Investigations in Support of Flood Strategy Development in BC

ISSUE B-2: FLOOD HAZARD INFORMATION

Final Report

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FINAL REPORT

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- Neil Peters (Senior Flood Management Specialist)
- David McLean (Senior Reviewer)
- Monica Mannerström (Project Manager and Technical Lead).

EXECUTIVE SUMMARY

The **Investigations in Support of Flood Strategy Development in British Columbia** is a province-wide initiative aimed at developing a comprehensive understanding of current challenges and opportunities relating to flood management across BC. The BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (BC MFLNRORD) retained the Fraser Basin Council (FBC) to manage and coordinate research and engagement across a broad range of flood management issues relating to governance, hazard and risk management, forecasting, and emergency response and recovery. Consulting teams were retained to undertake research and technical analysis with input from specialists, practitioners, and stakeholders from all four orders of government, the private sector, and other organizations. Each investigation produced recommendations to inform flood management program improvements at multiple scales and across many jurisdictions.

This report summarizes the Fraser Basin Council project "Investigations in Support of Flood Strategy Development in BC" as related to the B-2 issue: "Flood Hazard Information". The purpose of the investigation is to examine the state of floodplain mapping and dike deficiency information in BC and recommend approaches to manage this information and address knowledge and mapping gaps. As defined in the terms of reference, the focus of the project is on detailed floodplain mapping, as required for flood regulation and mitigation planning. Key investigations of the B-2 issue are:

- **B-2.1** Investigate the current state of flood mapping in the province, including gaps and limitations.
- **B-2.2** Recommend an approach to improve the spatial coverage, quality, utility and accessibility of flood hazard maps and other flood hazard information. Investigate the approximate level of effort to prepare flood hazard mapping to address current gaps for existing communities and future areas of development (including floodplain maps and channel migration assessments).
- **B-2.3** Investigate the current state of knowledge related to dike deficiencies and recommend an approach to improve the quality, consistency, review, utility and accessibility of this information.
- **B-2.4** Investigate the status of LiDAR standards for flood mapping and develop recommendations to improve standards if applicable.

The project developed comprehensive summaries of flood hazard information in BC and led to a series of concrete recommendations to improve the knowledge and understanding of flood related issues. Recommendations are listed in Appendix F.

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ABOUT THIS INITIATIVE

Many communities in BC are working to better manage their river and coastal flood risks through a wide range of flood management activities. But current approaches to managing flooding are not always efficient, coordinated, equitable, or cost-effective.

The **Investigations in Support of Flood Strategy Development in British Columbia** is a province-wide initiative aimed at developing a comprehensive understanding of current challenges and opportunities relating to flood management across BC. The focus is primarily on riverine, coastal, and ice jam floods, although other types of flooding are recognized where appropriate. This initiative recognizes that flood management is a multi-faceted, ongoing process requiring the coordination of many organizations, agencies, and orders of government and linked with broader processes, including climate change adaptation and disaster risk reduction, among others.

The BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development retained the Fraser Basin Council to manage and coordinate research and engagement across a broad range of flood management issues relating to governance, hazard and risk management, forecasting, and emergency response and recovery. Consulting teams were retained to undertake research and technical analysis with input from experts, practitioners, and stakeholders from all four orders of government, the private sector, and other organizations. Each investigation produced recommendations to inform flood management program improvements at multiple scales and across many jurisdictions.

Investigations were undertaken across 11 interrelated issues under 4 themes:

Project Investigations

Theme A – Governance		
A-1	**Flood Risk Governance**	Review current governance and delivery of flood management activities in BC involving all four orders of government and non-government entities, identify challenges, and recommend changes to improve coordination, collaboration, and overall effectiveness.

Theme B – Flood Hazard and Risk Management		
B-1	**Impacts of Climate Change**	Investigate the state of climate change information and new and existing tools that can support authorities in integrating climate change impacts in flood management.
B-2	**Flood Hazard Information**	Examine the state of flood mapping and dike deficiency information and recommend ways to fill current gaps in flood mapping and manage and maintain information about flood hazards and dike deficiencies.
B-3	**Flood Risk Assessment**	Explore approaches to completing flood risk assessments at various scales, methods for prioritizing risk reduction actions, and standards- versus risk-based approach to flood management.
B-4	**Flood Planning**	Examine the ability of local authorities to undertake integrated flood management planning and opportunities to improve capacity.
B-5	**Structural Flood**	Assess the potential for improvements to dike management,

	Management Approaches	improve the capacity of diking authorities, and implement innovative structural flood risk reduction measures.
B-6	**Non-Structural Flood Management Approaches**	Investigate current and alternative approaches to managing development in floodplains and opportunities for implementing non-structural flood risk reduction actions.

Theme C – Flood Forecasting, Emergency Response and Recovery		
C-1	**Flood Forecasting Services**	Identify gaps and opportunities for improvement in the province's flood forecasting services.
C-2	**Emergency Response**	Investigate roles, plans, and capabilities for flood response and opportunities for improving emergency response.
C-3	**Flood Recovery**	Examine approaches that would support recovery efforts and help reduce future flood risk.

Theme D – Resources and Funding		
D-1	**Resources and Funding**	Investigate resource and funding needs associated with actions to strengthen flood management and evidence in support of proactive flood mitigation.

1 INTRODUCTION

1.1 Project Description

This report summarizes the Fraser Basin Council project “Investigations in Support of Flood Strategy Development in BC” as related to the B-2 issue: “Flood Hazard Information”. The purpose of the investigation is to examine the state of floodplain mapping and dike deficiency information in BC and recommend approaches to manage this information and address knowledge and mapping gaps. As defined in the terms of reference, the focus of the project is on detailed floodplain mapping, as required for flood regulation and mitigation planning. It is recognized that other types of flood maps are also produced in BC and these are briefly described. Key investigations of the B-2 issue are:

- **B-2.1** Investigate the current state of flood mapping in the province, including gaps and limitations.
- **B-2.2** Recommend an approach to improve the spatial coverage, quality, utility and accessibility of flood hazard maps and other flood hazard information. Investigate the approximate level of effort to prepare flood hazard mapping to address current gaps for existing communities and future areas of development (including floodplain maps and channel migration assessments).
- **B-2.3** Investigate the current state of knowledge related to dike deficiencies and recommend an approach to improve the quality, consistency, review, utility and accessibility of this information.
- **B-2.4** Investigate the status of LiDAR standards for flood mapping and develop recommendations to improve standards if applicable.

The project primarily considers flood hazards from high river, lake and ocean levels and briefly discusses hazards stemming from channel migration and bank erosion. In BC, riverine flood events have historically been the most severe and costly, however surface run-off flooding from heavy rains is becoming more of a concern with climate change impacting rainfall intensity (King-Scobie, 2019). Flooding from geo-hazards (including debris floods and debris flows), dam failures, tsunamis or groundwater were not considered in the scope of this investigation. Secondary hydrogeomorphic processes often resulting from flooding, such as bank erosion, avulsion, scour and sediment deposition are noted as important considerations but are not described in detail.

1.2 Historical Project Context

In this report, flood hazard is defined as a potentially damaging flood event that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation. Flood hazards are typically summarized on floodplain maps that display information such as the estimated extents of flooding, water depths, water velocities, flood duration or other related information.

Flood management in BC has typically been prompted by large flood events, such as the 1948 Fraser River flood which led to the *Dike Maintenance Act* and Fraser River Flood Control Program. Similarly, the high snowpack and subsequent province-wide flooding in 1972 led to floodplain development legislation and a floodplain mapping program. The Province started the mapping work in 1974 and then entered into a joint federal-provincial floodplain mapping agreement from 1987 to 2003. The program was initiated to map flood hazards corresponding to 20 and 200-year return period (5% and 0.5% Annual Exceedance Probability respectively) riverine floods in population centres, primarily along rivers and lakes, with the purpose of setting Flood Construction Levels (200-year flood plus a freeboard allowance) for development permitting and to assist with flood emergency planning and response. Following technical review and approval of the maps by a joint steering committee, the mapped floodplain areas were officially designated by both federal and provincial ministers. The designations committed government departments and agencies from both levels of government to apply a number of floodplain management policies within the newly mapped areas. The mapping agreement (and designation policies) expired in 2003.

This early mapping program followed a consistent set of technical specifications and was led by the provincial government (Environment and Parks). To start, maps were developed internally by the Ministry of Environment and Parks but beginning in the late 1980's, engineering consultants were retained to do the analyses under the provincial government's guidance and review. However, all bathymetric surveys were carried out by the provincial survey team. Floodplain topography was based on air photography and typically 2 m contour-interval maps with spot heights. None of the data was digitally georeferenced. Hydrology estimates, based on records available at the time, were often completed by the government in-house team. Flood Construction Level (FCL) isolines were drawn manually. Overall, the maps were of high quality and served communities well for identifying their 200-year floodplain. The final maps under the program (Thompson Rivers at Kamloops) were completed in 2003.

Following the Flood Hazards Statutes Amendment Act (2003), the Ministry of Environment no longer approved floodplain subdivisions, bylaws, or variances and the responsibility was devolved to local governments (except the Ministry of Transportation retained subdivision approval authority in rural areas). This led to only a few floodplain maps being completed. The studies carried out were largely in response to severe flood events, for example the Prince George floods in 2007-2008, the Cowichan Valley flood in 2009 and the Alouette Rivers in Maple Ridge following the flood of 2007. These more modern maps used georeferenced survey data, incorporated updated hydraulic modelling software, in some cases using linked 1D and 2D models, and maps were developed using GIS, typically with orthophoto backgrounds. An updated Fraser River design flood profile (Hope to the Pacific Ocean) was developed in stages from 1999 to 2014, but official floodplain mapping for the valley was not produced.

More recently, several funding programs have been established that municipalities, regional districts and First Nations can apply for to develop floodplain maps. They include:

- The National Disaster Mitigation Program (NDMP), a five-year $200 million cost-shared program established in 2015 to reduce the impacts of flooding. (It was managed by Emergency Management BC - EMBC but has now concluded in the form it was first initiated.)
- The Community Emergency Preparedness Fund (CEPF), managed by the Union of BC Municipalities (UBCM). With $69.5 million funded (from inception to May 2019) by the Province of British Columbia, it is intended to enhance the resiliency of local governments,

First Nations and communities responding to emergencies (these funds are being spent on various emergency planning and structural mitigation projects, as well as flood risk assessment and floodplain mapping).

- The First Nation Adapt Program, announced by the federal government in 2016, provides $24.7 million over 5 years to identify and address climate change related impacts on infrastructure in First Nation communities.

These programs have led to the initiation of a number of recent floodplain mapping projects; however, many have not been completed to date. Whereas federal and limited provincial floodplain mapping guidelines have been developed, these are non-prescriptive and the standard of recent mapping varies. This topic is covered in more depth in Section 2.3.

Advances have been made to improve the understanding of flood hazards in BC, yet a number of gaps and limitations remain. This project provides a snapshot of current knowledge, discusses limitations and methods for improvement, including approximate effort required to achieve these. Large areas of BC are protected by dikes and understanding the status of diking is critical to flood safety. Topographic LiDAR information is an important component of flood mapping and present techniques and potential improvements are discussed.

Flood hazard assessments for private industry, such as mines, pipelines and energy companies are not considered in the present project.

2 INVESTIGATION B-2.1: CURRENT STATE OF FLOOD MAPPING

This section investigates the current state of floodplain mapping in BC and focuses on detailed floodplain maps for determining flood extents and setting Flood Construction Levels (FCLs). Map sources and available maps are presented and an assessment of general coverage, highlighting gaps, is provided. The accessibility of mapping is also addressed and available provincial and federal guidelines for developing flood maps are listed. The report then highlights common problems with specific steps in the mapping process and resulting errors. Other types of flood maps can be useful for purposes such as, high level flood hazard assessments, overview level risk assessments, debris flow assessments etc. as outlined in Section 2.5 . Included are discussions of channel migration mapping, mapping for non-standard purposes and a brief sampling of maps in other jurisdictions (Section 2.6). Recommendations for mapping improvements and the estimated effort required to implement these are described in Section 3.

2.1 Map Information Sources and Inventory

NHC developed an inventory of floodplain maps in BC (see Appendix B) using the following data sources:

- The BC provincial floodplain mapping website https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/flood-hazard-land-use-management/floodplain-mapping/floodplain-maps-by-region summarizes maps developed between 1974 and 2003 under the joint federal and provincial floodplain mapping agreement.

The site lists available maps and design briefs as summarized in Table 1 of Appendix B. For each area, the mapped water courses are identified, along with survey and map issuance dates, the availability of design briefs and if maps have been updated since originally produced. Figure 1 of Appendix B shows mapped areas, corresponding GIS and KMZ files are provided with the project deliverables. For some areas, river cross-sectional survey data is available from the provincial Ecological Reports Catalogue (EcoCat): https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/libraries-publication-catalogues/ecocat

- The BC Real Estate Association (BCREA) Floodplain Map Inventory Report covers maps developed between 2003 and 2015 https://pdf4pro.com/view/bc-floodplain-map-inventory-report-123476.html. Information available is summarized in Table 2 and Figure 2 of Appendix B, and was based on BCREA questionnaires/ interviews with municipalities. The table gives information on map type, year produced, funder, data used, accessibility and links to the maps. A few mapping studies completed by NHC during this time period but not listed by BCREA, were added to the table and included in the GIS inventory. BCREA is currently in the process of updating this summary, with completion scheduled for later this year.
- An EMBC spreadsheet summarizing flood mapping projects funded by NDMP/CEPF since 2017 as listed in Table 3 and shown on Figure 2 of Appendix B. Reports are presently not available from EMBC, however some reports were found online. The summary table includes information on project status (completed/in progress) and funding budgets. Flood risk reporting is provided in Table 4 of Appendix B.

In summary, all maps prepared under the joint federal and provincial floodplain mapping agreement were produced to a consistent high standard; detailed bathymetric surveys were completed and 1D modelling carried out. However, these maps are now out-dated.

The mapping summarized by BCREA served more diverse purposes and typically followed large flood events. The work was generally completed to a high standard.

EMBC lists 73 projects, with only 15 completed to date, six of which were carried out by NHC. Of the work undertaken by others, five had no on-line information and four reports were found on line. Of these, two corresponded to geomorphic memoranda, not incorporating detailed maps. Considering nearly $20M in grants have been provided to date, there are currently limited results readily available for review and quality assessment. The delivery and maintenance of floodplain maps is also important and requires additional funding.

The following First Nation information sources are referenced:

- In 2000, First Nations Emergency Services Society of BC, prepared a comprehensive report on flood and erosion hazards in four main areas of BC: i) West Coast and Vancouver Island; ii) Lower Fraser Valley; iii) Southern Interior; and iv) Northern Interior. The studies did not specifically develop floodplain maps but were based on flood level information available at the time.

- First Nations "ADAPT" funded projects starting in 2016 (Table 5 of Appendix B). The projects are generally not for floodplain mapping and corresponding reports were not found online. The program is First Nations driven, typically includes community involvement and has a focus on climate adaptation.
- An interview with Mr. Brent Baron of Aboriginal Affairs and Northern Development Canada (AANDC) held on 19 June 2020.

In the late 1980's and early 1990's, detailed floodplain maps were developed for some First Nations' lands in the Fraser Valley by NHC, Hay&Co and others. However, this work was based on a Fraser River flood profile from 1969 and is now outdated. Although AANDC has a library in Vancouver, these old reports are apparently not available.

2.2 Map Utility and Accessibility

Currently, floodplain mapping is the responsibility, but not a requirement, of Local Governments and First Nations, and it is the decision of these government bodies to make their mapping available to the public. A number of larger municipalities, with resources to maintain up-to-date websites provide online links to floodplain mapping studies. This is quite costly for smaller communities and First Nations.

Floodplain mapping that was completed under the NDMP and CEPF programs (except for the first CEPF intake in 2017) have funding clauses which allow the Provincial and Federal Governments full use and distribution rights of any floodplain maps or reports generated. EMBC is currently working to have the maps and reports available for emergency management within the provincial government as a first priority and then moving towards accessibility for all provincial ministries. Availability to the public is a longer-term goal. The Province is currently considering how to structure ongoing floodplain mapping as part of the BC Flood Risk Strategy, and the maps that have already been created need to be reviewed before they can be integrated into such a program. Ideally, these maps could form a part of a new provincial floodplain mapping program, although this may be challenging given the difference in standards noted in the mapping completed to date.

MFLNRORD will continue to make available historical mapping completed under the joint federal/provincial floodplain mapping agreement which expired in 2003. Ideally a single provincial agency will provide a mapping interface that allows for easy public viewing of mapping and reports, and for the downloading of geospatial data. This will require further inter-ministry planning and coordination in the future.

2.3 Flood Map Guidelines

Federal and provincial floodplain mapping guidelines have been developed in an attempt to bring some consistency to floodplain map products. The guidelines are non-prescriptive and outline best practices; it is up to engineering practitioners to ensure that accurate, high-standard maps are developed. There have been discussions to turn some federal guidelines into standards documents but these would likely need to be province-specific, considering the variation in flood hazards from province to province. Preparing actual standards would require much more detailed specifications and technical guidance than the existing guidelines. For example, the US-FEMA guidelines are very detailed, and required a large input of resources to prepare and update.

Given the very limited number of recent mapping studies available for this investigation it is difficult to assess how effective the guidelines have been in encouraging a consistent, quality product. In general, it appears that the mapping prepared following emergence of the guidelines adhere to the guidelines although variations have been noted. The quality of the mapping tends to be proportional to the project budgets available and the expertise of consultants carrying out the work.

2.3.1 Federal Floodplain Mapping Guidelines

In 2014, Public Safety Canada (PSC) retained MMM Group Ltd to prepare the report "National Floodplain Mapping Assessment – Final Report" containing general information on floodplain mapping. Natural Resources Canada (NRCan) is now leading the federal guidelines program. In 2017, AECOM developed National Principles, Best Practices and Guidelines – Flood Mapping. Other documents that have followed include:

- Federal floodplain mapping framework
- Federal hazard identification and priority setting (not yet released)
- Federal hydrologic and hydraulic procedures for flood hazard delineation
- Federal airborne LiDAR data acquisition guideline
- Case studies on climate change in floodplain mapping
- Federal geomatics guidelines for flood mapping
- Federal flood risk assessment (not yet released)
- Risk-based land-use guide: Safe use of land based on hazard risk assessment (not available from NRCan but report by this title available from Geological Survey of Canada, Open File 7772, dated 2015)
- Bibliography of best practices and references for flood mitigation

2.3.2 British Columbia Floodplain Mapping Guidelines

Fraser Basin Council issued an initial set of guidelines, "Floodplain Mapping Guidelines and Specifications" in 2004. Also in 2004, the Ministry of Water, Lands and Parks (MWLAP) developed "Flood Hazard Area Land Use Management Guidelines" which includes a brief section on floodplain mapping.

These documents were followed in 2017 by the Engineers and Geoscientists BC (EGBC) publication of "Professional Practice Guidelines – Flood Mapping in BC". The EGBC document provides professional practice guidelines for flood mapping and attempts to discourage unqualified practitioners from undertaking this type of work. The guidelines do not form a standards document. For example, the EGBC Guidelines include descriptions of best practices, roles/responsibilities, skill sets, and the quality management involved in floodplain mapping but do not specify the technical standards to be followed. A related guidelines document “Legislated Flood Assessments in a Changing Climate in BC - version 2.1”, was issued in August 2018.

For coastal floodplain maps, MFLNRO developed “Coastal Floodplain Mapping – Guidelines and Specifications” in 2011. Provincial LiDAR guidelines are discussed in Section 5.

The guideline documents will evolve as new methods and techniques are developed. For a recent floodplain mapping project in the Okanagan Valley, NHC developed a project-specific set of guidelines for mapping. A new type of mapping, showing flow velocity and direction was developed instead of traditional hazard maps (Figure 2-2). This mapping is particularly useful for flood emergency planning. As web-based mapping approaches become more common, it will be possible to display information in ways not cartographically possible on a static (pdf) map.

2.4 Detailed Floodplain Map Development

Considerable expertise is required to develop accurate, detailed mapping. Practitioners with limited experience may enter the field, potentially low-bidding to win work. Unfortunately, this may impact the quality of the mapping products. The quality of maps produced should be checked but detailed reviews have generally not been completed by the province or local governments, or remain to be completed. Only rarely are peer reviews by other consultants carried out. The main steps of detailed floodplain map development are briefly discussed below, with a focus on different approaches and common short comings. In some instances mapping approaches are based on the funding available rather than the complexity of the area to be mapped. Mapping guidelines, although useful in many respects, may not be sufficiently explicit to prevent simplifications, leading to inaccuracies in flood levels and flood extents.

2.4.1 Riverine Modelling and Detailed Mapping

Bathymetric Surveys, Topographic Data and DEMs

Accurate bathymetric surveys are critical for the overall accuracy of detailed floodplain mapping. Before bathymetric surveys are carried out, a decision should be made whether 1D or 2D hydraulic modelling will be performed, 2D models requiring more detailed data than a 1D model. Common problems are:

- LiDAR data not meeting specifications or, outdated/approximate bathymetric data are used to reduce the high cost of surveys. River channels typically convey the majority of flood flows and accurate bathymetric data is very important. LiDAR should always be flown at low flows, so that at least a portion of the channel is captured by LiDAR. Orthophotos should be collected at the same time. River surveys are not akin to ground surveys and should be completed by experienced river surveyors with appropriate instrumentation (multi- or single-beam depth sounders, RTK-GPS etc.) for the application at hand.
- High quality survey control standards are required and the data should be carefully checked. Gaps in GPS transmission, caused by bridge decks or thick vegetation can lead to errors. Also, errors in the datum may occur when converting between CGVD28 and updated 2013 datum. It is recommended that standards, or at least guidelines, be developed for bathymetric surveys.

- In developing Digital Elevation Models (DEMs) for 2D models, it is important to carefully review the surfaces developed and remove any artifacts, or software generated interpolations that do not represent actual conditions. Water-penetrating LiDAR is becoming more commonly used (Washington, Ontario and Quebec) and could revolutionize DEM development for clear and shallow water applications, reducing costs and making it easier to develop and use 2D models. There is likely potential for using this technology in BC.
- Inaccuracies in the base mapping could contribute to errors in flood extents.

Hydrology

Hydrologic analyses are carried out to estimate flood flows corresponding to different probability flows. These range from simple frequency analyses when reliable flow gauges are located within a study reach with sufficient data, to sophisticated joint probability analyses, for example when both ocean levels and river flows impact flood levels. A watershed may include storage reservoirs and flood estimates are complicated by how the reservoirs are operated. Also, flow gauges may be unavailable and regional analyses are required to estimate flood flows. Generally, hydraulic models are quite sensitive to the flood flows used and errors may lead to significant discrepancies in flood levels.

Historical large floods, without recorded flows but known to have occurred, are potentially overlooked leading to underestimated flows. In some cases, for example for the Lower Fraser River, conducting paleo-hydrologic analyses may be justified.

Climate change is likely to increase flood flows over time and EGBC guidelines recommend incorporating a minimum increase of 10% by end of the century for watersheds without current increasing trends, or 20% if trends are detected. Referring to simple application of these factors as a climate change analysis is misleading and does not account for a range of uncertainties, such as variability in greenhouse gas emissions. A comprehensive climate analysis is complex work, typically completed by climate scientists with access to sufficient budgets. (See report for issue B-1: Impacts of Climate Change).

Geomorphic Assessments

Geomorphic assessments may involve documenting past channel locations based on historic air photography, review of stage-discharge curves at stream gauges and a multitude of field work and sediment transport analyses. They provide important information on setting building setback requirements.

Flood mapping guidelines recommend that geomorphic assessments be carried out to assess the potential changes a river may undergo either over time or in response to a large flood. The work undertaken is a function of the river geomorphology and its sediment supply. Potential channel changes include bank erosion, avulsions, channel migration and aggradation/degradation. All these alterations may have major impacts on flood extents and levels, for example when defining flood extents on alluvial fans, where sudden channel relocations may occur. The work requires qualified geomorphologists with extensive professional judgement and experience.

Floodplain maps provide a 'snap-shot' in time, showing estimated flood levels at the time of the river/floodplain survey. A geomorphic assessment provides input on potential future changes and how these may impact flood levels as well as related erosion hazards.

The assumption that end-of-century climate conditions can be modelled with any kind of accuracy using present channel/floodplain configurations is flawed. Both sea level rise and increased flood flows will impact the channel geometry and planform, not to mention development in a floodplain. Sediment deposition patterns may also change over time for tidally influenced rivers, as the tidal influence on river flow velocities extends upriver due to sea level rise (Cadwick et al 2020, Moftakhari et al 2017, Ericson et al 2006, Parker and Muto 2003). Consequently, the estimated future flood levels are likely to be very approximate, even if the adopted climate change and sea level rise scenarios prove to be realistic.

A river's sediment load and rate of planform change are important factors that govern how soon flood maps need to be updated. Therefore, the geomorphic studies should be used to estimate when surveys and hydraulic models will need to be updated and to define monitoring programs for assessing long-term trends in channel characteristics. For example, the recently developed Lillooet River floodplain maps will likely need updating in about 5 years rather than the more standard 10 years due to the very large amount of sediment moving through the system from the Capricorn landslide.

Hydraulic Modelling

Historically, all floodplain maps were developed using 1D hydraulic modelling. Only in the last few years, has computing power improved sufficiently to allow 2D modelling of long river reaches. A 2D model requires high density geometric data, is generally more challenging to develop, trouble-shoot and calibrate but allows water level differences to be simulated perpendicular to flow. As cross-sectional variations in flood levels can be significant, they are often important to consider. Although the effort and costs are greater than 1D modelling, a 2D model will often provide more accurate and detailed results for complex channels and floodplains.

A 2D software with a proven track record for flood hazard modelling, such as HEC-RAS2D, TELEMAC2D, MIKE21 and TUFLOW should be used. Factors to consider include software cost, execution speed, user interface, treatment of hydraulic structures, suitability for dike breach modelling, code documentation, mesh type and technical support. For large important projects, developing test models using different software models may be warranted to determine which performs the best. For example, test HEC-RAS2D and TELEMAC2D models were developed for the Lower Fraser River 2D model. Following careful evaluation, the HEC-RAS2D software was selected, primarily for the ease of modelling dike breaches. Many applications require dike breach modelling and software capable of modelling overtopping or foundation failure mechanisms may be required.

The importance of accurate model calibration data at high flows, particularly approaching design conditions, cannot be emphasized enough. Often sufficient observed flow and water level data is a major challenge as many streams do not have a recorded history of these. In addition, channel/floodplain configurations and flow regimes may have changed due to a variety of factors that may skew historical floods. Where ever a large flood occurs, measuring flows and documenting water levels should be a routine procedure.

Dike Breach Modelling

Flood control dikes have been built along many rivers in BC but may breach for different reasons. With approximately 1,100 km length of diking (over 200 individual dikes) it is estimated that at least three-quarters of all people who live in BC floodplains are in areas protected by dikes. To model flood levels behind dikes, breach modelling should typically be carried out. Since dikes may breach at any point, a multitude of breaches may be required and a composite dike breach flood map developed, particularly for high consequence areas. (Composite mapping depicts the maximum flood level for a particular floodplain location, caused by a multitude of different breaches at various locations). Traditionally, maps developed through the Province of BC extended river flood levels outside dikes, horizontally across the floodplain without consideration of potential ponding resulting in higher flood levels, or lower levels from the hydraulic head-loss through a breach.

Areas protected by high consequence or major dikes are typically of high value and 2D breach modelling should routinely be performed. An example of such maps is recent work prepared for City of Chilliwack by NHC (2019a) as shown in Figure 2-1. Sophisticated hydraulic modelling, often involving simulating a range of dike failure scenarios, is required.

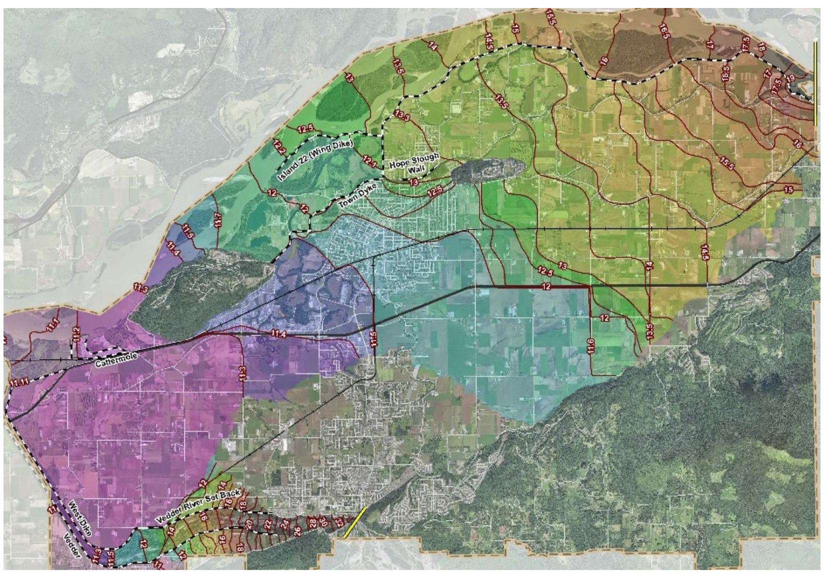

Figure 2-1 Sample composite dike breach mapping – City of Chilliwack

Special Considerations: Ice, Debris and Other Blockages

In some areas of BC, the most extreme flood levels are caused by frazil ice during freeze-up or by ice-jams during break-up. Flood levels corresponding to ice flooding can be significantly higher than open-water flooding, e.g. Nechako River at Prince George. Expertise in ice-engineering is required and typically a Monte Carlo modelling approach is adopted. In-depth assessments take considerable effort.

In rivers with woody debris, debris blockages may form, particularly at bridges or other channel constrictions. Some channel sections may be prone to large temporary sediment deposits, also raising flood levels. Such increases can be difficult to model and often reliance is put on historic observations. Overly conservative assumptions may lead to unrealistic, or higher than actual, flood levels.

Map Development

Once all data on dimensions, elevations and the shape of the river/ocean and floodplain has been compiled; flood flows estimated; and, the hydraulic model developed, calibrated and floods simulated; developing the detailed floodplain maps in GIS is relatively straightforward. Generally, the model output can readily be applied for mapping, except for adding freeboard which requires additional effort. At a minimum, three types of maps should preferably be developed, four where dike breach modelling is appropriate:

- Maps showing flood extents including freeboard and FCL isolines for the design (usually 200-year) flood. However, some communities may choose to map larger magnitude floods. This could be especially relevant in areas with significant exposure and vulnerability to flood-related consequences.
- Flood depth maps (no freeboard) for a range of different probability flows. (Modelling and mapping additional flood scenarios could support a risk-based approach to flood management.)
- Flood hazard severity maps (no freeboard) indicating the product of (velocity) x (depth) or depth-velocity direction and magnitude maps (Figure 2-2).
- If multi-breach modelling was completed, then composite mapping should be generated.

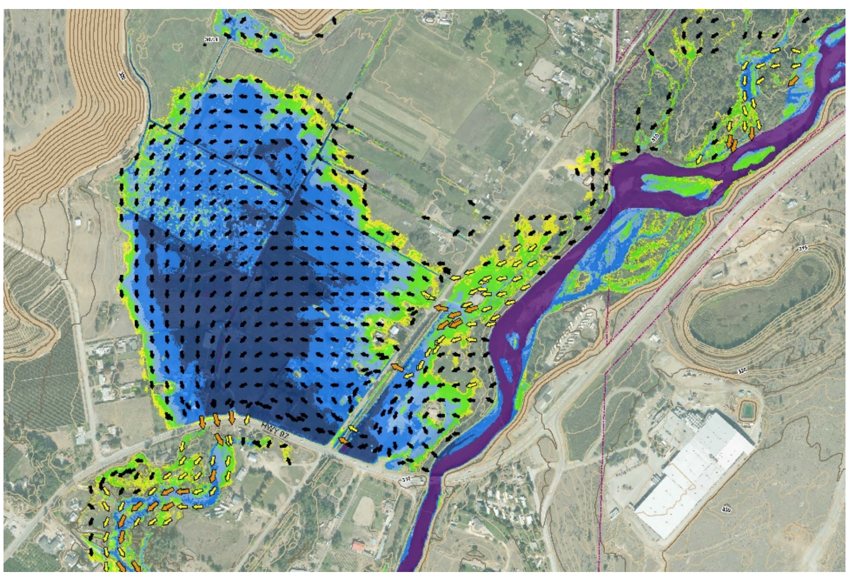

Figure 2-2 Sample depth-velocity direction and magnitude map (https://okanagan-basin-flood-portal-rdco.hub.arcgis.com/)

Freeboard

It is accepted practice in BC that a freeboard allowance be added to the design flood level in order to account for uncertainties associated with estimating the hydrologic/hydraulic parameters and other discrepancies. An additional allowance can be included to account for effects such as wave runup.

Freeboard can be viewed as the equivalent to a safety factor - a building would not be designed without a safety factor and similarly flood construction levels should incorporate a freeboard allowance. The amount of freeboard and whether it is shown on flood maps or incorporated in some other manner is up for discussion. Two approaches are described below.

Traditional Approach

Traditionally in BC, a fixed freeboard has been added to the computed 200-year flood (or flood of record) level to estimate the Flood Construction Level, adding 0.6 m to the water levels computed for the 200-year mean daily discharge or 0.3 m to the water levels computed for the 200-year maximum instantaneous discharge, adopting the higher of the two. More recently, a freeboard of 0.6 m has commonly been applied to most rivers and coastal areas. There is little information available explaining the justification for these values.

Freeboard allowances in other jurisdictions vary, for example:

- In Germany, the lowest allowable freeboard value is 0.8 m and can go up to 1.5 m to protect populated areas. A variety of sophisticated methods are used for computing the design discharge, water surface elevation and freeboard.
- In Hungary, a fixed value of 1.0 m or 1.5 m is added to the design flood water surface elevation, depending on wave conditions and potential for erosion to the dikes.
- In Japan, the freeboard increases with the magnitude of the design discharge. For small streams (flows less than 200 m^3/s) the minimum freeboard is 0.6 m. For large rivers (flows greater than 10,000 m^3/s), a freeboard of 2.0 m is used.

The BC usually adopted value of 0.3 to 0.6 m appears to be at the lower range, particularly for highly developed urban areas, as also concluded by BGC and Ebbwater (2017).

Uncertainty Approach

An uncertainty approach to freeboard is becoming more common in other jurisdictions, estimating the uncertainty of the predicted water levels by assessing factors such as limitations of estimating flood frequencies from relatively short hydrological records, uncertainties in computing flood levels due to limitations from hydraulic modelling, limitations in estimating channel roughness under design flood conditions, and accounting for morphological changes and sedimentation during floods. These factors cannot be estimated deterministically and are inherently random in nature.

Uncertainty analysis has been used in the United States since the mid-1990's by the US Army Corps of Engineers (USACE, 1996) to replace a fixed freeboard allowance. Typically, the uncertainty in water levels is based on an assessment of the accuracy of discharge, roughness and channel geometry. By quantifying error bounds on each dependant variable, the likely total error can be estimated using a

Monte Carlo simulation approach. NHC has used this approach to evaluate the reasonableness of adopting a freeboard of 0.6 m for some rivers. For example, in confined river reaches of Cowichan River, where small variations in flow and roughness result in relatively large variations in flood levels, a freeboard value of about 0.9 m would be more representative. Larger rivers, particularly in confined reaches, may require yet higher freeboard values. Freeboard application is further discussed in Section 3.

Williams and Griffiths (2012) listed issues that should be kept in mind when considering this approach:

1) The analysis removes hidden safety factors and lays open the assumptions of the practitioner's analysis. The practitioner then needs to make accurate and unbiased estimates of the probability of flooding and exposure, and communicate that information.
2) The analysis calls on the practitioner to openly acknowledge the uncertainty associated with a project and its performance, and to expose, quantify, and communicate that information.

2.4.2 Ocean/Lake Modelling and Mapping

The process of developing coastal flood maps comprises the definition of meteorological and oceanographic (metocean) conditions specific to an area of interest, followed by the assessment of wave interaction with the shoreline, commonly known as wave effects. The information most important for the analysis are wind measurement of long period of records, as well as detailed DEMs of the foreshore. Such DEMs need to adequately resolve the zone between the subtidal and the uplands, or the zone where wave transformation and effects occur. In many cases these zones are poorly defined given survey challenges. Surveying of the intertidal zone requires both planning and resources, whether undertaken by boat, from the air, or by foot, and often constitute the main challenge in coastal flood mapping assignments. Similar to river surveys, the LiDAR topography needs to be collected at low water (ebb tide) and bathymetry at high water (flood tide).

Coastal flooding is the result of high ocean water levels combined with wave effects extending beyond the shoreline boundary and referred to as wave overtopping. While ocean levels are generally straightforward to define, aside from the uncertainty associated with sea level rise (SLR), the phenomenon of wave overtopping is more complex and dependent on the topography of the shoreline. Technical guidance for desktop calculations is available to quantify overtopping, however the guidance is often limited to the conditions it was developed for and applying it outside of those conditions introduces uncertainty. This is a common challenge for practitioners. Because of the complexity of shorelines in BC, it is often necessary to rely on numerical modelling to assess wave overtopping. 2D (horizontal) spectral wave models can provide a preliminary estimate of wave-induced flooding, however their theoretical formulation generally does not fully capture the complexities of wave interaction with shorelines and structures. To that effect, their use should be within the applicability of the models. A better suited, alternative approach consists of dividing the shoreline into reaches of similar topography and of similar metocean exposure, and assessing overtopping using 1D time-resolving wave models specifically developed to reproduce wave transformation and wave interactions with the shoreline and structures.

Availability of data is often a limiting factor in coastal flood mapping projects. This data most often consist of topographic and bathymetric data, but also include wind data. The assessment of wave conditions typically rely on wind records that are collected away from the area under study and may not capture local effects that are specific to the site in question. Such uncertainty is associated with the definition of the incident wave climate. This gap can be reduced by installing anemometers at carefully selected locations, onshore and offshore, and record winds for some time before undertaking coastal flood mapping. These short-duration wind records can then be related to closest long-duration wind records to create site specific synthetic long-duration wind records.

For some projects, where tidal rivers drain into the ocean, a joint probability flood analysis could be required. Flood levels in tidal rivers are a result of a combination of incoming discharges and tide levels (including astronomical tide plus storm surge). In the upper reaches of the river, flood levels may be governed primarily by inflow discharges; near the river mouth, flood levels may be governed primarily by the still water ocean level; and, in the intermediate transition reach both conditions may need to be considered. Representing the corresponding designated flood level then requires consideration of the joint probability of river flows and tides or other long-term simulation methods (Hawkes, 2007, White 2007, NHC 2012). In contrast, on the lower Fraser River, where peak flood levels consistently occur during the freshet throughout most of the river, and winter ocean levels cause the highest levels downstream of the Alex Fraser Bridge, the flood profile is taken as the higher of either condition and a joint probability analysis is not required.

Sea Level Rise (SLR)

Global climate change is expected to result in increased sea levels from melting of global ice (ocean and glacier) and increased ocean volume due to rising water temperature and thermal expansion. The BC Provincial Sea Dike Guidelines recommend using an estimate of 0.5 m of SLR associated with global climate change by the year 2050 and 1.0 m by the year 2100, compared to year 2000 (Ausenco-Sandwell 2011, FLNRORD 2018).

One of the most recent comprehensive studies relevant to the BC coast was published by the National Oceanographic and Atmospheric Administration (NOAA) in 2017 (Sweet et al. 2017). Sweet et al. (2017) recommended a revised “extreme” upper bound scenario of 2.5 m by the year 2100. The authors stated that given the limitations of modelling and other uncertainties, any sea level rise values should be considered as only “plausible scenarios” rather than as actual projections. This limitation does not seem to be widely understood by the general community.

Ausenco-Sandwell built on a 2008 study by Fisheries and Oceans Canada (Thomson *et al.*, 2008) and MOE (Bornhold, 2008). The authors of those works acknowledge the design SLR for British Columbia is greater than the global mean SLR projected by the IPCC AR4 (2007) for the year 2100 (roughly 0.4 m greater). However, more recent studies, such as IPCC AR5 (2014), suggests global mean SLR of up to 1 m or more by the year 2100. These predictions are based on the Paris Accord being adopted and adhered to, which may not be the case.

Other studies have investigated the potential effect of a collapse of the Antarctic ice sheet and have shown that such an event would result in far greater SLR, with estimates that are several times larger than the 1 to 2 m projected over the next 100 to 200 years.

Although there has been considerable research on climate change and climate variability over the last several decades, there is still great uncertainty in how sea level rise will affect the magnitude and frequency of flood events along BC's coast. There is no widely accepted, reliable method to account for potential future variations and represent these on floodplain maps that are intended to represent flood hazards over time scales of several decades.

Several studies have been carried out to assess coastal flood hazards for BC, including sea level rise. The most appropriate approach may involve representing present day conditions and then conducting a sensitivity analysis to bracket the range of potential future conditions. The scenarios to use could be determined through a detailed risk assessment. Conceivably the selection of scenarios could also be a function of the particular application of the results, such as development approvals, emergency planning, long range planning, insurance or prioritization of flood defenses.

2.5 Other Maps

2.5.1 Channel Migration Mapping

Washington State, Department of Ecology defines channel migration as the natural process that describes how a stream or river channel moves over time:

"Channel migration can occur gradually, such as when a stream erodes away one bank and deposits sediment along the opposite side. It can also occur quite quickly during floods or high water events. While channel migration provides important habitats and natural diversity, this process can also damage or destroy homes and infrastructure located within these ever-changing zones. For existing communities near rivers and streams, it is important to know where channel migration zones exist and plan accordingly. Communities can manage these higher risk areas by guiding development away from channel migration zones. This strategy helps reduce flood and erosion hazards and costly repairs while preventing the loss of crucial floodplain habitat."

Appendix C describes how channel migration maps are developed and can be used. In its simplest form, the mapping can help determine appropriate setback limits. Whereas some channel migration mapping has been prepared in BC, e.g. Upper Squamish Valley (NHC 2018) and Cowichan River (NHC, 2009, NHC, 2020), this type of mapping is not common in BC. The mapping may be useful in limiting new development in lands potentially exposed to future erosion. For example, if applied along the Chilliwack River, a swath of previously developed land would be included in the high risk zone.

Recent projects by BGC have included probabilistic bank erosion modelling, where impact lines indicate, say, a 50% and 90% probability of exceedance for flows of a certain magnitude. This has proven to be a helpful addition to detailed hazard maps.

2.5.2 Overview Level Flood Mapping

In contrast to detailed floodplain mapping that allows delineating and officially designating the 200-year (0.5% probability event) flood extents and setting FCLs, a variety of approximate flood hazard maps are being developed to estimate flood insurance premiums, potential flood risks and broad estimation of hazards, among other uses. This type of mapping is generally less costly to develop. However, attempts to use overview level maps in lieu of detailed mapping could have serious consequences and is discouraged. Users may need guidance on the type of mapping required for a particular application. A risk-informed approach can be used to complete screening level assessments broadly, and allocate effort to complete more detailed mapping where it is needed most.

Methods briefly reviewed here include:

- Base-level Risk Assessment. For example, the JBA Risk Management method involves developing coarse-grid flood extents over large areas. It may be fairly well-suited for estimating floods from heavy rains and surface run-off, particularly in relatively flat areas, but as of yet, there appears to be little convincing evidence that the JBA method would work well for typical BC rivers and particularly as a means of replacing standard floodplain mapping. Instead, it provides a tool for approximating flood risk. To improve the accuracy of results, costs would likely increase exponentially. (https://scholar.google.ca/scholar?q=JBA+Risk+Management+Method&hl=en&as_sdt=0&as_vis=1&oi=scholart)
- The US Flood Factor method attempts to represent flooding from multiple risks, such as rain fall, high river/ ocean levels and storm surges. It proposes to complement Federal Emergency Management Agency's (FEMA's) Special Flood Hazard Areas mapping but not replace it. Its main purpose is to provide flood risk mapping for the US, relying on an Innovative Regionalized Flood Frequency Analysis approach. A core component of the model is the ability to also include rainfall events as probabilistic flood risks with depths and associated return periods in areas that are outside FEMA maps. (https://help.floodfactor.com/hc/en-us/articles/360048502394-FEMA-and-Flood-Factor-) A similar approach could be adopted for BC, particularly for communicating general flood hazards. Limitations of the method would have to be outlined and it would be important to assess the accuracy for a range of river conditions.
- The HAND technique stands for "Height Above Nearest Drainage". It measures the relative elevation of a point in the landscape from the stream it is flooded by, where 'Nearest' refers to the hydraulically nearest point. A cell is considered flooded if the HAND value of the cell is less than the flood depth in that location. Overall, the HAND method does not accurately capture inundated cells but is capable of highlighting regions likely to be at risk in 4th-order streams and higher. It should be used with caution when identifying flood boundaries or making decisions of whether a cell is dry or wet. To some extent, the accuracy of HAND modelling can be improved through applications of statistical hydrology to define approximate elevations related to flood discharge. (https://www.researchgate.net/publication/332156864_An_integrated_evaluation_of_the_National_Water_Model_NWM-Height_Above_Nearest_Drainage_HAND_flood_mapping_methodology)

The level of detail provided by the above approaches is limited by the accuracy of the input data and methods of analysis. The approaches clearly have a function but should not be confused with detailed mapping. The purpose of the assessments and application of results would need to be clearly stated to avoid associating a higher level of detail with approximated flood levels than warranted.

2.6 Flood Maps in other Jurisdictions

An overview of flood maps in other jurisdictions is provided in this section, noting features that may inform mapping improvements in BC as discussed in Section 3.

2.6.1 Alberta Practice

Following the catastrophic flooding in 2013, Alberta Environment and Parks (AEP) undertook a major program to update floodplain maps throughout the province. NHC has completed numerous floodplain mapping studies in Alberta and are very familiar with the procedures followed in that province. AEP has a competent group of river engineers who manage the projects, providing consultation and review. The HEC-RAS 1D module is used universally for hydraulic modelling, but 2D modelling is undertaken to inform the 1D modelling in complex river reaches.

The following work components are typically carried out:

1) survey and base data collection;
2) hydrologic assessments;
3) hydraulic model development and calibration;
4) open water flood inundation map production;
5) open water flood hazard identification;
6) ice jam modelling assessment and flood hazard identification;
7) governing flood hazard map production;
8) flood risk assessment and inventory;
9) channel stability investigation;
10) digital study file compilation; and
11) stakeholder engagement support.

The same approach is followed for each project, ensuring consistent products for the various projects, although they may be completed by different consultants. The studies and their prioritization are led by the Province of Alberta rather than individual communities. AEP selects consultants based on experience, expertise and approach, not on lowest cost. Also, AEP provides detailed review of mapping projects throughout the process to ensure products are produced with adequate quality and consistency.

The floodplain maps indicate floodways, where velocities exceed 1 m/s, depths exceed 1 m or where any development could increase flood levels by generally 0.3 m. Flood fringe areas border the floodway within the designated floodplain. Future development is prohibited in the floodway whereas development is permissible in flood fringe areas as long as development is raised above the estimated flood level plus a freeboard. Freeboard is not included in the flood levels shown on the maps but is added subsequently. (When using 1D models, the delineation of floodway/flood-fringe areas is useful and has been included for some BC maps prepared by NHC, e.g. Elk River. When applying 2D models, velocity-depth information is readily available from hazard severity mapping.)

Project budgets tend to be larger than mapping projects in BC. As an example, the budget for mapping a 120 km long reach of the upper Bow River downstream of Banff National Park was $1.7M. The mapping is done in long continuous reaches, rather than town by town. The maps are valuable for future land use planning since information will be available in areas prior to development.

2.6.2 US Experience

In the US, floodplain mapping guidelines are provided by FEMA as part of a mandatory national flood insurance program. FEMA also divides floodplains into "floodway" and "flood fringe" areas and uses various flood zone designations relating to hazard type in order to establish flood insurance rates. In general, there is a designated zone for:

- Floodway: which is the channel and any portion of the floodplain that if encroached upon would increase flood levels across the channel and floodplain. (In other words, the floodway is the channel of the river or stream and the adjacent land that should remain free from obstruction so that the 100-year flood can be conveyed downstream. Typically only a 0.5 ft (15 cm) surcharge is allowed in the flood fringe. The flood fringe is the remaining portion of the floodplain. FEMA and state regulations permit communities to allow the flood fringe to be obstructed and developed if standards (i.e., elevating and floodproofing structures) are met.
- High risk riparian flood areas: generally the 100-year floodplain, with various subdivisions based on the quality of the mapping and the level of hazard.
- High risk coastal flood areas: similar to the riparian designations except relating to coastal hazards.
- Undetermined areas: areas that have a flood hazard, but that have not been studied in detail.

Floodways are generally restricted from development except for specific uses such as parks or for habitat creation. Residential homes may be constructed in flood fringe areas provided acceptable flood proofing is carried out. State or local communities may produce more stringent guidelines. For example, some states or counties (such as King County in Washington) impose more severe "zero-rise" restrictions for defining the floodway. This means that any encroachment on the floodplain will be restricted unless some form of mitigation is carried out to ensure that flood levels at other locations are not affected. For example, the King County building code indicates that "developments in the flood fringe area must not reduce the 100-year flood storage volume on the floodplain".

The National Flood Insurance Program was started in 1969 and mapping is continuously updated and expanded. Residual risk and future conditions products are being recommended (ASFPM January 2020 and February 2020). To date, the US has invested over $10 B on flood hazard maps and an estimated $12 B is required to complete the mapping (ASFPM 2020). To roughly put the US experience in a Canadian context, MMM (2014) estimated that completing an additional 15,300 km of mapping in Canada would cost $365M.

2.6.3 European Practice

The European Union published guidelines for flood mapping (EXCIMAP, 2007) to help member countries meet the objectives of the 2007 European Flood Risk Directive by 2014. The Directive asked member countries to implement flood mapping to meet, at minimum, the following criteria:

"Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

- Floods with a low probability, or extreme event scenarios (varies depending on conditions)
- Floods with a medium probability (return period > 100 years) (< 1% Annual Exceedance Probability)
- Floods with a high probability where appropriate.

For each of these types of flood events, the following elements shall be shown:

- Flood extent
- Water depths or water level, as appropriate
- Where appropriate, the flow velocity or relevant water flow

Flood risk maps shall show the potential adverse consequences associated with flood scenarios:

- The indicative number of inhabitants potentially affected
- Type of economic activity in the area potentially affected
- Installations concerning integrated pollution prevention and control which might cause accidental pollution in the case of flooding and potentially affected protected areas."

The directive is not prescriptive though it promotes the development of detailed risk mapping, with the understanding that simpler maps such as flood extent and depth mapping may be better suited to some areas.

The floodplain maps are used for a range of purposes. Austria, Germany and Ireland use the maps to establish flood insurance rates as part of nation-wide flood insurance programs. Countries such as Switzerland, France, Spain, Italy, Holland and Belgium have sufficient socio-economic data and records of assets that they can compute actual flood risks. Most other countries use the maps to define flood hazards for zoning and emergency planning purposes.

2.7 A Critical Review of Detailed Floodplain Mapping in BC

Based on the previous sections, some general comments are provided below on the current status of floodplain mapping in BC, as grouped under general, accessibility, guidelines, quality and governance. Identified recommendations are carried to the next section.

General:

- Although funding grants for floodplain mapping have been available since 2015, only relatively few studies have been completed and map spatial coverage is still limited. Not all of the areas previously mapped under the joint federal-provincial mapping program have been updated nor do they have a mapping project "in progress" (see Figure 3 and Table 1 in Appendix B). There are a number of communities exposed to flooding that have no mapping. Mapping for First Nations' lands in BC is nearly non-existent.

- The federal-provincial mapping program did not map all important areas of BC, for example it omitted the Lower Fraser River.
- Current grant funding for flood mapping is comprised of an application-based process with prioritization based on several different factors, and typically with a budget cap of $150,000.
- In terms of reducing future flood losses, funding should go to the most critical areas requiring flood maps rather than those with the most capacity to compete for grants.
- Municipalities, regional districts and First Nations with shared hazards should coordinate and collaborate to prepare maps based on broader river-reaches or regional scale interests (such as recent work in the Lower Mainland, Okanagan and Thompson regions and the Regional District of Central Kootenay). This would likely lead to efficiencies and cost savings allowing for more mapping to be developed for the same cost.

Accessibility:

- In some instances, local governments make completed floodplain mapping readily available. The provincial government intends to make flood studies available on a web portal but there is presently no time-line for this. It is imperative that all mapping information undergo quality assurance and then be made available to the public. The same holds for all flood related reports funded by tax-payers. Some key considerations are:
    - It is in the public interest for the provincial government and local authorities to be transparent regarding flood hazards and risks and to make informed decisions.
    - The information made available supports accountability regarding use of public funding.
    - There is a public education and awareness benefit from making flood information accessible.
    - It is recognized that ensuring mapping accessibility requires additional resources, be the information delivered by local or provincial authorities.
    - There are many sensitivities related to the accessibility of flood information in relation to land values, insurance premiums, DFAA eligibility, lost development opportunities and other liabilities.

Guidelines:

- Existing provincial guidelines for floodplain mapping are not prescriptive and have significant flexibility in their application. While outlining best practices, the objectives of the documents are not setting specific standards for floodplain mapping. One important aim of the EGBC guidelines is to ensure that qualified practitioners undertake the work.
- The NRCan federal flood guidelines include a number of interesting topics. However, they are generally developed under limited budgets and do not cover topics in depth.

- Climate change impacts on flows and sea levels are addressed in several provincial documents. Recommendations are simplified and of a general nature. There appears to be little consensus on the type of climate change analysis that should be applied for specific projects. The end-of-century sea level rise estimate of 1 m should be recognized as a simplification.

Quality:

- Funding grants are commonly insufficient for completing thorough investigations and maps, unless additional local funding sources are available. (e.g. CEPF grants are typically limited to a maximum of $150,000 and some projects may require several cycles of funding to step through acquisition of baseline data (LiDAR/bathymetric surveys), hydrology/hydraulic work, and risk assessment.) The size of the grant may lead to inexperienced consultants under-bidding to win work; minimal investigations completed and potentially in some instances, sub-standard mapping being developed. Sufficient budgets must be made available, based on the intended uses and the complexity of the flood hazard and risk, or the quality of map products will suffer. Local governments may write RFPs that considerably over-scope a project in relation to the budget and more education is needed for those who prepare RFPs, to set appropriate expectations for what can be accomplished. This issue is often initiated by an RFP with over-optimistic expectations.
- Most recent mapping studies are still in progress and unavailable for review. Floodplain map development is complex and should be undertaken by qualified practitioners only. There appears to be limited review/quality control of the maps by independent reviewers. Adequate funding for this needs to be ensured.
- The BC approach to selecting and applying freeboard is generally outdated.
- Geomorphic assessments should be included in mapping projects for river channels undergoing change. Unfortunately, this is not always the case. For example, channel migration mapping, a useful tool for land-use planning, is not commonly prepared in BC.
- Simplified mapping for uses such as overview level flood vulnerability and risk assessments and insurance purposes has a function (see Section 2.5) but does not replace detailed floodplain designation mapping that informs requirements for new building construction and land use planning (E.g. FCLs and zoning).
- Multi-dike-breach modelling, critical for most areas protected by dikes, is not commonly undertaken. It should be a required component, particularly for areas behind high-consequence dikes.

Governance:

- Floodplain mapping responsibilities were transferred to local governments in 2003 and subsequently, fewer maps were developed in BC. The Province currently does not provide comprehensive technical standards, nor does it fulfil the pre-2003 role of technical review, approval and sign-off of all new floodplain maps. For maps produced after 2003, it is not clear who “owns” floodplain maps, beyond professional responsibility as outlined by the BC Engineers and Geoscientists Act, and the wording of contracts for individual assessments. Senior funding programs are the key drivers and for new mapping and have generally emerged prior to guidelines or standards being developed. Typically, limited prioritization based on level of risk is implemented.

- The allocation of funds for individual (mainly local government) floodplain mapping projects over the past five years through application based processes is administratively inexpensive for senior governments. However, this funding model/program has no overall objective, prioritization, standards, or quality control and does not commit the grant recipients to actually use the mapping (e.g. through updating and adoption of floodplain building bylaws). Although many projects are "in progress" the expenditure of $19.3M total to date (Table 3 in Appendix B) has yet to produce a significant quantity of quality floodplain mapping and little or no official designation and integration into policy.
- Collecting LiDAR data for limited specific areas to be mapped is inefficient compared to a more regional-wide basis. The Province has carried out some region wide LiDAR acquisition and has plans for more – but this does not necessarily coincide with the creation of mapping through the existing funding programs.
- While efforts are underway to resolve the LiDAR gap, there is no province-wide system to efficiently curate and distribute, or even be aware of, LiDAR data that may be collected by both the private and public sector. Extensive areas also exist where LiDAR data has been collected on spec by private operators, but has not been processed.
- Flood mapping of First Nations' lands is limited and the information available is commonly severely outdated. First Nations' mapping in the Lower Fraser River, with only a few exceptions, is based on the 1969 design profile, known to be 1 m lower than the current design profile at Mission. Having mapping for First Nations separate from other communities is inefficient.
- The status of flood maps in Alberta, the US and across Europe appears to be more comprehensive than in BC. Cost-benefit analyses have demonstrated the value of accurate and current flood maps and improvements to the present BC approach are required.

3 INVESTIGATION B-2.2: APPROACHES TO IMPROVE BC FLOOD MAPPING

This section explores potential opportunities and approaches to improve the general status, accessibility, guideline usage, quality and governance of flood hazard information in BC.

Some up-to-date detailed floodplain maps have been developed, or are currently under development. In certain instances, these projects have improved the understanding of flood hazards and brought communities together to discuss flood mitigation and risk reduction. Some have led to establishment of bylaw documents restricting or informing development in floodplains, the preparation of emergency response plans, infrastructure improvements and development of flood mitigation strategies. In addition to setting FCLs and delineating flood extents, the type of mapping prepared should be driven by its follow-up application/utilization. To further improve the mapping, it is recommended that post-project outcomes be tracked to see how results are used and the findings applied to future initiatives.

Map studies may be viewed by some communities as 'just an other study' and funding for specific flood mitigation projects would be preferred. However, the maps are a necessary first step for effective design of flood mitigation/adaptation measures. Accurate detailed maps can help ensure that flood mitigation measures are not over- or under-designed and may lead to significant savings in mitigation or recovery.

For example, simplified mapping methods that provide overly conservative flood levels may in turn lead to overly costly protection measures. Similarly, under-estimates may lead to potentially worse outcomes.

Accounting for climate change impacts on end-of-century flood flows and sea level rise, does not ensure that the maps prepared today will be representative of the flood hazard at the end of the century. At a minimum, maps prepared this year should be reviewed/updated in 2040, 2060, 2080 and 2100, each time reviewing climate science and revising flood extents and FCLs, requiring modification to bylaws, flood protection design etc. That said, climate change clearly needs to be considered to give an indication of future flood extents and levels; but uncertainties associated with climate change estimates and riverine and coastal configurations should be recognized and assessed. Future flood conditions must be distinguished from present information, prepared for purposes such as emergency response.

Input received during the project from different provincial government groups (FLNRORD and EMBC) and AANDC is incorporated in the following discussions.

3.1 Recommendations to Improve Mapping

3.1.1 General Improvements

Ideally, all communities in BC situated along rivers, lakes or the ocean should be mapped using detailed floodplain mapping techniques; however considering the costs involved, this may not be feasible. Although there would be benefit of mapping even small, sparsely populated communities, the cost may be difficult to justify. Alternative methods for approximating flood hazards (overview level mapping) are being developed and are relevant to certain uses. The accuracy of these products in BC is currently unclear. Available reviews provided by the developers/advocates of these methods suggest they are good. However, back-up information is limited and we recommend that independent assessments of the methods be completed.

The following approaches were adopted to identify areas with limited flood hazard information and an immediate need for new or updated detailed floodplain maps:

- The joint federal-provincial mapping agreement produced mapping for key flood-prone areas in BC but the information is now outdated. In many areas, the floodplain is confined between valley walls and updated flood extents are similar to before but often the FCLs are considerably higher. Areas previously mapped but without available updates were identified as high priority areas requiring new maps (See Figure 3, Appendix B).
- Areas protected by high consequence dikes, as identified by NHC (2019) have generally high flood risk and should be mapped (See Figure 4, Appendix B). Breach modelling should be included in floodplain mapping projects for all areas diked by high consequence and major dikes. (See also report prepared for Issue B-5: Structural Flood Mitigation Measures).
- At a minimum, communities located along rivers, lakes and the ocean that have present populations exceeding about 10,000 should be mapped (See Figure 5, Appendix B). A number of smaller communities would also benefit from coarse flood hazard mapping and it is recommended that overview level flood risk assessments be completed to prioritize which smaller communities would benefit most from more detailed floodplain mapping. In some areas,

overview level risk assessments have already been completed or are in progress (refer to Issue B-3: Flood Risk Assessment). Overview risk assessments could help prioritize where more detailed floodplain mapping would be beneficial.

Communities meeting the above three sets of criteria are listed in Table 6. Many of these communities have recent or ongoing grant funded projects (shaded green), and assuming this work has been or will be completed to adequate detailed floodplain mapping standards, the updating of maps from 1974-2003 is well under way. Main river reaches/ coastlines to consider for future mapping are included in the table.

The broad procedure for determining grant recipients is outlined in the funding application form but details on the process are unclear. Future floodplain mapping projects should be prioritized and the following considerations are suggested to aid the prioritization process:

- Risk prioritization/ vulnerability assessment results when available. A number of prioritization level risk assessments, preceding detailed floodplain mapping, are under way. Once available, the information should be used to prioritize mapping projects, except where detailed mapping is already available and used for the risk assessment. Extensive studies facilitated by the Fraser Basin Council have identified severe flood hazards in densely developed areas of the Lower Mainland, yet only limited up-to-date mapping has been developed. Completing floodplain mapping for the Lower Mainland should be a high priority and is strongly recommended. Where feasible, communities along the same water course in other areas should be mapped under one project.
- Observations of past flooding. It is recommended that a provincial database of annual flood event information be developed to track and record flood events by a designated provincial government department. Observed flood levels, flows, inundation extents, photographic material and information on consequences such as affected transportation corridors and other damages would be useful input for future floodplain mapping studies (e.g. hydraulic model calibration) and also their prioritization. Information compiled by Septer (2008) based on newspaper accounts from the late 1800's to early 2000's is a good source for historic floods, but is missing detailed information and data on recent floods.

The majority of First Nation reserves and treaty lands do not have up-to-date flood hazard mapping. Yet most of these lands have ocean, lake or river frontage (First Nations Emergency Atlas 2005) and are frequently exposed to flooding. The four FNESS reports from 2000 assessed flood and erosion hazards in BC, ranked the hazards, and developed potential mitigation measures. Risk points and risk reduction points were estimated and approximate costs were developed for various measures. Based on this information, the projects were prioritized. However, some First Nations regard this information as confidential, particularly data on asset values, and the information is not readily available. According to Indigenous Services Canada, the prioritization of projects is still largely valid, although it should be recognized that much of the flood level information is now outdated. To prioritize First Nations' floodplain mapping projects, we recommend:

- Reviewing the previously identified high priority projects.
- Reviewing the need for updating the flood levels in the previous work.

- Reviewing the severity and damage of past floods.
- Developing an outreach program for contacting First Nations and learning first-hand about current flood and erosion challenges and how First Nations leadership and community members would like to address these.
- Updating and expanding on the previous FNESS work, including new floodplain mapping where needed.

3.1.2 Map Accessibility Improvements

Flood map information sources were listed in Section 2.1 and current plans for future accessibility described in Section 2.2. A provincial government web portal, making flood maps and supplementary reports available to government and the public is encouraged. Currently, consultants are asked to provide the Province with all project information for federally/provincially funded projects; including survey files, DEMs, hydraulic modelling files and GIS files. If this material has been provided for projects completed to date is unclear. NHC supports that the Province compile the information, however like most practitioners, we have some reservations against providing hydraulic modelling files and the associated liability this could involve. If, in the future, the model files are used by others, unaware of modelling limitations and the purpose for which the model was developed, liability issues may arise. It should be recognized, that the original model developer takes no responsibility for usage by other practitioners. (Generally all information, except modelling files, can readily be provided.)

There is currently no timeline for the web-portal implementation but making information available to the public as soon as possible is encouraged.

Many larger communities, with sufficient resources and know-how, are making floodplain mapping and other engineering reports available on line. All communities having completed flood risk or mapping studies are encouraged to do the same. Reports paid for by any level of government (federal, provincial, local or First Nation) should be readily available to the public.

3.1.3 Improvements to Map Guidelines and Usage

Provincial and federal guideline documents were briefly discussed in Section 2.3. The guidelines are useful but do not guarantee that flood mapping is produced to a consistent and/or adequate standard by different practitioners. In particular, specifications are required for bathymetric surveying, climate change analyses, hydrology when basins include large reservoirs, geomorphic assessments, modelling standards (1D vs 2D software usage, calibration/ output type/ breach modelling), coastal wave modelling, freeboard, mapping detail/clarity and reporting standards. We support the development and up-keep of more prescriptive standards documents in addition to guidelines requiring qualified professionals to carry out the work. Third party review is also encouraged.

It is recognized that different types of mapping studies need to be developed based on the particular flood hazards facing a community, its setting, development density and overall profile of flood risk. Similar to the legislated BC flood hazard assessment guidelines (EGBC 2018), different categories of floodplain mapping studies could be specified and associated standards applied. This would help communities identify the level of assessment and standard of mapping they require and associated budget demands, to ensure more consistent bidding on a particular project and better standardization of products developed.

Federal guidelines are informative but conditions across Canada vary sufficiently to require specific standards to be developed on the provincial level.

3.1.4 Map Quality Improvements

Potential short falls of floodplain mapping projects were identified in Section 2.4 and a critical review was provided in Section 2.8. Specific recommendations for improving the overall quality of maps are:

- When awarding the project, a municipality/regional district or First Nation needs to hire the consultant offering the best overall value for the project, rather than the lowest budget. With clear standards in place, the selection process would become easier and would avoid introduction of future extra work. It should be recognized that grants obtained may not be sufficient to adequately fund a project. Additional, locally sourced funding may be required to supplement the grant. It should not be assumed that grant providers have an accurate idea of the true study costs and are providing full funding to complete a project.
- Appropriate training should be provided to local government staff members to prepare flood mapping scopes of work that reasonably reflect the available budget, and that contain realistic schedules. Flood mapping projects can be problematic from the outset if the scope, budget, and schedule are misaligned in a request-for-proposal and cannot be changed during the course of a project (potentially reducing quality). For example, scheduling LiDAR acquisition and bathymetric surveys in the fall/winter in an area where fieldwork cannot readily be done, is impractical. Studies commissioned in areas without LiDAR or survey data may be problematic unless it is recognized that hydraulic modelling needs to occur after LiDAR delivery, not in parallel. These schedule and budget issues should also be considered by those reviewing grant applications to evaluate whether a project has a realistic chance of success.
- Tentatively, an independent, quality control group could be established to review new mapping developed. This should be a technical team, with sufficient experience to provide meaningful review of project results. It should include professionals qualified in flood mapping (e.g. engineers and geoscientists), and professionals qualified in the digital delivery of flood information (e.g. GIS, database, and software professionals). It should also be advised by professionals qualified in the application of mapping in decision making (legal, planning, policy, regulation). This unbiased group would likely be part of a provincial government department and could provide oversight during a project.
- The traditional BC freeboard allowance of 0.6 m is outdated and should be replaced. It may represents a minimum for many situations. An uncertainty analysis should be included as part of standard hydraulic analysis to inform or verify the adopted freeboard (outlined in standards document). However, considering the associated costs, it may be feasible to develop a range of typical freeboard allowances suitable for certain situations and applying these particularly to small projects with limited budgets. (In some jurisdictions, no freeboard allowance is incorporated in the mapping and it is expected that map users add the amount of freeboard they feel is appropriate. In our opinion, this implies there is no uncertainty associated with map

development, which is clearly not the case (NHC 2020, BGC and Ebbwater 2017) In some instances, a risk-based approach to freeboard may instead be justified.

- Including geomorphic hazard assessments in the majority of mapping studies is advisable for unstable channels. In addition to assessing channel stability and erosion issues, these will determine how frequently the mapping needs to be updated. The EGBC suggested blanket time interval of about 10 years, is not representative of all situations. Given the instability of many rivers in BC and the inter-relationship between erosion and flood damages, channel migration zone mapping should be expanded and carried out in parallel with floodplain mapping projects where appropriate.
- Flood levels caused by ice events, woody debris or sediment deposits may significantly increase flood hazards and should be appropriately addressed. Mapping developed under the joint federal-provincial mapping agreement did not adequately estimate these.
- Where high consequence areas are protected by dikes, and where floodplains are large and hydraulically complex, dike breach modelling should be undertaken.
- Flow in most rivers should be modelled in 2D. However, 2D modelling is more costly in all aspects of the work, including collecting bathymetry, developing a DEM, model testing and calibration, modelling certain structures and adding freeboard to the results. Where river conditions are relatively linear and where funding is limited, a 1D model may be acceptable as a lower budget option.
- With mapping standards clearly defined, project deliverables will have a consistent quality.
- Estimates of climate change impacts on flows and ocean/lake levels need to be transparent and the assumptions made clearly stated. Again, appropriate guidance needs to be provided and standards need to be specified. It should be recognized that incorporating end-of-century climate change in an assessment does not mean flood maps are valid to year 2100. Channel and floodplain geometry changes will likely render the mapping outdated well before that, not to mention an evolving climate and evolving climate science.

3.1.5 Improvements to Floodplain Mapping Governance

The division of flood management responsibilities in BC is a conundrum. Through Disaster Financial Assistance Arrangements (DFAA), the federal government is liable for the majority of flood damage compensation but has no control over floodplain mapping or mitigation. The 2003 devolution of provincial power to local governments was introduced as a provincial government cost-saving measure. Since that time, local governments have responsibility for regulating new development in floodplain areas, where incentives exist to increase their tax base, but have limited overall liability for flood damages after an event. First Nations are supported by the federal government. Cooperation between local and First Nation governments is generally limited, although exceptions exist. Within BC, differing responsibilities also create inefficiencies for flood management. For example, the BC Ministry of Transportation and Infrastructure is responsible for flood management along its roadways, but liability concerns preclude consideration of risk to communities in the design of flood mitigation for roads traversing a community.

Although the current approach for detailed floodplain mapping led by local governments could potentially be improved, a model having an increased role for the provincial government in floodplain mapping could be considered based on the following two options or hybrids of these:

Option 1 – Provincial government to participate in the following tasks:

- Lead the collection of LiDAR on a more regional, or even provincial scale, rather than the community scale collection used over the past several years. This work is to some extent already underway by GeoBC, contracting LiDAR work for flood mapping purposes, specifying appropriate standards and supporting quality control. We recommend that the province consider the efficient distribution of data, and software development to support such distribution, as equally important to the collection of LiDAR data.
- Help coordinate flood studies on a watershed/regional basis, such as recent work in the Okanagan, the Lower Fraser and Thompson River watersheds. In some contexts this could be more efficient than mapping individual communities and would also better facilitate participation and inclusion of First Nations communities. This could also lead to more uniform standards being applied to broader areas. In some cases project management, coordination and/or facilitation could be delivered through regional organizations (e.g. Fraser Basin Council or Okanagan Basin Water Board).
- Develop a public facing, historic flood database, documenting observed flood information such as flows, flood levels and extents (including detailed high water mark surveys), photos and videos, damage summaries, transportation disruptions etc. The information would be highly useful for future flood hazard studies, floodplain mapping and risk assessment projects and also help prioritize areas or river systems that require new or updated mapping.
- Retain consultant(s) or professional association(s) to develop and (ensure updating of) floodplain mapping standards for BC, including bathymetric data collection. Coordinate with federal government floodplain mapping standards.
- Assuming funds are available, provide ongoing quality assurance of flood studies. As flood studies are received for posting on the proposed web-portal, a group of qualified technical reviewers would ensure that all maps meet standards. If the work is coordinated by say FBC, a centralized QA/QC team could be retained, for example modelled on the Forest Practices Board.
- Emphasize potential future uses of floodplain mapping. The funding of floodplain mapping could be made conditional on a community subsequently developing flood mitigation, preparedness and response plans, and bylaws to ensure compliance with zoning, FCLs, etc. Track the follow-up work carried out after mapping has been completed.

The above Option 1 would require allocation of about 2 full-time provincial government staff and the retaining of consultants on an as-needed basis.

Option 2 – Provincial government to set up a new provincial program (similar to that in Alberta) to:

- Develop or contract the development of a BC floodplain mapping standards document.
- Develop a public facing, historic flood database, documenting observed flood information.

- Prioritize areas to be mapped and work with local governments and First Nations to ensure that mapping developed will be useful and used as part of future Integrated Flood Management Plans (IFMPs) and/or other approaches to flood mitigation and risk reduction.
- Allocate adequate budgets for each project based on risk and hydraulic complexity.
- Prepare detailed Requests for Proposal (RFPs) and manage the contracts.
- Provide technical input and review throughout project.
- Sign-off on maps when completed.
- Publish reports and maps on provincial interactive web-site allowing users to enter their address to retrieve flood information.

It is suggested that the Option 2 government group consist of roughly 5 full-time hydraulic modelling specialists with extensive BC experience and/or staff with other relevant expertise.

3.2 Approximate Mapping Costs

The brief review of current detailed floodplain mapping in BC, carried out as part of this project, suggests that inconsistent products are being prepared that in some cases do not adequately inform the determination of FCLs and flood extents. Comprehensive cost-benefit analyses or detailed ranking of different approaches are not within scope for this project. Typically, high quality mapping will provide the most accurate information, lead to optimum flood mitigation/adaptation and likely minimize future flood losses where used in conjunction with bylaws, FCLs and other floodplain regulation tools. Low budget approaches may provide inaccurate results, limited reporting, studies that are potentially shelved and eventually, significant flood losses. Erroneous information may in fact be worse than having no information.

Please note that the preliminary cost estimates presented in this report will be compiled, reviewed, and potentially refined together with those from the other projects in this initiative as part of Issue D-1: Resources and Funding. For more information, refer to the D-1 report.

3.2.1 Typical Riverine Mapping Costs

Based on past studies by NHC, we developed an approximate cost per kilometre for floodplain mapping. The 17 projects reviewed were typically complex and had reach lengths of more than 25 km. Based on this small sample size of consistent quality mapping, the average total cost was about $15,000/km but ranged to as low as $10,000 in some instances (1D modelling). The unit cost of mapping shorter reaches was generally significantly higher, emphasizing the economy of scale when mapping several communities along the same river at the same time. The costs include bathymetric surveys but not LiDAR. (LiDAR unit costs vary considerably based on areas flown, quality, capture of orthophotos, etc.)

In rough numbers, bathymetric survey data collection, site inspections, DEM development and review of previous reports amount to 30% of the total budget; development and running of the hydraulic model 20%; and hydrologic investigations, map development and reporting about 10% each. The remaining 20% is for a combination of geomorphic assessments and other area-specific investigations. (LiDAR costs not considered.)

For comparison, MMM (2014) provided the following high level cost estimates per km for developing floodplain mapping:

- Urban areas (1D Modelling): $10,500
- Urban areas (2D Modelling): $50,000
- Rural areas (1D Modelling): $7,500
- Rural areas (2D Modelling): $50,000

Due to recently improved software products and better computing power, the NHC 2D estimates are considerably lower than MMM's, suggesting an improved business case for 2D modelling.

3.2.2 Typical Ocean Mapping Costs

Based on a similar approach, reviewing past work and cost estimates for about ten projects, the cost of coastal mapping studies was found to range from about $1,500/km for fairly simple coastlines to $2,500/km for more complex project shorelines or study areas with estuaries and exposed shorelines. The estimates assume project coastlines of 25 km or more.

The estimates do not include the cost of collecting LiDAR or bathymetric data. It is assumed that LiDAR data and bathymetric data are already available, but that ground truthing and check surveys are required to verify the data and also that DEMs are to be prepared (see also Section 2.4.2). Thus, a project to map 50 km of shoreline would have a budget of $75,000 to $125,000. The costs to map the estuaries of larger coastal rivers or streams where joint probability analyses are required would need to be estimated on a site specific basis.

3.2.3 Channel Migration Mapping Costs

For channel migration mapping, some combination of historical aerial imagery, high-resolution topography data, geologic or terrain mapping information, field reconnaissance, and hydraulic model output data is usually required. Costs of projects completed by NHC ranged from about $10,000 for a small site (less than 1 km reach) to $150,000 for a river-scale study (in the order of 10 km reach or more) including historical channel position mapping.

3.2.4 Approximate Costs to Map BC

Flood Hazard Study Budgets

Floodplain mapping projects can be grouped into two types, "straightforward" and "complex", depending on the area to be mapped (Table 3-1). The allocated budget should be a function of the river and/or coastline complexity and population density and other flood risk factors rather than the budget available for the project.

Table 3-1 Project Type

Study component	Complex Project (Higher Budget)	Straightforward Project (Lower Budget)
Bathymetric surveys	For 2D modelling	For 1D modelling
Hydrology and climate change	Standard hydrology including detailed climate change	Standard hydrology with application of flow ratios for

	assessment. Potential joint probability analysis.	climate change
Geomorphology	Field work, gauge analysis, air-photo analysis, sediment transport estimation	Channel known to be stable, detailed analysis not required
DEM/model development/ hydraulic model simulations	2D modelling including dike breach modelling	1D modelling, no dikes or small, simple floodplain
Freeboard	Uncertainty analysis	Application of standard values
Mapping	FCL map, flood depth maps, flood hazard maps; 3 or more scenarios	FCL map only, 1 scenario
Reporting	Comprehensive summary	Memorandum
Presentations and public consultations	Presentation of results, development of display material	No presentations or consultations

The project option selected should be a function of the area to be mapped (river complexity and flood risk) rather than the budget available for the project).

A cost saving strategy is to map rivers over long reaches, rather than on a municipal or regional district scale. This will allow a number of communities and First Nations to be covered within one project with efficiencies of scale and potential for cost-sharing.

As another potential cost saving measure, water-penetrating LiDAR could be considered. The technology is becoming more common in some jurisdictions and has potential to significantly reduce bathymetric survey costs in some rivers, where waters are clear and not very deep.

For coastal modelling projects, the major cost determinant is how wave effects are handled and if joint probability analysis is warranted regarding the riverine and coastal flood hazard interface. Water-penetrating LiDAR is a less useful tool where breaking waves entrain air bubbles. Breaking waves also disturb sand above the seabed, and getting a clear return on the seabed vs suspended sediments is a problem.

Flood levels based on overview level assessments can be used to inform risk analysis and prioritize areas to be mapped. However, the information is not suitable for floodplain map development and is not costed here.

Adequacy of Current Grant Funding

The assumption that “in progress” and “under review” projects (Appendix B -Table 3) will be completed to adequate mapping standards has not been verified. Unless other funding sources are available, the recently developed maps may not be sufficiently accurate. Based on a brief review, bathymetric data is often inadequate, LiDAR does not meet guidelines, hydrologic and climate change analyses are surficial, geomorphic assessments are missing, hydraulic modelling including calibration are of an overview level quality, mapping may lack FCLs and for coastal projects, wave analyses are missing.

As an example, the following Request for Proposal was recently reviewed for a roughly 100 km long reach of a fairly major river in BC. Assuming a unit cost of $10,000/km a budget in the order of $1.0M would be expected. A quote of $140K was received for obtaining previously flown LiDAR. Bathymetric surveys were estimated to cost at least $200K. With projected costs of say $50K for hydrology, mapping and reporting each, and modelling at a modest $100K with $60K for geomorphology, the NHC estimated cost of the project would be at least $650K. However, the grant for the project is only $150K, which the local authority expects will cover all the work necessary but would not allow for development of quality, detailed floodplain mapping for the reach required. This example suggests the current grant funding may be quite inadequate for producing quality mapping for some flood hazards and floodplains, without additional local funding or future grants. In general, local authorities seem unaware of the requirement to raise additional funding or wait for future additional grants.

It is critical that all recent mapping reports be made available for a thorough review to determine the quality and extents of mapping developed. Unless funding, in addition to the grants, is sourced for the projects, the mapping may in some cases be substandard. Specific standards documents for bathymetric data collection and floodplain map development should be prepared in order to review the mapping prepared to date, and ensure the quality of future mapping.

Estimated Future Costs

MMM(2014) estimated that flood map coverage in BC was available for 2,656 km and that another 2,650 km should be mapped. A total cost of $48.2M was estimated for producing new maps. With $20M spent to date, this estimate would imply the remaining mapping cost is about $30M. This estimate seems quite low but cannot presently be confirmed.

Based on the information reviewed, the following specific projects, with order of magnitude estimates shown, are recommended as a minimum. (Additional funding would be required for outlined Options 1 or 2.)

- Develop a bathymetric survey standards document (riverine and coastal) ($40K)
- Develop floodplain mapping standards (riverine and coastal). Include section on channel migration mapping. Consider future uses of all mapping ($200K). Upkeep additional.
- Once readily available, review recent floodplain mapping products for compliance with standards. Identify any sub-standard mapping and coverage. Recommend additional work. ($200K – Additional work not included.)
- Map the Fraser River (Hope to ocean, including main tributaries) according to standards (approach similar to Chilliwack project) ($2.5M).
- Map Lower Mainland coastal areas in locations where available mapping does not meet standards. ($0.5M)
- Review available flood risk information and past flooding. Review FNESS (2000) high priority projects/past First Nation studies. Complete First Nations out-reach program. Develop a province wide map-by-river or map-by-coastline plan and carefully prioritize future projects. Restructure funding program. ($0.5M)

- Complete large scale LiDAR collection. (Provincial government program, cost not known)
- Develop historic flood database. (Provincial government program/contracting. Estimate not known at this time)
- Complete the required mapping. (Provincial government program/contracting. Cost not known at this time, considering the unknown status of mapping completed to date.)
- Provide mapping quality assurance. (Provincial government program. Cost not known at this time but suggested by FLNRORD to be in the range of $150,000 to $300,000 per year)
- Provide for government restructuring to accommodate Option 1 or 2 as outlined in Section 3.1.5. (Cost not known)

4 INVESTIGATION B-2.3: DIKE STATUS INFORMATION

4.1 Introduction

BC's flood risk is different from most other provinces in Canada because the most densely developed floodplain lands are protected by dikes. However, the level of protection provided by individual dikes varies widely. Even the "good" dikes have significant limitations and can fail during large events. Therefore, to understand and manage flood risk in any specific diked area, a key component of strengthened flood risk management in BC would be to provide local authorities, provincial, federal and First Nation governments, professionals, insurers, and the public with access to detailed deficiency information for each dike.

In this report the term "deficiency" means a limitation in comparison to current provincial flood protection standards. Detailed knowledge of the current condition of a dike and its deficiencies relative to standards is needed to estimate the level of protection provided by the dike. This information is useful to support:

- effectively operating and maintaining diking systems
- land use planning and regulating development in protected floodplain areas
- responding to emergencies and planning recovery
- assessing risk and prioritizing funding for dike upgrades
- educating the public about dikes and associated flood risks

The scope of this investigation includes all dikes and appurtenant structures considered by the Inspector of Dikes (IOD) to be regulated under the *Dike Maintenance Act* (DMA), including "orphan" dikes. An effort was made to review all types of information on dikes in BC available from the Province and Fraser Basin Council, and where available, dike information developed by local governments and other diking authorities. While much information on dikes and diking authorities was available on the Dike Safety Program web pages, additional material was provided by the Inspector of Dikes and Deputy Inspectors of Dikes.

Over the past few years, federal and provincial governments have funded local governments and diking authorities to complete approximately 122 area-specific flood risk assessments and floodplain mapping studies in BC (also see Section 2.1). The majority of the study areas include dike protected floodplains, and it would be expected that these studies could be a source of information on the condition and level of protection provided by the dikes. However, many of these projects are still in progress and most of the reports were not available for this investigation.

The following sections provide background on dikes in BC, identify who needs dike deficiency information and how it is useful, and describe provincial dike safety standards. Section 4.5 reviews existing sources of dike deficiency information with respect to utility, accessibility, and quality/consistency. Possible ways to improve both the content and use of the information, conclusions and recommendations are summarized in Section 4.6. Section 4.7 provides estimates for the personnel and funding resources to implement the key recommendations.

Appendix D provides a few examples of some of the information sources. A potential method to estimate the level of protection provided by a dike is briefly described in Appendix E.

4.2 Background on Dikes in BC

Much of BC is comprised of mountainous terrain with many cities and towns located in valley floodplains. The construction of dikes in BC evolved along with the growth of these communities over the past 150 years. While there have been a few large dike building/upgrading programs such as the 1968 to 1994 Fraser River Flood Control Program in the lower Fraser Valley, many of the dikes were constructed as separate projects, usually after a significant flood had impacted that area. Not surprisingly, the standards of design and construction of dikes vary widely throughout the province.

Slightly more than one hundred diking authorities, the majority being local governments, own, operate and maintain 216 regulated dikes, with a total length of about 1,100 km. These dikes protect approximately 160,000 hectares of land, a few hundred thousand buildings (homes, businesses, industry, schools, hospitals etc.) transportation facilities and other critical infrastructure (Provincial Dike Management web pages). MFLNRORD's Dike Safety Program, led by the Inspector of Dikes (IOD) provides diking authority oversight, establishes flood protection standards, approves new dikes and changes to dikes, and provides technical support for major multi-jurisdictional flood issues (e.g. Fraser River design flood levels).

In BC there are also approximately 100 existing "orphan" flood protection works (dikes, berms and other structures) that were constructed during previous flood emergencies. However, most of these works are not being inspected or maintained by any responsible authority, are not engineered and have a high likelihood of failure during flood events. About 60 of these are considered by the IOD to be dikes regulated under the DMA. The majority of these works are located in about 75 smaller communities and rural areas outside of the Lower Mainland.

Several First Nations also own, operate, and maintain dikes and other flood protection structures. A few of these dikes are located on treaty lands or on non-federal lands and come under provincial jurisdiction through the DMA.

Some dikes are more significant than others. MFLNRORD recently completed the "BC Dike Consequence Classification Study" (NHC, 2019) to better understand the consequences of dike failure for the population and assets at risk in the protected areas behind the dikes. The study classified 35 dikes as high consequence, 36 dikes as major consequence, 90 dikes as moderate consequence, 43 dikes as minor consequence, and 8 dikes as insignificant consequence. The 35 dikes classified as high consequence protect 75% of the total area protected by all dikes analyzed, 95% of the total protected population, and 94% of the total protected building value. The importance of existing dike protection as a key component of flood risk management in BC cannot be overstated. It is roughly estimated that at least three quarters of all the people that live in BC floodplains are in floodplain areas protected by dikes.[1]

A dike can breach through several mechanisms including overtopping, river bank erosion, slope instability and uncontrolled seepage leading to piping. Piping is the internal erosion and formation of voids in the dike embankment and/or foundation due to removal of soil materials by seepage. The prevalent cause of the dike failures along the lower Fraser River in the 1948 flood was geotechnical instability (likely seepage/piping) rather than overtopping.

Actual failures are also likely to be related to a complex chain of events and contributing factors (e.g. a marginally safe design plus poor quality control during construction). Dike breach scenarios can be comprised of a multitude of variables including water levels, velocities, and hydrograph shape/duration (on both sides of the dike), dike geometry, foundation soils, dike fill materials, appurtenant structures, vegetation/animal burrows, bank erosion protection, the length of the dike, the success of flood fighting efforts, and many others. Furthermore, each dike is a "series system", where failure of one section or component (i.e. the weakest link) can result in catastrophic failure. Therefore dike deficiency information must address many other factors in addition to potential overtopping (i.e. dike crest elevation vs design flood level).

4.3 Who Needs Dike Deficiency Information and Why?

4.3.1 Diking Authority Operations Managers and Administrators

Comprehensive and detailed knowledge of every aspect of the diking system is vital for operations and maintenance of dikes as well as for planning and budgeting for upgrades, and applications for senior government funding. These individuals are largely responsible for developing the dike deficiency information that can be relied on by others.

4.3.2 Planners, Development Approval Officials, and Qualified Professionals Retained to Complete Flood Assessments

Local government flood management regulatory tools include official community plans, land use zoning, subdivision approvals, floodplain bylaws, and building and development permits. These plans and regulations establish the requirements for new development for floodplain areas, including those

[1] Based on 2011 census data and previously compiled floodplain map extents including the lower Fraser River floodplain, it was estimated that province wide, 424,000 people live on flood plains in BC, and that 315,000 people live on the Lower Fraser River floodplain (Ebbwater 2015). Given that almost all of the densely populated areas of the Lower Fraser River floodplain are diked (in addition to several other population centers e.g. Duncan, Kamloops, Squamish etc.) at least three quarters of the British Columbians that live in floodplains are living in areas protected by dikes.

protected by dikes. Knowledge of the adequacy of the dikes and level of protection provided by each dike is critical to creating and applying appropriate regulations.

As a prerequisite for development and construction in a flood-prone area, a development approving authority may require a proponent to obtain a Flood Assessment Report by a Qualified Professional (QP). The report may be required for the following purposes:

- to determine whether there is a potential flood hazard on the subject property;
- to meet the requirements of a local government bylaw;
- to confirm appropriate implementation of conditions in an existing covenant; and
- to ensure that the land "may be used safely for the use intended" in the absence of a bylaw, covenant, or other applicable regulation.

Engineers and Geoscientists British Columbia (EGBC) have developed professional practice guidelines, "Legislated Flood Assessments in a Changing Climate in BC" EGBC (2018). These guidelines explicitly describe the critical function of dikes and how the level of protection provided by the dikes should be considered in the QP's assessment of the hazard and recommendations for hazard mitigation.

Assessments and approval conditions depend on whether the flood protection works are considered to be "adequate" as defined in the guidelines. The basic direction to QPs in the guidelines is:

> "*In general, significant new development should not be located in floodplain and fan areas in the absence of a standard/adequate Dike or other Structural Mitigation Works.*"

While "standard dikes" are "those dikes considered by the Inspector of Dikes to meet minimum provincial standards", an "adequate dike" is described in the Guidelines as follows:

> "*If a Dike is to be considered adequate in the context of a flood assessment according to these guidelines, the following minimum standards must be met:*
>
> - *A local diking authority (typically local government) accepts responsibility for the Dike.*
> - *While the Dike may not fully contain the designated flood, it should be reasonably close to doing so and be within the capability of the local diking authority to address such deficiency.*
> - *While the Dike may not fully meet all current design and construction standards, any such deficiencies should be within the capability of the local diking authority to address.*
> - *Any deficiency in legal access must not unreasonably preclude the local diking authority from ensuring the overall integrity of the Dike.*
> - *The local diking authority accepts that the Dike is adequate for the purpose of the proposed project."*

For these Guidelines to be effectively implemented and to determine whether an existing dike is "adequate", QPs and development approval officials must have access to comprehensive dike deficiency information.

4.3.3 Emergency Planners and Responders

During a large flood event, the provincial government coordinates emergency planning and response as set out in the "Provincial Flood Emergency Plan" (MFLNRORD 2019a). All levels of government, First Nations, diking authorities and the private sector (e.g. major utilities, transportation, industry, agriculture) need to understand the level of protection provided by each dike as part of their specific emergency planning and response efforts. While all dikes have limitations, those areas protected by poor or inadequate dikes require immediate attention even during relatively small flood events.

Ideally, emergency planners should know well in advance at what flood level, or under what conditions any given dike may become unsafe and breach. Given complex logistics and the length of time for mass evacuations of people and livestock from protected areas (i.e. several days for larger communities in the Fraser Valley) evacuation trigger criteria need to be developed based on detailed dike assessment and deficiency information. It is difficult to get the trigger criteria "right" as unnecessary evacuations cause major disruption, but limited or late evacuations could result in loss of life.

Because dikes can breach through several different mechanisms in addition to overtopping, such as erosion or excessive seepage, knowledge of a range of factors, including how well the dikes have been maintained, should factor into any estimate of the level of protection that a dike can safely provide.

4.3.4 Administrators of Federal and Provincial Funding Programs

Funds for dike construction and major upgrades in BC have historically been provided by various federal and provincial government funding programs. Limited funds continue to be available from senior governments, but required costs have largely not been covered. While in some cases there is a local funding contribution, the primary role of local governments has been to provide the land (or rights of way) for the dike and to agree to take responsibility for the ongoing dike maintenance. Local governments and other diking authorities typically do not have sufficient resources for major dike upgrades.

The various funding programs generally prioritize funding allocations on the basis of flood risk assessments and criteria such as Return on Investment (ROI). Detailed knowledge of the condition, deficiencies and level of protection (i.e. the likelihood of dike breaching) of existing diking systems is an essential component of a credible risk assessment that evaluates the probability of dike failure, the cost of potential damages as well as the costs of flood mitigation projects.

4.3.5 The Public

Everyone living and/or working in the floodplain should be aware of at least the general level of protection of the dikes that protect their homes, businesses and other critical infrastructure and services. A high level of public awareness can help to:

- make dike maintenance and upgrading a local government priority with public support;
- ensure greater acceptance of local government taxation for dike maintenance and improvements;
- increase support for, and compliance with land use planning and development regulations;
- enhance public safety through increased compliance with emergency evacuation warnings; and

- prevent unintentional, or unauthorized tampering with a dike.

Insurers and re-insurers are particularly interested in understanding which floodplain areas are protected by "Flood Defences" and what standard of protection is provided. For example, JBA Risk Management has added a separate "Defended Areas" dataset to their global flood maps (JBA 2018). Given that flood insurance is a primary tool in managing residual risk, it is important that insurance for diked areas is priced appropriately.

4.4 Provincial Dike Standards

Except for the Lower Fraser River where the 1894 flood of record is the design standard (which currently is estimated to have roughly a 1:500 annual exceedance probability) the provincial design standard for riverine and coastal dikes is a flood with a 1:200 annual exceedance probability (i.e. a 1:200 chance per year, or 22% chance of being equaled or exceeded in 50 years). For densely developed floodplain areas, this is a relatively modest standard compared to some other jurisdictions such as the Netherlands which use a 1:2,000 to 1:10,000 annual exceedance probability standard (the 1:10,000 AEP standard applies to some of the coastal dikes). However, BC adopted the 1:200 standard in the 1970's when it also established the complementary land use policy that any new development in the floodplain behind dikes was to be floodproofed by raising all habitable areas above the flood level.

To date, the IOD has used a standards-based approach to establish dike design criteria. However, flood risk assessments are being undertaken at different scales across BC and there is increasing interest in considering risk-based approaches to flood management, including risk-based dike standards.

"Standard dikes" are defined in the EGBC Guidelines (EGBC,2018) to be:

> "*Those Dikes considered by the IOD to meet minimum provincial standards including the following:*
>
> - Design and construction to contain the designated flood (IOD Guidelines published on the provincial website)
> - Design and construction completed under the supervision of a Qualified Professional
> - An effective dike management and maintenance program by a local diking authority (typically local government)
> - *Legal access (rights of way or Land Ownership) for the diking authority to maintain the Dike*

Note that new dikes or major upgrades to existing dikes may need to meet additional standards (e.g. seismic and sea level rise)"

The IOD has published several dike design and construction guidelines that specify requirements with respect to hydrologic and hydraulic design, dike geometry, geotechnical investigations and design, and erosion protection. Detailed guidelines are also provided for dike inspections, and all operation and maintenance activities including vegetation management. Although several background studies and general guidance is available (e.g. EGBC 2017, 2018, Ausenco Sandwell 2011 Sea Dike Guidelines, and the Flood Hazard Area Land Use Management Guidelines Amendment, MFLNRORD 2018), detailed dike design standards to address climate change including sea level rise, have not yet been established.

As stated earlier, the term "deficiency" is used in this report primarily as a limitation in comparison to provincial flood protection standards. Detailed knowledge of the current condition of a dike and its deficiencies relative to the standards and guidelines published by the IOD is needed to assess the adequacy of the dike and to estimate the level of protection provided by the dike.

Because there are many modes of dike failure and it takes only one weak section and one mode of failure in several kilometres of dike to initiate a breach, even "standard dikes" in good condition can fail during floods less than the design event (Peters 2014). In this context, operation and maintenance, supported by information on dike deficiencies, is as important to dike safety as the original design and construction.

4.5 Review of Dike Deficiency Information

Information on dikes in BC is collected and retained by the provincial Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) and individual diking authorities.

The office of MFLNRORD's Inspector of Dikes (IOD) is located in Victoria and there are five regional Deputy Inspector of Dikes (DIOD) offices in other areas of the province. The IOD maintains a comprehensive "Dike Management" website that posts detailed information about dikes in BC including the Dike Safety Program, design standards, *Dike Maintenance Act* (DMA) administration, DMA Approval requirements, database lists, maps, drawings and much more.

The approximately 105 diking authorities (most being local governments) develop and retain information pertaining to the dikes that they own and manage.

Section 2 of the *Dike Maintenance Act* (DMA) gives the Inspector of Dikes certain powers and authority to require diking authorities to provide dike information (excerpt from Section 2(2)):

> "*2(2) The inspector may…*
> *(e) require a diking authority to provide routine or special reports on the construction or maintenance of dikes for which the diking authority is responsible,*
> *(f) inspect or make an order for the inspection of any books or records in connection with the construction or maintenance of dikes in the possession or control of a diking authority,*
> *(g) carry out or order an audit of a diking authority's program of construction and maintenance of dikes for which the diking authority is responsible, and*
> *(h) subject to this Act and the regulations, do any other thing or require a diking authority to do any other thing relative to the construction and maintenance of dikes, including orders respecting flood hazard planning*."

The focus of the IOD, DIODs and diking authorities is largely to develop dike deficiency information to support dike operation and maintenance, i.e. to maintain the standard that the dike was designed for. This information consists primarily of operation and maintenance manuals, annual inspection reports, and occasionally, DIOD audits of diking authority operations. Unless a special concern is identified, an engineering study to support a DMA approval is required, or the diking authority is planning to upgrade the structure, the routine operational information does not usually include assessment of the level of protection provided by the dike, or review of the design standards.

While there are multiple sources of information about the dikes, there is relatively little information about the level of protection provided by specific dikes. The level of protection is also a "moving target". Because dike design criteria evolve as new floods occur and river channels change, a so-called "standard" dike that may have been designed for a 1:200 Annual Exceedance Probability (AEP) event 30 to 50 years ago, is unlikely to meet current criteria. Changes in provincial standards and dike-specific design criteria changes make it very difficult to understand how "adequate" any particular dike may be.

Only a few studies have assessed the condition and level of protection of a large number of dikes with a consistent methodology. These include MFLNRORD's 2015 "Lower Mainland Dike Assessment" (NHC 2015), a provincial assessment of orphan dikes (BC Rivers Consulting, 2004), and FBC's Orphan Dike Risk Assessment Phase 2 (KWL 2020). However, two other current projects are developing important information that will support future dike assessments: MFLNRORD is currently working on a Provincial Dike Crest Elevation Survey Project, to be completed this year; and FBC is completing a "Regional Seismic Assessment" that will provide seismic vulnerability information for dikes at several locations in the lower mainland.

The information sources and the types of dike deficiency information provided are described in Table 4-1. Table 4-2 reviews the utility, accessibility, quality, and consistency for each of the information sources. Options and suggestions on ways to improve this information are offered in Table 4-3.

Examples of a few of these information sources are included in Appendix D.

Table 4-1 List of Dike Deficiency Information Sources

Item No.	Information Source	Dike Deficiency Information Provided
1	Provincial Dike Database - PDFs on MFLNRORD Website - MFLNRORD	None. Provides basic information about each dike. Orphan dikes are identified by the "No Local Authority" designation.
2	Provincial Dike Database - Flood Protection layers in iMap BC. - GeoBC	None. Shows centreline and appurtenant structure locations.
3	Provincial Dike Database - Internal Data Maintained by IOD and DIODs (uses Microsoft Access). Structure of database was developed for the LM Dike Assessment (NHC 2015) - MFLNRORD	Contains all dike ratings and deficiency information developed by the 2015 Lower Mainland Dike Assessment Project, but this information is not being updated. The database is being used to track DMA approvals issued by DIODs and key concerns and activities reported by diking authorities in their annual inspection reports.
4	Lower Mainland Dike Inventory Maps - pdf format - MFLNRORD	Identifies "standard" and "non-standard" dikes in the South Coast Region. Also identifies some known “low dike” and “special concern” locations (as of map date). Several of these maps were updated in 2011.
5	Ministry of Water, Land and Air Protection and Fraser Basin Council 1:100,000 Scale Wall Map "Floodplain of the Lower Fraser River" (2004)	Identifies "standard" and "non-standard" dikes in the South Coast Region by colour coding.
6	Diking Authority Annual Inspection Reports – MFLNRORD and Diking Authorities	Detailed identification of issues with dike access, crest and slopes, seepage, settlement, slumping, erosion protection, animal damage, unauthorized construction, channel change, vegetation, appurtenant works etc. with a summary of management activities and plans to address the issues.
7	Annual IOD Dike Inspection Compliance Reports - MFLNRORD	IOD tracks both the Report Submission Percentage and "Satisfactory Report" Percentage (both were approximately 80% in 2018).
8	Dike Safety Audits Completed by DIODs - MFLNRORD	Comprehensive reviews by DIODs of Diking Authorities' Dike Management Programs. Approximately 1-2 audits per MFLNRORD Region (i.e. 5 -10 audits per year in BC).
9	Diking Authority Operation and Maintenance Manuals, Record Drawings and Technical Reports	The O&M Manual and associated documentation should contain the original design criteria, record construction drawings, including drawings of any modifications and the most recent dike crest survey. This information is fundamental to assessing deficiencies

Item No.	Information Source	Dike Deficiency Information Provided
	Submitted in Support of DMA Approvals	and the level of protection. O&M Manual templates are provided on the IOD Dike Management web pages.
10	Provincial Dike Crest Elevation Survey Project - MFLNRORD - to be completed in 2020.	Detailed survey to provide updated alignment, crest elevation and locations/photos of appurtenant structures and dike features. Intent is to compare crest elevations with design flood levels, where available, which will allow assessment of freeboard, or extent of overtopping during the design event. Includes approx. 290 structures with a total length of approx. 1000 km but does not include orphan works.
11	Lower Mainland Dike Assessment Final Report (NHC 2015) - MFLNRORD	An overview assessment of each of 74 dikes in the Lower Mainland (including Squamish, Howe Sound and Fraser Valley from Richmond to Hope) to identify the current level of protection as far as feasible and identify major deficiencies. The project was a desk-top study utilizing information from MFLNRORD, diking authorities and available existing reports (over 900 reports and documents reviewed). No field investigations were carried out. The information was presented in detailed rating tables and colour coded maps. Dikes were evaluated for dike crest elevation/freeboard, embankment geometry, geotechnical stability, seismic stability, erosion, vegetation management, degree of encroachment by buildings/infrastructure, appurtenant structures, and operation and maintenance.
12	Lower Fraser Dike Crest Profile Comparison Drawings - MFLNRORD	Flood and dike crest profile drawings for dikes downstream of Mission provided by NHC (2008) (includes flood profiles for a range of Mission Gauge readings). MFLNRO (2014) provides comparisons for the dike crest elevations upstream of Mission with an updated MIKE 11 modelled 1894 flood magnitude design flood level profile.
13	Local Government Flood Risk Assessment Studies - EMBC/UBCM Funded 2017 to 2019 (68 studies costing approx. $ 14.4M)	• Floodplain areas protected by dikes are located within approximately 38 of the project study areas. • Reports were available for approximately 22 projects and 12 of these had study areas that contained dikes. These 12 reports were scanned for dike related information. • Only 4 of the 12 project reports provided dike deficiency information. Many of the projects explicitly excluded assessment of dike condition and the level of protection, but noted that this was a significant unquantified risk and recommended that this work be completed in future.
14	Local Government Floodplain Mapping Studies - EMBC/UBCM Funded 2017 to 2019 (54 studies	• Floodplain areas protected by dikes are located within approx. 40 of the project study areas. • Only 15 are “completed”, others are “in progress” or under review

Item No.	Information Source	Dike Deficiency Information Provided
	costing approx. $ 16.9M)	• Where the mapping developed a hydraulic model and a flood level profile, some information on dike freeboard and potential for dike overtopping for the designated flood was usually provided. Information on other deficiencies was generally not provided. Explicit assessment of the condition of the dikes and the level of protection provided was generally not within the scope of work.
15	Orphan Dike Risk Assessment - Fraser Basin Council (KWL 2020)	This project developed a method to assess the likelihood of dike failure (breaching) from both overtopping and other modes of failure (as one component of the risk assessment). The project will report the results of field assessments of 101 orphan structures. Significant effort was also made on assessing the consequences of failure of each orphan structure.
16	Lower Mainland Seismic Assessment - Fraser Basin Council (to be completed in 2020)	This project will provide estimated "Seismic-Induced Settlements" and "Damage State Index" for several locations throughout the Fraser Valley (and eventually Squamish).
17	Lower Mainland Flood Risk Assessment by IBI and Golder - Fraser Basin Council (to be completed in 2020)	"Fragility Curves" were prepared for both overtopping and piping failure (dike breach) modes. A fragility curve presents a relationship of failure probability to water level relative to the dike crest elevation. In this analysis, the piping fragility curve governed (i.e. dike failure would occur through piping failure before the dike was overtopped).
18	Flood Response Mobile Apps and Maps for Observers and Assessors - MFLNRORD 2018/2019	During major flood events, Provincial Flood Observers and Assessors use the App to record and communicate dike and river observations and submit assessment reports to emergency operations centres in near real-time and in a standard format.
19	Flood Safety Management E-Licensing – MFLNRORD (to be completed 2020/2021)	E-licensing is a platform used by the Province in several business areas. This application houses the new dike database housing all previous information from the Provincial Dike Database (Item #3) and will provide for workflow, DMA approval and enforcement actions to be carried out, monitored, and recorded.

Table 4-2 Utility, Accessibility and Quality of Dike Deficiency Information Sources

Item No.	Information Source	Utility	Current Accessibility	Quality and Consistency of Deficiency Information
1	Provincial Dike Database - PDFs on MFLNRORD Website - MFLNRORD	Provides basic information about each dike. Orphan dikes are identified by the "No Local Authority" designation.	Public - Accessible to all. Posted on the provincial "Dike Management" web pages. (sorted by "owner/authority" and by "watercourse")	N/A
2	Provincial Dike Database - Flood Protection layers in iMap BC. - GeoBC	Shows centreline and appurtenant structure locations.	Public - Accessible to all through the provincial iMap BC website. Also can view in Google Earth.	N/A
3	Provincial Dike Database - Internal Data Maintained by IOD and DIODs (uses Microsoft Access). Structure of database was developed for the LM Dike Assessment (NHC 2015) - MFLNRORD	Useful as a reference and information source for IOD and DIODs.	Microsoft Access database accessible only to IOD and DIODs. Content being transferred to E-licensing system (R. Sung pers com).	Tracking information for DMA Approvals and Inspection reports is up to date. The 2015 dike ratings and supporting deficiency information are still largely valid, but are not being updated as new information becomes available.
4	Lower Mainland Dike Inventory Maps - pdf format - MFLNRORD	Would be very useful for all purposes if updated and dikes rated with a consistent provincial system. As most of the dikes are now "non-standard" the colour coding is misleading.	Public - Accessible to all. Posted on the provincial "Dike Management" web pages.	The colour coding information is out of date and misleading because flood profile levels have significantly changed in most areas. Some of the "low dike" and "special concern" locations indicated may still be valid.
5	Ministry of Water, Land and Air Protection and Fraser Basin Council 1:100,000 Scale Wall Map "Floodplain of the Lower Fraser River"	Out of print - but many copies still in circulation and being used by both provincial and local government staff. A useful educational tool for both professionals and public.	Copies no longer available.	Out of date and dike colour coding for “Standard” and “Non-Standard” dikes is misleading.
6	Diking Authority Annual Inspection Reports -	A comprehensive annual inspection report is essential for	Accessible to the diking authority and DIOD office.	Highly variable according to IOD Dike Inspection Compliance

Item No.	Information Source	Utility	Current Accessibility	Quality and Consistency of Deficiency Information
	MFLNRORD	good dike operation and maintenance.		Reports. Approximately 20% of diking authorities do not submit annual inspection reports. Of the reports submitted about 20% are unsatisfactory (i.e. little or no details provided). (R Sung, DIOD pers com).
7	Annual IOD Dike Inspection Compliance Reports - MFLNRORD	Provides a measure of how well diking authorities are complying with inspection and reporting requirements.	Accessible to the IOD/DIOD offices in MFLNRORD. Public could access through a Freedom of Information (FOI) request.	The IOD office has monitored diking authority inspection reporting compliance since 2005.
8	Dike Safety Audits Completed by DIODs - MFLNRORD	Very useful dike safety management tool for both Diking Authorities and DIOD/IOD.	Accessible to the diking authority and the IOD	Very detailed and comprehensive as per standard template document.
9	Diking Authority Operation and Maintenance Manuals, Record Drawings and Technical Reports Submitted in Support of DMA Approvals	O&M manuals are a primary dike management tool.	O&M Manuals generally accessible only to the diking authority and DIOD offices. Various historic as-constructed drawings and reports are posted on the provincial Dike Management web pages.	Highly variable - many O&M manuals are out of date or incomplete.

Item No.	Information Source	Utility	Current Accessibility	Quality and Consistency of Deficiency Information
10	Provincial Dike Crest Elevation Survey Project - MFLNRORD - to be completed in 2020.	A critical project to support effective emergency planning and response, plus dike management. This is basic data that can be used to support a provincial dike rating system.	Specific dike surveys to be accessible to the respective diking authorities, local governments, First Nations and professionals. Will be available through a new "BC Flood Safety Information Portal" to be maintained by the IOD.	Detailed GPS survey to provincial specifications (min. 5cm vertical accuracy). Crest elevation points at maximum 25 m intervals. However, the quality and consistency of design flood profiles along each dike would be highly variable, depending on the most recent flood profile study and the details of the hydrologic and hydraulic analyses.
11	Lower Mainland Dike Assessment Final Report (NHC 2015) - MFLNRORD	Provides at least an overview assessment of each dike to support: emergency response, land use planning, funding prioritization and public awareness.	Public - Accessible to all. Posted on the provincial "Dike Management" web pages.	A comprehensive "Dike Evaluation Matrix" was developed and consistently applied to all the dikes. The primary limitation was that the assessments were based on existing information without new field and/or technical investigations.
12	Lower Fraser Dike Crest Profile Comparison Drawings - MFLNRORD	Critical information that shows where the Lower Fraser dikes are deficient in crest height relative to the design flood profile.	Reports and drawings are posted on the "Dike Management" web pages.	Varies. The design flood level profiles in these reports are the current "official" design levels specified by the IOD. However, the dike crest survey information in the 2008 report was from several sources and accuracy varied. The dike crest surveys in the 2014 update report was based on reliable 2012/2013 surveys by MFLNRORD.
Item	Information Source	Utility	Current Accessibility	Quality and Consistency of

No.				Deficiency Information
13	Local Government Flood Risk Assessment Studies - EMBC/UBCM Funded 2017 to 2019 (68 studies costing approx. $ 14.4M)	Very limited - (for the 12 reports that had dikes in the study area)	Varies. Reports not always posted on local government website.	Varies. Only a few reports included any information about the dikes within the study area and the extent of this information was limited.
14	Local Government Floodplain Mapping Studies - EMBC/UBCM Funded 2017 to 2019 (54 studies costing approx. $ 16.9M)	Any new flood profile information developed for floodplain mapping should be useful to assess dike freeboard, when combined with the results from the Provincial Dike Crest Elevation Survey Project.	Varies. Reports not always posted on local government website.	Varies. Only a few reports included any information about the dikes within the study area and the extent of this information was limited.
15	Orphan Dike Risk Assessment - Fraser Basin Council (KWL 2020)	The utility to assess the likelihood of dike failure is not known as the detailed project results are not yet available. The method may have some potential for wider application to dikes in BC. Given the consideration of failure consequences, the method will likely be very useful to identify high risk orphan structures and to prioritize mitigative actions.	FBC to publish report on web page?	Detailed results not yet available.
16	Lower Mainland Seismic Assessment - Fraser Basin Council (to be completed in 2020)	Very useful for land use regulation, seismic event recovery planning, risk assessments related to prioritizing funding.	FBC and/or MFLNRORD to publish report on web pages?	Good overview of seismic conditions in study area but site specific seismic assessments still required for individual dikes.
17	Lower Mainland Flood Risk Assessment by IBI and Golder - Fraser Basin Council (to be completed in 2020)	The curves were provided by Golder Associates Ltd. to IBI Group Inc for use in the flood risk assessment calculations. Dike crest elevations and flood profile	FBC to publish the final report on web page?	Upper and lower bound curves were estimated and a single average curve was used in the risk assessment for all dikes. However, Golder noted that the

		levels - i.e. estimates of average freeboard for a given dike would be needed to apply the fragility curve.		high variability in underlying ground conditions, dike construction, geometry and other factors would need to be considered in a rigorous assessment.
18	Flood Response Mobile Apps and Maps for Observers and Assessors - MFLNRORD 2018/2019	Observations and assessments of dikes during floods are documented in the "Common Operating Picture" portal and could be accessed post-event to follow-up on observed dike deficiencies and concerns.	Currently not used for dike management.	Expected to be highly variable, depending on the details of the dike concern and the knowledge and experience of the observer or assessor.
19	Flood Safety Management E-Licensing – MFLNRORD (to be completed 2020/2021)	Useful as a reference and information source for IOD, DIODs	Database accessible only to IOD and DIODs. Some fields will be linked to iMapBC in 2021 and DMA approval application and annual inspection reporting will be available to diking authorities	Tracking information for DMA Approvals and Inspection reports will be improved over current Provincial Database. The 2015 dike ratings and supporting deficiency information will be included.

Table 4-3 Options and Suggestions for Specific Information Sources

Item No.	Information Source	Options and Suggestions
1	Provincial Dike Database - PDFs on MFLNRORD Website - MFLNRORD	1.1 Add a field that indicates whether the diking authority is in compliance with Annual Inspection Reporting requirements. 1.2 Add a field that gives the dike rating, and the year that the dike was assessed. 1.3 Add the approximate level of protection based on the dike rating.
2	Provincial Dike Database - Flood Protection layers in iMap BC. - GeoBC	2.1 Colour code to give dike rating with year that dike was assessed. This information could also be made available through the new "Flood Portal" being developed by MFLNRORD.
3	Provincial Dike Database - Internal Data Maintained by IOD and DIODs (uses Microsoft Access). Structure of database was developed for the LM Dike Assessment (NHC 2015) - MFLNRORD	New E-licensing system could have a page(s) accessible to public (in addition to the pdf's described in Item 1). This page could provide the basic info as per existing database plus dike rating and inspection reporting compliance. Diking Authorities should be given access to view the detailed Dike Inspection, DMA approval and dike rating information, with a process for DAs to provide input to the DIOD office to make updates.
4	Lower Mainland Dike Inventory Maps - pdf format - MFLNRORD	Change colour coding of "standard/non-standard dikes" to a provincial dike rating. Update at least every five years, or sooner if there are significant changes in design criteria and dike rating. Consider sharing as an interactive digital layer map instead of, or in addition to pdfs.
5	Ministry of Water, Land and Air Protection and Fraser Basin Council 1:100,000 Scale Wall Map "Floodplain of the Lower Fraser River"	Consider preparing an updated map that could be reprinted every few years with updated dike ratings. Prepare a digital map with colour coded dike ratings.
6	Diking Authority Annual Inspection Reports - MFLNRORD	Consider posting individual inspection reports on Flood Portal to allow public access. This would provide an incentive for diking authorities to complete inspections and provide detailed inspection reports. (The IOD noted that digital copies of inspection reports and audits will be added to the E-Licensing system).
7	Annual IOD Dike Inspection Compliance Reports - MFLNRORD	Consider posting MFLNRORD's compliance summary on Flood Portal to allow public access. Would provide an incentive for diking authorities to complete inspections and provide detailed inspection reports.
8	Dike Safety Audits Completed by DIODs - MFLNRORD	IOD noted that digital copies of audits will be added to the E-Licensing system. Starting 2020 additional audits will be completed for diking authorities with any high consequence dikes where the diking authority has failed to submit an annual dike inspection report two years in

Item No.	Information Source	Options and Suggestions
		a row.
9	Diking Authority Operation and Maintenance Manuals, Record Drawings and Technical Reports Submitted in Support of DMA Approvals	DIODs should consider maintaining a digital file for each diking authority and dike within their region for storage and sharing of all technical information developed for that structure. This should be accessible to the diking authority, DIODs and IOD.
10	Provincial Dike Crest Elevation Survey Project - MFLNRORD - to be completed in 2020.	To maximize the utility of this new information, significant effort should be made to assemble and document design flood profiles for as many dikes as possible.
11	Lower Mainland Dike Assessment Final Report (NHC 2015) - MFLNRORD	Explore options to roughly estimate “level of protection” based on average dike rating.
12	Lower Fraser Dike Crest Profile Comparison Drawings - MFLNRORD	This information will be superseded by the information presented from the Provincial Dike Crest Elevation Survey Project (item 10 in this table) and available through the BC Flood Safety Information Portal. Recommend that these two Fraser flood profile reports continue to be posted on the web pages but with a note that newer dike crest elevation information is available through the Flood Portal.
13	Local Government Flood Risk Assessment Studies - EMBC/UBCM Funded 2017 to 2019 (68 studies costing approx. $ 14.4M)	Recommend that if dikes are located within the project study area and that if they have a Moderate, Major or High consequence classification, that a dike condition assessment and standard rating be developed as a component of the study scope of work.
14	Local Government Floodplain Mapping Studies - EMBC/UBCM Funded 2017 to 2019 (54 studies costing approx. $ 16.9M)	Recommend that if dikes are located within the project study area and that if they have a Moderate or higher consequence classification, that a dike condition assessment and standard rating be included in the study scope of work.
15	Orphan Dike Risk Assessment - Fraser Basin Council (KWL 2020)	Review potential for wider application of method when detailed results available.
16	Lower Mainland Seismic Assessment - Fraser Basin Council (to be completed in 2020)	Where new information available, use to update the Lower Mainland Dike Assessment ratings for "Geotechnical Stability - Seismic".

Item No.	Information Source	Options and Suggestions
17	Lower Mainland Flood Risk Assessment by IBI and Golder - Fraser Basin Council (to be completed in 2020)	The use of fragility curves could be considered as a possible approach to estimate the level of protection provided by a specific dike. Golder recommends that further comprehensive geotechnical assessment of the Lower Mainland dike system be completed to develop and confirm appropriate fragility curves for these dikes on a reach- and segment-specific basis.
18	Flood Response Mobile Apps and Maps for Observers and Assessors - MFLNRORD 2018/2019	DIODs to access the "Common Operating Picture" portal post flood events to extract any dike observation and assessment reports and follow-up, or at minimum add this to the dike's digital file with a copy to the diking authority.
19	Flood Safety Management E-Licensing – MFLNRORD (to be completed 2020/2021)	Review for potential upgrades when complete.

4.6 Dike Information - Conclusions and Recommendations

Comprehensive flood hazard information is the basis for effective risk management, and for BC, this includes detailed knowledge of the condition, the level of protection and the key limitations (i.e. deficiencies in comparison to provincial standards) of each dike and diking system. This information is needed to support:

- Effective operation and maintenance of diking systems
- Land use plans and regulations for development in protected floodplain areas
- Emergency response and recovery plans
- Flood Risk Assessments and prioritization of funding for dike upgrades
- Public awareness of flood risks

Many diking authorities have relatively good information with respect to operation and maintenance of their dikes. However, with the exceptions of the 2015 Lower Mainland Dike Assessment study and the Orphan Dike Risk Assessment project (KWL 2020), information on the deficiencies and level of protection provided by a specific dike is generally not available.

Currently QP's and land development approval officials (e.g. subdivision approving officers and building inspectors) do not have access to readily available information to support a determination of whether a dike is "adequate" to protect new development. Outdated colour coded maps indicating "standard" and "non-standard" dikes are still being referred to by emergency responders. The accuracy and usefulness of flood risk studies for diked areas is diminished if the level of protection of the dike is unknown.

4.6.1 Key Recommendation - Establish and Apply a Standardized Dike Assessment Rating System

With respect to existing dike deficiency information, some options and suggestions to enhance the availability and utility of these information sources are provided in Table 4-3. From Table 4-3 it is clear that a standardized dike assessment rating system is the primary tool needed to fill information gaps and to support effective flood management for dike protected areas.

Therefore, the key recommendation of this investigation is that BC should establish a standardized dike assessment rating system and develop a method to roughly determine the "Estimated Level of Protection" (i.e. annual probability of dike breach).

To include the full range of dike characteristics, condition, and deficiencies, the assessment and rating system should be based on a methodology similar to the method developed by the 2015 Lower Mainland Dike Assessment (NHC 2015) with modifications and improvements as needed. These dike ratings should then be used to roughly determine the "Estimated Level of Protection". While a number of approaches could be considered, a straightforward method to relate dike assessment rating and "Estimated Level of Protection" is presented in Appendix E.

As a first step, all 212 dikes in BC should be assessed at an overview level (i.e. complete a desktop study based on available reports and information). The next step would be to review the dike assessments for all “High” and “Major Consequence Dikes” (71 dikes) and include limited field or other investigations to fill in crucial information gaps. Reliance would be made on existing geotechnical information and studies. To maximize efficiency and consistency it is recommended that the dike assessments be completed via consultant contract, with subsequent ministry and diking authority updating as new information becomes available.

Dike ratings will change over time as design criteria (e.g. design flood profiles) are updated and/or where dikes are upgraded or modified. Maintaining current ratings and dike information will take significant ongoing work for the Dike Safety Program to identify the dikes that need updated ratings and to ensure that the ratings are revised. To assist in this effort, it is recommended that refinement/updating of dike ratings be included in project budgeting as part of Provincially funded risk assessment or mapping projects (such as Community Emergency Preparedness Fund (CEPF) projects) that contain dike protected areas.

The IOD also has the option to request that a diking authority provide specific dike information (e.g. updated crest surveys) or to update previous assessments. An effective approach would be to include this work as a condition of DMA approval for projects where the changes to the dike affect the dike rating. In this way the re-assessment and rating update can be included as part of routine design and construction report documentation.

The current definition of an “adequate” dike in the 2018 EGBC “Legislated flood assessments in a Changing Climate” guidelines is useful, but is highly subjective (see section 4.3.2 above). It is recommended that the EGBC guidelines and definition of “adequate” dike be amended with reference to the new provincial dike rating system, when available.

Assessment of the dikes with a standardized rating system would have the following benefits:

1. Support for effective operation and maintenance of diking systems:
    - Available dike information would be summarized in a consistent and accessible format.
    - Ratings would help prioritize the dike segments needing maintenance.
    - Ratings would help prioritize the dike segments that most need upgrading.
    - Diking authorities would be motivated to improve dike ratings through addressing the key deficiencies identified by the assessments.
    - New information, such as results from the Provincial Dike Crest Survey and the Lower Mainland Seismic Assessment could be incorporated into updated ratings.
2. Support for land use plans and regulation of development in protected floodplain areas:
    - Land use plans could be revised to reflect the level of protection provided by the dike (for example, new development could be restricted from areas where dike protection was significantly less than the provincial standard - i.e. the annual probability of failure was estimated to be in the range of 1:50 to 1:100).

- The ratings would support QPs in completing flood assessments where dikes protect the proposed development area (and would allow a more objective approach to be incorporated into amended EGBC professional practice guidelines).

3. Emergency planning, response and recovery:
    - Before flood events, emergency planners could use the dike assessment information to assist in determining the critical flood levels that would be used to initiate warnings and evacuation of people and/or livestock from dike protected areas.
    - During flood events, emergency planners, dike patrollers and flood fighters could prioritize the dike segments to be monitored and defended, based on the assessment information.
    - After the flood event, the re-building of dikes would usually be part of recovery plans. The dike assessment information would assist in developing dike upgrading plans.
4. Flood Risk Assessments and prioritization of funding for dike upgrades, or other mitigation options:
    - To quantify flood risk for a diked area, an estimate of the probability of dike failure is needed as well as an estimate of the consequences of dike breach flooding.
    - The dike rating information would support estimates of the flood mitigation benefits of a dike upgrading project and allow a more accurate calculation of the Return on Investment (e.g. as required by the federal "Disaster Mitigation and Adaptation Fund" program).
5. Public awareness of flood risks:
    - The inclusion of the dike ratings (with colour coding) on floodplain maps and local government interactive mapping platforms would help to inform the public of the presence of the dike, the area it protects, and the level of protection provided.
    - Where 2D modelling of dike breaching has been completed as part of floodplain mapping studies, the presentation of dike breach animations are useful to increase understanding of the potential progression of flooding through the floodplain. 3D visualizations may also be an effective communication tool.
    - An appreciation of the limitations of dike protection would help build public support for dike maintenance, upgrades, and increased compliance with evacuation orders during flood events.
6. Insurers:
    - It is expected that insurers would use the dike ratings and estimated level of protection to determine flood insurance premiums for specific dike protected areas.
    - High flood insurance costs, particularly for commercial and light industrial property, would help drive support for the dike maintenance and upgrading work needed to improve the dike rating.

4.6.2 Other Recommendations

Table 4.3 presents other options and suggestions to enhance the availability and utility of existing dike deficiency information sources. Three of the most significant of these actions are recommended as follows:

1) Publicize dike inspection reporting compliance information (e.g. via web page, provincial dike database, the Flood Portal and/or other). This would provide an incentive for diking authorities to complete inspections and provide detailed inspection reports.

2) Complete dike safety audits of all diking authorities having "High" and/or "Major Consequence Dikes" (71 dikes) at least every 5 years. This will approximately double the effort currently being made by DIODs from 5 to 10 audits per year provincially to 10 to 20 per year. Audits are a very useful dike safety management tool for both diking authorities and the DIODs/IOD.

3) Establish a standardized and easily accessible dike file system for sharing and storage of key technical information. Create one digital folder per dike with a consistent format and make accessible to the diking authority, DIODs and IOD. The information would include O&M manuals, dike crest surveys, record drawings, reports in support of DMA Approvals, audits, and inspection reports. Maintaining and sharing these files will also help to ensure efficient updating of dike assessment ratings.

4.7 Estimated Resources and Costs

The estimated resources and costs to implement the above recommendations are presented in Table 4-4. The establishment of a standardized dike rating system and the rating of all BC dikes is estimated to cost approximately $2.2 million, including a one time allocation of 0.7 FTE of provincial staff to provide direction, input and management of the necessary studies, including amendment of the EGBC flood assessment guidelines. While this estimate allows for prioritized field inspections and some additional analyses, it does not include any new geotechnical investigations. The geotechnical stability ratings would be based on existing geotechnical studies and/or regional soils information.

The provincial personnel time required to maintain and refine the ratings, primarily updating information for individual dikes, is estimated to be 0.3 FTE.

The cost to implement the other three recommendations (publicizing compliance information, increasing dike safety audits, and improving dike information file management) is roughly estimated to be $100K in contract funds and 0.2 FTE to set up, and 0.6 FTE for the ongoing work.

These costs assume that the ratings and additional dike information, as recommended above, can be integrated into the new Flood Safety Management E-Licensing platform currently being developed by MFLNRORD.

Table 4-4 Resources and Costs to Implement Investigation B-2.3 Recommendations

Ref. Nos.[1]	Directed to	Recommendation	Resources	Contract Costs ($K)	Personnel/FTE Costs ($K)	
		A. Establish and Apply Dike Rating System			One Time	Per Year
1, 2, 3, 4, 5, 10, 11, 16	MFLNRORD	**A1.** Establish a standardized dike rating system and a method to roughly determine the "Estimated Level of Protection" (i.e. annual probability of dike breach). Base on the 2015 Lower Mainland Dike Assessment methodology (NHC 2015) with modifications as needed.	Contract Funds 0.1 FTE to direct/manage contract 0.1 FTE for training of DIODs and adding to ministry information systems	$150	 $15 $15	
	MFLNRORD and Diking Authorities	**A2.** Apply the dike rating system to all dikes in BC (212 dikes). For consistency and efficiency, complete the dike assessments with one consultant contract, with subsequent ministry and diking authority work to update the ratings as new information becomes available. Costs estimated at $6.5K/dike.	Contract Funds 0.3 FTE to direct/manage contract 0.3 FTE ongoing to manage information and updates Diking Authority staff time (will vary – not estimated)	$1,340	 $45	 $30
	MFLNRORD	**A3.** For all "High and Major Consequence Dikes" (71 dikes) complete field inspections or other work to fill in key information gaps.	Contract Funds 0.1 FTE to manage contract	$700	 $15	
13, 14	EMBC and UBCM	**A4.** Include refinement/updating of dike ratings as part of CEPF or other Provincial funded risk assessment or mapping projects that contain dike protected areas.	Costs will vary but may be in order of 10% of project costs.			
	EGBC and MFLNRORD	**A5.** Amend the flood assessment professional practice guidelines (EGBC 2018) to incorporate dike ratings.	Contract Funds 0.1 FTE to participate in amendment	$20	 $15	
		Subtotal for A. Dike Ratings		**$2,210**	**$105**	**$30**
Ref.	**Directed to**	**Recommendation**	**Resources**	**Contract**	**Personnel/FTE**	

Nos.[1]				Costs ($K)	Costs ($K)	
		B. Other Recommendations			One Time	Per Year
1, 7	MFLNRORD	**B1.** Publicize dike inspection reporting compliance information (e.g. via web page, provincial dike database, the Flood Portal and/or other).	0.1 FTE ongoing to keep compliance information up to date and respond to enquiries.			$10
8	MFLNRORD and Diking Authorities	**B2.** Complete Dike Safety Audits of all diking authorities having “High” and/or “Major Consequence Dikes” (71 dikes) at least every 5 years. (this will approximately double the effort currently being made by DIODs from 5 to 10 audits per year provincially to 10 to 20 per year).	0.4 FTE ongoing (DIODs) Diking Authority staff time (will vary – not estimated)			$40
9	MFLNRORD and Diking Authorities	**B3.** Create one digital folder per dike with a standardized format for storage and sharing of key technical information developed for that structure. Make accessible to the diking authority, DIODs and IOD (e.g. O&M manuals, dike crest surveys, record drawings, reports in support of DMA Approvals, audits, inspection reports etc.)	Contract Funds 0.2 FTE to assist/manage contract 0.1 FTE ongoing to manage information and updates Diking Authority to provide reports, surveys and other information. Staff time (will vary – not estimated)	$100	$20	$10
		Subtotal for B. Other Recommendations		**$100**	**$20**	**$60**
		Total for A. Dike Ratings and B. Other Recommendations		**$2,310**	**$125** **0.9 FTE**	**$90** **0.9 FTE**

Notes:

1. 1. Reference Numbers denote the existing dike deficiency information sources described and listed in Tables 4.1, 4.2 and 4.3.
2. 2. To estimate MFLNRORD personnel costs (FTE = full time equivalent), used $100K/year for engineering tech; $150K/year for Professional Engineer/Project Manager.

5 INVESTIGATION B-2.4: STATUS OF LIDAR IN BC

Flood studies require high resolution topographic data (APEGBC, 2017; Natural Resources Canada and Public Safety Canada, 2019a). In Canada, this data is commonly acquired via airborne LiDAR. LiDAR data acquisition must be factored into overall planning of a flood study. This section describes the status of LiDAR standards and LiDAR availability for flood mapping in BC and provides recommendations for improvements.

In BC, LiDAR data collection is carried out by private providers hired by federal, provincial, or local governments or private companies. Data may be collected according to provincial specifications, federal guidelines, US specifications, or "industry standard" specifications as defined by the LiDAR provider and client for a specific project. Depending on the contract, LiDAR data may be privately owned, owned by government, or covered by an open data license. Information about existing LiDAR data in BC, whether publicly or privately owned, is not readily available.

The following sections summarize LiDAR guidelines and specifications applicable to flood mapping in BC; describe the current state of LiDAR data availability in BC; and list some key issues relating to LiDAR data use for flood studies. The final section provides recommendations for further development of LiDAR standards and for LiDAR acquisition and dissemination in BC.

NHC would like to acknowledge the following individuals who shared information for this report:

- LiDAR Providers: Ian Chong, Business Development Manager, McElhanney; Taylor Davis, LiDAR Applications Specialist, Terra Remote Sensing Inc.
- LiDAR Users: Tamsin Lyle, Principal, Ebbwater Consulting Inc.; Mark Rankin, GIS Specialist, Ocean Networks Canada
- Provincial Government: Brad Hlasny, Director, GeoBC
- Federal Government: Paula McLeod, Program Manager, Canada Centre for Mapping and Earth Observation (CCMEO), Natural Resources Canada – manager responsible for flood mapping at CCMEO; David Bélanger, Project Officer, Natural Resources Canada – project manager with the National Elevation Data Strategy at CCMEO

5.1 LiDAR Guidelines and Specifications

The following guidelines and specifications relate to LiDAR acquisition in BC.

5.1.1 Provincial

BC LiDAR-related specifications and guidelines of relevance to flood mapping are:

- GeoBC's "Specifications for Airborne LiDAR for the Province of British Columbia" (MFLNRORD, 2020)
- GeoBC's "Specifications for the Production of Digital Elevation Models for the Province of British Columbia" (MFLNRO, 2017)

- "Appendix D, LiDAR Mapping Specifications" in "Coastal Floodplain Mapping – Guidelines and Specifications" (MFLNRO, 2011)

While not specific to flood mapping, GeoBC's LiDAR and DEM specifications should be considered for any flood mapping LiDAR project. The DEM specifications are relevant, as they cover key LiDAR deliverables required for flood mapping. The "LiDAR Mapping Specifications" included in the Coastal Floodplain Mapping Guidelines and specifications provide a useful overview of LiDAR specifications, but are less detailed and less current than the GeoBC LiDAR specifications. They do not include any flood mapping-specific information.

5.1.2 Federal

Canadian federal guidelines for LiDAR acquisition are:

- "Federal Airborne LiDAR Data Acquisition Guideline, Version 2.0" (Natural Resources Canada and Public Safety Canada, 2018), including "Appendix 2, Flood Mapping"

These detailed guidelines are part of Natural Resource Canada's (NRCan) Federal Flood Mapping Guidelines series and should be considered for any flood mapping LiDAR project. An earlier version of the GeoBC LiDAR specifications was referenced in the development of these guidelines, and the documents are somewhat complimentary. "Appendix 2, Flood Mapping" provides specific guidance for collection of LiDAR for flood mapping applications. Version 3.0 of the federal LiDAR guidelines is due for release in fall 2020 and will include more information on bathymetric LiDAR.

Federal guidelines may eventually be converted to official Canadian standards. In February 2020, NRCan held a workshop with multiple stakeholders to discuss conversion of flood mapping guidelines to standards. There was agreement that some of the flood mapping guidelines should be converted: the LiDAR acquisition guidelines, the "Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation" (Natural Resources Canada and Public Safety Canada, 2019b), and the "Federal Geomatics Guidelines for Flood Mapping"(Natural Resources Canada and Public Safety Canada, 2019a). NRCan is currently working with the Standards Council of Canada to consult with the flood mapping community; a report is due for release later in 2020. The next step will be to seek resources to pursue the development of standards for flood assessment purposes. This process is supported by the community but is in very early stages of development. (P. McLeod, personal communication, May 20, 2020.)

5.1.3 United States

Relevant US guidelines include:

- US Geological Survey "Lidar Base Specification" (Heidemann, 2018)
- Federal Emergency Management Agency "Guidance for Flood Risk Evaluation and Mapping: Elevation Guidance" (FEMA, 2016)
- "ASPRS Positional Accuracy Standards for Digital Geospatial Data" (ASPRS, 2015)

These guidelines were referenced in the development of Canadian federal and provincial documents. A detailed review was not undertaken for this project, other than to confirm that essential requirements in these documents are covered in the Canadian federal and provincial documents.

Review of guidelines and specifications for other jurisdictions was beyond the scope of this project.

5.1.4 Comparison of Provincial and Federal Documents

The GeoBC's provincial LiDAR specifications (MFLNRORD, 2020) and the federal LiDAR guidelines (Natural Resources Canada and Public Safety Canada, 2018) are somewhat related. An earlier version of the provincial specifications was referenced in the development of the federal guidelines, and vice versa. However, specifications provided in the documents are not identical which makes it unclear which one should be used and causes some confusion for LiDAR providers and those contracting LiDAR acquisition.

Many LiDAR specifications are defined according to "quality level" (QL). Federal guidelines reference a minimum requirement of "Canadian Quality Level 1" (CQL1) with additional requirements depending on application, such as those provided for flood mapping applications in Appendix 2. GeoBC specifications refer to five quality levels, which are derived from US specifications. GeoBC's QL2 appears to correspond to CQL1. GeoBC's specifications do not include any specific guidance for flood mapping applications but are nonetheless suitable for acquiring data for flood mapping.

In many cases, specifications match between the two documents. For example, vertical accuracy defined as vertical root mean squared error (RMSEz) is <= 10 cm under both CQL1 and QL2. For flood mapping for the High Flood Risk category, federal guidelines recommend a higher accuracy of <= 5.0 to 7.5 cm, which is similar to GeoBC's QL1 with an RMSEz <= 5.0 cm.

Federal guidelines state that snow- and ice-free and leaf-off conditions are preferred but may be waived depending on local conditions and requirements. Shorelines and water courses should be free from significant ice buildup and there should be no unusual flooding or inundation. LiDAR should be collected during low flow conditions. Low tide conditions are not specified.

Similarly, GeoBC's standards require LiDAR collection during conditions that are free of snow cover and extensive flooding or other inundation. Leaf-off conditions are not necessarily required, but vegetation conditions (leaf-on/off) must be specified during mission planning. Low flow and low tide conditions are not mentioned, presumably because this is a specific requirement for flood mapping and the GeoBC specifications do not specifically address flood mapping.

The federal and provincial documents give slightly different requirements for LiDAR point classification. The provincial specifications require classification of bridge decks, but Canadian guidelines do not. The tiling scheme and file naming requirements differ between the two documents. The level of documentation required by the provincial specifications is greater than that required by federal guidelines.

Federal guidelines include recommendations about ownership and copyright of LiDAR data, and the federal LiDAR acquisition program incorporates a requirement for open data. Ownership and licensing requirements are not mentioned in the provincial specifications.

Federal and provincial documents both provide suitable specifications for flood mapping applications. Clarification regarding how the provincial specifications should be applied to flood mapping would be helpful, particularly for those who wish to use the specifications for non-government contracts. The larger problem is a lack of adherence to these specifications for many BC LiDAR projects.

5.2 LiDAR Availability for Flood Mapping in BC

5.2.1 Provincial

GeoBC has a "LiDAR BC Inventory Information Portal". This inventory has a web GIS format, but is not publicly accessible. The inventory includes:

- public data collected under contract to GeoBC,
- other public data,
- privately held data, where private companies were able to share the information,
- an in-progress and planning layer,
- licensing information (open data, Province-owned, 3rd party license, planned/in-progress), and
- password-protected data download.

Current data dissemination is limited. LiDAR collected under the NDMP program is made available to government partners but not to the private sector or academia for a variety of reasons (intellectual property, licensing, ability to support data requests and questions, etc.). Distribution of LiDAR collected under other programs varies for similar reasons.

Provincial LiDAR data ownership varies. GeoBC and other provincial entities are currently working on the issue of data licensing, but it has not been resolved yet. GeoBC anticipates eventually making some aspects of the LiDAR portal publicly accessible if data becomes available under an Open Government License (OGL). The long-term vision for this site includes provision of LiDAR derivative products on-the-fly through cloud processing.

A LiDAR Program is being considered for BC. No details are available from GeoBC at this time, but information and an RFP may be released soon.

Both provincial and federal entities report that they work together to coordinate LiDAR acquisition and dissemination to avoid major overlaps and share resources.

5.2.2 Federal

Canada's National Elevation Data Strategy, "…aims to increase high-resolution elevation data coverage for Canada and improve accessibility to the products."[2] One product is the High-Resolution Digital Elevation Model (HRDEM). The National Elevation Data Strategy includes development of the federal LiDAR guidelines, acquisition of LiDAR data, and an inventory of federal LiDAR data. The inventory does not currently incorporate information from private sources, as not all private vendors are able to share

[2] "High-Resolution Digital Elevation Model (HRDEM) generated from LiDAR – New data available!", https://www.nrcan.gc.ca/science-and-data/science-and-research/earth-sciences/geography/topographic-information/whats-new/high-resolution-digital-elevation-model-hrdem-generated-lidar-new-data-available/22350, accessed May 22, 2020.

this information. NRCan works with GeoBC to coordinate LiDAR acquisition and inventory efforts. (D.Bélanger, personal communication, May 20, 2020.)

Federal data will be available for download after July 2020. Federal data can be accessed in three ways:

- HRDEM via the Open Canada data portal (https://open.canada.ca/data); this product is currently available and will be updated as more LiDAR is incorporated
- A DEM mosaic of entire country
- LiDAR point cloud will be available for download later this year

All data included in the federal program should be covered by an open data license. NRCan is working with the BC government on this.

5.2.3 Local Government

Local governments often collect LiDAR for various purposes. Some of this data may be suitable for flood mapping. Data is collected under various specifications and data sharing agreements. Information is often available from local government websites or GIS, engineering, and planning departments. There is no publicly accessible central inventory of LiDAR data collected by local governments in BC.

5.2.4 Private

In addition to supporting public agency data collection, LiDAR providers also collect data for private organizations and may have data that they collected on spec. Some of this data is available for resale directly from LiDAR providers[3], but this depends on privacy issues, client priorities, and vendor resources. LiDAR providers typically retain records of the areas they have flown for various clients, but do not share this information publicly.

5.3 Key Issues and Concerns

There are several issues relating to LiDAR acquisition and use for flood mapping in BC.

5.3.1 LiDAR Acquisition

- While both the federal guidelines and the provincial specifications provide suitable guidance for LiDAR collection for flood mapping, it is not clear which document should be used in a given situation or how the provincial specifications specifically apply to flood mapping.
- LiDAR data often does not meet required specifications for flood mapping, compromising the accuracy of mapping. Causes of this problem include:
  - A lack of awareness of applicable specifications, so that they are not included in the LiDAR acquisition contract.

[3] For example, McElhanney's Vertisee application includes a public catalogue, https://vertisee.mcelhanney.com/.

- A lack of funding to meet LiDAR specifications, so that they are not fully included in the LiDAR acquisition contract.
- A failure to meet contract specifications, with no qualified review of data deliverables to ensure compliance.
- Data was collected for a different purpose and meets a LiDAR specification that is not suitable for flood mapping.
- Data is old and does not meet current specifications.

- Specific issues resulting from non-compliance to LiDAR specifications for flood mapping include:
  - Lack of metadata, such that data quality and suitability cannot be ascertained.
  - Insufficient documentation, incorrect file naming, incomplete files, and inaccurate data.
  - Data density is too low and cannot be used to produce a DEM sufficiently accurate for flood mapping.
  - During ground-truthing, the vertical accuracy is found to fall outside specified range.
  - Data was flown at high flows or high tide, limiting the extent of data collected and limiting desired overlap with bathymetric data.
  - Data was not collected after snow melt or during leaf off, limiting ground elevation returns.
  - Data was not accurately classified, such as where bars in active channels are mis-classified as water. Expert judgement is required to balance classification accuracy and level of effort (e.g. to determine where accurate point classification in active channels "matters" for the purpose of hydraulic modelling).
  - Data was not collected using the correct coordinate reference system (horizontal coordinate system, horizontal datum, and vertical datum).
- While overall the standards are suitable for flood mapping, there are some specific issues such as:
  - One LiDAR vendor noted that GeoBC's standard requirement of 8 pulses per square metre is insufficient in some areas to achieve the desired resolution of one classified bare earth point per square metre.
  - GeoBC's specifications do not include low flow requirements. Neither GeoBC's specifications nor the federal guidelines include low tide requirements.
- LiDAR data is often unavailable on the timeline required for flood mapping. LiDAR data is needed in advance of bathymetric and topographic ground surveys to ensure adequate overlap between LiDAR and ground survey data and is required before commencement of

hydraulic modelling. Weather conditions in BC, such as heavy cloud cover and coastal fog, often hinder LiDAR collection. Smoke from forest fires can also pose a challenge.

- LiDAR data may be out of date and not suitable for flood mapping. Older data may not meet current LiDAR specifications for flood mapping. A site may have changed significantly due to development, coastal erosion, river migration, local subsidence, new dike alignments, etc., since the LiDAR data was collected. LiDAR data collected too far in advance of bathymetric surveys increases the effort required to merge surveys with LiDAR data where channels have changed.
- Orthophotos are not always collected concurrently with LiDAR data. Orthophotos are useful for resolving questions such as, for example, where channel deposits should be classified as land or water.
- Project boundaries for LiDAR collection may be set to exclude important areas adjacent to the study area.
- In recent years, bathymetric LiDAR technology has evolved such may be suitable for riverine and nearshore bathymetric surveys to support flood studies. Although this technology is in use in some regions in North America, it is not yet common in BC. High water turbidity and poor water clarity may make bathymetric LiDAR less effective in BC than it is in other locations.

5.3.2 LiDAR Dissemination

- It is difficult to determine what data is available in BC. There is no publicly available central inventory of existing data, whether public or private data.
- It is difficult to acquire existing data. Many data sets, including some collected by public agencies, are not covered by an open data license and are not readily available.
- Data licensing and data sharing agreements are not consistent across the province, and terms are not always clear.
  - Under open data agreements, it is not clear whether private LiDAR vendors will be allowed to sell value-added products based on raw LiDAR.
  - Province's agreement includes following clauses; the impact of these requirements on flood mapping products partially derived from LiDAR data (such as flood depth rasters and flood extent polygons) is not clear:
  - The Licensee will provide the Province with access to or copies of all records (as defined in the Interpretation Act), software and other material or derivative works, whether complete or not, produced by the Licensee using the LiDAR Data or any part of the LiDAR data or any modifications thereto (the "Produced Material").
  - The Licensee hereby grants to the Province a perpetual, worldwide, non-exclusive license to use, reproduce, distribute and modify the Produced Material.

- Upon the Province’s request, the Licensee will deliver to the Province documents satisfactory to the Province that irrevocably waive in the Province’s favour any moral rights which the Licensee (or employees of the Licensee) may have in the Produced Material and that confirm the vesting in the Province of the copyright in the Produced Material.

5.4 Recommendations

5.4.1 LiDAR Guidelines and Specifications

- Do a detailed review of provincial LiDAR specifications in comparison to federal LiDAR guidelines, with an explanation of differences and clarification of which provincial specifications apply to floodplain mapping.
  - Clarify whether both provincial and federal standards are acceptable for acquisition of LiDAR data that will be incorporated in both provincial and federal LiDAR dissemination and flood mapping programs.
  - Expand the GeoBC specifications to include specific requirements for flood mapping applications regarding low flow, low tide, leaf-off, snow- and ice-free conditions. Specify which accuracy / quality level(s) apply to flood mapping.
  - Allow for some flexibility in the application of standards depending on local conditions if minimum requirements are met.
  - Continue to consult with the community, including LiDAR providers, to determine what requirements are suitable for flood mapping applications.
- Raise awareness of provincial specifications and federal guidelines with agencies responsible for LiDAR data collection.
- Monitor updates to provincial specifications and federal guidelines and ensure they remain harmonized.
- Monitor development of federal LiDAR standards based on existing guidelines.
- Collection of LiDAR data for flood mapping applications alone is unlikely to be cost effective. Ensure that guidelines and specifications continue to incorporate expertise from outside the flood mapping community so that they will be broadly accepted and applied.

5.4.2 LiDAR Acquisition

- Ensure LiDAR data collected for flood mapping meets specifications and floodplain mapping needs.
  - Ensure LiDAR acquisition follows a standard such as GeoBC’s LiDAR acquisition specifications or the federal LiDAR guidelines (including Appendix 2).
  - Include this requirement in the LiDAR acquisition contract.

- Review deliverables to ensure compliance. If agencies/clients do not have review capabilities in-house, third party review may be required. NRCan may be able to provide this service for LiDAR covered by open data agreements.

- Set LiDAR collection boundaries to include areas adjacent to the current study, such as upstream and downstream reaches, opposite riverbanks, and adjacent communities.
- Plan flood mapping projects with sufficient lead time to allow for appropriate LiDAR collection.
  - Develop a multi-year flood study plan.
  - Allow schedule and budget flexibility for adapting to weather conditions. Weather may delay LiDAR collection by months. Collecting LiDAR in sub-optimal conditions may result in data that is not sufficiently accurate to support flood mapping.
  - Allow time and budget for QA/QC review of LiDAR deliverables.
  - Obtain LiDAR data in advance of ground and bathymetric surveys related to the flood study.
  - Obtain LiDAR data in advance of hydraulic modelling.
  - Ensure that the flood mapping project includes a QA/QC process to tie ground and bathymetric survey data to LiDAR data.
  - Ensure that LiDAR collection includes coincident orthophoto collection.
- Plan for LiDAR updates to coincide with flood mapping updates, which are required about every 10 years (APEGBC, 2017).
- Develop a province-wide publicly funded ongoing LiDAR collection program.
  - Long-term planning could reduce conflicts caused by weather conditions and fiscal year limitations.
  - This approach would potentially result in better support from LiDAR providers, as they could develop business plans around multi-year contracts.
- Ensure provincial LiDAR acquisition efforts continue to be coordinated with federal, local and other efforts to avoid duplication and share resources.
- Monitor development and application of bathymetric LiDAR technology, including information in the upcoming revision of federal LiDAR guidelines. Sponsor research into the use of bathymetric LiDAR to support flood mapping in BC.

5.4.3 LiDAR Dissemination

- Require open data licenses for all LiDAR data collected with public money.
  - Establish this when a LiDAR acquisition contract is set, as this will affect costs.
  - Ensure licensing clarifies what value-added work can be done based on open data.

- Develop a sample open data sharing agreement for use by local governments and other agencies.
- Provide an inventory and data sharing portal for all available LiDAR data, hosted by the provincial government. This already exists, but it is not widely accessible. Search capabilities, including detailed metadata, should be made broadly available to facilitate project planning. Download capabilities should be made available to all agencies and organizations that would benefit from using LiDAR data.
  - Include both public and private data, where possible.
  - Incorporate data download for open source data and data access links for other data.
- Fund the provincial government to support LiDAR initiatives (data inventory, data download, open data licensing, data acquisition, QA/QC). GeoBC has already developed or is currently developing many of the necessary tools.
- Ensure provincial LiDAR dissemination efforts continue to be coordinated with federal, local, and other efforts to avoid duplication and share resources.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Flood Map Investigation

6.1.1 Current Status

Maps developed under the provincial program initiated in 1974 and the joint federal/provincial floodplain mapping agreement (1987-2003) are outdated but still provide useful information in terms of approximate flood extents. The quality of mapping produced since 2003 varies. A large number of flood mapping projects have received grant funding from 2015 to present but many are still in progress and assessing their quality is not possible. Making all mapping available to the public should be a long-term goal to raise awareness about flood hazards and risks.

Considerable expertise is required to develop accurate mapping. Practitioners with limited experience may enter the field, potentially low bidding to win work, impacting the quality of the mapping produced. In some instances mapping approaches are based on the funding available rather than the complexity of the area to be mapped. Provincial and federal mapping guidelines may not be sufficiently explicit to prevent simplifications, leading to inaccuracies in flood levels and flood extents. These issues are exacerbated when a scope of work is developed and issued for bidding, which cannot be achieved at an acceptable standard of practice on the available budget and/or schedule.

In contrast to detailed floodplain mapping that allows delineating the 200-year (0.5% probability) flood extents and setting FCLs, a variety of approximate flood hazard maps are being developed to estimate flood insurance premiums, potential flood risks and broad estimation of hazards. These methods do not provide detailed floodplain mapping sufficient for official designation, nor for establishing FCLs and other floodplain regulation policies.

The majority of First Nation reserves and treaty lands do not have up-to-date flood hazard mapping or floodplain mapping. Yet most of these lands have ocean, lake or river frontage and are frequently exposed and vulnerable to flooding.

6.1.2 Recommended Approach for Map Improvements

Recommendation: B-2.1 No. 1: Further Assessment of Flood Mapping

Numerous floodplain mapping projects are currently in progress. It is recommended that, once available, these be reviewed and their quality assessed.

Overview level flood maps do not serve the same purpose as detailed floodplain maps. It is recommended that the accuracy of overview flood maps be assessed and their suitability for specific applications be clarified.

Recommendation B-2.2 No. 1: Improve Spatial Coverage of Mapping

The joint federal-provincial mapping agreement produced mapping for key flood-prone areas in BC but the information is now outdated. Areas previously mapped but without available updates are identified as high priority areas requiring new maps.

Areas protected by high or major consequence dikes, as identified by NHC (2019) generally have a high flood risk and should be mapped.

Communities located along rivers, lakes and the ocean with populations, say exceeding 10,000, should generally be mapped. A number of smaller communities would also benefit from mapping and it is recommended that overview level flood risk assessments be completed to prioritize which communities would benefit most from more detailed floodplain mapping. (In some areas, overview level risk assessments have already been completed or are in progress.)

Communities that have experienced recent, severe flooding should be mapped. (A provincial database of annual flood event information should be developed to track and record flood events. Observed flood levels, flows, inundation extents, photographic material and information on consequences such as affected transportation corridors and other damages would be useful input for future floodplain mapping studies and their prioritization.)

The majority of First Nation reserves and treaty lands do not have up-to-date flood hazard mapping. Yet most of these lands have ocean, lake or river frontage and are frequently exposed to flooding. Previous work by FNESS (2000) assessed flood and erosion hazards in BC, ranked the hazards, and developed potential mitigation measures. It is recommended that:

- Previously identified high priority projects be reviewed, flood level information updated and floodplain mapping developed as needed.
- An outreach program be developed for contacting First Nations and learning first-hand about current flood and erosion challenges and how First Nations' leadership and community members would like to address these.

B-2.2 No. 2: Improve Mapping Accessibility

The provincial government is in the process of developing a web portal, making flood maps and supplementary reports readily available. There is currently no timeline for the web-portal implementation but making information available to the public as soon as possible is recommended.

Many larger communities, with sufficient resources and know-how, are making floodplain mapping and other engineering reports available on-line. All communities having completed flood risk or mapping studies are encouraged to do the same.

B-2.2 No. 3: Improve Map Guidelines and Usage

Provincial and federal guidelines are useful but do not guarantee that flood mapping is produced to a consistent and/or adequate standard by different practitioners. In particular, specifications are required for bathymetric surveys, climate change analyses, hydrology - particularly when basins include large reservoirs, geomorphic assessments, modelling standards (1D vs 2D software usage, calibration/ output type/ breach modelling), coastal wave modelling, freeboard, mapping detail/clarity and reporting standards. It is recommended that more prescriptive standards documents, in addition to guidelines, be developed and kept up to date. With mapping standards clearly defined, project deliverables will have a more consistent quality. Third party reviews are also recommended.

It is recognized that different types of mapping studies need to be developed based on the particular flood hazards facing a community, its setting, development density and overall profile of flood risk. It is recommended that different categories of floodplain mapping studies be specified and associated standards applied. This would help communities identify the level of assessment and standard of mapping they require and associated budget demands to ensure more consistent products. Federal guidelines are informative but conditions across Canada vary sufficiently to require specific standards to be developed on the provincial level.

B-2.2 No. 4: Improve Map Quality

It should be recognized that grants obtained by a local authority or First Nation may not be sufficient to adequately fund a particular project and locally sourced funding may be required to supplement a grant. Appropriate training should be provided to staff preparing flood mapping scopes to ensure that the work reasonably reflects the available budget, and that schedules are realistic. Schedule and budget issues should also be considered by those reviewing grant applications to evaluate whether a project has a realistic chance of success.

It is recommended that an independent, quality control group be established to review new mapping developed. This should be a technical team, with sufficient experience to provide meaningful review of project results. It should also be advised by professionals qualified in the application of mapping to decision making (legal, planning, policy, regulation).

It is recommended that present/future guideline and standards documents be adhered to.

B-2.2 No. 5: Improve Mapping Governance

Although the current approach for detailed floodplain mapping led by local governments could potentially be improved through implementation of the above recommendations, an increased role for the provincial government is essential to achieve consistent, high quality mapping to support floodplain land use management, emergency planning/response, and structural mitigation. Two options for an increased role of the provincial government in floodplain mapping are presented below; Option 2 is likely to be more cost-effective and therefore is recommended over Option 1:

Option 1 (Increased participation):

- Help coordinate flood studies on a watershed/regional basis.
- Develop a public facing, historic flood database, documenting observed flood information such as flows, flood levels and extents (including detailed highwater mark surveys), photos and videos, damage summaries, transportation disruptions etc.
- Retain consultant(s) or professional association(s) to develop and (ensure updating of) floodplain mapping standards for BC, including bathymetric data collection. Coordinate with federal government floodplain mapping standards.
- Provide ongoing quality assurance of flood studies.
- Emphasize potential future uses of floodplain mapping. (The funding of floodplain mapping could be made conditional on a community subsequently developing flood mitigation, preparedness/response plans, and bylaws to ensure compliance with zoning/FCLs. Track the follow-up work carried out after mapping has been completed.)

Option 2 (New program – Alberta model):

- Undertake or contract the development/upkeep of a BC floodplain mapping standards document.
- Prioritize areas to be mapped and work with local authorities/First Nations to ensure that mapping developed will be useful and used as part of future Integrated Flood Management Plans (IFMPs) and/or other approaches to flood mitigation and risk reduction.
- Allocate adequate budgets for each project based on risk and hydraulic complexity.
- Prepare detailed Requests for Proposal (RFPs) and manage the contracts.
- Provide technical input and review throughout project.
- Sign-off on maps when completed.
- Publish reports and maps on provincial interactive website allowing users to enter their address to retrieve flood information.

6.1.3 Mapping Improvement Cost Summary

Based on past studies by NHC, an approximate cost not including LiDAR, for developing floodplain mapping averages about $15,000/km (of river) but may range as low as $10,000/km in some instances (1D modelling). Costs may be substantially (several factors) higher if the work requires detailed geomorphological assessment, geotechnical assessment of dike stability, or dike breach modelling. Coastal mapping studies were found to range from about $1,500/km for fairly simple coastlines to $2,500/km for more complex shores. Channel migration mapping ranges from about $10,000 for a small site (<1 km) to $150,000 for a typical river-scale study (10 km).

MMM(2014) estimated that flood map coverage in BC was available for 2,656 km and that another 2,650 km should be mapped. The area proposed to be mapped should be interpreted with caution, given that province-wide floodplain mapping prioritization has yet to be completed, and requirements for flood mapping were not as well understood in 2014 as they are today. A total cost of $48.2M was estimated for producing new maps. With $20M spent to date (grant funding), this estimate would imply the remaining mapping cost is about $30M. This estimate cannot presently be confirmed and should be treated as a minimum, with actual costs potentially much higher.

Based on the information reviewed, the following specific projects, with order of magnitude estimates shown, are recommended as a minimum:

- Develop a bathymetric survey standards document (riverine and coastal). ($40K).
- Develop floodplain mapping standards (riverine and coastal). Include section on channel migration mapping. Consider future uses of all mapping. ($200K). Standards upkeep additional.
- Once readily available, review recent floodplain mapping products for compliance with standards. Identify any sub-standard mapping and coverage. Recommend additional work. ($200K – Additional work not included.)
- Map the Fraser River (Hope to ocean, including main tributaries) according to standards (approach similar to Chilliwack project). ($2.5M).
- Map Lower Mainland coastal areas in locations where available mapping does not meet standards. ($0.5M).
- Review available flood risk information and past flooding. Review FNESS (2000) high priority projects/past First Nation studies. Complete First Nations out-reach program. Develop a province wide map-by-river or map-by-coastline plan and carefully prioritize future projects. Restructure funding program. ($0.5M)
- Complete large scale LiDAR collection. (Provincial government program, cost not known)
- Develop historic flood database. (Provincial government program/contracting. Estimate not known at this time).
- Complete the required mapping. (Provincial government program/contracting. Cost not known at this time, considering the unknown status of mapping completed to date.)
- Provide mapping quality assurance. (Provincial government program. Cost not known at this time but suggested by FLNRORD to be in the range of $150,000 to $300,000 per year)
- Provide for government restructuring to accommodate Option 1 or 2 as outlined in Section 3.1.5. Cost not known, but Option 1 is estimated to involve about 2 full-time provincial government staff and the retaining of consultants on an as-needed basis. The Option 2 government group would consist of at least 5 full-time hydraulic modelling specialists with extensive BC experience and/or staff with other relevant expertise.

6.2 Dike Status Investigation

Comprehensive flood hazard information is the basis for effective risk management, and for BC, this includes detailed knowledge of the condition, the level of protection, and the key limitations (i.e. deficiencies in comparison to provincial standards) of each dike and diking system. This information is needed to support effective operation and maintenance of diking systems, land use plans and regulations for development in protected floodplain areas, emergency response and recovery plans, flood risk assessments, prioritization of funding for dike upgrades, and to increase public awareness of flood risks.

Many diking authorities have relatively good information with respect to operation and maintenance of their dikes. However, with the exceptions of the 2015 Lower Mainland Dike Assessment study and the Orphan Dike Risk Assessment project (KWL 2020), information on the deficiencies and level of protection provided by a specific dike is generally not available.

Currently qualified professionals and land development approval officials do not have access to readily available information to support a determination of whether a dike is "adequate" to protect new development. Outdated colour coded maps indicating "standard" and "non-standard" dikes are still being referred to by emergency responders. The accuracy and usefulness of flood risk studies for diked areas is diminished if the level of protection of the dike is unknown.

6.2.1 A Standardized Dike Assessment Rating System

Recommendation B-2.3 No. 1: Establish and Apply a Standardized Dike Rating System
The key recommendation of this investigation is that BC should establish a standardized dike assessment rating system and develop a method to roughly determine the "Estimated Level of Protection" (i.e. annual probability of dike breach).

To include the full range of dike characteristics, condition, and deficiencies, the assessment and rating system should be based on a methodology similar to the method developed by the 2015 Lower Mainland Dike Assessment (NHC 2015) with modifications and improvements as needed. These dike ratings should then be used to roughly determine the "Estimated Level of Protection".

As a first step, all 212 dikes in BC should be assessed at an overview level. The next step would be to review the dike assessments for all "High" and "Major Consequence Dikes" (71 dikes) and include limited field or other investigations to fill in crucial information gaps.

Dike ratings will change over time as design criteria (e.g. flood profiles) are updated and/or where dikes are upgraded or modified. Maintaining current ratings and dike information will take an investment of personnel time by the ministry and diking authorities. To assist in this effort, it is recommended that refinement/updating of dike ratings be included as part of Community Emergency Preparedness Fund (CEPF) or other Provincial funded risk assessment or mapping projects that contain dike protected areas.

6.2.2 Other Recommendations

Recommendation B-2.3 No. 2: Amend the 2018 EGBC flood assessment guidelines definition of "adequate" dike with reference to the new provincial dike rating system, when available.

Assessments and approval conditions outlined in the EGBC Guidelines depend on whether the flood protection works are considered to be "adequate" as defined in the guidelines. The basic direction to qualified professionals (QPs) in the guidelines is:

> "*In general, significant new development should not be located in floodplain and fan areas in the absence of a standard/adequate Dike or other Structural Mitigation Works.*"

Recommendation B-2.3 No. 3: Publicize dike inspection reporting compliance information

Publicize dike inspection reporting compliance information to provide an incentive for diking authorities to complete inspections and provide detailed inspection reports.

Recommendation B-2.3 No. 4: Increase the number of dike safety audits
Complete dike safety audits of all diking authorities having "High" and/or "Major Consequence Dikes" (71 dikes) at least every 5 years. This will approximately double the effort currently being made by DIODs from 5 to 10 audits per year provincially to 10 to 20 per year.

B-2.3 No. 5: Create one digital folder per dike with a standardized format for storage and sharing
Establish a standardized and easily accessible dike file system for sharing and storage of key technical information. Create one digital folder per dike with a consistent format and make accessible to the diking authority, DIODs and IOD.

The establishment of a standardized dike rating system and the rating of all BC dikes is estimated to cost approximately $2.2 million, including a one time allocation of 0.7 Full Time Equivalent (FTE) of provincial staff to provide direction, input and management of the necessary studies, including amendment of the EGBC flood assessment guidelines. The provincial personnel time required to maintain and refine the ratings, primarily updating information for individual dikes, is estimated to be 0.3 FTE.

The cost to implement the other recommendations (publicizing compliance information, increasing dike safety audits, and improving dike information file management) is roughly estimated to be $100K in contract funds and 0.2 FTE to set up, and 0.4 FTE for the ongoing work. The cost estimates assume that the additional dike information can be integrated into the new Flood Safety Management E-Licensing platform currently being developed by MFLNRORD.

6.3 LiDAR Investigation

Flood studies require high resolution topographic data, most commonly acquired via airborne LiDAR. LiDAR data acquisition must be factored into overall planning of a flood study. Collection and use of LiDAR data for BC flood studies can be improved. A detailed review of LiDAR collection guidelines and specifications would improve general understanding of how to apply these to LiDAR for flood studies, and should be accompanied by efforts to raise awareness about standards and ensure they are being applied. Improvements to LiDAR acquisition, including planning a province-wide ongoing LiDAR collection program, would ensure that LiDAR can be more effectively integrated into flood studies. Existing provincial and federal initiatives to inventory and share LiDAR data should be encouraged so that existing and future LiDAR data is readily available for flood studies. Recommendations are as follows (corresponding cost estimates not provided):

Recommendation B-2.4 No. 1: Establish Provincial LiDAR Guidelines and Specifications

It is recommended that a detailed review be undertaken of provincial LiDAR specifications in comparison to federal LiDAR guidelines, with an explanation of differences and clarification of which provincial specifications apply to floodplain mapping.

The awareness of provincial specifications and federal guidelines among agencies responsible for LiDAR data collection should be raised. It is recommended that updates to provincial specifications and federal

guidelines be monitored to ensure they remain harmonized. The development of federal LiDAR standards based on existing guidelines should also be monitored.
Collection of LiDAR data for flood mapping applications alone is unlikely to be cost effective. It is recommended that guidelines and specifications continue to incorporate expertise from outside the flood mapping community so that the information will be broadly accepted and applied.

Recommendation B-2.4 No. 2: Establish Procedures for LiDAR Acquisition

The following specific recommendations are provided:

- Ensure LiDAR data collected for flood mapping meets specifications and floodplain mapping needs. Set LiDAR collection boundaries to include areas adjacent to a current study, such as upstream and downstream reaches, opposite riverbanks, and adjacent communities. Ensure that LiDAR collection includes coincident orthophoto collection.
- Plan flood mapping projects with sufficient lead time to allow for appropriate LiDAR collection. Schedule should allow for adaptation to weather conditions, quality review of LiDAR deliverables, and collection in advance of ground and bathymetric surveys and hydraulic modelling.
- Plan for LiDAR updates to coincide with flood mapping updates.
- Develop a province-wide publicly funded ongoing LiDAR collection program. Ensure provincial LiDAR acquisition efforts continue to be coordinated with federal, local, and other efforts to avoid duplication and share resources.
- Monitor development and application of bathymetric LiDAR technology, including information in the upcoming revision of federal LiDAR guidelines. Sponsor research into the use of bathymetric LiDAR to support flood mapping in BC.

Recommendation B-2.4 No. 3: Establish Procedures for LiDAR Dissemination

The following specific recommendations are provided:

- Require open data licenses for all LiDAR data collected with public money. Develop a sample open data sharing agreement for use by local governments and other agencies. Provide an inventory and data sharing portal for all available LiDAR data, hosted by the provincial government. (This already exists, but information is not widely accessible.) Search capabilities, including detailed metadata, should be made broadly available to facilitate project planning. Download capabilities should be made available to all agencies and organizations that would benefit from using LiDAR data.
- Fund the provincial government to support LiDAR initiatives, such as data inventory, data download, open data licensing, data acquisition, and QA/QC. (GeoBC has already developed or is currently developing many of the necessary tools.)
- Ensure provincial LiDAR dissemination efforts continue to be coordinated with federal, local, and other efforts to avoid duplication and share resources.

7 GLOSSARY PROVIDED BY FBC

Term	Definition
Adaptation	The practice of adjusting or taking actions to limit or reduce vulnerability to changing hazard risk. In the context of climate change impacts on coastal flood hazard risk, specific adaptation actions might include improved coastal zone management, changes to planning, permitting, codes and standards, structural design, and social preparedness.
All Hazards	Referring to the entire spectrum of hazards, whether they are natural or human-induced. For example, hazards can stem from natural (e.g., geological or meteorological) events, industrial accidents, national security events, or cyber events.
All-Hazards Approach	An emergency management approach that recognizes that the actions required to mitigate the effects of emergencies are essentially the same, irrespective of the nature of the incident, thereby permitting an optimization of planning, response and support resources.
Annual Exceedance Probability (AEP)	The probability, expressed in percentage, of a flood of a given size being equalled or exceeded in any year. Accordingly, a flood that is estimated to recur once in 100 years (on average) has an AEP of 1/100 or .01 (1% AEP meaning a 1% chance of occurring in any year). A flood estimated to recur once in 500 years on average has an AEP of 1/500 or 0.002 (.2% AEP). Reference: http://www.lgam.info/annual-exceedance-probability
Assets-At-Risk	Refers to those things that may be harmed by hazard (e.g., people, houses, buildings, cultural assets, or the environment).
Asset Inventory or Database	An inventory of assets-at-risk including the location, and sometimes vulnerability or resiliency measures.
Barometric Set-Up (Set-Down)	The static rise (or fall) in water level due to changes in atmospheric pressure during the passage of storm events.
Coastal Flood Hazard	A potentially damaging flood event (or multiple events) in coastal regions, which may cause damage to buildings and infrastructure, and/or the loss of life, injury, property damage, social and economic disruption, or environmental degradation.

Coastal Flood Risk	The combination of the probability of a coastal flood hazard event (or multiple events) and the associated negative consequences.
Contents Damages	The damages to the contents within a building, such as appliances, furniture, electronics, etc.
Critical Infrastructure (CI)	Processes, systems, facilities, technologies, networks, assets, and services essential to the health, safety, security, or economic well-being of Canadians and the effective functioning of government.
Damages	The financial and non-financial impacts/consequences of a hazard event. For buildings and infrastructure, this may include structural damage or loss of performance, or damages due to loss of serviceability/operability.
Digital Elevation Model	A digital representation of relief composed of an array of elevation values referenced to a common vertical datum and corresponding to a regular grid of points on the earth's surface. These elevations can be either ground or reflective surface elevations.
Digital Surface Model	A representation of the earth's surface including vegetation and human-made structures. The Digital Surface Model (DSM) provides the height of the vegetation, canopies and structures relative to the vertical datum.
Digital Terrain Model	A representation of the bare ground surface without any objects, such as vegetation and buildings. The Digital Terrain Model (DTM) provides the height of the ground relative to the vertical datum.
Dike (or Dyke)	An embankment designed and constructed to prevent the flooding of land. A dike is supported by related works, such as floodboxes, gates and pumps that serve to hold back floodwaters while continuing to discharge water from behind the dike. *To learn more about dikes in the Lower Mainland, see Dikes and Related Works.* Reference: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/dike_des_cons_guide_july-2011.pdf
Direct Damages	The financial costs to repair or replace an asset to its pre-flood condition. Direct damages include structure and contents damages.
Disaster	A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of

	exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.
Disaster Risk Management	The application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.
Disaster Risk Reduction	The concept and practice of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters. Disaster risk reduction includes disciplines like disaster mitigation and preparedness.
Exposure	The presence of people, infrastructure, housing, or other assets-at-risk (or parts thereof) in places that could be adversely affected by hazards.
Flood and Flooding	The presence of water on land that is normally dry. Often used to describe a watercourse or body of water that overtops its natural or artificial confines. *See Flood 101 for a look at different types of flooding.* Reference: https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx
Flood Construction Level (FCL)	The minimum height required for a development to protect habitable living space from flood damage. Reference: https://www.newwestcity.ca/database/rte/files/Queensborough%20FCL%20Review%20-%20Final%20Report%20(Jan%2016-13).pdf
Flood Maps	Maps that display information related to a flood, such as the estimated extent of flooding, water depths, water velocities, flood duration or other information. *See Flood Maps for more on the types of maps and the information they display.* Reference: https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx
Flood Risk Assessment	Evaluation of a flood hazard (including the expected flood extent, depth and direction of flow) together with information about assets and people that are vulnerable to flooding to identify potential

	economic, social, cultural and environmental losses from flooding. Reference: http://www.ebbwater.ca/wp/services/flood-risk-assessment/
Floodplain	A floodplain is flat or nearly flat land that is susceptible to flooding from a watercourse, lake or other body of water. Reference: https://www.sciencedaily.com/terms/floodplain.htm Reference: https://city.langley.bc.ca/sites/default/files/uploads/Bylaws/Floodplain%20Elevation%20Bylaw.pdf
Floodplain Management	Floodplain management includes policies and regulations intended to reduce flood risks associated with land use and development in floodplains and flood hazard areas. Reference: https://www.fema.gov/floodplain-management
Floodproofing	In reference to development, actions taken at the site or property level that reduce the vulnerability of buildings and their contents to flood damage. See: https://www.fema.gov/floodproofing
Floodwall	A vertical artificial barrier designed to temporarily contain the waters of a river or other waterway. A floodwall is sometimes constructed instead of a dike in areas where space is restricted. Reference: https://en.wikipedia.org/wiki/Flood_wall
Hazard	A potentially damaging physical event, phenomenon, or human activity that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation.
Flood Hazard	A potentially damaging flood event that may cause the loss of life, injury, property damage, social and economic disruption, or environmental degradation.
Flood Mitigation	Steps to reduce flood damage by structural measures (such as dikes), non-structural measures (such as keeping populations and assets away from flood-prone areas or requiring floodproofing), or a combination of these measures. Reference: https://www.ncsl.org/research/environment-and-natural-resources/flood-mitigation.aspx
Hazard Assessment	Acquiring knowledge of the nature, extent, intensity, frequency, and probability of a hazard occurring.

Hazard Inventory or Database	An inventory of the location, nature, and extent of influence of any potential hazards in an area of concern. Generally compiled as a GIS database.
Hundred-Year Flood	A flood of a given size that is estimated to recur once in 100 years on average. This is an older term — the probability of flood recurrence is now more often expressed in terms of Annual Exceedance Probability (AEP).
Indirect Damages	The financial costs incurred as a result of a flood event. Indirect damages include flood fighting/mitigation, evacuation, temporary housing, employment and productivity losses, post-flood cleanup, etc. Areas outside the flood hazard may also experience indirect damages, such as business disruption.
Intangible Damages	The non-financial or otherwise non-quantifiable impacts due to a flood event including social, health, and environmental impacts. Areas outside the flood hazard may also experience intangible damages, such as due to the spill and transport of a deleterious material.
Likelihood	A general concept relating to the chance of an event occurring. Likelihood is generally expressed as a probability or a frequency of a hazard of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured, or extrapolated from records over a large number of years, and is usually expressed as the chance of a particular hazard magnitude being exceeded in any one year (i.e., the Annual Exceedance Probability, AEP).
Light Detection And Ranging (LiDAR)	A remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the earth.
Losses	Equivalent to damages that occur as a result of a flood event, both tangible and intangible.
Natural Hazard	Natural process or phenomenon that may cause loss of life, injury, other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.
Peak Flow	The maximum rate of water discharge during a flood at a given location on a river or other watercourse. Reference: https://www.oxfordreference.com/view/10.1093/oi/authority.20110

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Probability	In statistics, a measure of the chance of an event or an incident happening. This is directly related to likelihood.
Quantitative Risk Assessment	A risk assessment that is completed using quantified or calculated measures of risk.
Residual Risk	The risk that remains even when effective risk reduction measures are in place.
Residual Water Level	The difference between the absolute or total water level (as measured by a tide gauge) and the astronomical (tidal) component. As storm surge often represents the greatest contribution to the residual water level at a coastal site, the terms "storm surge" and "residual water level" are sometimes used interchangeably.
Resilience	The ability of a system (such as individual or multiple buildings or infrastructure assets), community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
Risk	The combination of the probability of a hazard event and its negative consequences.
Risk Assessment	A method to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed buildings, infrastructure, people, property, services, livelihoods, and the environment on which they depend. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards, such as their location, intensity, frequency, and probability; the analysis of exposure and vulnerability, including the physical, social, health, economic, cultural, and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities, with respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.
Risk Management	The systematic approach and practice of managing uncertainty to minimize potential harm and loss.

Susceptibility	An asset that could be adversely impacted by exposure to a hazard is susceptible to the hazard. For example, a typical residential building is susceptible to damage from floodwaters. A properly constructed concrete landscaping wall that has some floodwaters around it may not be adversely impacted and is therefore not susceptible to a flood hazard.
Storm Surge	The increase (or decrease) in still water level at a coastal site due to meteorological conditions. Storm surge may include wind set-up (or set-down) and barometric set-up (or set-down).
Structural Damages	Damages to the structural systems of a building or infrastructure, such as walls, floors, heating and cooling systems, etc.
Tangible Damages	Measurable financial impacts due to a flood event.
Tsunami	A series of waves caused by a rapid, large-scale disturbance of water. Tsunamis can be triggered by earthquakes, landslides, volcanic eruptions, meteor impacts, human activities (e.g., explosions), and meteorological/atmospheric phenomena (meteo-tsunamis).
Vulnerability	The characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard. For buildings and infrastructure assets, vulnerability is a product of both exposure and susceptibility to damage.
Wave Overtopping	When wave runup exceeds the crest elevation of a beach or coastal structure, water flows over the crest. This is referred to as “green water” overtopping. Another form of wave overtopping can occur when waves break on the seaward face of a structure, causing splash droplets to be carried over the crest by their own momentum or wind.
Wave Runup	The maximum elevation of wave uprush on the shore above the still water level. Wave uprush consists of two components: superelevation of the mean water level due to wave action (wave set-up) and fluctuations about that mean (swash).
Wave Set-Up	The increase in mean water level near the shoreline, which occurs as a result of a slope in the water level required to balance the onshore flux of wave momentum (radiation stress), usually associated with wave breaking. Wave set-up contributes to wave runup.
Wind Set-Up (Set-Down)	The downwind (or upwind) increase (or decrease) in water level occurring as a result of shear stress exerted by the wind on the water surface.

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Appendix A: All Investigations

Investigations in Support of Flood Strategy Development in BC

List of All Investigations

Theme A. Governance

Issue	Investigation
A-1 Flood Risk Governance	1. Identify the flood management services provided by each order of government in BC.
	2. Investigate the roles of non-government entities in flood management in BC.
	3. Identify challenges, gaps and limitations with current service delivery.
	4. Identify opportunities for improving collaboration and coordination within and across authorities and adjusting non-government entities' roles that would address challenges and improve efficiency and effectiveness.
	5. Recommend changes to support improved collaboration and coordination in flood management, including an analysis of benefits and costs/limitations for each recommendation.
	6. Investigate alternative options for distributing and integrating flood management responsibilities among authorities, including an analysis of benefits and costs/limitations for each option.

Theme B. Flood Hazard and Risk Management

Issue	Investigation
B-1 Impacts of Climate Change	1. Investigate the state of climate change science in relation to BC flood hazards and identify gaps and limitations in provincial legislation, plans, guidelines and guidebooks related to flood hazard management in a changing climate.
	2. Identify current sources of information and models used by experts in the province to predict future climate impacts and investigate opportunities for improved predictive modeling.
	3. Investigate the capacity of responsible authorities and other professionals and practitioners in the province to integrate climate change impacts and scenarios to inform flood planning and management.
	4. Investigate the legislative, policy, and regulatory tools available to responsible authorities in all levels of government for integrating climate change impacts in flood planning and management.

Issue	Investigation
B-2 Flood Hazard Information	1. Investigate the current state of flood mapping in the province, including gaps and limitations. Recommend an approach to improve the spatial coverage, quality, utility and accessibility of flood hazard maps and other flood hazard information.
	2. Investigate the approximate level of effort to prepare flood hazard mapping to address current gaps for existing communities and future areas of development (including floodplain maps and channel migration assessments).
	3. Investigate the current state of knowledge related to dike deficiencies and recommend an approach to improve the quality, consistency, review, utility and accessibility of this information.
	4. Investigate the status of LiDAR standards for flood mapping and develop recommendations to improve standards if applicable.
B-3 Flood Risk Assessment	1. Investigate approaches to completing a province-wide flood risk assessment, addressing effort required, level of detail, types of flood risk, current and future scenarios, scale, and any information required and data gaps.
	2. Determine the effort required to undertake a local-scale comprehensive flood risk assessment for multiple types of flood hazards (e.g. riverine, coastal).and for varying degrees of available data on flood hazard, exposure, vulnerability and risk.
	3. Investigate the effort required to develop and maintain a province-wide asset inventory and/or exposure dataset covering flood prone areas.
	4. Investigate the level of effort to develop a coarse local-scale flood risk map based on available flood hazard map(s).
	5. Investigate methods for valuing the benefits and costs/limitations of flood risk reduction actions in a holistic and consistent manner and develop a framework for project prioritization that could be applied or adapted across the province to reduce flood risk.
	6. Evaluate and compare the benefits and costs/limitations of taking a risk-based approach to flood management versus a standards-based approach.
B-4 Flood Planning	1. Investigate the ability of responsible authorities in the province to develop adaptation plans and strategies for flood management.
	2. Investigate opportunities to improve the knowledge and capacity of local authorities with regard to climate change adaptation and the benefits of proactive flood risk reduction.
	3. Investigate the potential content of a provincial guideline to support the development of local Integrated Flood Management Plans.
	4. Investigate the level of effort for a local authority to complete an Integrated Flood Management Plan and the possible role of the province in reviewing and/or approving these plans.

Issue	Investigation
B-5 Structural Flood Management Approaches	1. Investigate opportunities to incentivize or require diking authorities to maintain flood protection infrastructure and plan for future conditions such as changing flood hazards.
	2. Investigate opportunities to improve the knowledge and capacity of local diking authorities with regard to dike maintenance.
	3. Investigate opportunities to improve coordination amongst diking authorities under non-emergency conditions.
	4. Investigate impediments to and opportunities for implementing innovative structural flood risk reduction measures, including the role of incentives and regulation.
B-6 Non-Structural Flood Management Approaches	1. Investigate past and current approaches to land use and development decisions in floodplains by local and provincial authorities.
	2. Investigate alternatives to the current approach to managing development in floodplains, including returning regulatory authority for development approvals in municipal floodplains to the Province, and provide an analysis of the benefits and costs/limitations of both local and provincial authority.
	3. Investigate impediments to and opportunities for implementing available non-structural flood risk reduction actions, including the role of incentives and regulation.
	4. Investigate the nature of an educational campaign for regional, local and First Nations governments to raise awareness of flood risk and possible risk reduction options.

Theme C. Flood Forecasting, Emergency Response and Recovery

Issue	Investigation
C-1 Flood Forecasting Services	1. Investigate current capacity, coverage, value, and gaps in flood forecasting services.
	2. Visualize where flood forecasting gaps exist and estimate costs for improvement to end users.
C-2 Emergency Response	1. Investigate the future direction of the Federal government related to a National Flood Risk Strategy and the future of Disaster Financial Assistance Arrangements
	2. Investigate the Province’s expanding role in providing flood response to First Nations.
	3. Investigate the status of local authority flood response plans and recommend an approach to manage, update and improve this information.

Issue	Investigation
	4. Investigate flood response capabilities considering different flood hazards and different regions of the province.
	5. Investigate opportunities for improved organizational planning for emergency response in all levels of government.
C-3 Flood Recovery	1. Investigate the current status of coverage of existing overland flood insurance available to home-owners.
	2. Investigate the concept of "build back better" and impediments to implementation.

Theme D. Resources and Funding

Issue	Investigation
D-1 Resources and Funding	1. Investigate resource and funding needs associated with implementing recommendations to strengthen flood management in BC.
	2. Investigate evidence in support of investment in proactive flood planning and mitigation activities.

Appendix B: Tables and Figures

Table 1. Provincial Floodplain Map Inventory 1974-2003

Area	River/Lake	Tributaries/Lakes	Date of Survey	Design Brief	Update Avilable
Campbell River & Quinsam Rivers	Campbell River	Quinsam River	Jun-1987	✓	IP
Chemainus River	Chemainus River	Bonsall Creek	1986	✓	
Courtenay, Puntledge, & Tsolum Rivers	Courtenay River	Puntledge River, Tsolum River	Sep-1988	✓	✓
Cowichan Lake	Cowichan Lake	Cowichan River, Sutton Creek, Roberston River	Jul-1977		IP
Cowichan & Koksilah Rivers	Cowichan River	Koksilah River, Quamichan Lake & Creek, Somenos Lake & Creek, Macintyre Creek, Elkington Creek, Tzuhalem Creek, Richards Creek	1991	✓	✓
Cowichan River at River Bottom Road	Cowichan River		1991	✓	IP
Englishman River	Englishman River		Apr-1980		IP
Little Qualicum River	Little Qualicum River		1995	✓	
Nanaimo River	Nanaimo River	Haslam Creek, York Lake	Sept 1 1982		✓
Oyster River	Oyster River		July 24 1980		
Quaste River at Port Hardy	Quaste River	Spicer Creek, Boyden Creek	Jul-1988	✓	
Salmon & White Rivers	Salmon River	White River, Springer Creek	May-1976	✓	
Shawnigan Lake	Shawingan Lake		May-1978		IP
Somass River at Port Alberni	Somass River	Stamp River, Kisucksus Creek	1994	✓	IP
Sooke River	Sooke River		1992	✓	
Tahsis & Leiner Rivers at Village of Tahsis	Tahsis River	Leiner River	Jul-1990	✓	✓
Zeballos River	Zeballos River		Jul-1990		
Alouette & North Alouette Rivers	Alouette River	North Alouette River	Jun-1981	✓	✓
Cheakamus River	Cheakamus River		Sep-1976	✓	
Chilliwack River at Vedder Crossing	Chilliwack River	Sweltzer River	Jun-1976		IP
Coquihalla River at Hope	Coquihalla River		Sept 19 1983		
Coquitlam River	Coquitlam River		Jun-1976		✓
Fraser River Near Hope	Fraser River	Silver Hope Creek	Feb-1984		
Lillooet River	Lillooet River	Birkenhead River, Peg Creek, Xit'olacw Lake, Green River, One Mile Lake, Pemberton Creek, Ryan River, Miller Creek,Wolverine Creek	1985	✓	✓
Serpentine & Nicomekl Rivers	Serpentine River, Nicomekl River	Murray Creek, Mahood Creek	1991	✓	
Seymour River at North Vancouver	Seymour River		1992	✓	
Squamish River	Squamish River	Mamquam River, Stawamus River, Judd Slough, Hop Ranch Creek, Dryden Creek, Tantalus Creek, Pillchuk Creek, Cloudburst Creek, Ashlu Creek, High Falls Creek, Evans Creek	Sep-1976		✓
Vedder River	Vedder River		Jun-1976	✓	IP
Whistler Area	Whistler Area	Millar Creek, Alpha Lake, Nita Lake, Alta Lake, Alta Creek, Green Lake,	1983 to 1989	✓	IP
Boneaparte River	Bonaparte River		1990	✓	
Christina Lake	Christina Lake		1986	✓	
Kettle & Granby Rivers	Kettle River	Granby River, Christina Creek	1990	✓	
Kettle River at Midway-RockCreek-Westbridge	Kettle River	Boundary Creek, West Kettle River	1990-1995	✓	
Mission Creek	Mission Creek		Jun-1975		✓
Nicola River - Spemces Bridge to Nicola Lake	Nicola River	Coldwater River		✓	
North Thompson River	North Thompson River	Barriere River, Clearwater River	Oct 1974 & July 1975		
Okanagan Lake - Westbank to Peachland	Okanagan Lake		1980		IP
Okanagan River - Osoyoos to Penticton	Okanagan River	Osoyoos Lake, Tugulnuit Lake, Vaseux Lake, Skaha Lake	1978 to 1980	✓	IP
Salmon River - Salmon Arm to Spa Creek	Salmon River		Jul-1981	✓	
Salmon River - Spa Creek to Falkland	Salmon River	Bolean Creek	Jul to Aug 1981	✓	
Shuswap River, Bessette & Duteau Creeks	Shuswap River	Bessette Creek, Duteau Creek			
Shuswap River, Mara Lake to Mabel Lake	Shuswap River	Mara Lake, Rosemond Lake, Trinity Creek,	1974 to 1976		IP
Similkameen River at Keremeos	Similkameen River	Kermeos Creek, Ashnola River	Sep-1992		IP
Similkameen River at Princeton	Similkameen River	Tulameen River	Jul to Aug 1992	✓	IP
South Thompson River at Kamloops - Chase	South Thompson River		Oct 14 1974		✓
Thompson River - Kamloops Area	Thompson River		Oct 14 1974		✓
Tulameen River	Tulameen River	Otter Creek	May-1978		
Arrow Reservoir & Kuskanax Creek	Arrow Resevoir	Kuskanax Creek	Jun-1905	✓	
Beaver Creek - Beaver Falls to Meadows	Beaver Creek		Jun-1982	✓	
Columbia River - Columbia Lake to Windermere Lake	Columbia River	Dutch Creek	Oct-1978		
Columbia River at Golden	Columbia River	Kicking Horse River	Sep-1975		IP
Columbia at Revelstoke	Columbia River	Illecillewaet River, Tonkawatla Creek	Aug-1977		
Columbia River - Winderemere Lake to Radium	Columbia River	Forster Creek, Toby Creek, Windermere Lake	Aug-1976		
Crawford Creek Alluvial Fan	Crawford Creek	Beaver Creek	Aug-83	✓	
Duncan and Lardeau Rivers	Duncan River	Lardeau River	1994	✓	
Elk River - near Elkford	Elk River		Aug-1975	✓	IP
Elk River at Fernie	Elk River		Aug-1975		✓

Elk River and Michel Creek - Near Sparwood	Elk River	Michel Creek, Cummings Creek, Dalzell Creek	1991	✓	IP
Eagle River	Eagle River		Sep-1975		
Elk River at Sparwood	Elk River		Aug-1975		
Goat River at Creston	Goat River		Jun-1972		
Kaslo River at Kaslo	Kaslo River		Sep-1979		
Kootenay River - Columiba Lake at Canal Flats	Kootenay River	Columbia Lake	May-1989	✓	IP
Kootenay River - Kootenay lake to US Border	Kootenay River		Jun-1972		
Salmo River - Ymir to South Salmo River	Salmo River	Erie Creek	1986 & 1988	✓	✓
Slocan River	Slocan River	Little Slocan River	1980 & 1986	✓	
Bella Colla River	Bella Coola River		1981 & 1986	✓	IP
Fraser & Quesnel Rivers at Quesnel	Fraser River	Quesmel River	Jul-1989	✓	IP
Williams Lake	Williams Lake		Oct-1982	✓	
Bear River at Stewart	Bear River	Winachee Creel	Apr-1991	✓	
Bulkley River at Houston	Bulkley River	Buck Creek	Jun-1982	✓	
Bulkley River - near Quick	Bulkley River		Sep-1985	✓	
Bulkley River - Quick to Houston	Bulkley River	Morice River	1996	✓	
Bulkley River & Telkwa Rivers - Smithers to Telkwa	Bulkley River	Telkwa River	Jun-1982		
Kitimat River	Kitimat River	Hirsch Creek	Jun-1977		IP
Lakelse River and Lake	Lakelse Lake	Lakelse River	May-1988	✓	
Skeena & Bulkley Rivers at Hazelton	Skeena River	Bulkley River	May-1991	✓	
Skeena River - Lakelse - Terrace -Usk	Skeena River	Zymagotitz River, Kitsumkalum River, Newton Creek	Sep-1975		
Zymoetz (Copper River)	Zymoetz (Copper River)		Aug 1974 & Sept 1975		
Chilako River	Chilako River	Beaverley Creek	1993	✓	
Fraser & Nechako Rivers	Fraser River	Nechako River, Rancheree Creek	1997 & 1995	✓	
Naver & Hixon Creeks at Hixon	Naver Creek	Hixon Creek	1998, 1993, 1994	✓	
Nechako River at Vanderhoof	Nechako River		Jul-1977		
Peace River - BC/AB Border to Site 'C'	Peace River		May-1967	✓	IP
Salmon River near Prince George	Salmon River			✓	
Stuart River & Lake at Fort St. James	Stuart River	Stuart Lake, Necosli River, Nahounli Creek	May-1989	✓	

Table 2. BCREA Map Inventory + NHC Projects 2003-2015

Jurisdiction	Year	Funder	Data Used	Accessibility
Campbell River (City)	2007			
Coquitlam (City)	2014	Internal project	City's LiDAR data was used to produce the floodplain maps. 1D-2D coupled MIKE Flood model used for the Coquitlam River. Existing studies used for the Fraser River, "Fraser River Hydraulic Model Update" by Province in 2008 and "Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios — Final Report" by Province in 2014.	Will be released to the public after the report is finalized and received by Council.
Courtenay (City)	2013	EMBC (Emergency Management BC 2/3 grant)	LiDAR data, orthophoto, 2 & 3D MIKE Model.	Will be enshrined in the Floodplain Bylaw once Council adopts the final report that developed the data (May 4, 2015 Council Meeting). Bylaws available online at www.courtenay.ca/EN/main/city-hall/bylaws.html.
Cowichan Valley Regional District	2015	• Funding from First Nations and gas tax innovation funds, internal project	• High resolution LiDAR data. For the riverine-based analysis, a cross-linked model using MIKE 11, MIKE 21 and HEC RAS was used to develop the ISMP and resultant maps. • For the Coast area, high-resolution side cast LiDAR was collected and forecasted projections were made using GIS based on the provincial rational analysis methodology.	Available to the public on the CVRD ftp site (www.cvrd.bc.ca/index.aspx?nid=224) or by request. The coastal zone mapping has been provided to partners municipalities and interested stakeholders.
Elkford (District)	2004	Some disaster assistance funding and internal project.	Flood models and anecdotal information	Not publicly available.
Fernie (City)	2014	Gas Tax	Consultant did a geomorphic and hydraulic assessment of Coal Creek	Floodplain Management Bylaw will be prepared when new floodplain map is done.
Fraser Valley Regional District	2006	Internal project		
Gibsons (Town)	2012	Research funding through UBC and others (C-Change program)	Elevation of land, value of land and infrastructure, sea level rise scenarios, resulting in maps and tables.	Through OCP, Development Permit Area #1, Geotechnical Hazards (www.gibsons.ca/ocp).
Kamloops (City)	2005	Internal project	1D HEC – RAS Model DEM, river cross sections, historical river flows	Available as part of the Floodplain Bylaw and on the City's online interactive mapping. Available for free download from the City's open data download website (www.kamloops.ca/maps/maps.shtml#.VgxKR_lVhBe).

Kelowna (City)	2011	City of Kelowna funded program and KIA funded update.	Hydraulic model assessment of Mill Creek and its floodplain to estimate design flood water levels. Hydraulic model developed based on existing information and a field inventory of significant hydraulic structures. The model was calibrated by comparison of results to recorded flood events on Mill Creek. Hydrodynamic approach used to develop final flood level estimates.	Applied via Bylaw. The stream setbacks and FCL are to be met at time of application for development or building permits. Available on the City's website as a "regulatory" layer, along with zoning, Development Permit Areas and others.
Kent (District)	2007	BC Ministry of Environment	Maps were developed using the hydrodynamic model MIKE FLOOD which couples with the two dimensional hydrodynamic MIKE 21 model. High resolution topographic data of the floodplain area using LIDAR for data capture provided the detail required for tow dimensional modelling	The mapping can be reviewed by the public at the District office.
Kimberley (City)	2012			
North Cowichan (Municipality)	2009			Available in Zoning Bylaw No. 2950 (www. northcowichan.ca/ Documents/Cache/ Zoning%20Bylaw.pdf).
Sidney (Town)	2014	Contact CRD for information		Not publicly available from Sidney.
Cowichan Valley RD (CVRD)+B20:J23	2009, 2013	Some funding came from EMBC after a 2009 flood event.	DEM is available and the CVRD has invested in LiDAR.	
District of Squamish		Flood inundation mapping project will cost $375,000, and will be funded entirely through the Gas Tax.	DEM and LiDAR data available.	
City of Surrey			HEC-RAS 1D	
Maple Ridge		Work completed mostly through internal budgets and/ or staff time.	DEM and LiDAR available.	

RD of Central Kootenay (RDCK)		The Columbia Basin Trust tried to help bring four regional districts work together on floodplain mapping and did significant background work.	Minimal information or data available to the regional district.	
District of North Vancouver		Total cost was about $100,000	DEM and LiDAR available.	
City of Prince George		Total costs of flood investigations was about $500,000,	DEM and LiDAR available.	
City of Vancouver		Mapping cost about $400,000	DEM data available.	

Table 3. Recently Funded Flood Mapping Projects

Source: Disaster Mitigation Unit, Emergency Management BC

Project Details					Budget Details
Funding Program	Intake	Proponent	Project Name	Project Status	Total Project Value
NDMP	Intake 2	Prince Rupert, City of	S1 - Tsunami Flood Risk Assessment	Completed	$ 480,000.00
NDMP	Intake 3	Chilliwack, City of	S2 - Floodplain Mapping	Completed	$ 341,850.00
NDMO	Intake 3	Delta, Corporation of	S1 - Flood Protection System Risk Assessment	Completed	$ 161,250.00
NDMP	Intake 3	East Kootenay Regional District	S2 - Elk River Flood Mapping and Hydrology Study	Completed	$ 250,000.00
NDMP	Intake 3	Fraser Basin Council	S2 - Hydraulic Modelling and Mapping in BC's Lower Mainland	Completed	$ 1,010,000.00
NDMP	Intake 4	Alberni- Clayoquot, Regional District of	S2 - Somass Watershed Flood Management Program	In Progress	$ 523,000.00
NDMP	Intake 4	Central Okanagan, Regional District of	S2 - RDCO Lakeshore Flood Mapping	In Progress	$ 288,000.00
NDMP	Intake 4	Cowichan Valley Regional District	S2 - Updated Cowichan Koksilah Flood Mapping	In Progress	$ 291,000.00
NDMP	Intake 4	Okanagan-Similkameen Regional District	S2 - RDOS Okanagan River and Lakes Flood Mapping	In Progress	$ 594,000.00
NDMP	Intake 4	Squamish First Nation	S2 - Flood Modeling - Lower Capilano River	In Progress	$ 194,000.00
NDMP	Intake 5	Capital Regional District	S2 - Capital Region Coastal Flood Inundation Mapping	In Progress	$ 741,844.00
NDMP	Intake 5	Central Kootenay, Regional District of	S2 - Flood Hazard Mapping, Regional District of Central Kootenay	In Progress	$ 3,060,000.00
NDMP	Intake 5	Comox Valley Regional District	S2 - CVRD Flood Mapping Project	In Progress	$ 516,500.00
NDMP	Intake 5	Cowichan Valley Regional District	S2 - Cowichan Lake Rockslide Wave Induced Flood Assessment	In Progress	$ 354,750.00
NDMP	Intake 5	Cowichan Valley Regional District	S2 - Shawnigan Lake Flood Preparedness	In Progress	$ 129,000.00
NDMP	Intake 5	Cranbrook, City of	S2 - City of Cranbrook/Joseph Creek - Flood Hazard Assessment	In Progress	$ 200,000.00
NDMP	Intake 5	Dawson Creek, City of	S2 - City of Dawson Creek Flood Mapping	In Progress	$ 320,125.00
NDMP	Intake 5	Golden, Town of	S2 - Flood Mapping for the Town of Golden	In Progress	$ 274,600.00
NDMP	Intake 5	Quesnel, City of	S2 - Update Floodplain Mapping	In Progress	$ 251,800.00
NDMP	Intake 5	Whistler, Resort Municipality of	S2 - Whistler Flood Mapping	In Progress	$ 572,500.00
CEPF	Intake 2017	Armstrong	Flood Mapping and Mitigation Planning	Completed	$ 79,302.00
CEPF	Intake 2017	Bulkley-Nechako Regional District	Flood Risk Assessment, Flood Mapping, Flood Mitigation Planning: Ebenezer Flats	Under Review	$ 121,000.00
CEPF	Intake 2017	Campbell River	Flood Risk Assessment, Mapping, Mitigation Planning: Sea Level Rise Assessment	Under Review	$ 348,000.00
CEPF	Intake 2017	Central Coast Regional District	Flood Mapping: Bella Coola Valley Flood LiDAR Survey and Orthoimagery	In Progress	$ 154,500.00
CEPF	Intake 2017	Central Kootenay Regional District	Flood Mapping: LiDAR Initiative	In Progress	$ 134,626.43
CEPF	Intake 2017	Central Okanagan Regional District	Flood Mapping: Central Okanagan LiDAR Acquisition & Mission Creek Floodplain Mapping Update & Dike Breach Analysis	In Progress	$ 150,000.00
CEPF	Intake 2017	Columbia Shuswap Regional District	Flood Mapping: Bastion Mountain Geomorphic Assessment	Completed	
CEPF	Intake 2017	Grand Forks	Flood Risk Assessment, Flood Mitigation Planning: Grand Forks Floodplain Risk Assessment Project	In Progress	$ 225,700.00
CEPF	Intake 2017	Kelowna, City of	Flood Mitigation Planning & Mapping: Mill Creek	In Progress	$ 150,000.00
CEPF	Intake 2017	Nanaimo Regional District	Flood Mapping: Sea Level Rise Adaptation Program	Completed	$ 220,000.00
CEPF	Intake 2017	North Okanagan Regional District	Greater Vernon Lakeshore Flood Mapping and Shuswap River Flood Mapping	In Progress	$ 165,000.00
CEPF	Intake 2017	Penticton	Flood Risk Assessment	Completed	$ 76,475.00
CEPF	Intake 2017	Salmo	Flood Mapping	Completed	
CEPF	Intake 2017	Tahsis	Flood Risk Assessment, Flood Mapping, Flood Mitigation Planning: Sea level Rise Coastal Mapping Assessment	Under Review	$ 126,500.00
CEPF	Intake 2017	Tofino	Flood Mapping Project	Completed	$ 162,000.00
CEPF	Intake 2017	Zeballos	Zeballos River Floodplain Modernization & Future Landslide Risk Assessment	Completed	$ 150,000.00
CEPF	Intake 2019	Canal Flats	Kootenay River Flood Risk Assessment and Flood Mapping	In Progress	$ 168,000.00
CEPF	Intake 2019	Cariboo Regional District	Screening Level Floodplain Mapping, Thompson River Watershed & Floodplain Prioritization within CRD	In Progress	$ 150,000.00
CEPF	Intake 2019	Greenwood	Flood Risk Assessment, Flood Mapping and Flood Mitigation Planning	In Progress	$ 149,668.00
CEPF	Intake 2019	Keremeos	Similkameen River Regional Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan.	In Progress	$ 149,982.00
CEPF	Intake 2019	Midway	Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan	In Progress	$ 159,317.00
CEPF	Intake 2019	Mission	Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan	In Progress	$ 150,000.00
CEPF	Intake 2019	Nanaimo	Jump Creek & South Fork Dams Inundation Study	In Progress	$ 200,000.00

CEPF	Intake 2019	Okanagan-Similkameen Regional District	Similkameen River Regional Flood Risk Assessment and Flood Mapping Project	In Progress	$	138,957.00
CEPF	Intake 2019	Penticton	Flood Mitigation Plan	In Progress	$	67,850.00
CEPF	Intake 2019	Princeton	Similkameen River Regional Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan	In Progress	$	149,940.00
CEPF	Intake 2019	Thompson-Nicola Regional District	Screening Level Flood Mapping in the Thompson River Watershed	In Progress	$	150,000.00
CEPF	Intake 2019	Ucluelet	Flood Mapping Project	In Progress	$	165,000.00
CEPF	Intake 2019	Vernon	Upper and Lower BX Creek Flood Risk Assessment, Mapping and Flood Mitigation Planning - Phase 1	In Progress	$	204,000.00
EOY Funding	2017	Nelson, City of	Nelson Non-Structural Flood Mitigation	Completed	$	150,000.00
EOY Funding	2017	Squamish-Lillooet Regional District	Flood Hazard Mapping and Risk Assessment - Upper Squamish Valley	Completed	$	150,000.00
DMU Funding	2016/17	Cowichan Valley Regional District	Koksilah Cowichan Bay Flood Mitigation	In Progress	$	300,000.00
DMU Funding	2016/17	Pemberton Valley Dyking District	Pemberton Valley Flood Mapping	Completed	$	600,000.00
DMU Funding	2017/18	Central Coast Regional District	Bella Coola Valley Risk Assessment and Flood Modeling	In Progress	$	500,000.00
DMU Funding	2018/19	Okanagan-Similkameen Regional District	S2 - Park Rill, Horn Creek and Kearns Creek Watershed Flood Mapping	In Progress	$	125,000.00
DMU Funding	2018/19	qathet Regional District	S2 - qathet Regional District Coastal Flood Mapping	In Progress	$	216,500.00
CEPF	Intake 2020	Enderby	Flood Mapping and Risk Assessment	In Progress	$	120,000.00
CEPF	Intake 2020	Hazelton	Flood Risk Assessment, Flood Mapping and Flood Mitigation Plan	In Progress	$	150,000.00
CEPF	Intake 2020	Ka:'yu:'k't'h'/Che:k'tles7et'h' First Nations	Assessment and Mapping: Northwest Vancouver Island Tsunami Mapping Project	In Progress	$	150,000.00
CEPF	Intake 2020	Kitimat	Kitimat River Flood Mapping Study	In Progress	$	150,000.00
CEPF	Intake 2020	Kootenay-Boundary Regional District	Flood and Geohazard Risk Assessment for the Boundary Region	In Progress	$	149,845.00
CEPF	Intake 2020	Kwantlen First Nation - 564	Lower Mainland Coast Salish First Nation Flood Risk Assessment	In Progress	$	150,000.00
CEPF	Intake 2020	Lhoosk'uz Dene Government (Kluskus)	South Dakehl Nation Alliance Flood Risk Assessment	In Progress	$	150,000.00
CEPF	Intake 2020	Masset	Masset Flood Risk Assessment and Mapping	In Progress	$	121,358.00
CEPF	Intake 2020	Merritt	Detailed Flood Hazard Mapping: City of Merritt	In Progress	$	150,000.00
CEPF	Intake 2020	Nanaimo Regional District	Englishman River Flood Hazard Mapping	In Progress	$	150,000.00
CEPF	Intake 2020	North Coast Regional District	Flood Risk Assessment and Mapping for Tlell and Sandspit	In Progress	$	148,019.00
CEPF	Intake 2020	Nuchatlaht	Northwest Vancouver Island Tsunami Mapping Project	In Progress	$	150,000.00
CEPF	Intake 2020	Peace River Regional District	Flood Mapping for Chetwynd Fringe, Moberly Lake and Tomslake-Pouce Coupe Rural Area	In Progress	$	150,000.00
CEPF	Intake 2020	Port Clements	Flood Risk Assessment and Mapping	In Progress	$	88,509.00
CEPF	Intake 2020	Queen Charlotte	Village of Queen Charlotte Flood Risk and Mapping	In Progress	$	142,113.00
CEPF	Intake 2020	Strathcona Regional District	Northwest Vancouver Island Tsunami Mapping Project	In Progress	$	150,000.00
CEPF	Intake 2020	Vernon	Lower BX Creek and Vernon Creek Flood Risk Assessment, Mapping and Flood Mitigation Planning	In Progress	$	149,950.00
				Total:	$	19,281,330.43

Notes:

1. Out of 73 recent mapping studies, 58 are in progress or under review. Reports/maps are currently unavailable.
2. Out of 15 recent mapping studies completed, 6 were carried out by NHC. Online information was unavailable for 5 studies.
3. Online information was available for 4 studies. Of these 2 are memos without detailed maps.

Table 4. Flood Risk Assessment Projects

Source: Disaster Mitigation Unit, Emergency Management BC

Project Details					
Funding Program	Proponent	Project Name	Project Status	Provincial Contribution	
NDMP	Emergency Management BC	Public Education - Flood Hazard Checklist for Property Purchasers	Completed	$	25,000.00
NDMP	Emergency Management BC	Hazard, Risk and Vulnerability Analysis (HRVA) Tool Update	In Progress	$	50,000.00
NDMP	Comox Valley Regional District	S1 - Oyster River/ Saratoga Beach Flood Risk Assessment	Completed	$	38,000.00
NDMP	Cowichan Valley Regional District	S1 - Lake Cowichan/ Youbou Torrent Flow Assessment	Completed	$	97,250.00
NDMP	Pitt Meadows, City of	S1 - Flood Hazard Risk Assessment	Completed	$	42,500.00
NDMP	Prince Rupert, City of	S1 - Tsunami Flood Risk Assessment	Completed	$	225,000.00
NDMP	Squamish, District of	S1 - Quantitative Risk Assessment for Squamish River Floodplain	Completed	$	89,000.00
NDMP	Whistler, Resort Municipality of	S1 - Integrated Flood Hazard Management Risk Assessment	Completed	$	67,000.00
NDMP	Central Kootenay, Regional District of	S1 - Flood and Geohazards Risk Review	Completed	$	250,000.00
NDMP	Cowichan Valley Regional District	S1 - Coastal Sea Level Rise Risk Assessment	Completed	$	45,000.00
NDMP	Cowichan Valley Regional District	S1 - Regional Risk Assessment of Floodplain Areas	Completed	$	50,000.00
NDMP	Cowichan Valley Regional District	S1 - Regional Dam Safety Analysis and Risk Assessment	Completed	$	128,000.00
NDMP	Delta, Corporation of	S1 - Flood Protection System Risk Assessment	Completed	$	75,000.00
NDMP	Fraser Basin Council	S1 - Thompson Watershed Multi-jurisdictional Assessment	Completed	$	300,000.00
NDMP	Golden, Town of	S1 - Kicking Horse River Ice Jam Flooding Risk Assessment	Completed	$	42,000.00
NDMP	Nanaimo, Regional District of	S1 - RDN and Town of Qualicum Beach Risk Assessment	In Progress	$	80,000.00
NDMP	Powell River Regional District	S1 - Assessment of Coastal Hazards and Risks	Completed	$	31,500.00
NDMP	Richmond, City of	S1 - Steveston Island Flood Risk Investigation	Completed	$	405,000.00
NDMP	Armstrong, City of	S1 - Armstrong Risk Assessment	Completed	$	43,500.00
NDMP	Coquitlam, City of	S1 - Mayfair Industrial Park Risk Assessment	Completed	$	23,500.00
NDMP	Cranbrook, The Corporation of the City of	S1 - Flood Risk Assessment	Completed	$	28,000.00
NDMP	Gitga'at First Nation	S1 - Hartley Bay Tsunami and Flood Risk Assessment	Completed	$	70,500.00
NDMP	Kelowna, City of	S1 - Kelowna Major Systems Flood Risk Assessment	Under Review	$	125,000.00
NDMP	Okanagan Nation Alliance	S1 - Flood Risk Assessment	Under Review	$	114,400.00
NDMP	Peace River Regional District	S1 - PRRD Chetwynd Fringe Risk Assessment	Completed	$	33,500.00
NDMP	Peace River Regional District	S1 - PRRD Moberly Lake Risk Assessment	Completed	$	33,500.00
NDMP	Peace River Regional District	S1 - PRRD Pouce Coupe - Tomslake Risk Assessment	Completed	$	30,000.00
NDMP	Shxw'owhamel First Nation	S1 - Shxw'owhamel First Nation Flood Risk Assessment	Under Review	$	20,000.00
NDMP	Spallumcheen, Township of	S1 - Spallumcheen Flood Hazard Risk Review	Completed	$	50,000.00
NDMP	Squamish-Lillooet Regional District	S1 - SLRD Identification & Risk-based Prioritization of Flood Hazards	In Progress	$	256,100.00
NDMP	Strathcona Regional District	S1 - Salmon and White Rivers Risk Assessment	Completed	$	32,750.00

NDMP	Tofino, District of	S1 - Tofino Coastal Flood Risk Assessment	Completed	$	80,000.00
NDMP	Columbia Shuswap Regional District	S1 - Risk Assessment for the Columbia Shuswap Regional District (Eastern Portion)	In Progress	$	150,000.00
NDMP	Fraser Basin Council	S1 - Lower Mainland Flood Risk Assessment	In Progress	$	340,000.00
CEPF	Bulkley-Nechako Regional District	Flood Risk Assessment, Flood Mapping, Flood Mitigation Planning: Ebenezer Flats	Under Review		
CEPF	Campbell River	Flood Risk Assessment, Mapping, Mitigation Planning: Sea Level Rise Assessment	Under Review		
CEPF	Clinton	Flood Risk Assessment: Upper Clinton Creek Reservoir Dam Break Analysis	Under Review		
CEPF	Grand Forks	Flood Risk Assessment, Flood Mitigation Planning: Grand Forks Floodplain Risk Assessment Project	In Progress		
CEPF	Penticton	Flood Risk Assessment	Completed		
CEPF	Port McNeill	Flood Risk Assessment, Flood Mitigation Planning: Storm Water & Beach Drive Landslide Risk Assessment	Completed		
CEPF	Tahsis	Flood Risk Assessment, Flood Mapping, Flood Mitigation Planning: Sea level Rise Coastal Mapping Assessment	Under Review		
CEPF	Zeballos	Zeballos River Floodplain Modernization & Future Landslide Risk Assessment	Completed		
CEPF	Canal Flats	Kootenay River Flood Risk Assessment and Flood Mapping	In Progress		
CEPF	Cariboo Regional District	Screening Level Floodplain Mapping, Thompson River Watershed & Floodplain Prioritization within CRD	In Progress		
CEPF	Courtenay	Dike Replacement and Flood Protection Strategy: Phase 2	In Progress		
CEPF	Greenwood	Flood Risk Assessment, Flood Mapping and Flood Mitigation Planning	In Progress		
CEPF	Keremeos	Similkameen River Regional Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan.	In Progress		
CEPF	Kitimat-Stikine Regional District	Skeena and Lower Kalum River Channel Management Program Phase 2	In Progress		
CEPF	Midway	Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan	In Progress		
CEPF	Mission	Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan	In Progress		
CEPF	Nanaimo	Jump Creek & South Fork Dams Inundation Study	In Progress		
CEPF	North Vancouver City	Lynn Creek Flood Risk Assessment and Reduction Management Plan	In Progress		
CEPF	Okanagan-Similkameen Regional District	Similkameen River Regional Flood Risk Assessment and Flood Mapping Project	In Progress		
CEPF	Peachland	Flood Risk Assessment and Mitigation Plan for Okanagan Lakeshore	In Progress		
CEPF	Princeton	Similkameen River Regional Flood Risk Assessment, Flood Mapping & Flood Mitigation Plan	In Progress		
CEPF	Squamish	Squamish River Dike - Judd Slough Dike Seismic Risk Assessment and Mitigation Strategy	In Progress		
CEPF	Ucluelet	Flood Mapping Project	In Progress		
CEPF	Vernon, City of	Upper and Lower BX Creek Flood Risk Assessment, Mapping and Flood Mitigation Planning - Phase 1	In Progress		
Grants	Cache Creek, Village of	Cache Creek Non-Structural Flood Mitigation	In Progress	$	150,000.00
Grants	Chetwynd, District of	Chetwynd Non-Structural Flood Mitigation	Completed	$	150,000.00
Grants	Dawson Creek, City of	Dawson Creek Non-Structural Flood Mitigation	Completed	$	150,000.00
Grants	Elkford, District of	Elkford Non-Structural Flood Mitigation	Under Review	$	150,000.00
Grants	Fernie, City of	Fernie Non-Structural Flood Mitigation	Under Review	$	150,000.00
Grants	Lumby, Village of	Lumby Non-Structural Flood Mitigation	Completed	$	150,000.00
Grants	Nelson, City of	Nelson Non-Structural Flood Mitigation	Completed	$	150,000.00
Grants	Squamish-Lillooet Regional District	Flood Hazard Mapping and Risk Assessment - Upper Squamish Valley	Completed	$	150,000.00
Grants	Sparwood, District of	Sparwood Non-Structural Flood Mitigation	Completed	$	150,000.00

Grants	Telkwa, Village of	Telkwa Non-Structural Flood Mitigation	Completed	$	150,000.00
Grants	Central Coast Regional District	Bella Coola Valley Risk Assessment and Flood Modeling	In Progress	$	500,000.00
Grants	Stewart, District of	Stewart Avalanche Risk Assessment	Completed	$	80,000.00
Total				$	5,551,000.00

Table 5. Flood Related Projects for BC First Nations

https://www.sac-isc.gc.ca/eng/1397740805675/1535120329798

The following projects have been completed or are in progress to address potential flooding issues:

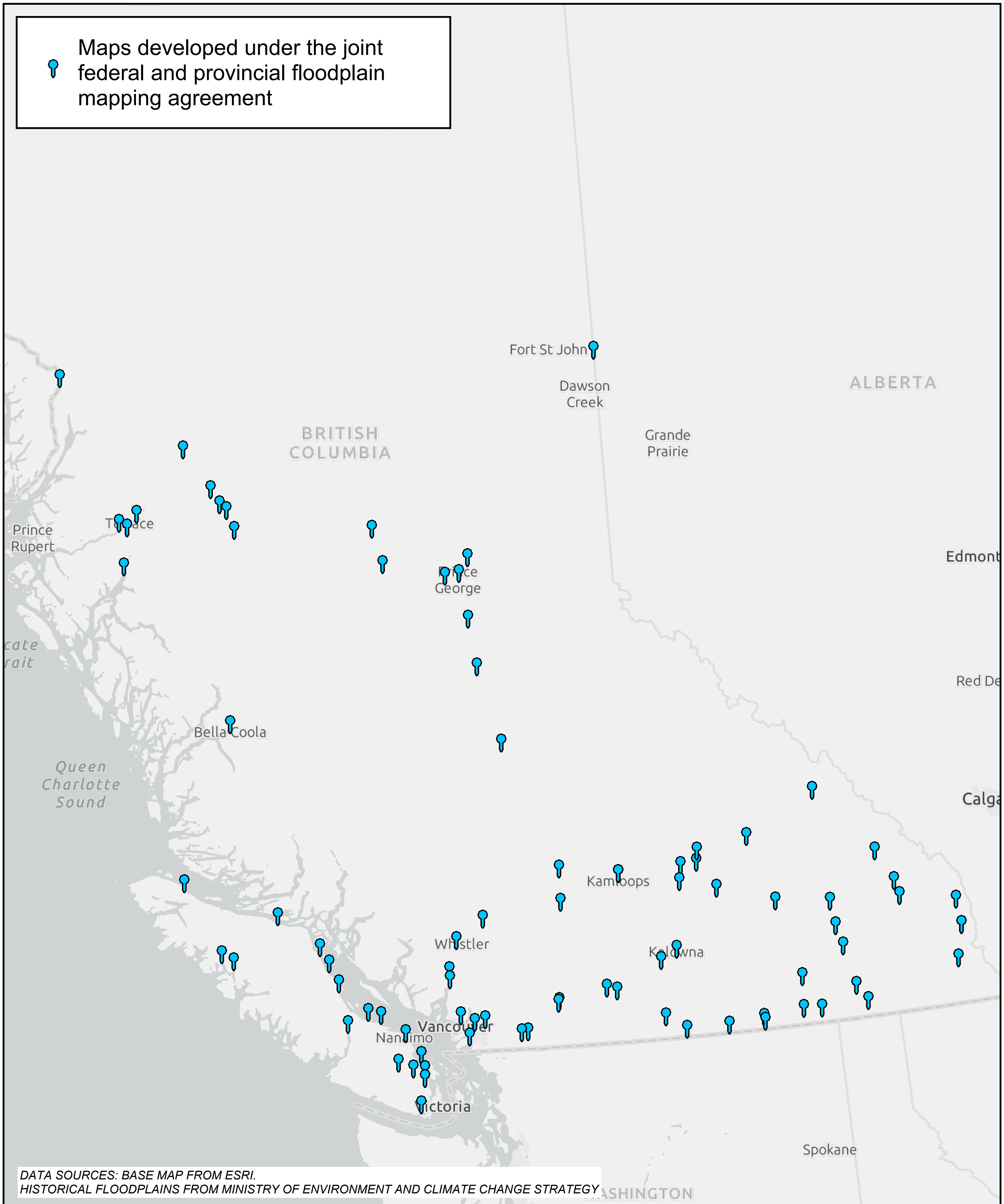
- Gitanmaax
  - Bulkley River bank erosion protection of an existing community access road. Design currently in progress
- Kwantlen First Nation
  - bank erosion protection for infrastructure and lands on McMillan Island IR 6. Construction completed and the project is currently in the environmental and installation monitoring stage
- Lower Kootenay
  - dike reconstruction which included creating new set-back dikes protecting on and off reserve assets. Construction completed and the project is currently in the environmental and installation monitoring stage
- Nisga'a Village of Laxgalt'sap
  - project studies related to dredging Greenville Creek and dike are completed
  - raising adjacent subdivision lands above the flood plain levels using the river dredging materials is completed
  - tsunami wave and storm surge event flood risk study on the Nass River is completed
- Nooaitch
  - design and construction of long-term erosion mitigation works at bank failure locations along the main access road to Nooaitch IR 1 is in progress
- Nuu-Chah-Nulth Tribal Council
  - a coastal vulnerability study project is in progress to develop models for 30 coastal communities around Vancouver Island to help predict estimated sea level rise, accompanying storm surge and its effects on infrastructure for communities on the West Coast of Vancouver Island
  - as of May 2019, 6 communities have been completed:
    - Nuchatlaht
    - Hesquiaht
    - Ahousaht
    - Tla-o-qui-aht First Nations
    - Ehattesaht
    - Ka:'yu:'k't'h'/Che:k:tles7et'h' First Nations
  - a draft report completed in 2019 identified areas vulnerable to tsunami and storm event flooding in Toquaht, Ucluelet First Nation, Hupacasath, Huu-ay-aht, Tseshaht, and Uchucklesaht. Planned investigations for 2019 to 2020 include Ditidaht, Nuchatlaht, Pacheedaht First Nation, T'Sou-ke First Nation, Beecher Bay, Esquimalt, and Songhees Nation

- Skidegate
  - a north coastal vulnerability study is in progress to develop models for 30 coastal communities to help predict estimated sea level rise, accompanying storm surge and its effects on the infrastructure of First Nations communities in Northern British Columbia.
  - as of May 2019, 9 communities have been completed:
    - Skidegate
    - Old Massett Village Council
    - Gitga'at
    - Haisla Nation
    - Nisga'a Village of Gingolx
    - Nisga'a Village of Laxgalts'ap
    - Lax Kwa'laams
    - Metlakatla First Nation
    - Gitxaala Nation
  - a draft report completed in 2019 identified areas vulnerable to tsunami and storm event flooding in:
    - Kitasoo
    - Heiltsuk
    - Nuxalk Nation
    - Wuikinuxv Nation
    - Dzawada'enuxw First Nation
  - planned investigations for 2019 to 2020 include:
    - Gwa'Sala-Nakwaxda'xw
    - Gwawaenuk Tribe
    - Kwakiutl
    - Namgis First Nation
    - Kwikwasut'inuxw Haxwa'mis
    - Mamalilikulla First Nation
- Skwah, Shxwhá:y Village and the City of Chilliwack
  - a joint flood and erosion protection project of both First Nations and the City of Chilliwack is currently in design. Construction is planned to start in fiscal year 2020 to 2021
- Soowahlie
  - reconstruction of a failed dike section completed in 2018. Construction of river training works completed in 2019
- Gwa'Sala-Nakwaxda'xw
  - coastal flood protection investigations of the community are in progress
- Tsawout First Nation
  - coastal erosion protection works of existing infrastructure. Construction was completed in 2019
- Metlakatla First Nation
  - coastal erosion protection works for existing infrastructure. Phase 1 construction started in 2018-2019 and phase 2 construction is planned to start in 2019 to 2020
- Ts'kw'aylaxw First Nation
  - construction of a debris flow berm for the protection of existing infrastructure

- Peters First Nation
    - initiating assessment and design of flood protection upgrades for existing homes, as well as identifying upgrades to address climate change predictions identified for the overall river valley. Design was funded in 2018 and construction is in progress in 2019
- Kwikwasut'inuxw Haxw'mis
    - investigations of coastal erosion works to protect existing homes are in progress
- Sto:lo Nation and Lower Fraser Fisheries Alliance
    - in fiscal year 2018 to 2019, funded the creation of a secretariat to facilitate, collaborate and consolidate the coordination of 60 First Nations in the Lower Fraser River Valley with the Fraser Basin Council and the Lower Fraser Flood Plain Strategy
- Samahquam
    - started design in 2018 for community flood protection works. Construction is planned to start in fiscal year 2019 to 2020
- Seabird Island
    - started designs for upgrades to the community flood protection works to address level updates and climate change predictions on the Lower Fraser River
- Cowichan
    - ongoing sediment removal program to maintain flow capacity of the river system through the community
- Squamish
    - flood protection investigations of the Capilano River system within the community is in progress
- K'ómoks First Nation
    - started design for coastal erosion works in 2018. Project is in progress
- Kwadacha
    - flood protection investigations to update design levels with recent monitoring information and potential climate change impacts is in progress

Table 6. Identification of Communities and River Reaches/Coastlines for Mapping

Locations with population greater than 10,000 near water body	Communities protected by 'High Consequence' Dikes	Communities with no recent flood maps but mapped in the past	Main river reaches/coastlines to consider for mapping
Abbotsford	Abbotsford	Quaste River at Port Hardy	Lower Fraser + Tribs (Hope to Ocean)
Burnaby	Burnaby	Bear River at Stewart	Lower Mainland Coastal
Campbell River	Chilliwack	Bulkley River - Quick to Houston	Skeena River - Hazelton, Terrace
Central Saanich	Coquitlam	Lakelse River and Lake	(Lakelse River and Lake)
Chilliwack	Delta	Skeena River - Lakelse - Terrace -Usk	Bulkley River - Quick, Hazelton
Colwood	Kamloops	Zymoetz (Copper River)	Nechako/Fraser + Tribs
Comox	Maple Ridge	Chemainus River	Thompson Rivers
Coquitlam	New Westminster	Little Qualicum River	Chilako River
Courtenay	Pitt Meadows	Oyster River	Columbia River + Tribs
Cranbrook	Port Coquitlam	Salmon & White Rivers	Bear River at Stewart
Dawson Creek	Prince George	Sooke River	
Esquimalt	Richmond	Cheakamus River	
Kamloops	Surrey	Coquihalla River at Hope	
Kelowna	Harrison Hot Springs	Fraser River Near Hope	
Langford	Kent	Boneaparte River	
Langley (City&Township)	Squamish	Nicola River - Spemces Bridge to Nicola Lake	
Lynn Valley	Duncan	Tulameen River	
Maple Ridge	North Cowichan	Chilako River	
Mission	Golden	Naver & Hixon Creeks at Hixon	
Nanaimo	Pemberton	Nechako River at Vanderhoof	
Nelson		Salmon River near Prince George	
New Westminster		Stuart River & Lake at Fort St. James	
Delta		Christina Lake	
North Saanich		Kettle & Granby Rivers	
North Vancouver		Salmon River - Salmon Arm to Spa Creek	
Oak Bay		Salmon River - Spa Creek to Falkland	
Parksville		Shuswap River, Bessette & Duteau Creeks	
Penticton		Shuswap River, Mara Lake to Mabel Lake	
Pitt Meadows		Arrow Reservoir & Kuskanax Creek	
Port Alberni		Beaver Creek - Beaver Falls to Meadows	
Port Coquitlam		Columbia River - Columbia Lake to Windermere Lake	
Port Moody		Columbia at Revelstoke	
Powell River		Columbia River - Winderemere Lake to Radium	
Prince George		Crawford Creek Alluvial Fan	
Prince Rupert		Duncan and Lardeau Rivers	
Quesnel		Eagle River	
Richmond		Goat River at Creston	
Rutland		Kaslo River at Kaslo	
Saanich		Kootenay River - Kootenay lake to US Border	
Salmon Arm		Salmo River - Ymir to South Salmo River	
Sidney		Slocan River	
Sooke			
Surrey			
Squamish			
Summerland			
Surrey			
Terrace			
Tsawwassen			
Vancouver			
Vernon			
Victoria			
View Royal			
Whistler			
White Rock			
Williams Lake			
Note:	Green shading indicates project recently mapped or in progress under CEPF, NDMP or other funding		



DATA SOURCES: BASE MAP FROM ESRI.
HISTORICAL FLOODPLAINS FROM MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

Fraser Basin Council

nhc northwest hydraulic consultants

SCALE - 1:6,000,000
0 100 200 KM
N

Coordinate System: NAD 1983 BC ENVIRONMENT ALBERS
Units: METRES

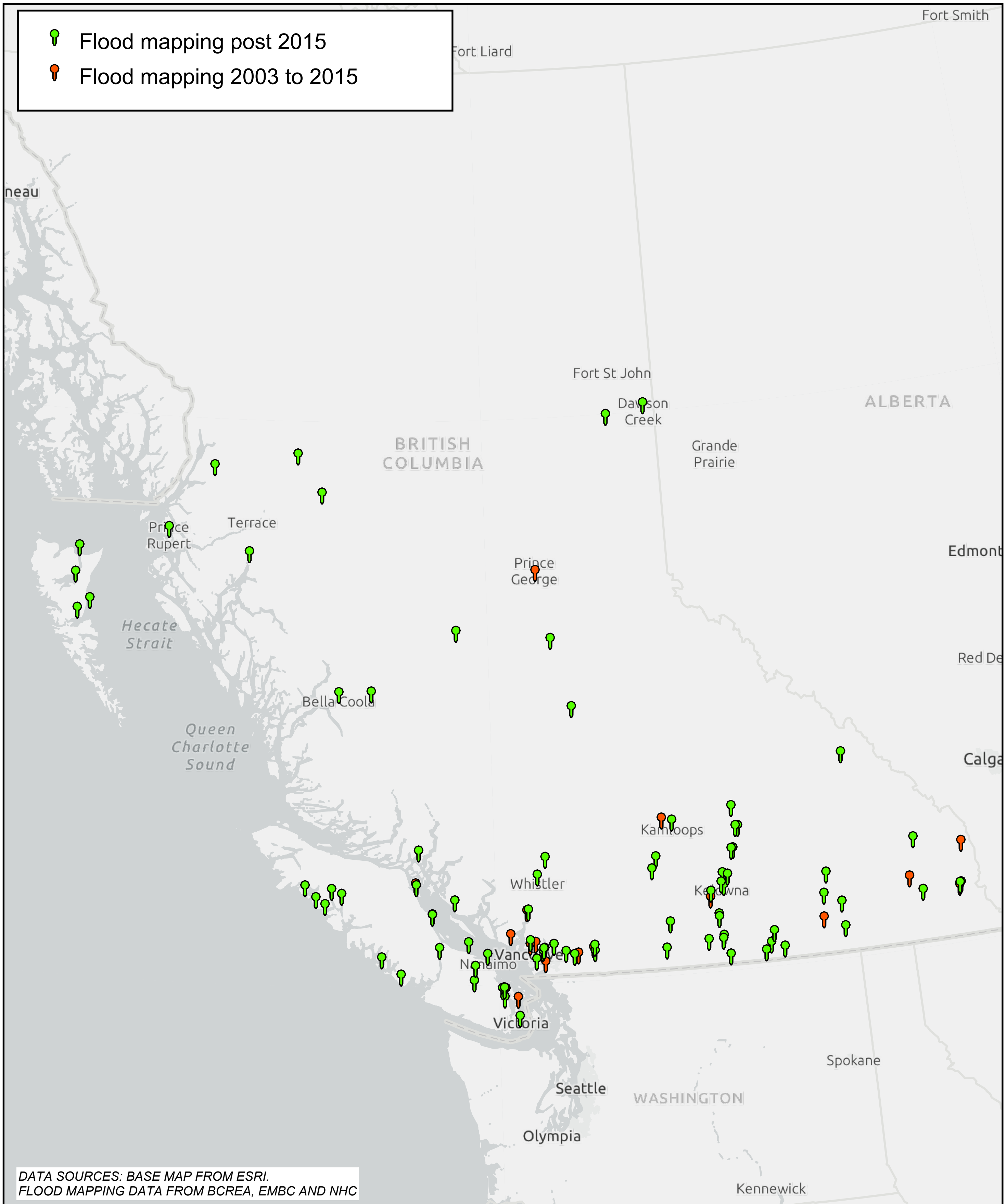
Job: 3005405 | Date: 17-MAR-2021

FLOOD MAPPING IN B.C.

FLOODPLAINS MAPPED 1974 to 2003

FIGURE 1

CLC/MSN, \\mainfile-van\Projects\Active\3005405 FBC Flood Hazards\95 GIS\3005405_MSN_BCFloodplainMapping2.aprx



Fraser Basin Council

SCALE - 1:7,000,000

0 100 200 KM

N

northwest hydraulic consultants

Coordinate System: NAD 1983 BC ENVIRONMENT ALBERS
Units: METRES

Job: 3005405

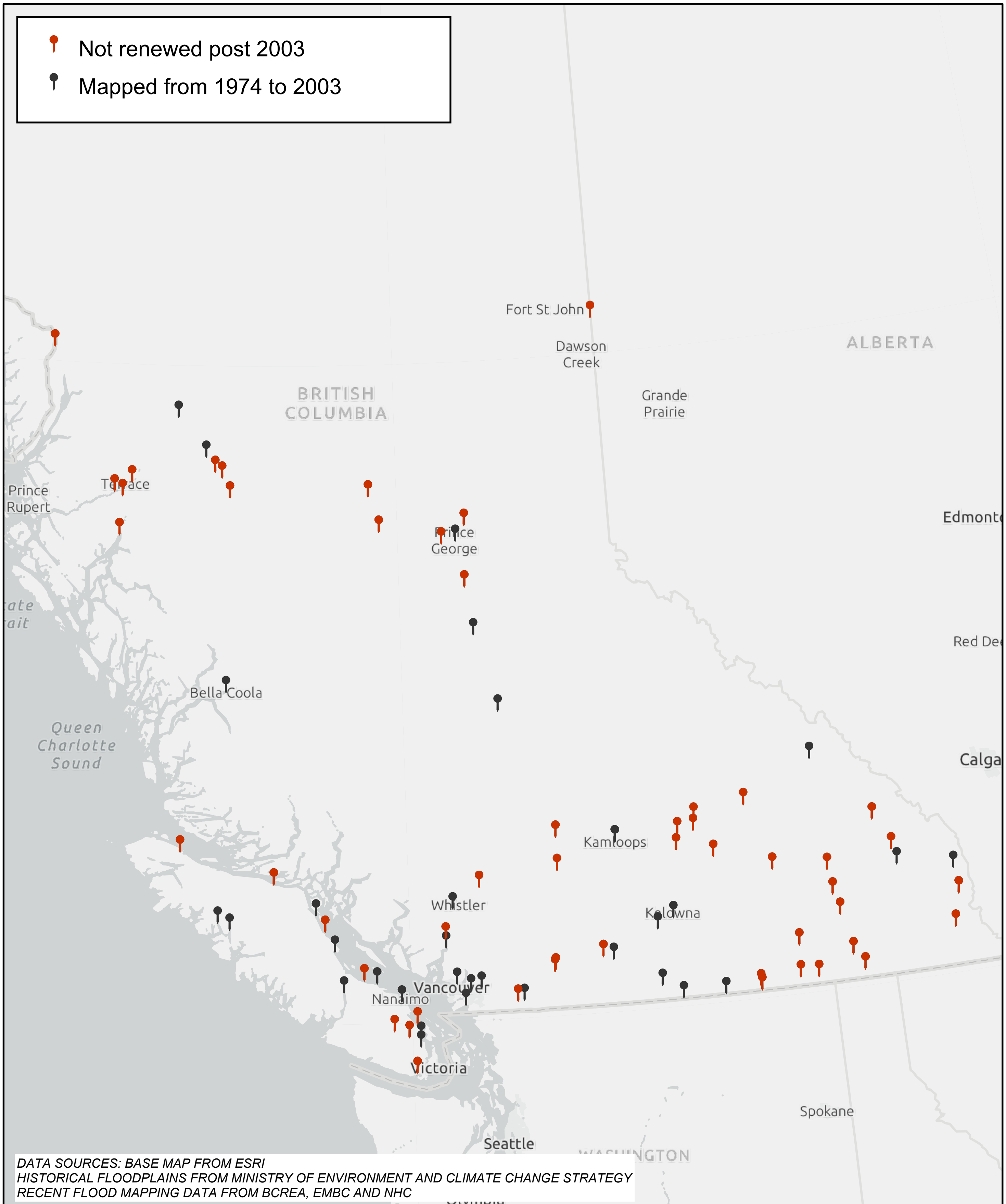
Date: 17-MAR-2021

FLOOD MAPPING IN B.C.

FLOODPLAINS MAPPED OR IN PROGRESS SINCE 2003

FIGURE 2

CLC/MSN, \\mainfile-van\Projects\Active\3005405 FBC Flood Hazards\95 GIS\3005405_MSN_BCFloodplainMapping2.aprx



Fraser Basin Council

SCALE - 1:6,000,000

0 100 200 KM

N

FLOOD MAPPING IN B.C.

1974 to 2003 FLOODPLAIN MAPS NOT RENEWED POST-2003

nhc northwest hydraulic consultants

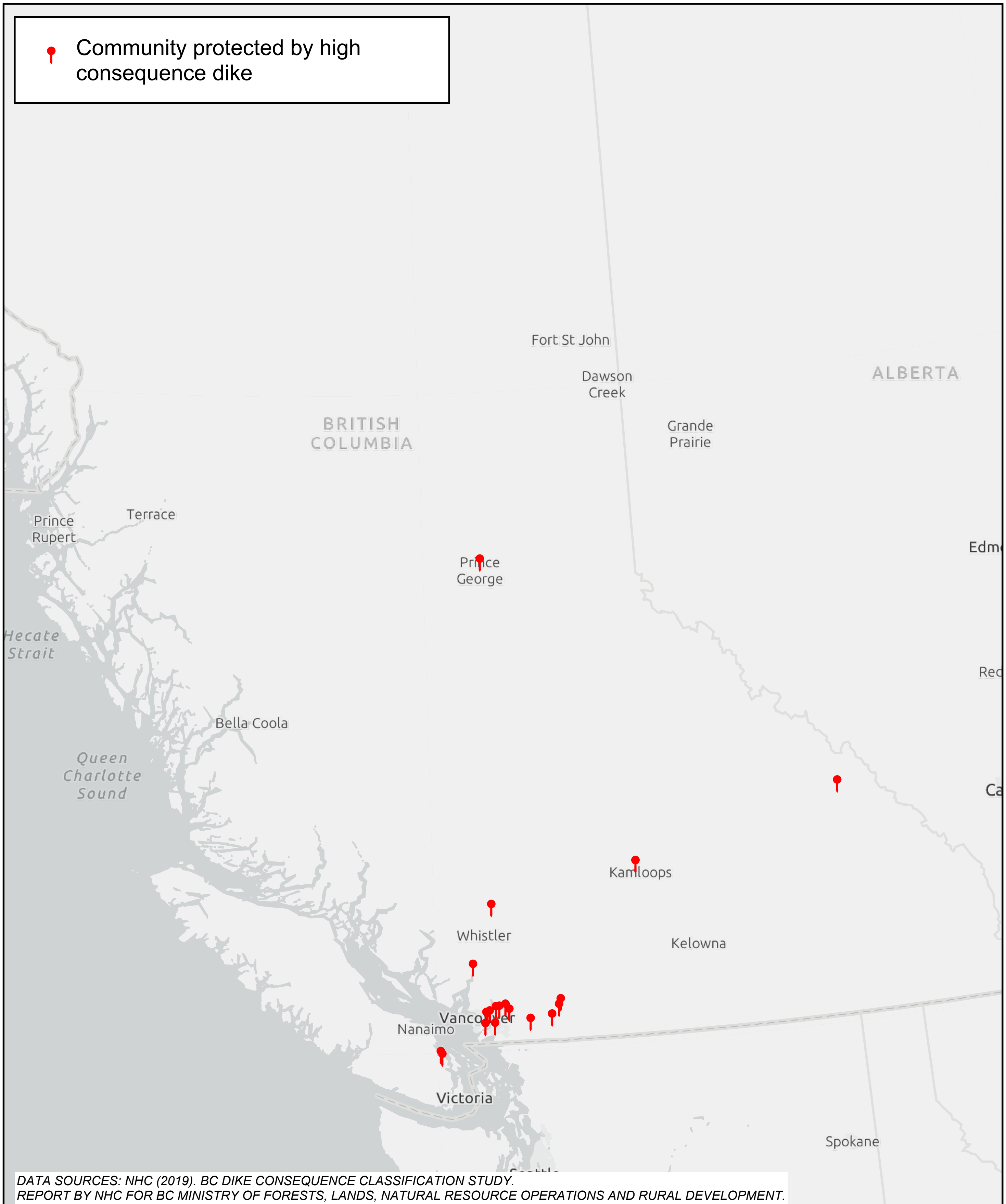
Coordinate System: NAD 1983 BC ENVIRONMENT ALBERS
Units: METRES

Job: 3005405

Date: 17-MAR-2021

FIGURE 3

CLC/MSN, \\mainfile-van\Projects\Active\3005405 FBC Flood Hazards\95 GIS\3005405_MSN_BCFloodplainMapping2.aprx



DATA SOURCES: NHC (2019). BC DIKE CONSEQUENCE CLASSIFICATION STUDY.
REPORT BY NHC FOR BC MINISTRY OF FORESTS, LANDS, NATURAL RESOURCE OPERATIONS AND RURAL DEVELOPMENT.

Fraser Basin Council

SCALE - 1:6,000,000

0 100 200 KM

N

nhc northwest hydraulic consultants

Coordinate System: NAD 1983 BC ENVIRONMENT ALBERS
Units: METRES

Job: 3005405

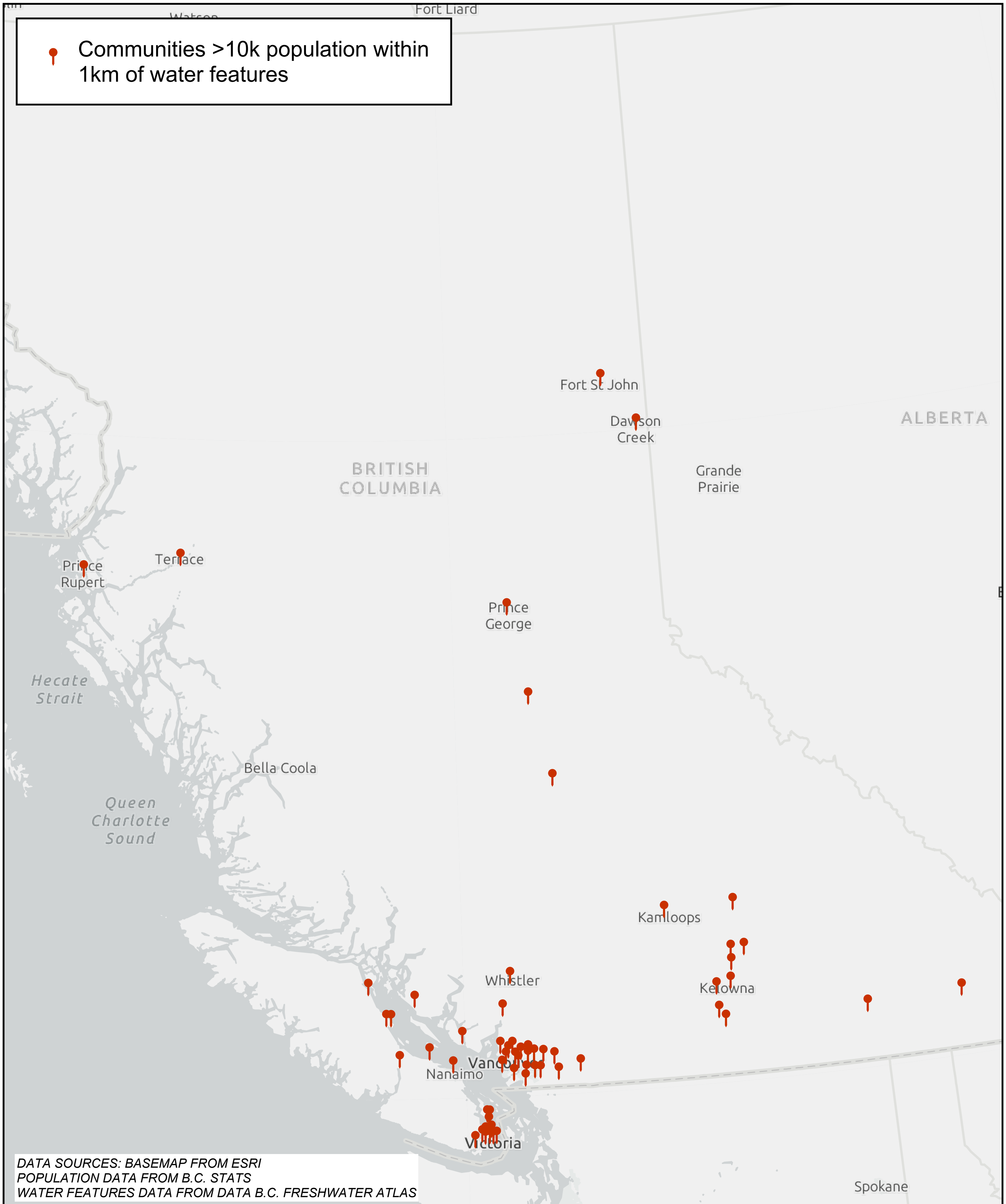
Date: 17-MAR-2021

COMMUNITIES PROTECTED BY HIGH CONSEQUENCE DIKES

USED WITH PERMISSION FROM FLNRORD

FIGURE 4

CLC/MSN, \\mainfile-van\Projects\Active\3005405 FBC Flood Hazards\95 GIS\3005405_MSN_BCFloodplainMapping2.aprx



Fraser Basin Council

SCALE - 1:6,000,000

0 100 200 KM

N

FLOOD MAPPING IN B.C.

COMMUNITIES IN B.C. WITH POPULATION GREATER THAN 10,000 AND WITHIN 1KM FROM WATER FEATURES

nhc
northwest hydraulic consultants

Coordinate System: NAD 1983 BC ENVIRONMENT ALBERS
Units: METRES

Job: 3005405

Date: 17-MAR-2021

FIGURE 5

CLC/MSN, \\mainfile-van\Projects\Active\3005405 FBC Flood Hazards\95 GIS\3005405_MSN_BCFloodplainMapping2.aprx

Appendix C: Channel Migration Mapping

APPENDIX C – CHANNEL MIGRATION MAPPING

Flowing water has the power to transport sediment, resulting in channel migration. Sediment and wood carried by rivers and streams can accumulate and block the path of the flow, resulting in sudden shifts in the channel location during floods. Because they fundamentally re-shape the valley bottom, these processes can cause fluvial hazards to impact areas outside the floodplain that would be predicted by a hydraulic model for any given flow. In the United States, the total annual damage related to flooding along streams with severe erosion problems is approximately US$ 1.5B (ASFPM, 2016), and much of this damage is believed to result from erosional processes related to flooding rather than direct inundation. Furthermore, these processes can create a direct risk to human life and safety because of the way they can rapidly reshape the landscape and shift the locations of fast and deep flow.

Notwithstanding the negative interaction that can occur between channel migration and human infrastructure, channel migration is a vital process to sustain river- and riparian health. It allows the river channel to dynamically adjust to changing inputs of water, sediment, and wood (Church, 2006), produces topographic variability across the floodplain to support diverse aquatic and terrestrial habitats (Jones, 2006; Latterell et al., 2006), is a primary mechanism by which large wood is entrained into rivers (Abbe and Montgomery, 1996), and ultimately creates the complexity and diversity in channel hydraulics that is necessary for the flourishing of aquatic organisms. For example, the importance of lateral channel migration in underpinning the health of the fluvial ecosystem was formally recognized by the United States National Marine Fisheries Service in a 2008 Biological Opinion that declared the FEMA floodplain management program resulted in harm—a “take”—to endangered Puget Sound Chinook Salmon, steelhead, and Orca Whales that depend on these (NMFS, 2008). Proactive planning to minimize conflict between human infrastructure and channel migration, therefore, is needed both to protect human safety and property and fluvial ecosystem health.

Channel Migration Zone (CMZ) delineation and related mapping of areas affected by fluvial hazards is one valuable tool that can support such planning efforts. CMZ mapping seeks to identify the area where lateral channel migration is likely to affect the landscape. CMZ mapping is an emerging discipline. To date, the most advanced programs and guidance in North America have been implemented in the states of Colorado (Colorado Water Conservation Board, 2020), Washington ((Rapp and Abbe, 2003; Forest Practices Board, 2004; Legg and Olsen, 2014; Olson et al., 2014; Washington Department of Ecology, 2020), and Vermont (Kline and Dolan, 2008), but programs exist in other jurisdictions (See Appendix A of Colorado Water Conservation Board, 2020 for a helpful review) and several CMZ mapping and geomorphic risk studies have been completed in conjunction with flood hazard studies in BC (e.g. NHC, 2018a, 2018b).

Apart from simple buffer-based rules, three basic approaches are typically used to define Channel Migration Zones, and these rely on variable assumptions regarding the relationship between future likely channel migration and historical channel migration. Rapp and Abbe (2003) and Forest Practices Board (2004) rely on documentation of historic channel positions and measurement of past channel migration rates to determine the extent of the CMZ, as illustrated in (Figure 2.1). This approach works well where a long record of historical aerial imagery capturing the full range of expected flood flow, sediment, and large wood inputs is available to calculate typical lateral channel migration rates, but it has difficulty in accounting for potential channel responses to unusual flood events or defining what kind of channel migration may be expected under natural conditions in streams that have been highly modified.

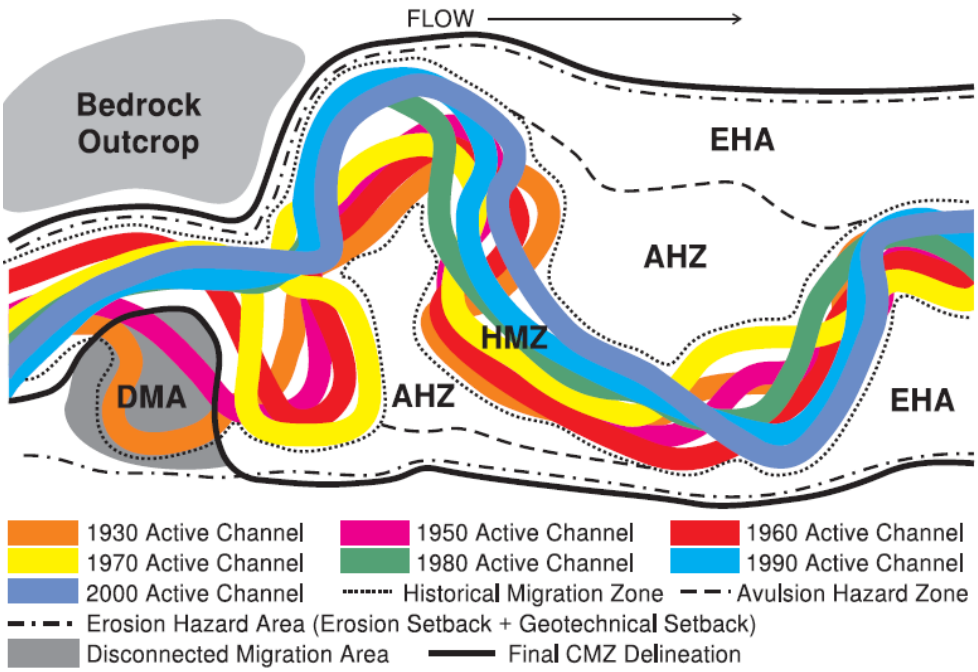


Figure 2.1: Illustration from Rapp and Abbe (2003) summarizing their CMZ delineation procedure. The Historic Migration Zone (HMZ) is the area that the channel has occupied over the historic period documented in maps and aerial photos, the Avulsion Hazard Zone (AHZ) is the area where the channel might suddenly shift during a flood, and the Erosion Hazard Area (EHA) is a buffer calculated based on the observed historic rate of channel migration and delineation timeframe. The DMA is an area within the unconstrained CMZ where channel migration is prevented by human infrastructure.

A second approach relies on the recognition of fluvial landforms to define the area where the channel has moved and is typically based on the interpretation of high-resolution topographic data (e.g. LiDAR) to define the area where the land has been formed by contemporary fluvial processes (the contemporary geomorphic floodplain). The Washington State Planning Level CMZ delineation procedure (Olson et al., 2014) and Fluvial Signature Protocol of Colorado Water Conservation Board (2020) are two related methods that apply this approach. Figure 2.2 illustrates the results of applying the Washington State Planning Level CMZ to define the channel migration zone for a portion of the Upper Squamish River. This approach is extremely robust where fluvial landforms have not been obliterated by human activities but is more difficult to apply in urban areas. It also tends to be fairly conservative from a human-hazard standpoint, as the fluvial landscape across BC has formed over the past several thousand years and so fluvial-landscape signatures may be present in locations that are only occupied by a given river on a millennial timescale.

Incorporation of additional tools to constrain likely future channel movement –like the evaluation of recent lateral channel migration rates and patterns, expected channel widening during a large flood, or areas at high risk of avulsion—can be overlaid on maps produced using this method to delineate a separate high hazard zone. Definition of erosion hazard area buffers around the core contemporary geomorphic floodplain in approaches following this method typically relies on an understanding of the erodibility of the material bounding the contemporary geomorphic floodplain, its geotechnical failure characteristics, and the likelihood of the channel reaching that boundary.

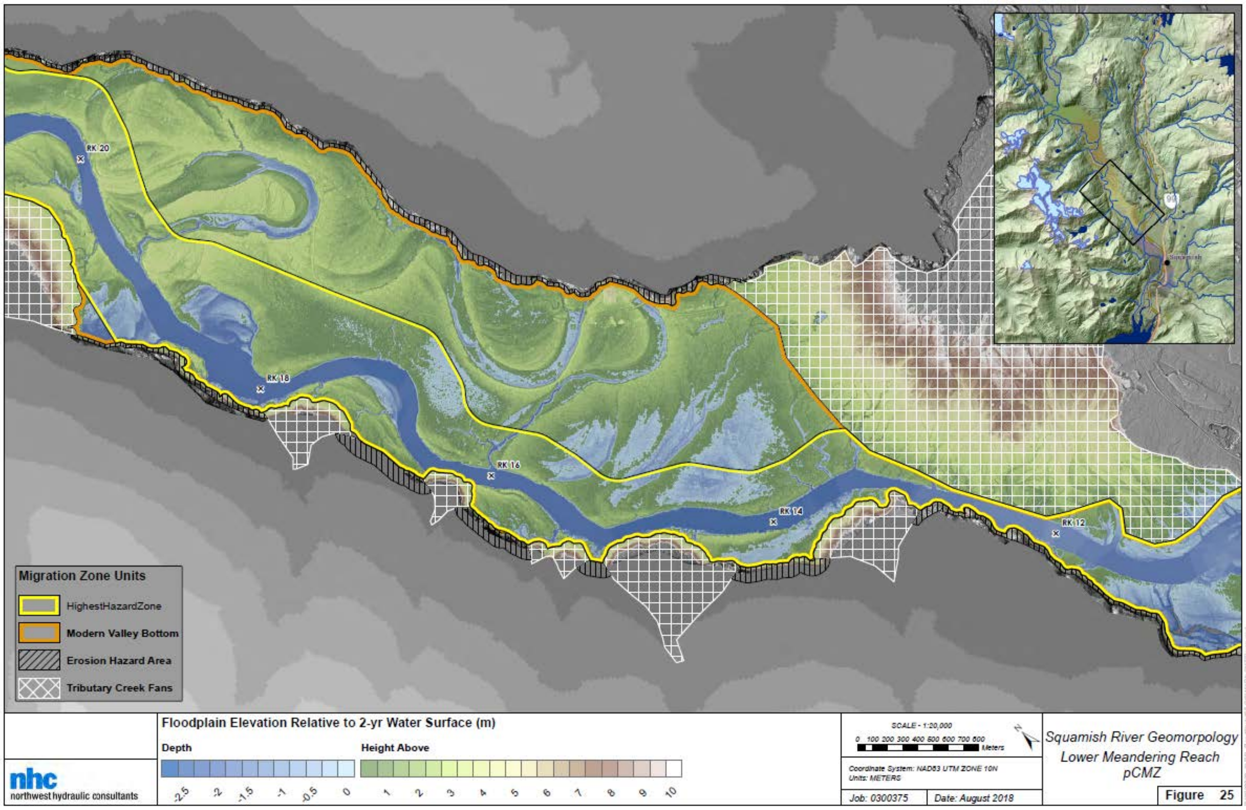


Figure 2: Illustration of application of the Washington State pCMZ analysis procedure to the Upper Squamish River in BC (NHC 2018b). Note how careful visualization of the detailed LiDAR topography data highlights fluvial landforms including abandoned oxbows, meander scrolls, and erosional floodplain channels.

A related approach is appropriate for meandering rivers in very broad valleys relative to typical lateral channel migration rates of the stream. This approach relies on defining the meander belt within which down valley meander translation is likely and undergirds the Vermont-based River Corridor Protection Guide (Kline and Dolan, 2008) and was adapted for the Meander Belt Protocol of the Colorado Water Conservation Board (2020). This approach may understate risk along the margin of the meander belt where meander amplification is occurring or could occur.

The final approach relies on an understanding of likely channel widening during a single large flood event, which is a particularly useful tool in highly developed areas where the fluvial landscape signature has been obliterated from the landscape and where channel migration is likely to be controlled to the extent practicable. This has been best developed by the Colorado Water Conservation Board (2020), who rely on the concept of unit stream power to define the minimum width needed by channels to dissipate the energy of flood flows. They adopted thresholds of 300 W/m^2 for fully channelized and 100

W/m^2 for partially channelized urban streams based on observations of channel response to extreme flooding along the Front Range of Colorado in 2013 and Tropical Storm Irene in Vermont. Other tools for evaluating expected channel width following extreme flooding that have more site-specific information, such as the UBC Regime model (Eaton et al., 2004; Eaton and Church, 2007; Eaton, 2015; Davidson and Eaton, 2018) may also serve such analysis well.

There is a strong consensus among established guidance documents for Channel Migration Zone delineation that it is a task that should be primarily completed by Fluvial Geomorphologists (geoscientists with a specialty in understanding river processes) in conjunction with input from hydraulic and river engineers, hydrologists, and GIS professionals. Specific data requirements to complete CMZ mapping studies depend on the adopted approach. Some combination of historical aerial imagery, high-resolution topography data, geologic or terrain mapping information, field reconnaissance, and hydraulic model output data is usually required. Costs to complete CMZ delineation studies depend on the analyst's familiarity with the subject waterbody, availability and quality of the data listed above, accessibility of the project site, and reporting requirements. Recent CMZ studies completed by the author have ranged from about $10,000 for a small site with which there was a prior intimate familiarity to $150,000 for a river-scale study including historical channel position mapping.

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Appendix D: Examples of Dike Information Sources

APPENDIX D

EXAMPLES OF DIKE INFORMATION SOURCES

List of Examples – Items are referenced to the item numbers in Tables 4.1, 4.2 and 4.3 in Report

Item No.	Information Source	Description and Reference/Link
1	Provincial Dike Database - PDFs on MFLNRORD Website	Example pages for Chilliwack Dike 19 and Nicomen Dike 144 https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/dikes_listed_by_ownerauthority.pdf
4	Lower Mainland Dike Inventory Maps - pdf format - MFLNRORD	Excerpts from Chilliwack and Nicomen Island Maps https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management/flood-protection-structures/dike-inventory
8	Dike Safety Audit Report Outline - MFLNRORD	Excerpts from Audit Checklist/Outline M. Hahn, Inspector of Dikes (pers.com.)
11	Lower Mainland Dike Assessment Final Report (NHC 2015) – MFLNRORD	1) Excerpt from Dike Evaluation Matrix 2) Example rating for Nicomen Dike 144 Segment 1 3) Excerpt from Average Dike Rating Map showing Nicomen Island and Chilliwack https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/nhc_final_lower_mainland_dike_assessment.pdf

Item 1. Pages from Provincial Dike Database on MFLNRORD Website – Dikes 19 and 144

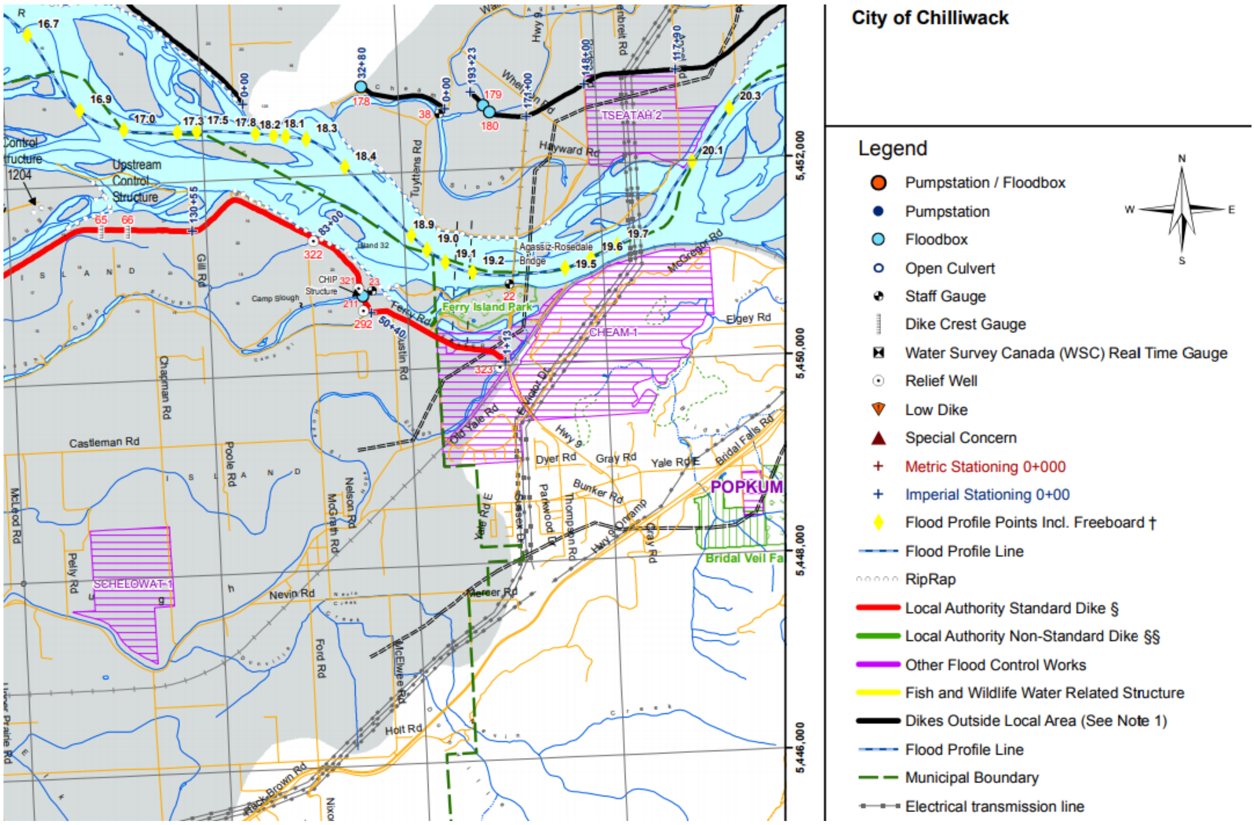
Chilliwack, City of

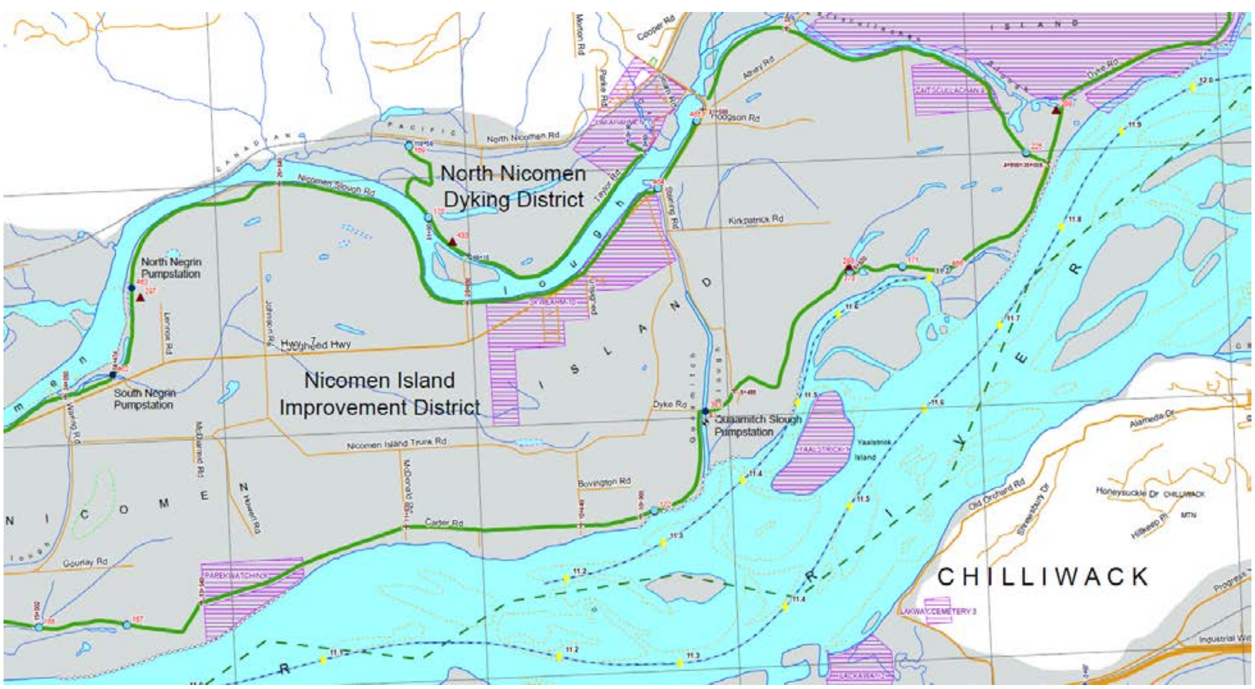
Water Course	**Fraser River**	**Structure Type**	Dike
Water Course 2		**Ancilliary Works**	5 Flood Boxes
GPS Number	19	**Structure Length**	16.434 km
Dike Name	East Dike Rosedale to Young Rd	**NAD 83 Map Number**	92H011
Region	Lower Mainland	**Floodplain Maps**	N/A
Owner/Administrator	Chilliwack, City of	**UTM Northing 1**	5451799 **UTM Northing 2** 5451799
Address	8550 Young Road	**UTM Easting 1**	586286 **UTM Easting 2** 586286
City	Chilliwack	**Service Area**	11,412 Ha
Province	BC	**Land Use**	Rural residential, Agricultural, Commercial, Industrial, Institutional, First Nations and Park Land (wildlife)
Postal Code	V2P 8A4	**Number of Buildings Protected**	800+
Contact Person	Frank Van Nynatten (Assistant Manager of Environmental Services)	**Infrastructure Protected**	Hospital, Schools, Fire Halls, BC Hydro, Telecomm
Telephone	604-793-2720	**Geographic Feature**	Riverine
Fax	604-795-2756	**Type of Flooding**	Spring Freshet
		Local Authority under EPA	Chilliwack, City of
		Regulated under DMA	Yes

Nicomen Island Improvement District

Water Course	**Fraser River**	**Structure Type**	Dike
Water Course 2	Nicomen Slough	**Ancilliary Works**	5 Pump stations, 2 with floodboxes. 10 floodboxes
GPS Number	144	**Structure Length**	35 km
Dike Name	Nicomen Island	**NAD 83 Map Number**	92G018/019
Region	Lower Mainland	**Floodplain Maps**	N/A
Owner/Administrator	Nicomen Island Improvement District	**UTM Northing 1**	5444574 **UTM Northing 2** 5450993
Address	9990 Tremblay Road	**UTM Easting 1**	559527 **UTM Easting 2** 572578
City	Deroche	**Service Area**	2153 Ha
Province	BC	**Land Use**	Rural residential, Agricultural
Postal Code	V0M 1G0	**Number of Buildings Protected**	270 Homes and 150 Barn structures
Contact Person	John Kerkhoven	**Infrastructure Protected**	Roads
Telephone	604-820-0450	**Geographic Feature**	Riverine
Fax		**Type of Flooding**	Spring Freshet
		Local Authority under EPA	Fraser Valley Regional District
		Regulated under DMA	Yes

Item 4 – Lower Mainland Dike Inventory Maps – Excerpts from Chilliwack and Nicomen Island Maps





Item 8 – Pages 1 and 2 from Dike Safety Audit Check List/Report Outline

Dike Safety Audit Check List/Report Outline

Date of Audit: ______________ File Number:____________

Diking Authority: ____
Dike Name(s): _________________________________ GPS Nos. _______
Water Course: _________________________________
Deputy Inspector of Dikes (DIOD) __________________

Diking Authority Contact Information (include both the official "Contact" person and any other personnel providing information for this audit):
Name: ____
Title: ____
Address: ____
Telephone: ________________________ Fax: ________________
Email: ___________________________

1. **Audit Objectives:**
   a) Review diking authority's management program
   b) Examine diking authority's maintenance records and financial statements
   c) Complete joint inspection of key facilities and problem areas.
   d) Prepare an Audit Report including action plan and implementation schedule

2. **Overview of the Diking Authority's Management Program**
   Briefly describe the diking authority's resources, capabilities, organization and personnel.

3. **Documents and Records:**
Does the diking authority have all the documents below? Are the documents complete and up to date? For all "No"s - identify action items and completion dates. If legal access is incomplete, include a detailed discussion of issues and actions required.

Document	Yes	No
Operation & Maintenance Manual		
As – Constructed Drawings and Plans		
Rights of Way and Legal Access to all sections of diking system		
Vegetation Management Plan		
Dike Crest Survey (typically should be less than 10 years old)		
Current Inspection Report (see 5. below)		
Current Maintenance Work Plan and Schedule (see 6. below)		
Flood Emergency Plan (see 8. below)		

4. **Diking Authority's Financial Statements:**
   a) Budget allocated for annual operation and maintenance $_______
   b) Amount spent on annual maintenance in the last fiscal year $_________

c) Additional amounts required to fix urgent repairs in the next fiscal year $__________
d) Additional amounts required for assessments, studies and proposed capital improvements $_______________
e) Identify and describe funding issues and possible solutions (i.e. raise taxes, apply for FPP funds etc.)

5. Inspections:
Complete a detailed review of the inspection records maintained by the diking authority as follows:

a) Annual Inspections:
- Date of Most Recent Inspection: _______________
- Was the report submitted to IOD/DIOD? _________ (Yes/No)
- Was the report detailed and comprehensive? __________ (Yes/No)
- Is the Contact familiar with the design, the drawings, the O&M Manual, and the complete diking system? _______ (Yes/No)
- Does the Contact have the knowledge and training to address the problems observed? _____ (Yes/No)
- List problem areas that still need to be addressed to the *Action Items* with completion dates if applicable.
- Is vegetation being adequately controlled to allow for access and visual inspection? _____ (Yes/No)
- Are there structures or obstacles on the dike that need an Order to be removed? _____ (Yes/No)
- Gather any outstanding inspection reports they may have, but did not file, and submit to Rudy Sung, Senior Flood Safety Engineer.

b) Special Inspections:
- Was there a high-water event (or other special event such as ice jam, debris jam, earthquake) this year? __________ (Yes/No)
- Was an inspection and/or professional study completed to assess damage, record high water marks etc. __________ (Yes/No)
- Was the report submitted to IOD/DIOD _________ (Yes/No)
- Review the special inspection report (if completed), the need for further professional assessment and add any required actions to the *Action Items*

6. Maintenance/Repair Plan (Joint Inspection):
Complete a joint inspection of key facilities and problem areas with the person(s) responsible for inspection and maintenance. Use the ministry "Flood Protection Inspection Report" as a guide and take photos to document the critical problem areas.

Following the joint inspection, review the diking authority's maintenance work plan and schedule with the Contact. Is this plan complete and effective in addressing dike safety issues? Address any concerns by adding *Action Items* with expected completion dates to this audit's recommended action plan.

Item 11 – Lower Mainland Dike Assessment Report (NHC 2015)

1) **Excerpt from Dike Evaluation Matrix** (showing typical rationale for "Good" and "Fair" ratings)

Rating Item	Good (=4)	Fair (=3)
1. Crest Elevation vs DCL	Dike ties into high ground or otherwise prevents backwater flooding. Crest levels exceed DCL's (freeboard requirements are fully met). Long-term bed aggradation or debris depositions are unlikely to impact the design profile significantly or, there is a regular channel maintenance program in effect. Lateral channel changes are unlikely to raise the design profile.	Dike ties into high ground or otherwise prevents backwater flooding. A minimum freeboard of 0.3 m is available over most of the dike length. Some lower spots exist that can be plugged during floods. Long-term bed aggradation or debris depositions may to some extent impact the design profile but the channel is fairly well maintained or rates are low. Lateral channel changes may to some extent change the design profile.
2. Geometry - Crest width - Landside slope - Waterside slope	Crest width meets applicable standards and side slopes meet or exceed relevant specifications. (Crest width $\geq$ 4 m, landside slope $\geq$ 3H:1V, waterside slope $\geq$ 2.5H:1V).	Crest width and side slopes generally meet applicable standards. Deficiencies unlikely to compromise the dike stability.
3. Geotechnical Stability - General - Dike stability under flood conditions	Dike is stable during present design flood conditions and can likely be raised (<1 m) for future design levels without affecting stability.	Minor stability problems expected during design flood event but these will unlikely diminish the dike performance. Raising the dike for future design flood conditions may be problematic.
- Seepage (piping and landside heave)	Seepage and landside heave have not been observed in the past and are not expected for present design flood conditions.	Minor seepage problems may occur.
- Long term settlement	Long-term settlement is minimal.	Settlement may require minor raising of dike to maintain design levels.
4. Geotechnical Stability - Seismic	Dike meets seismic standards.	Dike almost meets seismic standards.
5. Erosion Protection - Location of dike - Exposure to erosion - Quality of protection	No protection is required because dike is well set back from river or ocean and flow velocities are low/ wave action limited. Or, dike has adequate erosion protection.	There is erosive action but it does not jepordize the stability of the dike. Riprap appears to be properly designed but has some weaknesses. Erosion protection needs monitoring.
6. Vegetation/Animal Control - Vegetation type/ sod cover - Animal burrows, other animal activities impacting dike sideslopes and/or crest	No woody vegetation or brush obscuring dike slopes. Vegetation is predominantly grasses that are regularly mowed. No reported animal burrows, other animal damage or acivities impacting dike sideslopes / crest.	Minimal woody vegetation. Dike slopes generally well maintained. Some animal burrows and/or other activity impacting dike sideslopes / crest reported but damage has been repaired.
7. Encroachments - Buildings - Road - RW crossings/ land use	No buildings or fences encroach on the dike ROW / access and there are no road / RW crossings affecting the dike. The dike is not used as a road/railroad and there are no conflicting land-uses.	Some buildings marginally enroach on dike ROW. Roads / RWs cross the dike, causing a slight lowering in the dike crest. A main road is located on the dike. No fences or conflicting land-uses.
8. Appurtenant Structures - Types of structures - Operational status - Interface seepage - Pipe crossings - Buried utilities	Pumpstations and floodboxes are in good working order. Seepage is prevented along structure / dike interface. Culverts are flapgated and in good order. Or, there are no appurtenant structures. No buried utilities cross the dike.	Pumpstations and floodboxes are operational. Structures are aging and were built to previous standards. Some seepage has been observed but adequate repairs have been made. Culverts / flapgates have some corrosion / weathering. A few buried utilities cross the dike.
9. Administrative Arrangements - Status of ROW's and legal access - Operation/ Maintenance Manual - Regular inspections - Emergency supplies/response	Standard ROWs are in place, there is legal access to all parts of the dike. IOD approved OM manuals are available. Dike is regularly inspected and reports provided to IOD. Emergency supplies are available and there is a flood response plan.	ROWs and legal access are available but some refinements are required. There is an OM manual and the dike is inspected. There is no emergency response plan.

2) Example Dike Assessment Rating for Nicomen Island Dike 144 Segment 1

Dike Segment Deficiency Matrix

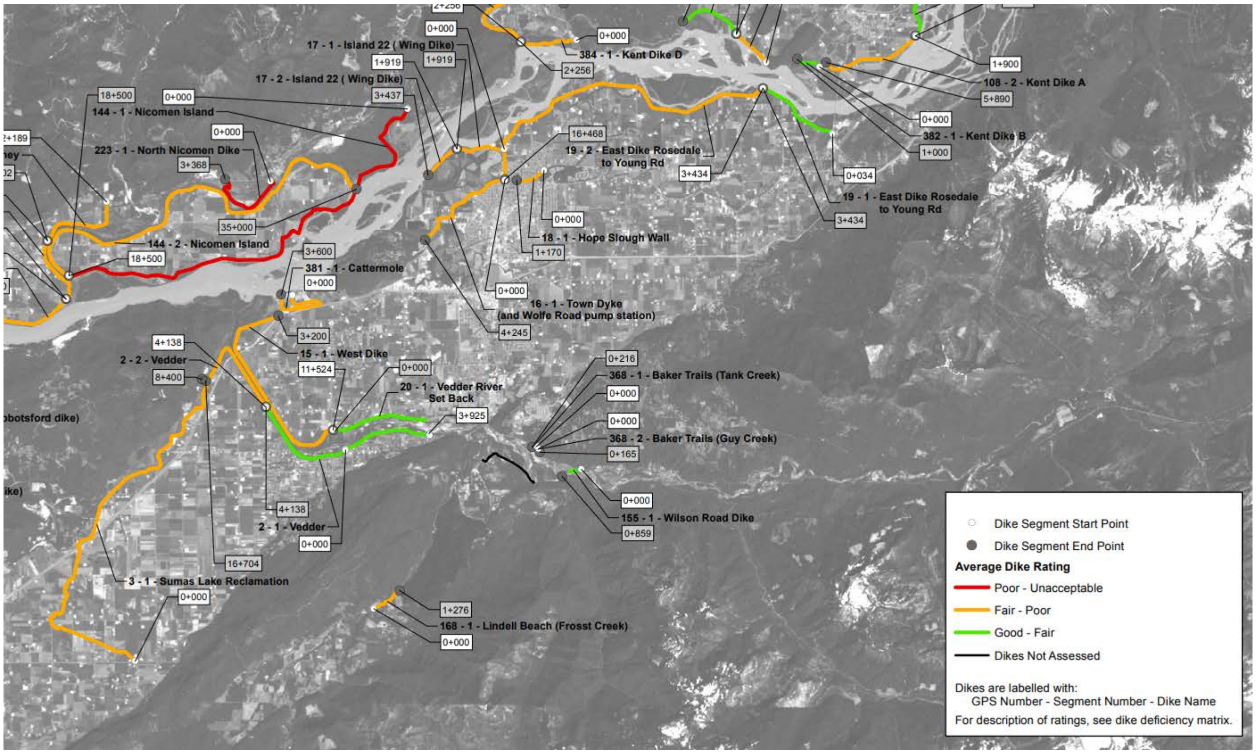
Region 2: Lower Mainland
Authority: Nicomen Island Improvement District
Dike 144: Nicomen Island
Dike Segment 1: 0+000 to 18+500

Rating values range from 1 (Unacceptable) to 4 (Good)

Crest Elevation Rating 1
Avg. Dike Seg. Rating 1.75

Rating Item	Rating	Lib.Ref.Codes	Rationale
1. Crest Elevation vs DCL	1	OR-004	Dike crest is well below DCL and there is no freeboard allowance (eg at 9+000, the DCL is 11.5m and 2014 crest elevation survey is 10.4m).
2. Geometry	2	iMaps BC; W-2383; W-2202; OR-034	Crest width for new works is reported to meet the minimum width of 4m, landside slope is 4H:1V, riverside slope is 2-2.5H:1V, meeting standards. A 2007 assessment reported that crest widths were narrow and dike slopes were often steeper than 2H:1V on both slopes therefore it is likely that older sections of the dike do not meet current standards.
3. Geotechnical Stability - General		DIR-067; OR-034; W-3052	"Sinkhole approximately one foot in diameter was found on the landside of the dike a couple of metres from the toe. After excavation it was found to be a rotting piece of wood. A 2007 assessment noted ponding occuring on the landside of the dike. Active sand boils noted."-nhc
4. Geotechnical Stability - Seismic	1	W-3052	Liquefaction and lateral displacements likely.
5. Erosion Protection	2	LMDIM-Nicomen; DIR-067	Some riverbank, upstream of recent works in exposed Fraser River locations, is experiencing scouring and riprap armouring may have deteriorated since the 2012 dike inspection. Some poorly interlocked and displaced riprap around Floodbox No 172. Overall, the dike is setback for most of its length.
6. Vegetation/Animal Control	1	DIR-067; OR-034	Trees reported to be growing on the dike slopes, animal burrows and pathways are noted along the dike section.
7. Encroachments	3	LMDIM-Nicomen	Multiple road crossings
8. Appurtenant Structures	2	iMAP BC; LMDIM-Nicomen; OR-021	8 Floodboxes, 2 Pump Stations, 1 Culvert. Inspection of the flapgate on Floodbox 168 showed that the flapgate was appropriately sealed however that seepage was likely entering the drain pipe through cracks. After inserting an inflatable plug in the downstream end of the drain pipe to induce greater hydrostatic pressures within the dike fill, it was noted that seepage increased and a boil developed on the landside of the dike.
9. Administrative Arrangements	2	DIR-067; FVR-OM-M-3	Annual inspection, O&M manual exists, 2007 dike assessment noted several private gates on the dike crest were damaged or inoperable.

3) **Excerpt from Average Dike Rating Map – Nicomen Island and Chilliwack** (note: Chilliwack East Dike Rosedale to Young Road (Dike 19) has been extensively upgraded by the City of Chilliwack following the 2015 assessment and the ratings for this dike are out of date)



Appendix E: Potential Method to Relate Dike Assessment Rating to Estimated Level of Protection

APPENDIX E

POTENTIAL METHOD TO RELATE DIKE ASSESSMENT RATING TO ESTIMATED LEVEL OF PROTECTION

The rigorous assessment of a dike and estimation of its performance during future flood events is a challenging task. Dikes can breach through several possible failure modes. Actual failures are also likely to be related to a complex chain of events and contributing factors (e.g. a marginally safe design plus poor quality control during construction). Dike breach scenarios can be comprised of a multitude of variables including water levels, velocities, and hydrograph shape/duration (on both sides of the dike), dike geometry, foundation soils, dike fill materials, appurtenant structures, vegetation/animal burrows, bank erosion protection, the length of the dike, the success of flood fighting efforts, and many others. Furthermore, each dike is a "series system", where failure of one section or component (i.e. the weakest link) can result in catastrophic failure.

Other jurisdictions have devised a range of methods for assessing probable dike performance. For example, the International Levee Handbook (CIRIA 2013) states:

> "There are several different possible results of a levee (dike) performance assessment:
> - Threshold (a limit load)
> - Conditional chance of failure (for a given load)
> - Fragility curve (conditional chance of failure given for a range of loads)
> - Safety Factor
> - Index (e.g. on 0-5 or 0-10 scale)
> - Qualitative (e.g. very good, good, fair, poor, very poor).
>
> The form of the result depends largely on the used method, but also on the way it will be used thereafter. It is possible to build equivalences between the different types of results. Uncertainties, incompleteness, imperfections can be integrated into the assessment process, in order to produce an assessment result in a probabilistic form, or in other forms qualifying its uncertainties."

Previous Estimates of Fraser River Dike Breaching Probability

In 1975, the Fraser River Joint Advisory Board completed the report, "Estimating Flood Damages in the Fraser River Basin" to assist with an assessment of the benefits and costs of constructing upstream storage reservoirs and/or the McGregor River Diversion as means to reduce flood damages along the lower Fraser River (Book and Princic 1975). To complete the analyses, the economists needed assumptions with respect to the likely performance of the diking system (i.e. a fragility curve, which is a relationship of failure probability to water level relative to the dike crest elevation). Their report discussed the importance of these assumptions with respect to attributing flood mitigation benefits to the dikes vs. potential upstream storage or diversion projects.

During the 1948 Fraser River flood, most of the 12 major dike failures occurred through piping and seepage rather than overtopping (NHC 2019b). Given this history and experience, the Board provided the following assumptions (i.e. their estimated "fragility curve") as a basis for the economic analyses:

- The Fraser River Flood Control Program (FRFCP) dikes (approx. 250 km in length) would be upgraded to the 1894 design flood profile plus 2 feet of freeboard. (Other “unimproved” dikes were assumed to provide much less protection than the “improved” FRFCP dikes and more conservative assumptions were applied.)
- The dikes would provide perfect protection and have 0% probability of breaching for all flood levels up to 4 feet below the dike design crest level.
- The dikes would have a 50% probability of breaching when the flood level reached 4 feet below the dike design crest level and up to 2 feet below the design crest level.
- The dikes would have a 100% probability of breaching when the flood level reached 2 feet below dike design crest level (i.e. flood level at the design profile level).

More recently, as part of the “Lower Mainland Flood Risk Assessment Project” currently being completed for the Fraser Basin Council, a fragility curve for the lower Fraser River dikes was developed for use in the risk assessment calculations (Golder 2020). Fragility curves were prepared for both overtopping and piping failure (dike breach) modes. In the Golder analysis, the piping fragility curve governed (i.e. dike failure would occur through piping failure before the dike was overtopped). Upper and lower bound curves were estimated and a single average curve was proposed for use in the risk assessment for all dikes. As in the 1975 FRFCP studies, dike crest elevations and flood profile levels are needed to apply the fragility curve.

For the recent analysis, only one curve was used in the damage assessment calculations (this assumes that all the dikes perform the same way given the same relative water level/freeboard). However, Golder noted that the high variability in underlying ground conditions, dike construction, geometry and other factors would need to be considered in a rigorous assessment.

The use of fragility curves could be considered as a possible approach to estimate the level of protection provided by a specific dike. There is extensive literature describing a number of different ways to develop such curves. For example, Acosta et al (2019) developed an analytical methodology to obtain fragility curves of a homogeneous earth levee. However, they recommended that sensitivity analyses of the geotechnical parameters should also be completed. Similarly, Golder (2020) recommended that further comprehensive geotechnical assessment of the Lower Mainland dike system be completed to develop and confirm appropriate fragility curves for these dikes on a reach and segment-specific basis.

Proposed Method

With a risk of over-simplification, it is suggested that the annual probability of a dike breach, referred to here as “Estimated Level of Protection”(ELP), could be roughly estimated by relating the annual probability of breaching to the assessment “rating” of the dike using the dike evaluation matrix developed for the Lower Mainland Dike Assessment (NHC 2015). The steps, descriptions, and key assumptions are outlined below. The “Estimated Level of Protection” for three example dikes (Nicomen Island #144-1, Pitt Meadows #244-1 and FVRD Wilson Road #155) are also provided.

Step 1: Rate the dike using the Dike Evaluation Matrix (Table 1 in NHC 2015) and determine the average dike segment score.

The evaluation matrix rates each of the following nine items on a scale from Unacceptable (=1) to Good (=4) for a designated segment of the dike:

- crest elevation vs. design crest level (without climate change allowance)
- dike geometry
- geotechnical stability - seepage, slope stability, settlement
- geotechnical stability - seismic
- erosion protection
- vegetation/animal control
- encroachments - buildings, roads, railway crossings
- appurtenant structures - operational status, interface seepage, pipe crossings, buried utilities
- administrative arrangements - inspections, maintenance, legal access, emergency response plans

Item No. 11 in Appendix D includes an excerpt from this evaluation matrix showing the rationale for "Good" and "Fair" ratings. An example rating for a segment of the Nicomen Island dike is also provided.

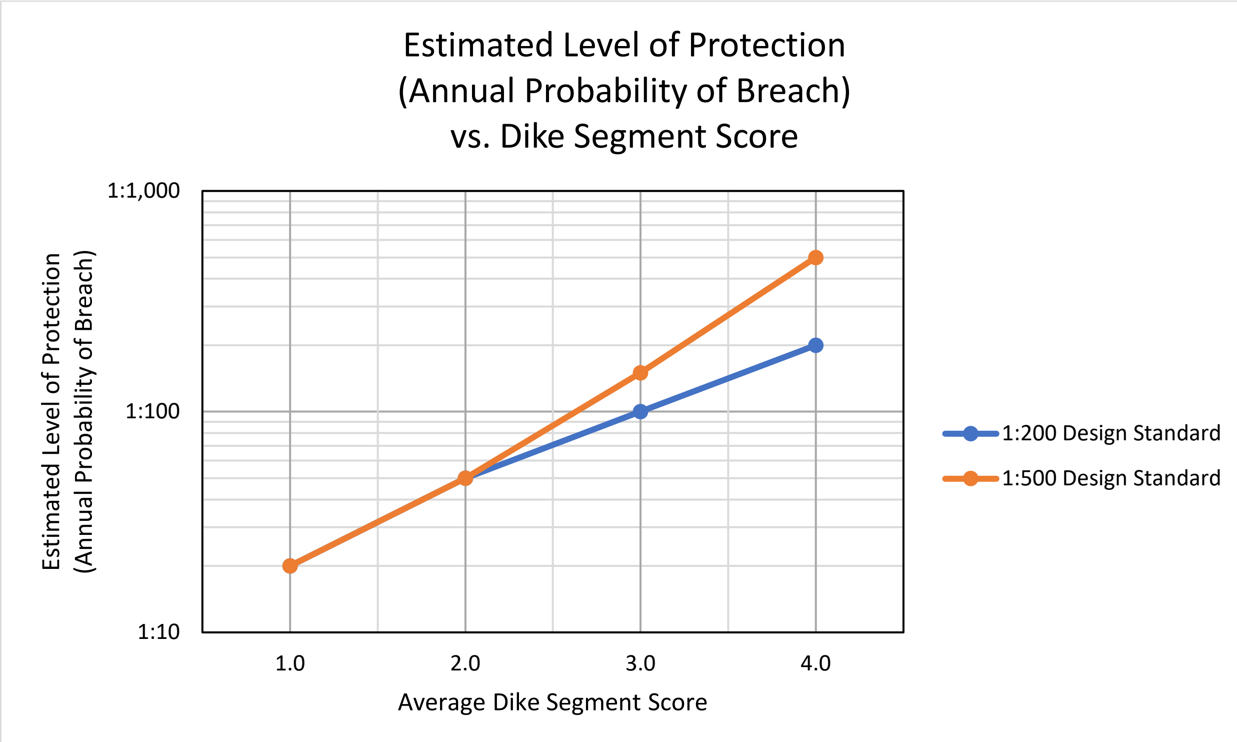
Step 2: Apply a relationship between Average Dike Segment Score and Estimated Level of Protection (ELP).

A first approximation of a possible relationship is provided in Table E-1 and Figure E-1 below. Two curves are shown, one for the Lower Fraser River, where the flood of record (approx. 1:500 AEP) is the design standard, and one for the remainder of the province where a 1:200 flood is the design standard.

Table E-1 Relating Estimated Level of Protection to Average Dike Segment Score

Average Dike Segment Score	**Descriptive Rating**	**Estimated Level of Protection (1:200 Design Std)**	**Estimated Level of Protection (1:500 Design Std)** (Lower Fraser River)	**Examples from Lower Mainland Dike Assessment (NHC 2015)**
1.0 to 2.0	Unacceptable to Poor	1:20 to 1:50	1:20 to 1:50	Nicomen Dike #144-1 Score of 1.8. ELP = 1:40 (1:500 Design Std)
2.0 to 3.0	Poor to Fair	1:50 to 1:100	1:50 to 1:150	Pitt Meadows #244-1 Score of 2.6. ELP = 1:100 (1:500 Design Std)
3.0 to 4.0	Fair to Good	1:100 to 1:200	1:100 to 1:500	FVRD Wilson Rd #155 Score of 3.5. ELP = 1:140 (1:200 Design Std)

Figure E-1 Estimated Level of Protection vs. Dike Segment Score



Notes and assumptions:

1) The Estimated Level of Protection (ELP) of a dike or dike segment is an approximation of the annual probability that the dike will breach and is based on the average dike segment score.
2) The dike provides protection against all flood magnitudes smaller than the ELP. With occurrence of a flood event (peak flow AEP) equal to or larger than the ELP, the dike will breach (i.e. assumed threshold limit load).
3) If a dike meets all standards without deficiencies, the dike will have an ELP equal to the Annual Exceedance Probability (AEP) of the design flood.
    - Dikes with a "perfect" average dike segment score of 4.0 on the Lower Fraser River would have an ELP of 1:500 per year.
    - Other dikes where the provincial design standard is 1:200, with a "perfect" score of 4.0 would have an ELP of 1:200 per year.
4) The example ELPs shown for the Nicomen, Pitt Meadows and Wilson Road dikes were interpolated from the plots in Figure E-1 above.

Discussion

The advantages of this assessment method, including the expression of results as an Estimated Level of Protection include:

- The dike evaluation matrix rates nine different items related to individual dike performance, all of which could ultimately be part of a complex scenario and contribute to dike failure.
- The dike ratings can be readily updated as new information becomes available (e.g. provincial dike crest survey and regional seismic vulnerability projects).

- The Estimated Level of Protection is a more meaningful concept than just a numerical score. For example, knowing the Pitt Meadows dike has a score of 2.6 on a scale from 1 to 4 is likely to be less profound than as knowing this dike has an estimated 1:100 annual probability of breaching.
- With public awareness of the ratings and pressure on politicians to provide better protection, local governments and diking authorities will want to improve their average dike ratings and level of protection. This can be achieved through addressing and improving on any of the nine factors and resolving some of the specific issues identified by the assessment.

A limitation of the method is that there is no statistical basis for the estimated dike breach probabilities, other than the flood frequency analyses performed to derive the design flows and water levels needed to evaluate freeboard and geotechnical stability. The method simply equates an index number (Average Dike Segment Score) with another type of index (Estimated Level of Protection) expressed as an annual probability. Despite this limitation, there is considerable knowledge about the individual dike's vulnerability built into the Estimated Level of Protection value, through the evaluation and assessment process.

Possible refinements of the method could include:

- Rather than using an average assessment rating, the rating items could be "weighted" to give more importance to certain factors (i.e. give more weight to "dike crest elevation vs design crest level" than to "encroachments").
- Dikes could be divided into more segments to capture additional detail and variability in dike conditions.
- The assessment scale could be expanded (e.g. 0 to 5), or could include additional factors (such as dike length).
- The ELP based on average rating should be checked against the possibility that overtopping probability would not govern (i.e. as could be in the case of a well maintained, stable and constructed dike with a low section of dike crest).
- The ELP vs rating score curves could be adjusted to be more, or less conservative.
- More consideration could be given as to how, or if climate change effects should be accounted for.

Book, A.N. and Princic, R. (1975) Estimating Flood Damages in the Fraser River Basin, report for the Fraser River Joint Advisory Board, Inland Waters Directorate, Canada Department of the Environment.

CIRIA (2013) International Levee Handbook, Construction Industry Research and Information Association, French Ministry of Ecology, and USACE, London UK.

NHC (2019b) Hydraulic Modelling and Mapping in BC's Lower Mainland, prepared for Fraser Basin Council, May 2019

Acosta, N.P. et al (2019) Obtaining Fragility Curves on Levees Subjected to Flooding, Proceedings of the XVII ECSMGE-2019 European Conference on Soil Mechanics and Geotechnical Engineering, Reykjavik.

Appendix F: Recommendations

Recommendation: B-2.1 No. 1: Further Assessment of Flood Mapping

Numerous floodplain mapping projects are currently in progress. It is recommended that, once available, these be reviewed and their quality assessed.

Overview level flood maps do not serve the same purpose as detailed floodplain maps. It is recommended that the accuracy of overview flood maps be assessed and their suitability for specific applications be clarified.

Recommendation B-2.2 No. 1: Improve Spatial Coverage of Mapping

The joint federal-provincial mapping agreement produced mapping for key flood-prone areas in BC but the information is now outdated. Areas previously mapped but without available updates are identified as high priority areas requiring new maps.

Areas protected by high or major consequence dikes, as identified by NHC (2019) generally have a high flood risk and should be mapped.

Communities located along rivers, lakes and the ocean with populations, say exceeding 10,000, should generally be mapped. A number of smaller communities would also benefit from mapping and it is recommended that overview level flood risk assessments be completed to prioritize which communities would benefit most from more detailed floodplain mapping. (In some areas, overview level risk assessments have already been completed or are in progress.)

Communities that have experienced recent, severe flooding should be mapped. (A provincial database of annual flood event information should be developed to track and record flood events. Observed flood levels, flows, inundation extents, photographic material and information on consequences such as affected transportation corridors and other damages would be useful input for future floodplain mapping studies and their prioritization.)

The majority of First Nation reserves and treaty lands do not have up-to-date flood hazard mapping. Yet most of these lands have ocean, lake or river frontage and are frequently exposed to flooding. Previous work by FNESS (2000) assessed flood and erosion hazards in BC, ranked the hazards, and developed potential mitigation measures. It is recommended that:

- Previously identified high priority projects be reviewed, flood level information updated and floodplain mapping developed as needed.
- An outreach program be developed for contacting First Nations and learning first-hand about current flood and erosion challenges and how First Nations' leadership and community members would like to address these.

B-2.2 No. 2: Improve Mapping Accessibility

The provincial government is in the process of developing a web portal, making flood maps and supplementary reports readily available. There is currently no timeline for the web-portal implementation but making information available to the public as soon as possible is recommended.

Many larger communities, with sufficient resources and know-how, are making floodplain mapping and other engineering reports available on-line. All communities having completed flood risk or mapping studies are encouraged to do the same.

B-2.2 No. 3: Improve Map Guidelines and Usage

Provincial and federal guidelines are useful but do not guarantee that flood mapping is produced to a consistent and/or adequate standard by different practitioners. In particular, specifications are required for bathymetric surveys, climate change analyses, hydrology - particularly when basins include large reservoirs, geomorphic assessments, modelling standards (1D vs 2D software usage, calibration/ output type/ breach modelling), coastal wave modelling, freeboard, mapping detail/clarity and reporting standards. It is recommended that more prescriptive standards documents, in addition to guidelines, be developed and kept up to date. With mapping standards clearly defined, project deliverables will have a more consistent quality. Third party reviews are also recommended.

It is recognized that different types of mapping studies need to be developed based on the particular flood hazards facing a community, its setting, development density and overall profile of flood risk. It is recommended that different categories of floodplain mapping studies be specified and associated standards applied. This would help communities identify the level of assessment and standard of mapping they require and associated budget demands to ensure more consistent products. Federal guidelines are informative but conditions across Canada vary sufficiently to require specific standards to be developed on the provincial level.

B-2.2 No. 4: Improve Map Quality

It should be recognized that grants obtained by a local authority or First Nation may not be sufficient to adequately fund a particular project and locally sourced funding may be required to supplement a grant. Appropriate training should be provided to staff preparing flood mapping scopes to ensure that the work reasonably reflects the available budget, and that schedules are realistic. Schedule and budget issues should also be considered by those reviewing grant applications to evaluate whether a project has a realistic chance of success.

It is recommended that an independent, quality control group be established to review new mapping developed. This should be a technical team, with sufficient experience to provide meaningful review of project results. It should also be advised by professionals qualified in the application of mapping to decision making (legal, planning, policy, regulation).

It is recommended that present/future guideline and standards documents be adhered to.

B-2.2 No. 5: Improve Mapping Governance

Although the current approach for detailed floodplain mapping led by local governments could potentially be improved through implementation of the above recommendations, an increased role for the provincial government is essential to achieve consistent, high quality mapping to support floodplain land use management, emergency planning/response, and structural mitigation. Two options for an increased role of the provincial government in floodplain mapping are presented below; Option 2 is likely to be more cost-effective and therefore is recommended over Option 1:

Option 1 (Increased participation):

- Help coordinate flood studies on a watershed/regional basis.
- Develop a public facing, historic flood database, documenting observed flood information such as flows, flood levels and extents (including detailed highwater mark surveys), photos and videos, damage summaries, transportation disruptions etc.
- Retain consultant(s) or professional association(s) to develop and (ensure updating of) floodplain mapping standards for BC, including bathymetric data collection. Coordinate with federal government floodplain mapping standards.
- Provide ongoing quality assurance of flood studies.
- Emphasize potential future uses of floodplain mapping. (The funding of floodplain mapping could be made conditional on a community subsequently developing flood mitigation, preparedness/response plans, and bylaws to ensure compliance with zoning/FCLs. Track the follow-up work carried out after mapping has been completed.)

Option 2 (New program – Alberta model):

- Undertake or contract the development/upkeep of a BC floodplain mapping standards document.
- Prioritize areas to be mapped and work with local authorities/First Nations to ensure that mapping developed will be useful and used as part of future Integrated Flood Management Plans (IFMPs) and/or other approaches to flood mitigation and risk reduction.
- Allocate adequate budgets for each project based on risk and hydraulic complexity.
- Prepare detailed Requests for Proposal (RFPs) and manage the contracts.
- Provide technical input and review throughout project.
- Sign-off on maps when completed.
- Publish reports and maps on provincial interactive website allowing users to enter their address to retrieve flood information.

Recommendation B-2.3 No. 1: Establish and Apply a Standardized Dike Rating System

The key recommendation of this investigation is that BC should establish a standardized dike assessment rating system and develop a method to roughly determine the "Estimated Level of Protection" (i.e. annual probability of dike breach).

To include the full range of dike characteristics, condition, and deficiencies, the assessment and rating system should be based on a methodology similar to the method developed by the 2015 Lower Mainland Dike Assessment (NHC 2015) with modifications and improvements as needed. These dike ratings should then be used to roughly determine the "Estimated Level of Protection".

As a first step, all 212 dikes in BC should be assessed at an overview level. The next step would be to review the dike assessments for all "High" and "Major Consequence Dikes" (71 dikes) and include limited field or other investigations to fill in crucial information gaps.

Dike ratings will change over time as design criteria (e.g. flood profiles) are updated and/or where dikes are upgraded or modified. Maintaining current ratings and dike information will take an investment of personnel time by the ministry and diking authorities. To assist in this effort, it is recommended that refinement/updating of dike ratings be included as part of Community Emergency Preparedness Fund (CEPF) or other Provincial funded risk assessment or mapping projects that contain dike protected areas.

Recommendation B-2.3 No. 2: Amend the 2018 EGBC flood assessment guidelines definition of "adequate" dike with reference to the new provincial dike rating system, when available.

Assessments and approval conditions outlined in the EGBC Guidelines depend on whether the flood protection works are considered to be "adequate" as defined in the guidelines. The basic direction to qualified professionals (QPs) in the guidelines is:

> "*In general, significant new development should not be located in floodplain and fan areas in the absence of a standard/adequate Dike or other Structural Mitigation Works.*"

Recommendation B-2.3 No. 3: Publicize dike inspection reporting compliance information
Publicize dike inspection reporting compliance information to provide an incentive for diking authorities to complete inspections and provide detailed inspection reports.

Recommendation B-2.3 No. 4: Increase the number of dike safety audits
Complete dike safety audits of all diking authorities having "High" and/or "Major Consequence Dikes" (71 dikes) at least every 5 years. This will approximately double the effort currently being made by DIODs from 5 to 10 audits per year provincially to 10 to 20 per year.

B-2.3 No. 5: Create one digital folder per dike with a standardized format for storage and sharing
Establish a standardized and easily accessible dike file system for sharing and storage of key technical information. Create one digital folder per dike with a consistent format and make accessible to the diking authority, DIODs and IOD.

The establishment of a standardized dike rating system and the rating of all BC dikes is estimated to cost approximately $2.2 million, including a one time allocation of 0.7 Full Time Equivalent (FTE) of provincial staff to provide direction, input and management of the necessary studies, including amendment of the EGBC flood assessment guidelines. The provincial personnel time required to maintain and refine the ratings, primarily updating information for individual dikes, is estimated to be 0.3 FTE.

The cost to implement the other recommendations (publicizing compliance information, increasing dike safety audits, and improving dike information file management) is roughly estimated to be $100K in contract funds and 0.2 FTE to set up, and 0.4 FTE for the ongoing work. The cost estimates assume that the additional dike information can be integrated into the new Flood Safety Management E-Licensing platform currently being developed by MFLNRORD.

Recommendation B-2.4 No. 1: Establish Provincial LiDAR Guidelines and Specifications

It is recommended that a detailed review be undertaken of provincial LiDAR specifications in comparison to federal LiDAR guidelines, with an explanation of differences and clarification of which provincial specifications apply to floodplain mapping.
The awareness of provincial specifications and federal guidelines among agencies responsible for LiDAR data collection should be raised. It is recommended that updates to provincial specifications and federal guidelines be monitored to ensure they remain harmonized. The development of federal LiDAR standards based on existing guidelines should also be monitored.

Collection of LiDAR data for flood mapping applications alone is unlikely to be cost effective. It is recommended that guidelines and specifications continue to incorporate expertise from outside the flood mapping community so that the information will be broadly accepted and applied.

Recommendation B-2.4 No. 2: Establish Procedures for LiDAR Acquisition

The following specific recommendations are provided:

- Ensure LiDAR data collected for flood mapping meets specifications and floodplain mapping needs. Set LiDAR collection boundaries to include areas adjacent to a current study, such as upstream and downstream reaches, opposite riverbanks, and adjacent communities. Ensure that LiDAR collection includes coincident orthophoto collection.
- Plan flood mapping projects with sufficient lead time to allow for appropriate LiDAR collection. Schedule should allow for adaptation to weather conditions, quality review of LiDAR deliverables, and collection in advance of ground and bathymetric surveys and hydraulic modelling.
- Plan for LiDAR updates to coincide with flood mapping updates.
- Develop a province-wide publicly funded ongoing LiDAR collection program. Ensure provincial LiDAR acquisition efforts continue to be coordinated with federal, local, and other efforts to avoid duplication and share resources.
- Monitor development and application of bathymetric LiDAR technology, including information in the upcoming revision of federal LiDAR guidelines. Sponsor research into the use of bathymetric LiDAR to support flood mapping in BC.

Recommendation B-2.4 No. 3: Establish Procedures for LiDAR Dissemination

The following specific recommendations are provided:

- Require open data licenses for all LiDAR data collected with public money. Develop a sample open data sharing agreement for use by local governments and other agencies. Provide an inventory and data sharing portal for all available LiDAR data, hosted by the provincial government. (This already exists, but information is not widely accessible.) Search capabilities, including detailed metadata, should be made broadly available to facilitate project planning. Download capabilities should be made available to all agencies and organizations that would benefit from using LiDAR data.
- Fund the provincial government to support LiDAR initiatives, such as data inventory, data download, open data licensing, data acquisition, and QA/QC. (GeoBC has already developed or is currently developing many of the necessary tools.)
- Ensure provincial LiDAR dissemination efforts continue to be coordinated with federal, local, and other efforts to avoid duplication and share resources.