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City of Pitt Meadows

Report

Pitt Meadows Flood Hazard Risk Assessment

April, 2018

ISL Engineering and Land Services

ISL Engineering and Land Services Ltd. is an award-winning full-service consulting firm dedicated to working with all levels of government and the private sector to deliver planning and design solutions for transportation, water, and land projects.

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1.0 Introduction

This flood hazard risk assessment report was prepared by ISL Engineering and Land Services Ltd. (ISL) for the City of Pitt Meadows (City) as a resource to aid in its emergency management and preparedness. Thurber Engineering Ltd. (Thurber) was a sub-consultant to ISL and provided high-level geotechnical engineering reviews of the City's diking system. This report provides an assessment of the potential for flooding and the potential impacts on the community should flooding occur.

The project was undertaken as part of the National Disaster Mitigation Program (NDMP) under Stream 1 Risk Assessments. Stream 1 allows for a high-level risk assessment and was designed to identify flood hazards and complete risk assessments for chosen risk events. Subsequent NDMP streams will provide the opportunity for more detailed assessments of the selected risk events.

The identification, assessment and ranking of risks and impacts serves to provide a framework for the City in its risk mitigation planning to help determine flood risk mitigation opportunities.

ISL's approach to completing this risk assessment included the below main tasks.

1. Establish a study baseline. This phase of the study was to compile and review existing regional studies, and mapping.
2. Analyze the regional data to determine the design flood and resultant flood levels. Identify hazard scenarios that may contribute to a design flood event.
3. Simulate the effects of the design floods by comparing the modelled design flood mapping on a 3-dimensional (3D) model of Pitt Meadows. This included additional model iterations including each of the various hazard scenarios.
4. Identify the risks based on the consequences of the resultant flood levels from the 3D model by identifying the affected existing developed lands and associated land uses.
5. Assign values to each of the identified consequences and determine the probability of the loss of each occurring.

The risk assessment was based on anticipated inundation depths from hazards defined in previous studies conducted in the region. Comprehensive risk assessments may include analysis of factors not reviewed in this assignment, including: flow velocities, duration of inundation, time of year, sediment loads, and pollution.

1.1 National Disaster Mitigation Program

The NDMP is a federal program developed in 2014 that seeks to build safer and more resilient communities. The objective of the NDMP is to reduce the impacts of natural disasters on Canadians by investing in significant and recurring flood risk mitigation. The four streams of the NDMP are listed below.

- Stream 1 – Risk Assessments
- Stream 2 – Flood Mapping
- Stream 3 – Flood Mitigation Planning
- Stream 4 – Investments in Non-structural and Small Scale Structural Mitigation Projects

Stream 1 allows for an overview of flood hazards in communities and assessments of risk events. Stream 2 allows for more comprehensive risk assessments and flood and hazard maps. Streams 3 and 4 provide funding for the flood mitigation planning and implementation of flood mitigation projects.

ISL prepared this flood hazard risk assessment report in consideration of the below guidelines and resources.

- National Disaster Mitigation Program Risk Assessment Information Template (RAIT), Public Safety Canada
- Risk Assessment Information Template Users' Guide, Emergency Management British Columbia (EMBC) Disaster Mitigation Program
- Professional Practice Guidelines - Legislated Flood Assessments in a Changing Climate in BC, Engineers and Geoscientists of British Columbia (EGBC, formerly the Association of Professional Engineers and Geoscientists of BC)

The NDMP Risk Assessment Information Template is designed to be a tool for improved understanding and prioritizing future resources on a national level. The RAIT is the final deliverable for the Pitt Meadows Flood Hazard Risk Assessment and a condition of NDMP funding. The completed RAIT tables for each risk event can be found in **Appendix A, B, and C**.

1.2 Rationale

Flooding in BC can be attributed to many common factors, including: climatic conditions, geomorphic process (debris flows, debris floods, etc.), structural failures of flood protection, and human activity (urbanization).

The City of Pitt Meadows is susceptible to flooding due to heavy rain, rain-on-snow, spring freshet, and mechanical failure of pump stations. Freshet by definition is a river flood due to heavy rain or snow melt. In the Lower Mainland, freshet is generalized to be spring flooding of rivers caused by annual snow melt. The freshet period in Pitt Meadows typically extends from April to July. Freshet is forecasted using snowpack estimates during winter which improve readiness for downstream municipalities. Other meteorological events such as heavy or intense rain events can be more difficult to predict.

Approximately 95% of the City lies within the Fraser River and Pitt River floodplains. The Alouette River divides the City and confluences with the Pitt River. The City is protected by standard and non-standard (agricultural) diking system of approximately 60 km in length. The municipality is divided into four distinct drainage areas that are defined by dikes and serviced by floodboxes and pump stations. Most of the City's dikes (and drainage pump stations) were built to design criteria established by the Fraser River Flood Control Program (1969) and Agricultural and Rural Development Subsidiary Agreement (ARDSA) and do not meet current provincial design standards.

The Fraser River is the most significant flood hazard in the City as it undergoes annual freshet and has the ability to cause the most damage to the region due to a drainage area of roughly 250,000 sq.km. that extends from the Rocky Mountains to the Lower Mainland of BC. The City of Pitt Meadows' top of dike elevations are at 5.4 m geodetic which approximately corresponds to 8.4 m at the upstream Mission Fraser River hydrometric data gauge. Flood levels of 8.4 m or higher as measured at Mission would cause overtopping of the Pitt Meadows dikes. This threshold was exceeded during the flood of 1984, when the water surface elevation reach an estimated 8.9 m (**Figure 1.1**).

According to the Fraser Basin Flood Management Strategy, a present day Fraser River flood equal to the 1894 flood of record, could result in a total economic loss of $22.9 Billion, displacement of 266,000 people, and an agricultural loss of $67-200M for the Lower Mainland.

EMBC identifies the four components of emergency management as mitigation, preparedness, response and recovery. Preparedness, response, and recovery measures allow for impact management once a disaster occurs. However, mitigation can prevent a disaster from occurring or reduce the potential impacts of a disaster. EMBC qualifies the importance of mitigation as follows: "Investment in disaster mitigation leads to significant relative savings in future response and recovery costs (compared to costs if no mitigation measures were taken)."

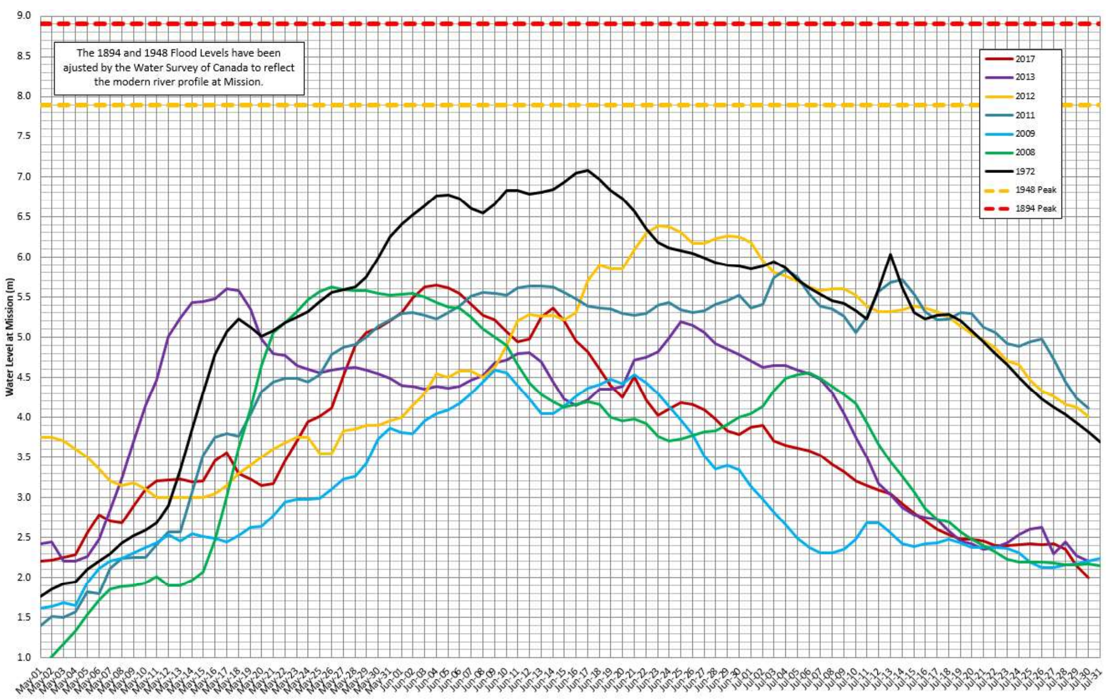


Figure 1.1: Fraser River Water Levels at Mission, BC (Water Survey of Canada)

Within the Professional Practice Guidelines, EGBC indicates that the population of BC is anticipated to grow by one third by 2035. This will have an impact on housing affordability in urban centers, particularly in Greater Vancouver and the Fraser Valley, and will increase development pressure in flood-susceptible areas. This flood hazard risk assessment will help to inform decision-making regarding where future development should be located, and the associated flood hazard related risks for new development areas.

1.3 Project Team

The City of Pitt Meadows Flood Hazard Risk Assessment was led by the project team listed below.

- City of Pitt Meadows Working Group
- ISL Engineering and Land Services Ltd.
- Thurber Engineering Ltd.

The City's Working Group consisted of members from Engineering, Operations, Environmental, Building, and Emergency Coordination divisions and committees. The City provided in-house expertise related to past information and reports, technical information required for the assessments, and coordination of the stakeholders and public meetings.

ISL Engineering led the consultant team and was the primary contact for Pitt Meadows. ISL was consulted on the flood hazards, provided input of flood hazards, compiled risk events, and completed the high level risk assessments.

Thurber Engineering conducted high-level assessment of the City's diking infrastructure. Thurber's report covered general geotechnical considerations for seepage, settlement, and stability (seismic and non-seismic).

Other stakeholders that did not directly contribute to this Stream 1 risk assessment but that may be involved with related future work include:

- Fraser Basin Council;
- Metro Vancouver Utilities Sector;
- Katzie First Nation;
- Maple Ridge Hammond Community;
- BC Ministry of Forests, Lands & Natural Resources Operations;
- BC Ministry of Transportation and Infrastructure;
- Canadian Pacific Railway;
- BC Hydro; and
- Fortis BC.

The structure and composition of the project team and stakeholder group may vary periodically based on the interests of each party during subsequent stages of future work.

Additionally, a public open house was conducted to inform Pitt Meadows residents and businesses to generate public feedback on ideas and important topics related to flooding and flood risks. The objectives of the open house were to gain an understanding of the City's preparedness, and to understand perspectives and priorities for future flood mitigation work.

2.0 Background

2.1 Flood Hazards

Floods hazards in Pitt Meadows vary from high frequency/low consequence (debris blockage of culvert) to low frequency/high consequence (dike breach). Certain hazards may warrant a stand-a-lone risk assessment, such as the diking system and risk of failure due to seismic events. Flood hazards in Pitt Meadows identified for this risk assessment are shown in the **Table 2.1** below.

Table 2.1: Flood Hazards in the Project Area

Flood Hazards in Project Area	Prioritization Rationale
Freshet causing dike overtopping	Freshet occurs annually; since 1894, three significant (causing flooding) Fraser River floods have occurred (1894, 1948, 1972); the City's perimeter (standard) dikes are expected to overtop in a flood similar to the flood of 1894 (considered as 1:500 year).
Dike breach	Dike breaches are difficult to determine the likelihood but the impact can be severe due to the potential to occur without warning.
Storm surge	More common than the above events and less severe, storm surge (or prolonged heavy rainfall during high tides) can overcome the City's drainage infrastructure (pump stations, storm sewers, and ditch network) and cause damage to agricultural land.
Drainage pump station failure/ Power loss	The City's drainage system relies on dikes, flood boxes, and drainage pump stations. The City's 6 drainage pump stations are currently without backup power - in the event of station failure or power loss, the drainage system relies on floodboxes for drainage relief (only operational when the drainage system water levels are higher than the river water levels).
Sea level rise	Sea level is expected to rise by 1m from 2000 to 2100, which will affect the Fraser and Pitt Rivers Dam breach (upstream Alouette River Dam) may come with little warning and in the event of complete failure, signficant flooding in the City.
Upstream dam breach	The Alouette River dam is upstream of Pitt Meadows. BC Hydro has a detailed flood mapping and is responsible to action plan. A complete failure may be unlikely but could be catastrophic to Pitt Meadows and Maple Ridge.
Beaver dams/ Debris build up	Beaver dams are a common issue in the drainage issues but are generally confined and cause local backwater effects and/or flooding.

2.2 Project Area

The project area boundary for the Pitt Meadows Flood Hazard Risk Assessment was focused on the Pitt Meadows Municipal Boundary. However, the flood inundation maps included a portion of Maple Ridge, demarcated as the Model Extent (**Figure 2.1**). The Maple Ridge area was included as it could be affected by flooding caused by a hazard within the City of Pitt Meadows Municipal Boundary and Pitt Meadows is the Diking Authority for this section of Maple Ridge. The study area as it pertains to the flood hazard risk assessment was limited to the City of Pitt Meadows Municipal Boundary.

Pitt Meadows is bound by the Pitt River to the north and west, the Fraser River to the south, the City of Maple Ridge to the east, and the Thompson Mountain Range to the northeast. Two arms of the Alouette River (North Alouette and South Alouette) divide the city, along with a system of sloughs and ditches that convey drainage to the surrounding rivers. The municipality is divided into four drainage areas that are defined by dikes and serviced by floodboxes and pump stations.

2.3 Land Uses and Key Infrastructure

Pitt Meadows is a primarily agricultural and rural residential community with a distinct urban boundary, referred to as the urban area. The urban area includes the Pitt Meadows Airport and the City Center and is bounded by the Lougheed Highway to the north, Maple Ridge to the east and the Fraser River to the south. The west is bound by the Agricultural Land Reserve (ALR) with the exception of a stretch of land that follows the Canadian Pacific Railway (CPR) and Lougheed Highway to the Pitt River.

The population of Pitt Meadows is projected to increase from 15,623 in 2006 to 21,000 by 2028, requiring roughly an additional 2,700 housing units, over the same timeframe. The 2016 Statistics Canada Census lists the City's population as 18,573. The ALR limits the potential for development on agricultural lands and most of this growth must take place on non-ALR zone lands within the urban area. Through land use changes and other strategies outlined in the City's Official Community Plan (OCP), the urban area will develop into a more compact, metropolitan area.

Pitt Meadows and the regional district of Metro Vancouver are growing at a comparable rate. Situated near other rapidly developing communities of Maple Ridge, Coquitlam, Port Coquitlam, Surrey and Langley, Pitt Meadows is involved in ongoing regional transportation improvements. These improvements are designed to connect the entire Metro Vancouver and improve accessibility for the growing population. The City is a connection point that contains the following regional commercial, and transportation and other key infrastructure:

- Pitt River Quarries (PRQ);
- Provincial Infrastructure (Lougheed Highway);
- Regional Infrastructure (Metro Vancouver Water Booster Station and Chlorination Analyzer; Metro Vancouver Sanitary Pump Station);
- Pitt Meadows Regional Airport; and
- Canadian Pacific Rail and Vancouver Intermodal Facility.

Agricultural land use is predominant in Pitt Meadows with approximately 86 percent of total area designated as Agricultural Land Reserve (ALR). Agricultural parcels in the City range from small to large and uses vary from berry farms, horticultural products, crops, grazing and dairy farms. The Agricultural Land Commission must support land use changes of existing ALR land to non-ALR uses.

FIGURE 2.1
PROJECT AREA
FLOOD RISK ASSESSMENT
COQUITLAM
PITT MEADOWS
Pitt Polder
Ecological Reserve
Pitt Polder
DPS
Fenton
DPS
Pitt River
Quarries
COQUITLAM
PORT COQUITLAM
Alouette
Flood Gates
Alouette River
Alouette
DPS
McKennie
DPS
Pitt River
PITT MEADOWS
MAPLE RIDGE
Metro Vancouver
Chlorination Station
Kennedy
DPS
PORT COQUITLAM
PITT MEADOWS
CP Rail
Harris Road
North Lougheed
SLS
190A
SLS
124A
SLS
Lougheed Highway
Harris
SLS
Metro Vancouver
SLS
Meadowtown
SLS
Metro Vancouver
Maple Ridge
Pump Station
City
Hall
Hammond
SLS
Pitt Meadows Airport
114B
SLS
PORT COQUITLAM
SURREY
PITT MEADOWS
SURREY
MAPLE RIDGE
LANGLEY
Golden Ears
Business Park
Joyner
SLS
Baynes
DPS
City Works
Yard
Fraser River
BARNSTON
ISLAND
Katzie
First
Nations
SURREY
LANGLEY
Legend
Model Extent
Municipal Boundary
Kilometers
0 0.5 1 2
1:55,000 UTM Zone 10 Northern Hemisphere
ISL Engineering and Land Services
City of Pitt Meadows
The Natural Place
Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

3.0 Risk Events

Risk events were developed based on the identified hazards listed in **Section 2.0**. Although there are an infinite number of risk events that could be explored, three events were selected, that:

- Met the NDMP criteria;
- Supported the previous regional reports and context;
- Were applicable to the interests of stakeholders; and
- Offered a range in likelihood of occurrence to output structural and non-structural flood mitigation projects with a scale of cost (low to high cost) and timeframe (short to long term).

3.1 Previous Reports

There were previous reports that provided the basis for the development of the risk events and high-level economic loss estimates and flood inundation. The purpose of this flood hazard risk assessment was apply the regional assessments to the City of Pitt Meadows using refined data and information. The primary reports referenced for this risk assessment are below.

- Lower Mainland Flood Management Study, by Kerr Wood Leidal, commissioned by Fraser Basin Council, May 2015
- Lower Mainland Flood Management Strategy Project 2: Regional Assessment of Flood Vulnerability, by Northwest Hydraulic Consultants, commissioned by the Fraser Basin Council, April 2016
- City of Pitt Meadows Drainage and Irrigation Study, by ISL Engineering, commissioned by the City of Pitt Meadows, January, 2018

The Northwest Hydraulic Consultants (NCH) and Kerr Wood Leidal (KWL) commissioned by the Fraser Basin Council provided were the basis for Risk Events 1 and 2.

ISL's drainage and irrigation study, completed in 2018 for the City of Pitt Meadows, provided the basis for Risk Event 3.

3.2 Risk Event 1 – 1 in 500 Year Fraser Freshet

Risk Event 1 was developed by KWL (2015) and modelled by NHC (2016) and was considered to be representative of the 1894 Fraser River flood of record. The flood equates to a peak flow of 17,000 m^3/s at Hope and a 1 in 500 year return period or 0.2% AEP. Current conditions were assumed for land use, population, and sea levels. Refer to the Risk Event 1 inundation map **Figure 3.1.**

3.3 Risk Event 2 – 1 in 500 Year Fraser Freshet + Climate Change + Sea Level Rise

Risk Event 2 was developed by KWL (2015) and modelled by NHC (2016). The flood scenario included the 1 in 500 year Fraser River flood from Risk Event 1 and factored a 17% climate change impact and a sea level rise of 1m (by 2100). Although uncertainty remains in climate change and sea level rise impacts, the event is intended to serve as longer term scenario that is relevant to flood protection infrastructure life spans. Current conditions were assumed for land use, and population. Refer to the Risk Event 2 inundation map **Figure 3.2.**

3.3.1 Risk Event 3 – Storm Surge

Risk Event 3 was designed to approximate the winter storm of January, 2005 in which the City received prolonged rainfall during saturated ground conditions and high river water levels.
The scenario was developed using an existing ISL drainage model for the City and approximated using aerial photographs of the actual 2005 flood. The scenario utilized the Agricultural and Rural Development Subsidiary Agreement (ARDSA) 5 day, 10 year rainfall event which is consistent with regional long duration storms. The event also considered drainage ditches with higher than average water levels, drainage pumps on, but river water levels high so that floodboxes are not operational (freshet and or high tide condition). Current conditions were assumed for land use, population, and sea levels. Refer to the Risk Event 3 inundation map **Figure 3.3.**

3.4 Climate Change

Climate change factors were not incorporated into Risk Events 1 and 3 at the risk assessment stage. Climate change is recommended to be assessed during future work such as the implementation of structural flood mitigation projects. Currently, climate change effects on flooding are difficult to predict. Common approaches in the industry to combat climate change unknowns include designing storm-related infrastructure to events with longer return periods (1 in 200 year) or adding a climate change safety factor (10-20%).

3.5 Existing Flood Hazard Mitigation Measures

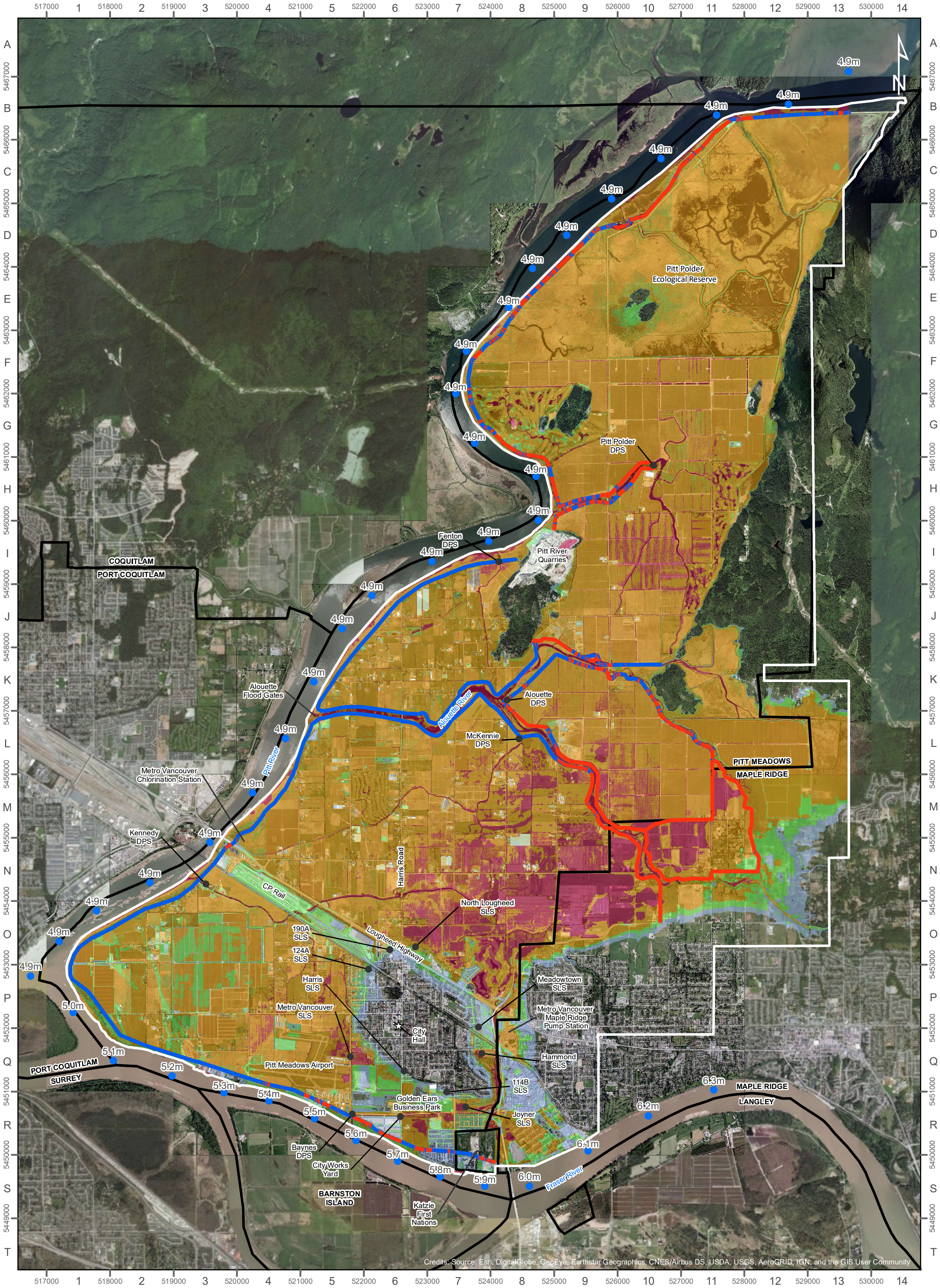
3.5.1 Drainage and Diking Infrastructure

The City's current flood mitigation infrastructure consists of its dikes, ditches, pump stations, and flood boxes. The City is almost entirely protected by perimeter dikes which are critical to protecting the City's low lying areas and key infrastructure from riverine flooding. Pitt Meadows is divided into four main drainage and diking areas:

- Area 1 (Dike Area 1/Alouette Pump Station Catchment), discharges to the Alouette River
- Area 2 (Fenton Drainage Area), discharges to the Alouette and Pitt Rivers
- Area 3 (Kennedy Drainage Area, including McKechnie), discharges to the Alouette, Pitt and Fraser Rivers
- Area 4 (Pitt Polder Catchment Area), discharges to the Pitt River

A fifth catchment area, the Pitt-Addington Catchment Area, is mainly undeveloped.

The majority of the areas are drained through rural (ditch and culvert) systems, with the exception of the urban development Area 3, which is serviced by a combination of ditches, culverts and storm sewers. Because of the low elevation of the catchment areas, at or near sea level, these areas are drained to the Pitt, Alouette and Fraser Rivers by a combination of flood boxes and pump stations (for discharge during higher river water level periods). A list of the pump stations and flood boxes in the study area is provided in **Table 3.1**.



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Kilometers
0 0.5 1 2
1:55,000 UTM Zone 10 Northern Hemisphere

Date: 2018-03-13 Document: \\cgyfs\GIS_DATA\Projects\31889_CoPM_NDMP_Stream_1\251_Figures\31889_flood_scenario_one_11x17.mxd

Legend

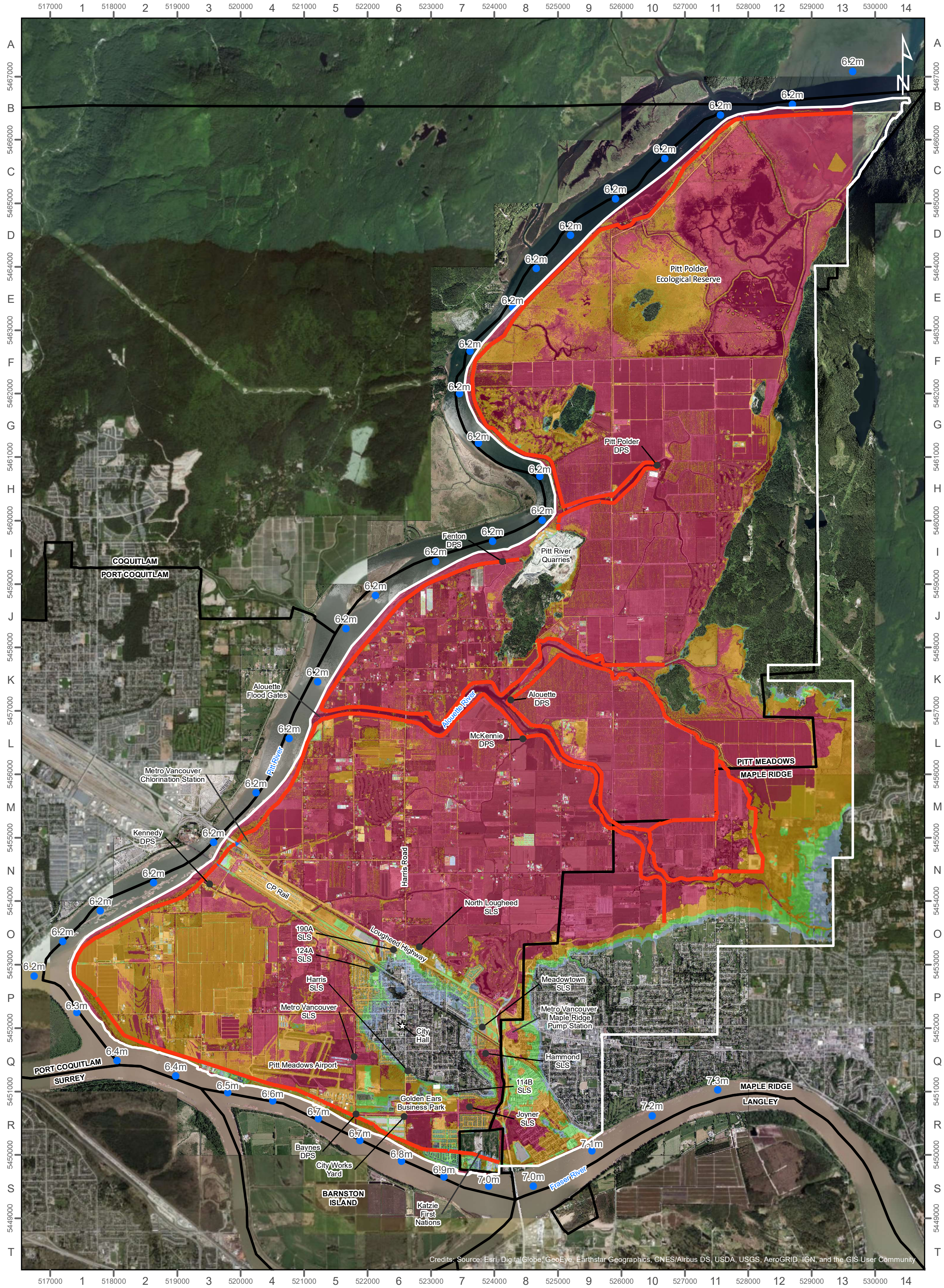
- Water Elevation
- Dike
- Overtopping
- Model Extent
- Municipal Boundary

Flood Depths
1:500 - Year Freshet
- 0 - 1 m
- 1 - 2 m
- 2 - 4 m
- > 4 m

DPS - Drainage Pump Station
SLS - Sanitary Lift Station

City of Pitt Meadows
The Natural Place

FIGURE 3.1
1:500 - YEAR FRESHET
FLOOD PLANE
FLOOD RISK ASSESSMENT



Legend

- Water Elevation
- Dike
- Overtopping
- Model Extent
- Municipal Boundary

Flood Depths

1:500 - Year Freshet + Climate Change + Sea Level Rise

- 0 - 1 m
- 1 - 2 m
- 2 - 4 m
- > 4 m

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Kilometers 0 0.5 1 2

1:55,000 UTM Zone 10 Northern Hemisphere

DPS - Drainage Pump Station
SLS - Sanitary Lift Station

City of Pitt Meadows — The Natural Place

FIGURE 3.2
1:500 - YEAR FRESHET +
CLIMATE CHANGE + SEA LEVEL RISE
FLOOD PLANE
FLOOD RISK ASSESSMENT

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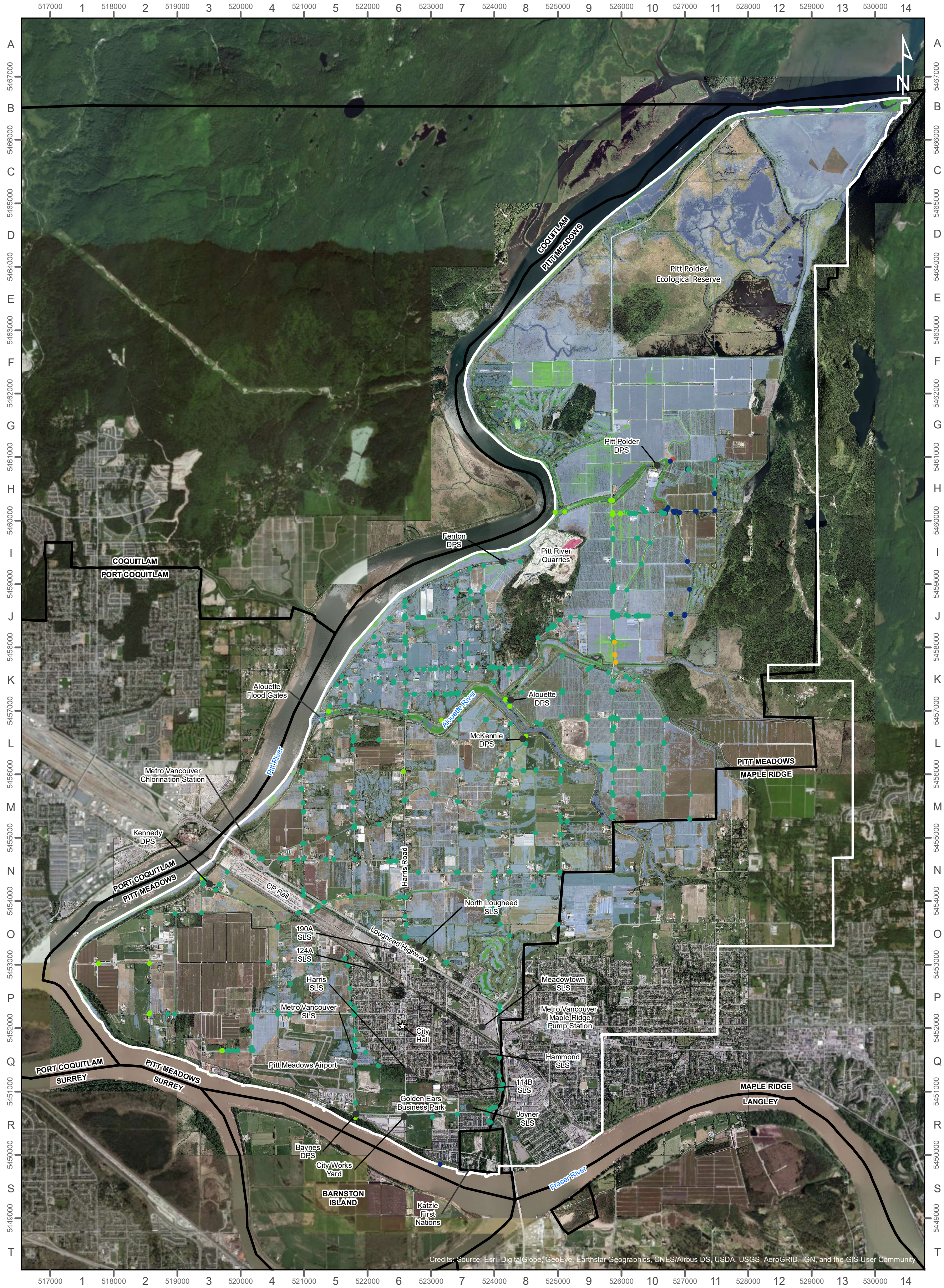

ISL Engineering and Land Services

0 0.5 1 2 Kilometers

1:55,000 UTM Zone 10 Northern Hemisphere

Date: 2018-03-13 Document: \\cgyfs\GIS_DATA\Projects\31889_CoPM_NDMP_Stream_1\251_Figures\31889_flood_scenario_four_11x17.mxd

Legend

Water Elevation

- 0 - 1.0 m
- 1.0 - 2.0 m
- 2.0 - 3.0 m
- 3.0 - 4.0 m
- > 4.0 m

Model Extent

Municipal Boundary

Flood Depths

Storm Surge

- 0 - 1 m
- 1 - 2 m
- 2 - 4 m
- > 4 m

DPS - Drainage Pump Station
SLS - Sanitary Lift Station

City of Pitt Meadows
The Natural Place

FIGURE 3.3
STORM SURGE
FLOOD PLANE
FLOOD RISK ASSESSMENT

Table 3.1: Pump Stations and Flood Boxes in the Study Area

Area	Name	Location	Catchment or Subcatchment	Flood Box	No. of Pumps	Total Rated Pumping Capacity (m^3/s)
1	Alouette Pump Station	14401 Neaves Rd	Alouette	Yes	2	2.5
2	Charlier Floodgate	14495 Charlier Rd	Fenton	Yes	0	N/A
	Fenton Pump Stations	15400 Harris Rd	Fenton	Yes	2	5.46
3	Kennedy Pump Station	17641 Kennedy Rd	Kennedy	Yes	4	7.07
	Cranberry Floodgate	14179 Reichenbach Rd	Cranberry	Yes	0	N/A
	Baynes Pump Station	18800 Airport Way	Ford	Yes	2	3.54
	McKechnie Pump Station	14352 McKechnie Rd	McKechnie	No	3	6.76
4	Sturgeon Slough Floodgate	16391 Rannie Rd	Polder	Yes	0	N/A
	Polder Pump Station	16390 Rannie Rd	Polder	No	2	5.46

The City of Pitt Meadows operates and maintains approximately 60 km of dikes over the four drainage and diking areas which include a portion of the dikes in Maple Ridge. Thurber Engineering Ltd. provided high-level geotechnical engineering considerations regarding the existing diking system. Thurber's report can be found in **Appendix D**.

Table 3.2: Diking Inventory by Area

Dike Name	Length (km)
Area 1	9.9
Area 2	8.7
Area 3	23.4
Area 4	17.7

Dikes were generalized into standard or non-standard categories, referencing the Ministry of Forests, Lands, and Natural Resource Operations and Rural Developments (MFLNRORD's) standard earth fill dike. Non-standard dikes generally are considered low-consequence agricultural dikes and usually have steeper side slopes and narrower crests than standard dikes.

Most of the dikes in Areas 2 and 3 were considered to be standard dikes and were rebuilt between 1977 and 1989 and constructed to 1969 design elevations. As of 2006, the Fraser River design criteria are considered too low.

The dikes in Areas 1 and 4 were considered to be primarily non-standard dikes constructed in the late 1940s and early 1950s. Based on the 2006 design criteria, the dikes in these areas are also too low. The dikes provide protection from the North and South Alouette Rivers.

3.5.2 Response Plans

The City follows the Pitt Meadows Operational Flood Response Plan which is followed during periods of high river levels. The provincial River Forecast Centre assesses flood risks in British Columbia including the analyses of snow pack and prediction of flows. The Fraser River gauges at Hope, BC (08MF005) and Mission, BC (08MH024) are the primary locations in which flood forecasting is predicted for the Lower Mainland communities. The Operational Flood Response Plan is based on the existing dike system relative to the stage readings at Mission. Refer to **Figure 3.5** outlining the City's planned response for corresponding stages.

Fraser River Stages & Response		
Stage at Mission	**Response Action**	**Potential Impacts**
I to 5.99 meters	Periodic patrols to ensure dykes are clear & accessible. Complete urgent mitigative works as required.	Below Bank Full Conditions
6.0 meters	FLOOD WATCH: Regular dyke patrols and gauge level readings. Monitor conditions	The river has risen beyond its natural banks.
6.5 meters	FLOOD ALERT: Daily dyke patrols are commenced, noting all changes and marking seepage points. EOC Activation Level I Evacuation notification possible given conditions.	The river has risen beyond its banks and is on the dyke structure, but has not spilled over.
7.0 meters	Daily inspections. River bank erosion and areas of seepage/boils monitored and repaired as necessary. Evacuation order considered for all low lying areas depending on river forecast.	The level of the river is well up onto the dyke structure. Flooding areas outside of the city's dyking system.
7.57 meters	Possible declaration of local emergency 24 hour dyke patrols commenced. If conditions persist, widespread evacuation considered.	All non-standard dyking systems at risk of failure if water levels persist for several days.
8.06 meters	Larger scale flood fighting is possible on all dykes. Monitor and repair points of seepage. Final evacuation ordered.	High water is within 0.6 meters (2 feet) of crest of dykes.
8.3 meters	Flood fighting ceased emergency responders are pulled from the affected areas.	Water is at the crest of the dyke; overtopping expected. There is a high probability of dyke failures throughout the Fraser Valley.

Figure 3.5: City of Pitt Meadows Flood Response Plan for Fraser River Stages at Mission, BC (Pitt Meadows, 2013)

4.0 Vulnerability

4.1 Approach

Vulnerabilities for each risk event were estimated using flood inundation maps, aerial photographs, and land use and population information from the City's OCP. Vulnerable populations were considered as those within defined categories that experienced inundation.

The flooding extents were approximated by extrapolating the maximum water surface elevations of each risk event and projecting the surface plane horizontally against the City's 2016 Lidar surface (0.5m contours). This approach is considered to be an overview to identify the vulnerable assets – other factors such as flow velocities, duration of inundation, time of year, sediment loads, and pollution were not considered.

Dike overtopping was considered in Risk Events 1 and 2. As the river stage increases, the hazard of dike breach general increases. Dike breach, although a significant hazard, was not considered in this risk assessment. The developed flood maps are intended to give an indication of the flooding extents for each event. For the purpose of this risk assessment, the affected listed in the following sections were shown as inundated to a depth greater than 0.1 m.

High-level vulnerability was assessed for residential, commercial, industrial, institutional, and agricultural land use. Critical infrastructure was also included, such as dikes, municipal infrastructure (utilities, roads, bridges), and regional infrastructure (water, sewer, highways, rail, airports). Police, fire, and ambulance emergency services were not found to be vulnerable to inundation under the risk events.

4.2 Residential, Commercial, Industrial and Institutional

The urban area in Pitt Meadows is higher in elevation that most of the surrounding flood plain. Risk Event 3 had little effect on the residential, commercial, industrial and institutional land uses compared to Risk Events 1 and 2, summarized in **Table 4.2**. The number of people affected were estimated based on 2.6 people per housing unit. The commercial areas affected included both the Meadowtown and Meadow Vale Shopping Centres. The City's public schools would not be directly affected under Risk Events 1 and 3. However, under Risk Event 2, the Edith McDermott Elementary school will be inundated. The City's main industrial area along Airport Way will only be affected under Risk Events 1 and 2. Although the Pitt River Quarries appears to be elevated above the inundated depth, it would be isolated without accessibility under Risk Events 1 and 2.

Table 4.2: Residential, Commercial, Industrial and Institutional Vulnerability

Affected	Risk Event 1 – Fraser Freshet	Risk Event 2 – Fraser Freshet (2100)	Risk Event 3 – Storm Surge
Housing Units	5,850	6,250	590
People	15,195	16,250	1,530
Commercial/Industrial (floor area)	11.3 ha	11.3 ha	-
Institutional	-	1 school	-

4.3 Agricultural

The farms in Pitt Meadows are the most vulnerable under all three risk events as shown in **Table 4.3**. Based on the inundation maps, the Risk Events 1 and 2 would cause approximately 5,700 ha of flooding in Pitt Meadows. Although, Risk Event 2 would likely be more damaging due to deeper flooding. Risk Event 3 would also include significant inundation in the low lying areas – although shallow in depth, the inundation may also be damaging to farm land. The vulnerability did not consider types of agriculture (livestock, berries, greenhouses, dairy, etc.).

Table 4.3: Agricultural Vulnerability

Affected	Risk Event 1 – Fraser Freshet	Risk Event 2 – Fraser Freshet (2100)	Risk Event 3 – Storm Surge
ALR Affected (hectares)	5,700 ha	5,700 ha	2,900 ha

4.4 Diking System

ISL reviewed the potential for the diking system to be overtopped under the flood scenarios. Under the Risk Events 1 and 2, wide spread overtopping is projected.

Table 4.5: Diking System Vulnerability

Affected	Risk Event 1 – Fraser Freshet	Risk Event 2 – Fraser Freshet (2100)	Risk Event 3 – Storm Surge
Diking System	9 km	50 km	-

In addition to overtopping, ISL consulted Thurber Engineering Ltd. to provide geotechnical engineering input regarding the existing diking system with respect to seepage, settlement, and stability. Thurber's review was limited to a desktop study of available information. Thurber's review has been summarized in **Table 4.4**.

Table 4.4: Existing Diking Considerations

Design Consideration	Existing Diking System Considerations
Seepage	• Area 2 and 3 dikes may have been raised with poorly graded sand. This portion of the fill could be susceptible to piping.
Settlement	• Dikes are likely undergoing long term secondary compression settlement and could be settling in the range of 2mm/year to 5mm/year.
Stability (Seismic and Non-seismic)	• Standard dikes are anticipated to be generally stable in floods. • Non-standard dikes in Areas 1 and 4 have higher risk of not meeting non-seismic targets for stability factor of safety. • Dikes are anticipated to be underlain by sand. Under the 1 in 2,475 year return period earthquake, extensive liquefaction sand is anticipated. • Ground improvements may be required to meet the displacement criteria for the 1 in 475 year return period earthquake and likely required for the 1 in 2,475 year return period earthquake.

4.5 Municipal Infrastructure

Pitt Meadows key infrastructure is exposed under Risk Events 1 and 2. Municipal buildings (City Works Yard), drainage infrastructure, sanitary infrastructure, potable water infrastructure, and municipal transportation were reviewed. Only above ground infrastructure was considered for the vulnerable inventory (pump station, pressure reducing valve (PRV) stations, etc.). However, potable water would likely be compromised in the event of flooding due to loss of sanitation. Collector and arterial roads were reviewed in the vulnerability assessment. Risk Event 3 would likely result in some localized flooding to arterial and collector roads but would not hinder accessibility for extended durations.

Table 4.6: Municipal Infrastructure Vulnerability

Affected	Risk Event 1 – Fraser Freshet	Risk Event 2 – Fraser Freshet (2100)	Risk Event 3 – Storm Surge
Drainage Pump Stations	6 pump stations	6 stations	-
Sanitary Lift Stations	7 lift stations	7 lift stations	-
Potable Water (PRVs)	5 PRVs	5 PRVs	-
Transportation - Roads	27.8 km	36.1 km	-
Transportation - Bridges	5 bridges	5 bridges	-

4.6 Regional Infrastructure

Canadian Pacific (CP) Railway has an intermodal terminal (Vancouver Intermodal Terminal) in Pitt Meadows which is vulnerable under Risk Events 1 and 2. Under Risk Events 1 and 2, most of Highway 7 (Lougheed Highway) will be inundated. Metro Vancouver infrastructure, including the Maple Ridge Booster Station, Chlorination Station and Baynes Road Pump Station will be affected. Hydro substations and telecommunications and gas were not included in the inventory. The Pitt Meadows Airport would be affected by all three risk events.

Table 4.7: Regional Infrastructure Vulnerability

Affected	Risk Event 1 – Fraser Freshet	Risk Event 2 – Fraser Freshet (2100)	Risk Event 3 – Storm Surge
Metro Vancouver Potable Water	2 buildings	2 buildings	-
Metro Vancouver Sanitary Sewer Pump Station	1 building	1 building	-
Lougheed Highway (MOTI)	5.2 km of highway	5.2 km of highway	-
Pitt Meadows Regional Airport	1 airport	1 airport	1 airport
Canadian Pacific Railway	2.7 km	5.7 km	-
Canadian Pacific Vancouver Intermodal Terminal	1 facility	1 facility	-

5.0 Economic Loss Estimates

The economic losses for each risk event were estimated. To align with the regional context, the Fraser Basin Council report by NHC was referenced where possible to obtain loss estimate values.

The NDMP RAIT categories were followed in the estimation of losses. The loss section of the asset inventory included the following for the affected critical assets:

- Key asset-related information;
- Location and size;
- Structure replacement costs;
- Content value;
- Displacement costs;
- Rating rationale;
- Vulnerability rating;
- Average daily cost to operate; and
- Total estimated value of physical assets.

The loss estimates focused primarily on direct losses of structure damage repair and replacement costs of the vulnerable populations and displacement costs for the affected population. Indirect costs that would be experienced, such as: debris cleanup, business shut downs and disruption, contaminated systems, were not accounted for in this risk assessment. However, indirect loss estimates for agricultural damage was included to be to be consistent with the ongoing regional loss estimates prepared by NHC for the Fraser Basin Council.

For the Pitt Meadows Flood Hazard Risk Assessment, economic loss estimates were largely based on the NHC report and Natural Resource Canada (NRCan) published loss estimates, using the approximated inundation depths of vulnerable populations. The NRCan values mostly pertain to direct damage to repair and replace buildings and contents. NRCan has developed depth-damage curves which were referenced for this assessment. Generally, the damage due to flooding will be more extensive as the depth increases. For this high-level loss estimate, the depth at which the damage was maximized was used as the unit cost for each building type.

For infrastructure such as rail, highways, and regional based, ISL used replacement costs from the NHC report for the Fraser Basin Council.

For building types and infrastructure not included in NRCan depth-damage relationships, the structure replacement costs were estimated by the project team experienced in design and construction of similar structures in the City or in nearby municipalities. NRCan also provided the basis for displacement periods.

Consequence ratings were developed using the below rationale.

- **High** - inundation depths > 1.0m; 60-100% of asset class affected; provincial/national impact; may affect accessibility, evacuation required
- **Medium** - indundation depth > 1.0m; 30-60% of asset class affected; regional impact; significant disruption; rehabilitation/replacement required
- **Low** - indundation depth 0.1m < d < 1.0m; 0-30% of asset class affected; local impact; minimal disruption and/or rehabilitation required

The completed RAIT asset inventories can be found for each risk event in the appendices. **Table 5.2** displays the loss estimates for each risk event with specific assumptions to the calculations made.

Table 5.2 Approximate Damage and Loss

Asset Type	Quantity Affected			Displacement Estimate (ppl)			Structure Replacement Cost ($/unit)	Content Value ($/unit)	Average Daily Cost to Operate ($/day)	Corresponding Loss Estimates (Million $)			Assumptions
	Risk Event 1 (Fraser Freshet)	Risk Event 2 (Fraser Freshet + CC + SLR)	Risk Event 3 (Storm Surge)	Risk Event 1 (Fraser Freshet)	Risk Event 2 (Fraser Freshet + CC + SLR)	Risk Event 3 (Storm Surge)				Risk Event 1 (Fraser Freshet)	Risk Event 2 (Fraser Freshet + CC + SLR)	Risk Event 3 (Storm Surge)	
Residential (low, medium and high)	5,850 housing units 15,195 people	6,250 housing units 16,250 people	590 housing units 1,530 people	15,195 / 2 = 7,600	16,250 / 2 = 8,125	80	$300,000[3]	$100,000 [3]	$25[3]	$208.2	$222.5	$2.4	• 2.6 people/housing unit • Long term displacement for inundated residents only. In reality, Risk Event 1 and Risk Event 2 could see the majority of residents evacuate the City for an extended period (> 4 weeks). • 5% of estimated structure and content for inundated housing units • 50% of people find shelter not requiring paid accommodation[1] • Displacement estimated at 240 Days[1] at $50/p/day • Damage curve used at maximum damage 1.0m depth ($2,500/m^2) • For Risk Event 3, 5% of flooding population assumed to require accommodation[3]
Commercial/Industrial/Insitutional	11.3 ha building space	13.7 ha building space	-	-	-	-	$0.01[1]	$0.15[1]	-	$27.1	$32.9	-	• Estimated area from aerial photographs; ground floor only • Damage curve used at maximum damage 2.5m depth ($100/m^2) • Edith Mcdermott Elementary school inundated
Agricultural	5,700 ha ALR	5,700 ha ALR	2,900 ha ALR	-	-	-	$15,200[2]	-	-	$85.1	$85.1	$4.4	• Structure replacement is estimated to cover lost gate sales; damage to equipment; damage to buildings; and replanting loss • Risk Event 3, 10% of estimated damage cost of total amount
Municipal Critical Buildings (City Hall, Works Yard, Police Station, Fire Hall, Hospital)	1 works yard	1 works yard	-	-	-	-	$2,500,000[2]	-	-	$4.0	$4.0	-	Content value is included in the replacement cost. Amount estimated with City staff.
Municipal (Pitt Meadows) Drainage (Pump Stations)	6 pump stations	6 pump stations	-	-	-	-	$5,000,000[3]	$1,000,000[3]	$100[3]	$9.1	$9.1	-	Content value to cover electrical mechanical equipment; no/limited damage to u/g
Municipal (Pitt Meadows) Sanitary Sewer (Lift Stations)	7 pump stations	7 pump stations	-	-	-	-	$600,000[3]	$100,000[3]	$25[3]	$1.3	$1.3	-	Content value to cover electrical mechanical equipment; no/limited damage to u/g
Municipal (Pitt Meadows) Potable Water (PRVs)	5 PRVs	5 PRVs	-	-	-	-	$300,000[3]	$100,000[3]	$25[3]	$0.26	$0.26	-	Content value to cover electrical mechanical equipment; no/limited damage to u/g
Diking System	9 km overtopped dikes	50 km overtopped dikes	-	-	-	-	$5,000[2]	-	-	$45.0	$250.0	-	Total replacement unlikely; overtopped dikes require $5,000/m of repair/ rebuilding
Regional (MV) Potable Water (Chlorination Analyzer, Maple Ridge Pump Station)	2 buildings	2 buildings	-	-	-	-	$6,000,000[3]	$4,000,000[3]	$100 [3]	$10.0	$10.0	-	50% of building costs require upgrades
Regional (MV) Sanitary Sewer (Baynes Road Pump Station)	1 building	1 building	1 building	-	-	-	$6,000,000[3]	$4,000,000[3]	$100 [3]	$5.2	$5.2	$0.5[3]	50% of building requires upgrades
Municipal Transporation (Collector and Arterial Roads, Bridges)	5 bridges; 27.8 km road	5 bridges; 36.1 km road	13.0 km road	-	-	-	$500,000/km $1,000,000 / bridge [3]	-	-	$18.9	$23.1	$1.3	Repairs to bridges required; collector and arterial roads requiring repairs (0-10 years)
Provincial (MOTI) Transportation (Lougheed Highway)	5.2 km of Lougheed Highway	5.2 km of Lougheed Highway	-	-	-	-	$12,500,000[2]	-	-	$65.0	$65.0	-	
Airport (Pitt Meadows Regional Airport)	1 Airport	1 Airport	1 Airport	-	-	-	$3,200,000[2]	-	-	$3.2	$3.2	$0.32	• Content value is included in the replacement cost • 10% used for Risk Event 3
Rail (Canadian Pacific Rail)	2.7 km of CP Rail	5.7 km of CP Rail	-	-	-	-	$1,900,000 (2)	-	-	$5.2	$10.8	-	Total replacement unlikely; spot repairs likely required
Vancouver Intermodal Terminal (Canadian Pacific Rail)	1 Facility	1 Facility	-	-	-	-	$3,300,000 (2)	-	-	$1.7	$3.3	-	• 50% of estimated replacement cost for Risk Event 1 • 100% of estimated replacement cost for Risk Event 2
										$489.3	**$725.8**	**$8.4**	

[1] *Canadian Guidelines and Database of Flood Vulnerability Functions Draft (Natural Resources Canada; Public Safety Canada, March, 2017)*
[2] *Lower Mainland Flood Management Strategy Project 2: Regional Assessment of Flood Vulnerability (April 25, 2016)*
[3] *Estimated by the Project Team*

6.0 Conclusions and Recommendations

6.1 Conclusions

1. There are a number of flood hazards in Pitt Meadows and the City is vulnerable to flooding based on the three risk events explored. Risk Events 1 and 2 are expected to generate costly floods that would likely affect the region. Risk Event 3 would be costly and disruptive to the City. The flood hazard risk assessments completed to date for Pitt Meadows and the region warrant significant improvements to flood mitigation programs and flood protection systems.
2. The urban area is elevated and would not be significantly inundated under the risk events. However, under Risk Events 1 and 2, the urban area would be landlocked and residents would likely be evacuated for an extended period of time. The displacement due to this isolation was not included in the loss estimates.
3. Future land use was not considered – although the City is largely within the ALR and land use change is regulated, this may become a factor in loss estimates. Particularly for longer term (Risk Event 2) hazards.

Thurber Engineering provided the high-level assessments of the project area diking system, the following conclusions are offered with respect to the dikes.

4. The City's dikes are deficient by the current design flood elevations and are likely to have poor seismic performance due to liquefaction and displacement for seismic return periods of 1 in 475 year and 1 in 2,475 year design earthquakes.
5. Dike upgrades to both standard and non-standard may require upgraded seepage control measures under the current design flood or future higher design floods.
6. Overbuilding dikes may be required to compensate for settlement.
7. Stability modifications could be appropriate for dikes where non-seismic stability is a concern. Upgrades could include constructing toe berms on the landside of the dike or installing a seepage cut-off and filter within the dike.
8. Seismic stability due to liquefaction and displacement for return periods of 1 in 475 year and 1 in 2,475 year.
9. The higher dikes (Area 2 and 3) and riverside dikes are anticipated to have poorer seismic performance due to deeper riverbanks and river channels.

Of the other known flood hazards, dike breaching due to flood or earthquake are considered to be high priority for further exploration.

6.2 Recommendations

1. The City should consider applying for NDMP Stream 2 – Flood Mapping program funding. Outcomes from Stream 2 may include the below.
   a) Hazards maps that include velocities, depths and land use.
   b) Detailed economic loss estimates. This may also include a GIS-based modelling, such as the Hazus (or similar) to estimate the economic loss.
   c) Additional stakeholder discussions (where the parties are available) that may add value to any future flood mitigation initiatives.
2. ISL recommends undertaking a more detailed geotechnical assessment of the City's diking system. The City may consider starting with Area 3, as the dikes are of highest consequence and protect the largest population. The assessment should include a structural assessment of the dikes and offer potential upgrade options.
3. Large scale structural projects such as raising the perimeter dikes may not be practical in the short or medium term. The following smaller-scale projects may add value to the City's existing flood hazard mitigation measures.
   a) River stage gauges (upstream) and warning systems. Installation of supervisory control and data acquisition (SCADA) integrated level gauges at key locations along ditches, sloughs, and rivers.
   b) Backup power for the drainage pump stations. The City's drainage pump stations are critical infrastructure and in the event of power outage, the drainage system relies on floodboxes to drain. Backup power would likely consist of diesel generator sets at each pump station.
   c) Localized dike upgrades – likely an output from the detailed geotechnical review and may require property acquisition. Legal survey of the property lines parallel to the diking system may also be an asset for planning and design purposes.
4. The City should develop a Flood Mitigation Strategy – the strategy may follow the priority of dike assessments. Risk mitigation measures outside of structural protections measures exist. Below are common generalized examples of risk mitigation.
   a) Provide protection against flood risks (dikes). This could also include increasing the building elevations using structural fill to an elevation that is considered low risk to flood hazards.
   b) Land use planning. Rezone land use out of higher risk areas – typically the critical infrastructure would be located in low risk areas. This also is considered in planning – new developments and infrastructure consider these areas prior to building.
   c) Education/Tolerable risk. Established through public consultation how much risk can be tolerated by stakeholders.
   d) Emergency planning – improve warning systems and planning. Emergency planning may also include interim structural improvements – such as using inflatable bladder (water) dams to temporarily raise the dike in lower dike areas or high consequence land use areas.