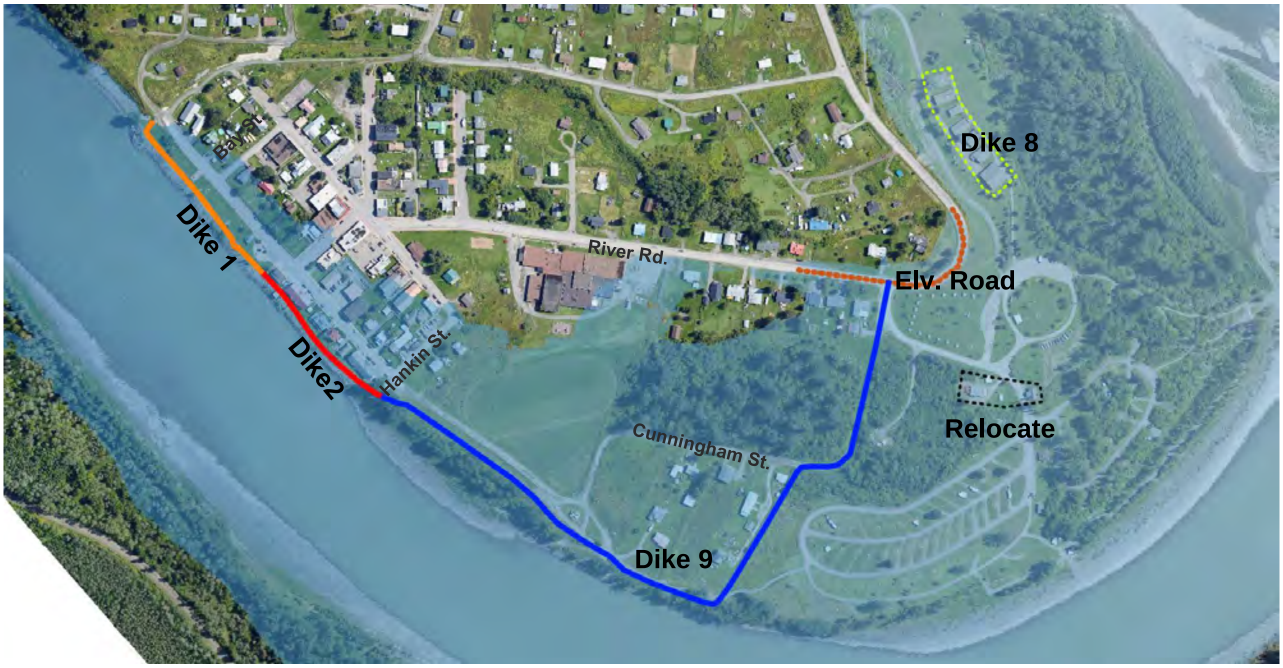
Based on this limited analysis, to protect assets at risk in all zones, it is recommended to implement the structural mitigation options in Table 5-14 and Figure 5-8.

Recommendations of combined structural mitigation options are given here for the identified assets at risk based on modelled 200-year flood hazards. Further hydrotechnical analysis is required to understand the impacts of building a dike and cutting off a significant portion of the floodplain. This will likely result in increased flood depths and velocities. As well, geotechnical studies are required to assess the ground stability and feasibility of building dike structures on the riverbanks. These studies may result in modifications or changes to the recommended structural mitigation design.

Table 5-14: Recommended Structural Mitigation Combination

Zone	Structural Mitigation Option	Comments
1	Earthen berm (Dike 1)	This location already has an earthen berm which can be added onto. This is a permanent structure that requires little maintenance and does not rely on the deployment of walls.
2	Demountable Flood Walls (Dike 2)	Space is limited at this location, and property owners likely won't want a barrier blocking their river view. Demountable flood walls can withstand more hydraulic force than temporary flood walls which is important for this integral section of dike.
3, 4	Earthen berm (Dike 9)	Zone 3 has an existing earthen berm which can be added onto. In Zone 4, this berm can be integrated into existing roadways. The 3:1 slopes provide a safer environment for vehicular traffic (as compared to the vertical lock block retaining wall). This dike would tie-in to River Road, which would need to be elevated approximately 0.4 m for a 250 m section.
5	Relocate	Floodwaters are approximately 3 m high in this area and it would be difficult to elevate the buildings and expensive to dike. Finding an appropriate area to relocate to may be difficult given these buildings are associated with the 'Ksan campground operations. It could also be considered to leave the buildings as is, with the understanding that they may need to be replaced after significant flood events. Preparations could be made by removing valuable items or ensuring the are readily mobile.
6	Temporary flood walls (Dike 8)	'Ksan historical village is well-known a tourist attraction in Gitanmaax, so relocation is not a suitable option. Permanent dike structures and demountable flood wall concrete foundations would detract from the natural setting. The flood hazards are relatively low at this location (lower depth and velocity), so temporary flood walls are a good option to protect these structures.

Figure 5-8: Recommended Structural Mitigation Combination



5.3 Cost Estimate

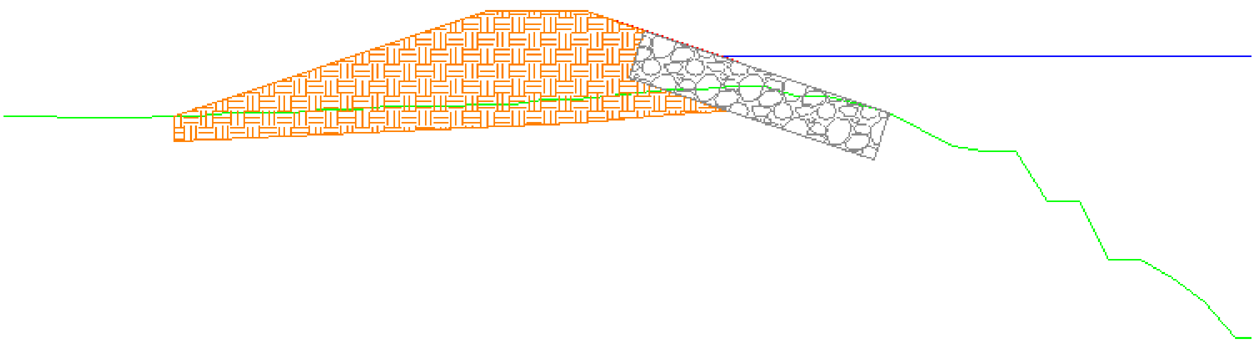
An estimated level of cost +/- 50% (Class D Cost Estimate) was prepared for each mitigation option for the purposes of financial review. In general, these estimates did not consider the cost of land acquisition for the structure or the required right-of-way. All cost estimate references with foreign currencies were converted to Canadian Dollars. All cost estimate references were updated to 2021 Canadian Dollars using an inflation calculator (Webster 2021). Subtotals were rounded up to the nearest thousand dollars.

A summary of cost estimates for each structural mitigation options is presented in the following.

5.3.1 Earthen Berm

Earthen berm cost estimates were based off a typical cross-sectional geometry and proposed length. A typical cross section was cut from the existing terrain and overlain with a proposed earthen berm to obtain quantities of construction materials. An example of a typical cross section is shown in Figure 5-9.

Figure 5-9: Typical Earthen Berm Structure



A typical earthen berm had the following properties:

- Height of 0.3 m above the 200-year water elevation (with 0.6 m freeboard);
- Slopes of three (Horizontal):one (Vertical) as per the Dike Design and Construction Guide – Best Management Practices for British Columbia (Ministry of Water, Land, and Air Protection [MWLA] 2003);
- Berm width of 2 m for a walking path when other access is available (e.g., Dike 1, Dike 2, and Dike 3) and 4 m for a roadway when no other access available (e.g., Dike 5, Dike 6, Dike 7, Dike 8, Dike 9, Dike 10);
- Excavation 0.5 m deep over area dike footprint;
- Riprap rock protection on riverward side, 1.0 m thick from toe to 0.5 m above design flood elevation;
- Seeding areas not covered with riprap plus 10 m for working area; and
- Roadway tie-ins (e.g., driveways, streets) constructed at a 6% grade.

Unit prices of materials were gathered from similar dike project cost estimates throughout BC and unit price averages from Alberta Transportation (2020).

Soft costs, including project management, engineering design, environmental monitoring, construction supervision, and inspection, were added as a percentage of the construction costs. Provincial records from Ministry of Transportation and Infrastructure (MOTI) suggests 25% for soft costs (2013) and was adopted for these estimates. A contingency of 30% was also added as a percentage of the construction costs to account for uncertainties and risks.

Calculated earthen berm cost estimates were compared to those given by Aerts (2018) as a check. The costs were reported in $ per linear metre per metre of height of dike: $2,580/m/m to $7,180/m/m (Aerts 2018). The calculated cost $ per linear metre per metre of height was generally on the lower end or below this range. This difference is likely due to not including the cost of land acquisition in the following estimates.

An estimate of each earthen berm dike considered is summarized in Table 5-15 through Table 5-23.

Table 5-15: Zone 1, Dike 1 Earthen Berm, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	205 m	-	-
Height	1.5 m	-	-
Excavation	8.4 m^2 x L	\$25 / m^3	\$43,000
Bulk Dike Fill	16.4 m^2 x L	\$70 / m^3	\$236,000
Riprap Rock	5.3 m^2 x L	\$140 / m^3	\$151,000
Hydroseeding	20.0 m x L	\$10 / m^2	\$41,000
Soft Costs	+25%	-	\$118,000
Contingency	+30%	-	\$142,000
		Total	**\$731,000**
		\$/linear metre/height	\$2,377

Table 5-16: Zone 2, Dike 2 Earthen Berm, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	180 m	-	-
Height	1.9 m	-	-
Excavation	9.9 m^2 x L	\$25 / m^3	\$45,000
Bulk Dike Fill	25.1 m^2 x L	\$70 / m^3	\$316,000
Riprap Rock	6.7 m^2 x L	\$140 / m^3	\$170,000
Hydroseeding	21.2 m x L	\$10 / m^2	\$39,000
Soft Costs	+25%	-	\$143,000
Contingency	+30%	-	\$171,000
Subtotal			\$884,000
Relocation*	6 buildings	\$500,000 / building	\$3,000,000
		Total	**\$3,884,000**
		\$/linear metre/height	\$2,585**
* Relocation unit cost estimate based on Aerts 2018.			
** Not including building relocation costs.			

Table 5-17: Zone 3, Dike 3 (Tie-In) Earthen Berm, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	175 m	-	-
Height	1.9 m	-	-
Excavation	6.3 m^2 x L	\$25 / m^3	\$28,000
Bulk Dike Fill	14.8 m^2 x L	\$70 / m^3	\$182,000
Riprap Rock	4.7 m^2 x L	\$140 / m^3	\$115,000
Hydroseeding	17.9 m x L	\$10 / m^2	\$32,000
Soft Costs	+25%	-	\$90,000
Contingency	+30%	-	\$108,000
		Total	**\$555,000**
		\$/linear metre/height	\$1,669

Table 5-18. Zone 4, Dike 5 (River Road Residences) Earthen Berm, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	415 m	-	-
Roadway Surface Length (RL)	105 m	-	-
Roadway Tie-Ins (#)	2	-	-
Height (H)	2.9 m	-	-
Excavation	10.6 m^2 x L	\$25 / m^3	\$111,000
Bulk Dike Fill	54.0 m^2 x L	\$70 / m^3	\$1,568,000
Hydroseeding	31.7 m x L	\$10 / m^2	\$132,000
Roadway Surface	4 m x RL	\$110 / m^2	\$47,000
Roadway Tie-In (# (H / 6%))	96.7 m	\$2,460 / m**	\$238,000
Soft Costs	+25%	-	\$524,000
Contingency	+30%	-	\$629,000
		Total	**\$3,249,000**
		\$/linear metre/height	\$2,700
* Riprap rock not included b/c dike is setback and velocities are less than 1 m/s			
** Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.			

Table 5-19: Zone 4, Dike 6 (Cunningham St. Residences Ring Dike) Earthen Berm, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length Riprap Protection (Lr)	260 m	-	-
Length no Riprap Protection (Lnor)	290 m	-	-
Roadway Surface Length (RL)	245 m	-	-
Roadway Tie-Ins (#)	7	-	-
Height (H)	3.1 m	-	-
Excavation	11.1 m^2 x (Lr+Lnor)	\$25 / m^3	\$154,000
Bulk Dike Fill with Riprap	42.7 m^2 x Lr	\$70 / m^3	\$778,000
Bulk Dike Fill without Riprap	51.3 m^2 x Lnor	\$70 / m^3	\$1,042,000
Riprap Rock*	8.6 m^2 x Lr	\$140 / m^3	\$313,000
Hydroseeding with Riprap	24.1 m x Lr	\$10 / m^2	\$63,000
Hydroseeding without Riprap	32.6 m x Lnor	\$10 / m^2	\$95,000
Roadway Surface	4 m x RL	\$110 / m^2	\$108,000
Roadway Tie-In (# (H / 6%))	361.7 m	\$2,375 / m**	\$860,000
Soft Costs	+25%	-	\$854,000
Contingency	+30%	-	\$1,024,000
		Total	**\$5,291,000**
		\$/linear metre/height	\$3,103

* Riprap rock not included where velocities are less than 1 m/s

** Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-20: Zone 5, Dike 7 ('Ksan Campgound Ring Dike) Earthen Berm, Quantity and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	350 m	-	-
Roadway Surface Length (RL)	80 m	-	-
Roadway Tie-Ins (#)	6	-	-
Height (H)	3.7 m	-	-
Excavation	14.6 m^2 x L	\$25 / m^3	\$128,000
Bulk Dike Fill	54.4 m^2 x L	\$70 / m^3	\$1,335,000
Riprap Rock	9.4 m^2 x L	\$140 / m^3	\$463,000
Hydroseeding	29.9 m x L	\$10 / m^2	\$105,000
Roadway Surface	4 m x RL	\$110 / m^2	\$36,000
Roadway Tie-In (# (H / 6%))	370.0 m	\$2,530 / m*	\$937,000
Soft Costs	+25%	-	\$751,000
Contingency	+30%	-	\$902,000
		Total	**\$4,657,000**
		\$/linear metre/height	\$3,596

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-21: Zone 6, Dike 8 ('Ksan Historical Village) Earthen Berm, Quantity and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	320 m	-	-
Roadway Tie-Ins (#)	4	-	-
Height (H)	2.4 m	-	-
Excavation	9.9 m^2 x L	\$25 / m^3	\$80,000
Bulk Dike Fill	45.9 m^2 x L	\$70 / m^3	\$1,029,000
Hydroseeding	30.1 m x L	\$10 / m^2	\$97,000
Roadway Tie-In (# (H / 6%))	160.0 m	\$2,170 / m**	\$348,000
Soft Costs	+25%	-	\$389,000
Contingency	+30%	-	\$467,000
		Total	**\$2,410,000**
		\$/linear metre/height	\$3,138
* Riprap rock not included b/c dike is setback and velocities are less than 1 m/s			
** Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.			

Table 5-22: Zone 3 And Zone 4, Dike 9 (Riverfront Dike) Earthen Berm, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	845 m	-	-
Roadway Surface Length (RL)	680 m	-	-
Roadway Tie-Ins (#)	4	-	-
Height (H)	2.6 m	-	-
Excavation	8.4 m^2 x L	$25 / m^3	$177,000
Bulk Dike Fill	32.5 m^2 x L	$70 / m^3	$1,924,000
Riprap Rock	4.2 m^2 x L	$140 / m^3	$494,000
Hydroseeding	22.9 m x L	$10 / m^2	$194,000
Roadway Surface	4 m x RL	$110 / m^2	$300,000
Roadway Tie-In (# (H / 6%))	173.3 m	$1,680 / m*	$292,000
Soft Costs	+25%	-	$846,000
Contingency	+30%	-	$1,015,000
		Total	**$5,242,000**
		$/linear metre/height	$2,383

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-23: Zone 3, Zone 4, And Zone 5, Dike 10 (Riverfront Dike) Earthen Berm, Quantity, and Cost Estimate

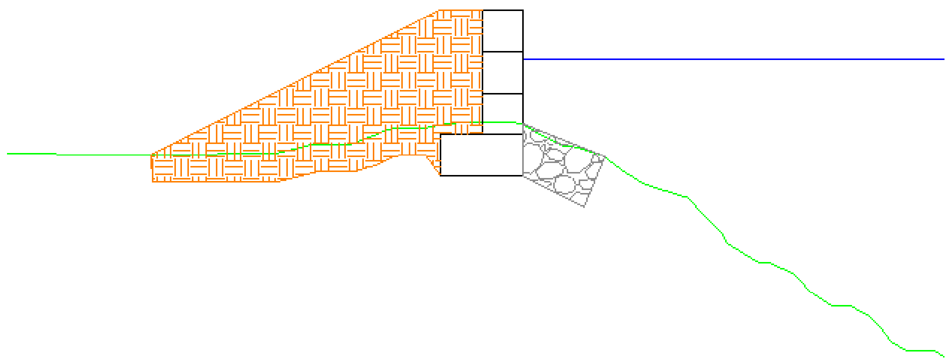
Item	Quantity	Unit Cost	Cost
Length – Partial Dike 9 (L_9)	570 m	-	-
Length – Dike 10 (L_{10})	500 m	-	-
Roadway Surface Length (RL)	160 m	-	-
Roadway Tie-Ins ($\#_9$ / $\#_{10}$)	3 / 4	-	-
Height – Partial Dike 9 (H_9)	2.6 m	-	-
Height – Dike 10 (H_{10})	3.5 m		-
Excavation – Partial Dike 9	8.4 m^2 x L_9	\$25 / m^3	\$120,000
Excavation – Dike 10	12.7 m^2 x L_{10}	\$25 / m^3	\$160,000
Bulk Dike Fill – Partial Dike 9	32.5 m^2 x L_9	\$70 / m^3	\$1,298,000
Bulk Dike Fill – Dike 10	76.6 m^2 x L_{10}	\$70 / m^3	\$2,680,000
Riprap Rock – Partial Dike 9	4.2 m^2 x L_9	\$140 / m^3	\$333,000
Riprap Rock – Dike 10	9.3 m^2 x L_{10}	\$140 / m^3	\$649,000
Hydroseeding – Partial Dike 9	22.9 m x L_9	\$10 / m^2	\$131,000
Hydroseeding – Dike 10	25.8 m x L_{10}	\$10 / m^2	\$130,000
Roadway Surface	4 m x RL	\$110 / m^2	\$71,000
Roadway Tie-In ($\#_9$ (H_9 / 6%))	130.0 m	\$1,680 / m*	\$219,000
Roadway Tie-In ($\#_{10}$ (H_{10} / 6%))	233.3 m	\$3,280 / m*	\$766,000
Soft Costs	+25%	-	\$1,640,000
Contingency	+30%	-	\$1,968,000
		Total	**\$10,165,000**
		\$/linear metre/height	\$3,115

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

5.3.2 Retaining Wall

Retaining wall cost estimates were based off an assumed lock block structure with earthen backfill, as shown in Figure 5-10. This structure was chosen because it is less rigid and allows for flexibility in freeze/thaw cycles. As well, a lock block retaining wall requires less stabilization from the footing (as compared to a concrete cantilever wall). Other configurations of retaining walls could be considered if space saving is required. Note that this may result in a more expensive structure.

Figure 5-10: Typical Lock Block Retaining Wall



A typical cross section was cut from the existing terrain and overlain with a proposed retaining wall to obtain quantities of construction materials. A typical lock block retaining wall was assumed to have the following properties:

- Height of 0.3 m above the 200-year water elevation (with 0.6 m freeboard);
- Slopes of two (Horizontal):one (Vertical) on landward side;
- Berm width of 1.5 m for a walking path;
- Lock blocks size 0.75 m (height) x 0.75 m (width) x 1.5 m (length);
- Bottom anchoring lock block is perpendicular to blocks above;
- Excavation 0.5 m deep over dike area footprint;
- Riprap rock protection on riverward side, 1.0 m thick on disturbed areas;
- Seeding areas not covered with lock blocks/riprap plus 10 m for working area; and
- Roadway tie-ins (e.g., driveways, streets) constructed at a 6% grade.

Unit prices of materials were gathered from similar dike project cost estimates throughout BC, unit price averages from Alberta Transportation (2020), and lock block cost estimates (supply and deliver) from local suppliers (Skeena Concrete, personal communication, February 12, 2021).

Soft costs, including project management, engineering design, environmental monitoring, construction supervision, and inspection, were added as a percentage of the construction costs (25% as suggested by MOTI 2013). A contingency of 30% was also added as a percentage of the construction costs to account for uncertainties and risks.

An estimate of each lock block retaining wall considered is summarized in Table 5-24 through Table 5-31.

Table 5-24: Zone 1, Dike 1 Lock Block Retaining Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	205 m	-	-
Height	1.5 m	-	-
Excavation	4.9 m^2 x L	\$25 / m^3	\$26,000
Bulk Dike Fill	7.1 m^2 x L	\$70 / m^3	\$102,000
Lock Blocks	2.7 blocks/m x L	\$350 / block	\$192,000
Riprap Rock	1.7 m^2 x L	\$140 / m^3	\$48,000
Hydroseeding	15.4 m x L	\$10 / m^2	\$32,000
Soft Costs	+25%	-	\$100,000
Contingency	+30%	-	\$120,000
		Total	**\$620,000**
		\$/linear metre/height	\$2,016

Table 5-25: Zone 2, Dike 2 Lock Block Retaining Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	180 m	-	-
Height	1.9 m	-	-
Excavation	5.4 m^2 x L	\$25 / m^3	\$25,000
Bulk Dike Fill	10.4 m^2 x L	\$70 / m^3	\$131,000
Lock Blocks	3.3 blocks/m x L	\$350 / block	\$210,000
Riprap Rock	1.3 m^2 x L	\$140 / m^3	\$33,000
Hydroseeding	16.6 m x L	\$10 / m^2	\$30,000
Soft Costs	+25%	-	\$108,000
Contingency	+30%	-	\$129,000
		Total	**\$666,000**
		\$/linear metre/height	\$1,947

Table 5-26: Zone 4, Dike 5 (River Rd. Residences) Lock Block Retaining Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	310 m	-	-
Roadway Surface Length (RL)	105 m	-	-
Roadway Tie-Ins (#)	2	-	-
Height (H)	2.9 m	-	-
Excavation	6.8 m^2 x L	$25 / m^3	$71,000
Bulk Dike Fill	23.0 m^2 x L	$70 / m^3	$670,000
Lock Blocks	4.0 blocks/m x L	$350 / block	$581,000
Riprap Rock	1.8 m^2 x L	$140 / m^3	$106,000
Hydroseeding	18.4 m x L	$10 / m^2	$78,000
Roadway Surface	4 m x RL	$110 / m^2	$47,000
Roadway Tie-In (# (H / 6%))	96.7 m	$1,331 / m*	$129,000
Soft Costs	+25%	-	$421,000
Contingency	+30%	-	$505,000
		Total	**$2,608,000**
		$/linear metre/height	$2,167

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-27: Zone 4, Dike 6 (Cunningham St. Residences Ring Dike) Lock Block Retaining Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length with riprap (L_{RR})	260 m	-	-
Length no riprap (L_{noRR})	290 m		
Roadway Surface Length (RL)	245 m	-	-
Roadway Tie-Ins (#)	7	-	-
Height (H)	3.1 m	-	-
Excavation	7.1 m^2 x (L_{RR}+L_{noRR})	\$25 / m^3	\$99,000
Bulk Dike Fill	24.5 m^2 x (L_{RR}+L_{noRR})	\$70 / m^3	\$943,000
Lock Blocks	4.0 blocks/m x (L_{RR}+L_{noRR})	\$350 / block	\$770,000
Riprap Rock	1.8 m^2 x L_{RR}	\$140 / m^3	\$65,000
Hydroseeding	20.2 m x (L_{RR}+L_{noRR})	\$10 / m^2	\$112,000
Roadway Surface	4 m x RL	\$110 / m^2	\$108,000
Roadway Tie-In (# (H / 6%))	361.7 m	\$1,385 / m*	\$501,000
Soft Costs	+25%	-	\$650,000
Contingency	+30%	-	\$780,000
		Total	**\$4,028,000**
		\$/linear metre/height	\$2,429

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-28: Zone 5, Dike 7 ('Ksan Campgound Ring Dike) Lock Block Retaining Wall, Quantity and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	350 m	-	-
Roadway Surface Length (RL)	80 m	-	-
Roadway Tie-Ins (#)	6	-	-
Height (H)	3.7 m	-	-
Excavation	11.3 m^2 x L	\$25 / m^3	\$100,000
Bulk Dike Fill	34.5 m^2 x L	\$70 / m^3	\$846,000
Lock Blocks	4.7 blocks/m x L	\$350 / block	\$572,000
Riprap Rock	2.0 m^2 x L	\$140 / m^3	\$98,000
Hydroseeding	27.4 m x L	\$10 / m^2	\$97,000
Roadway Surface	4 m x RL	\$110 / m^2	\$36,000
Roadway Tie-In (# (H / 6%))	370.0 m	\$2,530 / m*	\$937,000
Soft Costs	+25%	-	\$672,000
Contingency	+30%	-	\$806,000
		Total	**\$4,164,000**
		\$/linear metre/height	\$3,215

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-29: Zone 6, Dike 8 ('Ksan Historical Village) Lock Block Retaining Wall, Quantity and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	320 m	-	-
Roadway Tie-Ins (#)	4	-	-
Height (H)	2.4 m	-	-
Excavation	3.4 m^2 x L	\$25 / m^3	\$27,000
Bulk Dike Fill	8.2 m^2 x L	\$70 / m^3	\$185,000
Lock Blocks	3.3 blocks/m x L	\$350 / block	\$374,000
Hydroseeding	15.5 m x L	\$10 / m^2	\$50,000
Roadway Tie-In (# (H / 6%))	160.0 m	\$2,170 / m**	\$348,000
Soft Costs	+25%	-	\$246,000
Contingency	+30%	-	\$296,000
		Total	**\$1,526,000**
		\$/linear metre/height	\$1,987

* Riprap rock not included b/c dike is setback and velocities are less than 1 m/s

** Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-30: Zone 3 And Zone 4, Dike 9 (Riverfront Dike) Lock Block Retaining Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	845 m	-	-
Roadway Surface Length (RL)	680 m	-	-
Roadway Tie-Ins (#)	4	-	-
Height (H)	2.6 m	-	-
Excavation	7.4 m^2 x L	\$25 / m^3	\$157,000
Bulk Dike Fill	19.4 m^2 x L	\$70 / m^3	\$1,150,000
Lock Blocks	4.0 blocks/m x L	\$350 / block	\$1,183,000
Riprap Rock	1.7 m^2 x L	\$140 / m^3	\$207,000
Hydroseeding	18.9 m x L	\$10 / m^2	\$160,000
Roadway Surface	4 m x RL	\$110 / m^2	\$300,000
Roadway Tie-In (# (H / 6%))	173.3 m	\$1,213 / m*	\$211,000
Soft Costs	+25%	-	\$842,000
Contingency	+30%	-	\$1,011,000
		Total	**\$5,221,000**
		\$/linear metre/height	\$2,376

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

Table 5-31: Zone 3, Zone 4, And Zone 5, Dike 10 (Riverfront Dike) Lock Block Retaining Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length – Partial Dike 9 (L_9)	570 m	-	-
Length – Dike 10 (L_{10})	500 m	-	-
Roadway Surface Length (RL)	160 m	-	-
Roadway Tie-Ins ($\#_9$ / $\#_{10}$)	3 / 4	-	-
Height – Partial Dike 9 (H_9)	2.6 m	-	-
Height – Dike 10 (H_{10})	3.5 m		-
Excavation – Partial Dike 9	7.4 m^2 x L_9	\$25 / m^3	\$106,000
Excavation – Dike 10	9.1 m^2 x L_{10}	\$25 / m^3	\$114,000
Bulk Dike Fill – Partial Dike 9	19.4 m^2 x L_9	\$70 / m^3	\$776,000
Bulk Dike Fill – Dike 10	38.0 m^2 x L_{10}	\$70 / m^3	\$1,329,000
Lock Blocks – Partial Dike 9	4.0 blocks/m x L_9	\$350 / block	\$798,000
Lock Blocks – Dike 10	4.7 blocks/m x L_{10}	\$350 / block	\$817,000
Riprap Rock – Partial Dike 9	1.7 m^2 x L_9	\$140 / m^3	\$140,000
Riprap Rock – Dike 10	1.8 m^2 x L_{10}	\$140 / m^3	\$128,000
Hydroseeding – Partial Dike 9	18.9 m x L_9	\$10 / m^2	\$108,000
Hydroseeding – Dike 10	22.3 m x L_{10}	\$10 / m^2	\$112,000
Roadway Surface	4 m x RL	\$110 / m^2	\$71,000
Roadway Tie-In ($\#_9$ (H_9 / 6%))	130.0 m	\$1,213 / m*	\$158,000
Roadway Tie-In ($\#_{10}$ (H_{10} / 6%))	233.3 m	\$1,883 / m*	\$440,000
Soft Costs	+25%	-	\$1,275,000
Contingency	+30%	-	\$1,530,000
		Total	**\$7,902,000**
		\$/linear metre/height	\$2,421

* Combination of excavation, bulk dike fill, and roadway surface for cross section; assumed excavation and bulk dike fill profile as a triangle over tie-in length to account for 6% sloping down.

5.3.3 Demountable Flood Wall

Demountable flood wall cost estimates were based off an assumption of using RS Demountable Flood Barrier type (Flood Control Canada) that mounts to a permanent concrete footing, as shown in Figure 5-11. Other demountable flood walls are available and viable; costs may vary.

Figure 5-11: RS Demountable Flood Barrier (from Flood Control Canada)

A typical demountable flood wall was assumed to have the following properties:

- Total height included concrete footing and metal panel walls;
- Total height of 0.3 m above the 200-year water elevation (with 0.6 m freeboard); and
- Concrete footing estimated size varied:
  - Widths of 0.5 – 1.5 m, with larger widths for higher floodwall height;
  - Footing embedded depth of 0.5 m; and
  - Heights based on required design water elevation and metal panel heights.

Unit price of concrete was obtained from similar dike project cost estimates throughout BC and unit price averages from Alberta Transportation (2020). Metal panel wall (supply and deliver) cost estimates were obtained from local suppliers (Flood Control Canada, personal communication, February 2 – 9, 2021). An operation and maintenance cost (11% of capital costs based on Aerts 2018) was included in the panel cost per metre. A flood event deployment cost was also incorporated in the panel cost per metre. It was assumed there would be five flood events in the product lifetime that would require deployment, and it would take four people ($60 / hour) approximately one hour to deploy 100 m of flood wall.

Soft costs, including project management, engineering design, construction supervision, and inspection, were added as a percentage of the construction costs (25% as suggested by MOTI 2013). A contingency of 30% was also added as a percentage of the construction costs to account for uncertainties and risks.

An estimate of each earthen berm dike considered is summarized in Table 5-32 through Table 5-38.

Table 5-32: Zone 1, Dike 1 Demountable Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	205 m	-	-
Height (H)	1.5 m	-	-
Concrete Foundations	0.5 m thick x 0.5 m wide	-	-
Concrete	0.25 m^2 x L	$850 / m^3	$44,000
Panels (1.5 m high)	L	$2066 / m	$424,000
Soft Costs	+25%	-	$117,000
Contingency	+30%	-	$141,000
		Total	**$726,000**
		$/linear metre/height	$2,361

Table 5-33: Zone 2, Dike 2 Demountable Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	180 m	-	-
Height (H)	1.9 m	-	-
Concrete Foundations	0.9 m thick x 0.5 m wide	-	-
Concrete	0.45 m^2 x L	$850 / m^3	$79,000
Panels (1.5 m high)	L	$2066 / m	$372,000
Soft Costs	+25%	-	$113,000
Contingency	+30%	-	$136,000
		Total	**$700,000**
		$/linear metre/height	$2,047

Table 5-34: Zone 3, Dike 4 (Pump Station) Demountable Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	70 m	-	-
Height (H)	2.6 m	-	-
Concrete Foundations	0.7 m thick x 1.0 m wide	-	-
Concrete	0.70 m^2 x L	$850 / m^3	$42,000
Panels (2.4 m high)	L	$5582 / m	$391,000
Soft Costs	+25%	-	$109,000
Contingency	+30%	-	$130,000
		Total	**$672,000**
		$/linear metre/height	$3,692

Table 5-35: Zone 4, Dike 5 (River Rd. Residences) Demountable Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	415 m	-	-
Height (H)	2.9 m	-	-
Concrete Foundations	1.0 m thick x 1.0 m wide	-	-
Concrete	1.0 m^2 x L	\$850 / m^3	\$353,000
Panels (2.4 m high)	L	\$5582 / m	\$2,317,000
Soft Costs	+25%	-	\$668,000
Contingency	+30%	-	\$801,000
		Total	**\$4,139,000**
		\$/linear metre/height	\$3,439

Table 5-36: Zone 4, Dike 6 (Cunningham St. Residences) Demountable Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	550 m	-	-
Height (H)	3.1 m	-	-
Concrete Foundations	1.2 m thick x 1.0 m wide	-	-
Concrete	1.20 m^2 x L	\$850 / m^3	\$561,000
Panels (2.4 m high)	L	\$5582 / m	\$3,071,000
Soft Costs	+25%	-	\$908,000
Contingency	+30%	-	\$1,090,000
		Total	**\$5,630,000**
		\$/linear metre/height	\$3,302

Table 5-37: Zone 5, Dike 7 ('Ksan Campground Offices) Demountable Flood Wall, Quantity and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	240 m	-	-
Height (H)	3.7 m	-	-
Concrete Foundations	1.8 m thick x 1.5 m wide	-	-
Concrete	2.7 m^2 x L	\$850 / m^3	\$551,000
Panels (2.4 m high)	L	\$5582 / m	\$1,340,000
Soft Costs	+25%	-	\$473,000
Contingency	+30%	-	\$568,000
		Total	**\$2,932,000**
		\$/linear metre/height	\$3,302

Table 5-38: Zone 6, Dike 8 ('Ksan Historical Village) Demountable Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	320 m	-	-
Height (H)	1.3 m	-	-
Concrete Foundations	0.5 m thick x 0.5 m wide	-	-
Concrete	0.25 m^2 x L	\$850 / m^3	\$68,000
Panels (1.5 m high)	L	\$2066 / m	\$662,000
Soft Costs	+25%	-	\$183,000
Contingency	+30%	-	\$219,000
		Total	**\$1,132,000**
		\$/linear metre/height	\$2,721

5.3.4 Temporary Flood Wall

Temporary flood wall cost estimates were based off an assumption of using a 1.7 m high barrier made of metal (e.g., INERO flood barriers) or plastic (e.g., Muscle Wall), as shown in Figure 5-12. Other types of temporary flood walls are available and viable; costs will vary.

Figure 5-12: INERO Flood Barrier and Muscle Wall (from Flood Control Canada)

Metal and plastic temporary flood wall cost estimates (supply and deliver) were obtained from local suppliers (Flood Control Canada 2021) and averaged. An operation and maintenance cost (11% of capital costs based on Aerts 2018) was included in the cost per metre. A flood event deployment cost was also incorporated in the cost per metre. It was assumed there would be five flood events in the product lifetime that would require deployment, and it would take four people (\$60 / hour) approximately one hour to deploy 100 m of flood wall.

A contingency of 30% was also added as a percentage of the costs to account for uncertainties and risks.

An estimate of each earthen berm dike considered is summarized in Table 5-39 through Table 5-41.

Table 5-39: Zone 1, Dike 1 Temporary Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	205 m	-	-
Height (H)	1.5 m	-	-
Panels (1.7 m high)	L	$1670 / m	$343,000
Contingency	+30%	-	$103,000
		Total	**$446,000**
		$/linear metre/height	$1,450

Table 5-40: Zone 2, Dike 2 Temporary Flood Wall, Quantity, and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	205 m	-	-
Height (H)	1.9 m	-	-
Panels (1.7 m high*)	L	$1670 / m	$301,000
Contingency	+30%	-	$91,000
		Total	**$392,000**
		$/linear metre/height	$1,146
* panel height slightly too low for design height; need to evaluate risk of this option.			

Table 5-41: Zone 6, Dike 8 ('Ksan Historical Village) Temporary Flood Wall, Quantity and Cost Estimate

Item	Quantity	Unit Cost	Cost
Length (L)	320 m	-	-
Height (H)	1.3 m	-	-
Panels (1.7 m high)	L	$1670 / m	$535,000
Contingency	+30%	-	$161,000
		Total	**$696,000**
		$/linear metre/height	$1,673

5.3.5 Wet Flood Proofing, Building Elevation, and Building Relocation

Wet Flood Proofing, Building Elevation, and Building Relocation cost estimates were based off Aerts (2018). This study gave ranges of average costs per building in various countries. An average of the high end of the range for countries in North America were used for this cost estimate. The US dollar cost estimates were converted to Canadian Dollars and updated to 2021 Canadian Dollars using an inflation calculator (Webster 2021). The cost estimate per building used is presented in Table 5-42.

Table 5-42: Cost Estimate for Various Building Structural Flood Mitigation Options

Structural Mitigation Option	Cost per Building	Comments
Wet Flood Proofing	$30,000	› Wet flood proofing +0.9 – 2.7 m. › Examples from United States. › Residential buildings.
Building Elevation	$150,000	› Raise building +1.8 m. › Examples from United States. › Doesn't include surrounding infrastructure adjustments.
Building Relocation	$500,000	› Example from United States. › Average building.

6 Summary and Recommendations

This report outlines the quantitative flood hazard and qualitative flood risk assessment for the Skeena River and Bulkley River simultaneous 200-year flood (with allowance for climate change) near the village of Hazelton and Gitanmaax communities. Flood hazards were quantified by multiplying the modelled depth by velocity. The majority of areas had values greater than 0.8 m^2/s (hazard to all); these were further subdivided in to 'Very High' hazards for prioritization purposes.

Qualitative flood risks were established based on overlaying the flood hazard map on an orthoimage and identifying assets at risk. Flood hazard areas with similar assets at risk were divided into zones (six zones total) and ranked on their subjective importance. Green spaces and roadways were given relatively low importance, buildings, and essential services (e.g., fire hall) were given higher importance. The assets at risk were ranked as follows:

- 'Ksan administration buildings;
- Cunningham Street residences;
- Hankin Street to Omineca Street (residences, fire hall, community buildings);
- River Road residences;
- Pump Station (Ferry Road);
- 'Ksan historical village; and
- Omineca Street to Bay Street (residences, park).

A number of non-structural options were provided for the village of Hazelton and Gitanmaax communities. Non-structural options complement the structural options; the level of effort to develop these depends on structural options implemented.

Several different structural options were developed for every zone. Some options could be implemented independently (protecting individual zones) and some options could be combined to protect multiple zones simultaneously. Preliminary cost estimates were also provided for each structural option. The feasibility of structural options has to be assessed with further studies (e.g., river level response to dike encroachment, geotechnical investigations, land availability).

Structural recommendations were given for the protection of all flood inundated zones, which included:

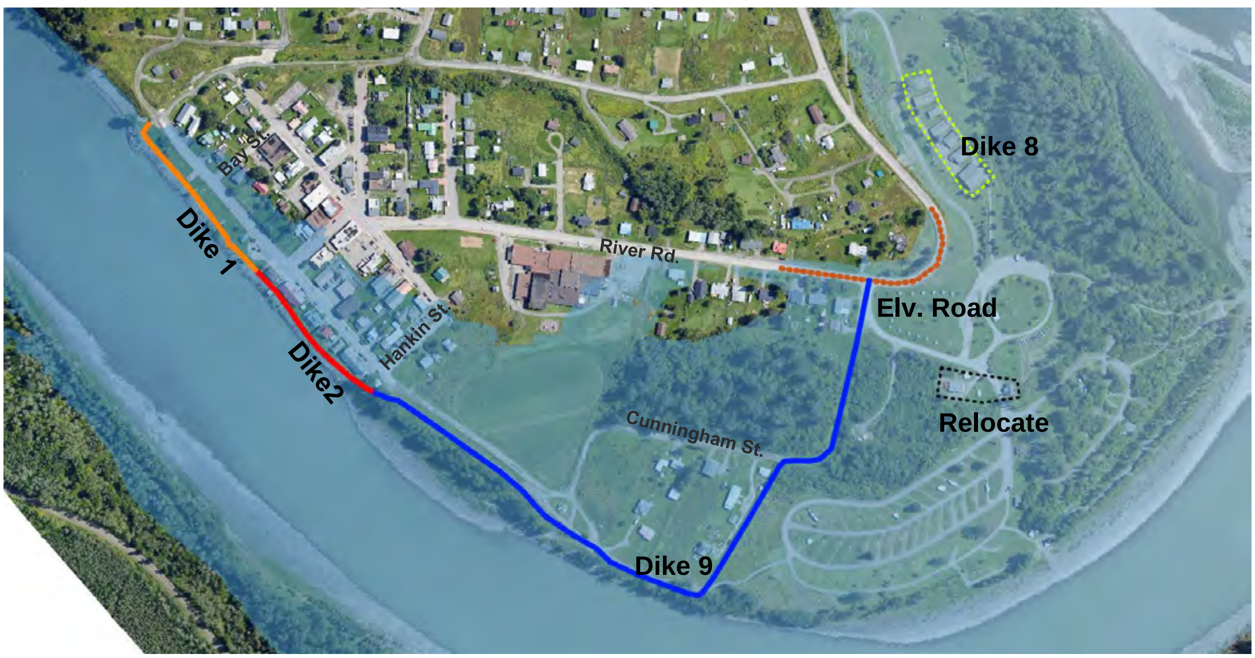
- Relocate 'Ksan administration buildings;
- Build Dike 1, Dike 2, and Dike 9 to protect Hankin Street to Bay Street buildings, pump station, Cunningham Street residences, and River Road residences;
- Build earthen berm for Dike 1;
- Acquire and build demountable flood wall for Dike 2;
- Build earthen berm for Dike 9 and elevate portion of River Road; and
- Acquire temporary flood wall (Dike 8) for 'Ksan historical village buildings.

This combination of structural mitigation options is shown in Figure 6-1. These options require further hydrotechnical and geotechnical studies and design to assess their feasibility.

Implementation of mitigation measures should consider both non-structural and structural. Therefore, it is also recommended that the village of Hazelton and Gitanmaax:

- Develop a flood emergency response plan that incorporates the deployment of temporary and demountable flood walls;
- Provide flood inundation maps and flood hazard maps online and hold an information session to educate the community on flooding hazards;
- Monitor BC River Forecast Centre during flooding seasons to be aware of potential floods; and
- Revise Zoning Bylaw No. 478 to reflect latest floodplain inundation maps.

Figure 6-1: Recommended Structural Mitigation Combination to Protect All Zones



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