FLOOD MAPPING IN BC

APEGBC PROFESSIONAL PRACTICE GUIDELINES

V1.0

Professional Engineers
and Geoscientists of BC

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V1.0 January 2017

PREFACE

The Professional Practice Guidelines – Flood Mapping in BC have been developed with the support of the Ministry of Transportation and Infrastructure – Emergency Management BC. The guidelines will assist professionals in developing flood maps in a consistent manner, incorporating best practices.

The guidelines have been written for the information of APEGBC members, statutory decision-makers, regulators, the public at large and a range of other stakeholders who might be involved in, or have an interest in, flood mapping in British Columbia. They provide a common level of expectation for various stakeholders with respect to the level of effort, due diligence and standard of practice to be followed when carrying out flood mapping in BC. The guidelines outline the appropriate standard of practice at the time that they were prepared. However, this is a living document that is to be revised and updated, as required, in the future, to reflect the developing state of practice.

Although these guidelines are intended to be used on projects in BC, the guidance provided can also be considered by APEGBC members when working in other jurisdictions in Canada or other global jurisdictions.

DEFINITIONS

The explanations of the terms below are specific to these guidelines. All of these terms are italicized the first time they appear in the text.

APEGBC
The Association of Professional Engineers and Geoscientists of British Columbia.

APEGBC members
Professional engineers, professional geoscientists, and licensees who are members or licensees of APEGBC.

Assurance statement
The Flood Mapping Assurance Statement, in Appendix A of these guidelines.

Client
An individual or company who engages a qualified professional to carry out a flood mapping project. In relation to flood mapping, the client could be a landowner, a development consultant, the local government, the provincial government, a First Nation government or the federal government.

Dike
A dike is defined in the *Dike Maintenance Act* as "an embankment, wall, fill, piling, pump, gate, floodbox, pipe, sluice, culvert, canal, ditch, drain or any other thing that is constructed, assembled or installed to prevent the flooding of land." Dikes can include alluvial/debris fan training berms, basins and barriers. Structures that are primarily for erosion protection, drainage or municipal stormwater control are typically not considered to be regulated dikes. For practical purposes, the inspector of dikes has published a provincial flood protection structure database, which currently includes approximately 210 dike structures that are considered to be regulated under the *Dike Maintenance Act*.

Engineers and Geoscientists Act
Engineers and Geoscientists Act, RSBC 1996, Chapter 116, as amended.

Flood
A condition in which a watercourse or body of water overtops its natural or artificial confines and covers land not normally under water.

Flood construction level (FCL)
FCL is determined using freeboard along with observed or calculated water surface elevation for the designated flood.

Flood hazard maps
Maps that go beyond inundation maps by providing information on the hazards associated with defined flood events, such as water depth, velocity, and duration of flooding.

Flood risk maps
Maps that reflect the potential damages that could occur as a result of a range of flood probabilities, by identifying populations, buildings, infrastructure, residences and environmental, cultural and other assets that could be damaged or destroyed.

Freeboard
A vertical distance added to the actual calculated flood level to accommodate uncertainties (hydraulic and hydrologic variables) and potential for waves, surges and other natural phenomena.

Hazard
A source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to health, property, the environment, and other things of value; or some combination of these, as defined by the Canadian Standards Association (CSA 1997).

Higher high water, large tide (HHWLT)
The average of the highest high waters, one from each of 19 years of predictions (from Fisheries and Oceans Canada).

Inundation maps
Topographic maps showing the extent of floodwater in plan, under defined flood events.

Municipality
A corporation into which the residents of an area are incorporated under the *Local Government Act* or another act, or a geographic area of the municipal corporation.

Professional engineer
A person who is registered or licensed as a professional engineer under the *Engineers and Geoscientists Act*.

Professional geoscientist
A person who is registered or licensed as a professional geoscientist under the *Engineers and Geoscientists Act*.

Qualified professional (QP)
A professional engineer or professional geoscientist with appropriate education, training and experience to provide professional services related to flood mapping in BC, as described in these guidelines.

Regulatory authority
The regulatory authority tasked with managing the regulatory requirements of a dam project, as decreed by statutes and regulations of BC. Regulatory authorities may include the Ministry of Energy and Mines; Ministry of Environment; Ministry of Forests, Lands and Natural Resource Operations (MFLNRO); Parks Canada; Canadian Nuclear Safety Commission; or International Joint Commission.

INTRODUCTION

1.1 PURPOSE OF THESE GUIDELINES

This document provides guidelines on professional practice for *APEGBC members* who prepare *flood* maps for river, creek and coastal flooding in BC. The guidelines will provide a common approach to be followed when carrying out a range of professional activities.

The specific objectives of these guidelines are to:

1. Describe the standard of care APEGBC members should follow in providing professional services related to this professional activity.
2. Specify the tasks that should be performed by APEGBC members so as to meet an appropriate standard of care that fulfills the member's professional obligations under the *Engineers and Geoscientists Act*. These obligations include the member's primary duty to protect the safety, health and welfare of the public and the environment.
3. Outline the professional services that should generally be provided by the APEGBC member conducting this type of work.
4. Describe the typical roles and responsibilities of the various participants/stakeholders involved in such work. The guidelines will assist in delineating the roles and responsibilities of the various participants/stakeholders, which will include the *qualified professional* (QP) having overall responsibility for the preparation of the flood map, as well as *clients*, authorities having jurisdiction, and statutory decision-makers.
5. Define the skill sets that are consistent with the training and experience required to carry out this professional activity.
6. Provide an *assurance statement*, which the QP must seal with signature and date. This assurance statement will confirm that, with respect to the specific professional activity carried out, the appropriate requirements have been met (both regulatory and technical).
7. Describe how the intent of the seven quality management requirements under the *Engineers and Geoscientists Act* and APEGBCBylaws are to be met when carrying out the professional activity covered in these professional practice guidelines. This will include outlining expectations regarding peer review and independent checking.

1.2 INTRODUCTION OF TERMS

For the purposes of these guidelines, a QP is a *professional engineer* or *professional geoscientist* with appropriate education, training and experience to provide professional services related to flood mapping in BC (refer to Section 5) and accepts overall responsibility for the preparation of the flood map as described in these guidelines.

A flood is a condition in which a watercourse or body of water overtops its natural or artificial confines and covers land not normally under water. When a flood becomes a source of potential harm to humans, property, infrastructure, the environment and other assets, it becomes a hazardous flood.

The Canadian Standards Association (1997) defines a *hazard* as "a source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to health, property, the environment, and other things of value; or some combination of these."

The term "flood risk" combines the probability of a hazardous flood occurring and the potential consequences to elements at risk.

1.3 HISTORY OF FLOOD MAPPING IN BRITISH COLUMBIA

A provincial floodplain mapping program began in BC in 1974, aimed at identifying flood risk areas. This was in part due to the large Fraser River flood of 1972, which resulted in damage in the BC Interior (particularly on the North Thompson River near Kamloops). From 1975 to 2003, the province managed development in designated floodplain areas under the Floodplain Development Control Program. From 1987 to 1998, the rate of mapping increased through the Canada/British Columbia Agreement Respecting Floodplain Mapping. The agreement provided shared federal–provincial funding for the program and included provisions for termination of the agreement as of March 31, 2003. The terms of the federal/provincial agreement were not renewed and are no longer in effect. While the resulting maps are now outdated, their use is still advocated by the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), as they are often the best information available.

The province provides information on locations of floodplains, floodplain maps and supporting data through the iMapBC portal (Government of BC 2016a). The maps and associated design briefs are also available on the MFLNRO website (2016b).

In 2003, the Floodplain Development Control Program ended. This resulted in a significant change in how the MFLNRO participated in land use regulation in flood-prone areas. In January 2004, legislative changes transferred the responsibility for developing and applying floodplain mapping tools to local governments, with the proviso that provincial guidelines be taken into consideration. However, the position of inspector of *dikes* was retained by the province. Without a central database for the most recent flood maps, it is necessary to approach the appropriate local government to obtain floodplain management information. Fewer than 10 local governments undertook floodplain mapping between 2008 and 2013 (BCREA 2016).

More recently, emergency planning flood maps have been produced for the Lower Fraser River (MFLNRO 2011) and the Hope to Mission reach profile (MFLNRO 2014a). While useful for emergency planning, these maps are not intended to be used for other purposes.

The Fraser Basin Council (FBC) is a non-profit collaboration of federal, provincial and local governments; First Nations; the private sector; and civil society. It has been a lead organization with regard to flood studies in the Lower Mainland in recent years. From 2014 to 2016, FBC implemented Phase 1 of a Lower Mainland Flood Management Strategy, during which overview maps of select coastal and Fraser River flood scenarios were developed. Sub-regional maps indicate flood extents under two different flood scenarios for coastal flooding and another two for Fraser River flooding, representing different assumptions regarding sea level rise and river discharge. The scenarios were developed by Kerr Wood Leidal Associates (KWL 2015) on behalf of the FBC, and the flood vulnerability was assessed by Northwest Hydraulic Consultants (NHC2016). The Phase 1 work also included the Lower Mainland Dike Assessment (NHC2015).

The BC Real Estate Association (BCREA) has been active since 2013 in promoting the provincial government's role in flood mapping and awareness of flood risks among its members and the public. Significant achievements include the development of the BC Floodplain Maps

Action Plan, which has been continually updated as a series of progress reports since the initial plan was published in April 2013. The BCREA published its *Floodplain Mapping Funding Guidebook for BC Local Governments* in 2014 and updated it in April 2016 (BCREA 2016).

Another important publication is the *BC Floodplain Map Inventory Report* (Parsons and BCREA 2015), which notes that 21 percent of 49 communities surveyed have floodplain maps that have been updated in the last 10 years, while 31 percent do not have any floodplain maps. It should be noted that non-governmental organizations and the private sector were not covered by this study, and many *inundation* maps resulting from dam breaches have been produced by dam owners, such as BC Hydro. The report lists or refers to 20 local governments that have flood maps generated or updated outside the BC Floodplain Mapping Program.

The BCREA's *Floodplain Mapping Backgrounder* (Sustainability Solutions Group and Ebbwater 2014) provides information on the number of communities mapped in BC and the types of maps in use.

The following broad uses of flood maps can be identified, each of which has different requirements with regard to map content:

- flood damage reduction and mitigation
- floodplain management (land use planning)
- emergency planning
- private sector (real estate, public awareness, potential insurance)

The insurance industry in Canada is now offering overland (but not coastal) flood insurance and has developed, or is in the process of developing, a set of *flood risk maps* designed to assist insurance companies in their business decisions (Insurance Institute of Canada 2016). It is not known whether this information will be available to those outside the insurance industry.

The federal and provincial governments, on occasion, implement cost-sharing programs to enable the development or updating of flood maps. However, standards and criteria for all aspects of flood mapping have not been established by the federal government or the province. For floodplain mapping, the province refers to a designated flood based on the 1-in-200-year flood (Ministry of Water, Land and Air Protection [MWLAP] 2004). There are no provincial standards for *freeboard*.

While flood maps have a number of applications, they are only one aspect of floodplain management. Flood maps provide information on the nature of the hazard and risk, but need to be complemented by a range of other measures for effective land use planning and regulation of development on the floodplain. Integrated flood risk management includes floodplain bylaws to address issues such as the requirement for floodproofing and permitted floodproofing methods. It also includes emergency response and recovery, and structural flood protection.

1.4 ROLE OF APEGBC

These guidelines have been formally adopted by the Council of APEGBC and form part of APEGBC's ongoing commitment to maintaining the quality of services that members and licensees provide to their clients and the general public. Members and licensees are professionally accountable for their work under the *Engineers and Geoscientists Act*, which is enforced by APEGBC.

In accordance with the *Engineers and Geoscientists Act,* APEGBC members must exercise professional judgment when providing professional services; as such, application of these guidelines will vary depending on the circumstances. APEGBC supports the principle that appropriate financial, professional and technical services be provided to support the QP responsible for carrying out flood mapping, APEGBC will review these guidelines every five years to determine whether updating is necessary.

1.5 SCOPE OF THE GUIDELINES

These guidelines summarize the standard of practice related to flood mapping in BC. The guidelines include the elements necessary to prepare flood maps for river, creek and coastal flooding and will focus on the three main types of flood maps: inundation maps, *flood hazard maps* and flood risk maps.

Essentially, there are four stages in the production of a flood map (adapted from MMM 2014):

- Base mapping – topography, bathymetry, land cover, infrastructure
- Hydrology – estimation of design flows
- Hydraulics – calculation of flood elevations by numerical modelling
- Flood mapping – graphical representation of floodlines, elevations and associated hazards

The following types of flood mapping are not included in these guidelines:

- Downstream inundation from dam failures – guidelines are available from the Canadian Dam Association (CDA 2007)
- Flood mapping prepared as part of urban drainage analysis (e.g., resulting from pluvial or snowmelt overland flooding, pipe surcharging)

1.6 APPLICABILITY OF THE GUIDELINES

These guidelines provide guidance on professional practice for APEGBC members carrying out flood mapping activities in BC. The guidelines are not intended to provide step-by-step instructions for carrying out flood mapping, but to outline the considerations that go into flood mapping activities.

The QP's decision not to follow one or more aspects of these guidelines does not necessarily mean a failure to meet required professional obligations. Such judgments and decisions depend upon weighing facts and circumstances to determine whether another reasonable and prudent QP, in a similar situation, would have conducted himself/herself similarly.

ROLES AND RESPONSIBILITIES

2.1 CLIENT

The client may be a landowner, a development consultant, the local government, the provincial government, a First Nation government or the federal government. Typically, the client should establish the general extent and use of the proposed flood mapping.

The QP should enter into a professional services agreement with the client prior to undertaking work on the project. In order to protect both parties, the agreement should be based on a proven standard agreement, such as the Master Municipal Construction Documents (MMCD) Client–Consultant Agreement or Association of Consulting Engineering Companies of Canada (ACEC) Document 31. Some specific points for consideration regarding the agreement are as follows:

- In recognizing that natural hazards projects inherently have high potential liability, the agreement should establish an appropriate limitation of liability.
- The agreement should confirm the scope to the extent that it is known at the time of agreement. (Natural hazards projects typically involve several scope modifications during the project, which should be documented.)
- The agreement should establish a budget estimate, for hourly services, lump sum or otherwise (recognizing that modifications to scope will typically impact the budget).
- The budget estimate should reflect the need for an appropriate level of review (internal project review and possibly independent peer review).

The agreement should also include a clause that deals with potential disclosure issues due to the obligation of the QP under APEGBC Code of Ethics Principles 1 and 9 (hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety within the workplace; and report to their association or other appropriate agencies any hazardous, illegal or unethical professional decisions or practices by members, licensees or others). In certain circumstances the QP may have to convey adverse assessment findings to parties that may not be directly involved but that have a compelling need to know. Following is suggested wording for such a clause:

> Subject to the following, the QP will keep confidential all information, including documents, correspondence, reports and opinions, unless disclosure is authorized in writing by the client. However, in keeping with APEGBC's Code of Ethics, if the QP discovers or determines that there is a material risk to the environment or the safety, health and welfare of the public or worker safety, he/she shall notify the client as soon as practicable of this information and the need that it be disclosed to the appropriate authorities. If the client does not take the necessary steps to notify the appropriate authorities in a reasonable amount of time, the QP should contact APEGBC to discuss how to proceed.

After the flood mapping is complete, it is helpful if the client:

- reviews the documents, and understands the limitations and qualifications that apply
- discusses the documents with the QP and seeks clarification if desired
- directs the QP to complete an assurance statement

2.2 QUALIFIED PROFESSIONAL

The QP is responsible for carrying out the flood mapping. Prior to carrying out the project, the QP should:

- confirm that he/she has appropriate training and experience to carry out the flood mapping in view of the terrain characteristics and the type of potential flood hazard
- review relevant provincial legislation and local government regulations, policies and floodplain bylaws
- appropriately educate the client regarding pertinent aspects of flood mapping and determine the type of flood mapping that will be consistent with the client's intended use
- discuss and agree with the client the criteria appropriate to the client's needs to be applied for the flood mapping
- consider the need for and scale of investigations that address future land use changes and climate change
- consider the need for the involvement of other specialists and stakeholders
- establish an appropriate mechanism for internal checking and review
- consider the need for independent peer review

In accordance with APEGBC Bylaw 17, the QP must inform his/her client as to whether he/she carries professional liability insurance.

During the assessment, the QP should follow the guidance provided in Section 3. Furthermore, the QP should:

- assist the client in obtaining relevant information
- make reasonable attempts to obtain from the client and others all relevant information necessary to produce the flood map
- notify the client as soon as reasonably possible if the project scope and/or budget estimate requires modification
- address any significant comments arising from the internal or peer reviews
- discuss with the client, prior to final submission, any recommendation for a significant variance from a guideline
- where appropriate, arrange for a review of the deliverable by the client and other parties
- submit a final deliverable accompanied by supporting digital information

2.3 MUNICIPAL, PROVINCIAL AND FEDERAL ROLES

Land use in flood-prone areas is regulated under the following BC acts (MFLNRO 2016c):

- *Local Government Act* – for development permits and floodplain bylaws, variances, exemptions, official community plans, zoning bylaws
- *Land Title Act* – for subdivision approval
- Bare Land Strata Regulations of the *Strata Property Act* – for strata plan approvals
- Community Charter – for building permits
- Vancouver Charter – zoning and building bylaws
- *Environmental Management Act* – for guidelines, regulations, flood hazard management plans

For historical information:

- *Flood Hazard Statutes Amendment Act*
- *Miscellaneous Statutes Amendment Act*

The Local Government Act (Section 524) addresses construction requirements in relation to floodplains. Specifically, this section of the *Act* empowers local government to enact a bylaw that designates a floodplain area and specifies corresponding flood levels and setbacks. Any new construction or reconstruction within the designated floodplain area must comply with these protection measures.

(When dealing with building renovations, the flood protection measures are often not required if the renovation does not exceed 25 percent of the building footprint.)

In developing its bylaws, the local government must consider provincial guidelines and comply with the provincial regulations and any plan or program developed by the local government under those regulations. To date, there are no provincial regulations and therefore no local government plans or programs developed under regulation. However, the *Flood Hazard Area Land Use Management Guidelines* (MWLAP 2004), provides guidance for developing bylaws under Section 524 of the *Local Government Act*. Through this section of the *Act,* local governments may, by bylaw, designate specific floodplain areas. More information on legislation related to flood mapping can be found in Appendix D of *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (APEGBC 2012).

Flood maps are being prepared under the auspices of the Federal National Disaster Mitigation Program for the period 2015 to 2020, which will fund up to 50 percent of eligible projects, selected for funding through a competitive process. Such projects are cost-shared with the provincial or territorial government, which can collaborate with and redistribute funding to eligible entities such as municipal or local governments. A flood map identifies the boundaries of a potential flood event based on type and likelihood, and can be used to help identify the specific impacts of a flood event on, for example, structures, people and assets (Public Safety Canada 2016).

The Federal Flood Mapping Committee (FMC) has designed a collection of documents, entitled the Canadian Floodplain Mapping Guidelines Series, consisting of the following:

1. *Canadian Floodplain Mapping Framework* (March 2017)
2. *Flood Hazard Identification and Priority Setting* (to be developed)
3. *Canadian Hydrologic and Hydraulic Procedures for Floodplain Delineation* (March 2017)
4. *Canadian Airborne LiDAR Data Acquisition Guideline* (March 2017)[1]
5. *Case Studies on Climate Change in Floodplain Mapping* (to be developed)
6. *Canadian Floodplain Mapping Guidelines and Specifications* (March 2017)
7. *Flood Risk Assessment* (to be developed)
8. *Risk-Based Land-Use Guide: Safe Use of Land Based on Hazard Risk Assessment* (2015)[2]
9. *Bibliography of Best Practices and References Related to Flood Mitigation* (March 2017)

Completed initial drafts of the first four of these documents have been prepared for technical review prior to publication.

[1] This document is also being developed to support data requirements for floodplain mapping.
[2] This document has already been published by Natural Resources Canada but is included in the series to support mitigation planning.

GUIDELINES FOR PROFESSIONAL PRACTICE

3.1 CATEGORIES OF FLOOD MAPPING

There are three main types of flood maps in use currently and a number of less common variations. These guidelines focus on the three most important categories for BC, which currently are inundation maps, flood hazard maps and flood risk maps.

Inundation maps
Inundation (or flood extent) maps are topographic maps showing the extent of floodwater in plan, under defined flood events. For many years, these were the only flood maps used and were known simply as floodplain maps. In the past, the calculated flood levels were incremented by a freeboard to give a *flood construction level* for use in the regulation and design of dikes and other structures in the floodplain. However, this is no longer standard practice. Inundation maps can be made more comprehensive by showing areas of ponding caused by inadequate drainage not related to river or coastal flooding, and areas susceptible to flooding through failure of flood protection infrastructure or areas designated to flood through historic agreements.

From 1975 to 2003, floodplains identified and mapped under the Floodplain Development Control Program became "designated" floodplains as a result of that program. Once designated, a floodplain became subject to certain restrictions with regard to both governments undertaking works in the floodplain, and financial assistance for development was discouraged. Local authorities were encouraged to restrict undertakings in designated floodplains and adopt floodproofing bylaws that commonly referenced the flood levels shown on the floodplain maps. These maps reflected current policy with regard to flood risk management. There are 140 sets of designated floodplain maps on the MFLNRO (2016b) website. These maps are still referenced on the basis of being the best information available, even if they are up to 30 years old. It should be noted, however, that the floodplains are no longer considered to be "designated" by the province.

Flood hazard maps
Hazard maps go beyond inundation maps by providing information on the hazards associated with defined flood events, such as water depth, velocity, and duration of flooding. Hazard maps typically indicate various degrees of hazard, such as low, medium and high, based on one or more parameters (e.g., depth or a function of depth and velocity).

Some jurisdictions use hazard maps to distinguish between the floodway and flood fringe (where water is shallower and velocities are lower than in the floodway) on hazard maps. Floodway and flood fringe together constitute the floodplain.

Various other types of flood hazard maps are described in the BCREA's *Floodplain Mapping Backgrounder* (Sustainability Solutions and Ebbwater 2014), including flood event maps, which document specific historic events; flood velocity and propagation maps, requiring the use of two-dimensional dynamic modelling; channel migration maps, focusing on potential erosion; and evacuation maps, showing disaster response routes. In the United States, there are flood insurance rate maps.

Flood risk maps
Risk maps reflect the potential damages that could occur as a result of a range of flood probabilities, by identifying populations, buildings, infrastructure, residences, and environmental, cultural and other assets that could be damaged or destroyed. Most practitioners favour the definition:

Risk = Probability of Hazard x Consequences

Unfortunately, the term "flood risk maps" has been used somewhat loosely in the past to refer to hazard maps. This is because the terms "hazard" and "risk" tend to be used synonymously and interchangeably, even by some provincial jurisdictions. This stems from the lay use of "risk" for what professionals involved with flood management call "hazard." In simplistic terms, if there is nothing and no one on a floodplain, there is no risk (because there are no consequences), but there is still a hazard. The European Commission literature makes this distinction quite clear (EXCIMAP 2007b).

3.2 CLIMATE CHANGE CONSIDERATIONS

With increasing amounts of carbon dioxide and other greenhouse gases in the atmosphere, climate science predicts an increase in the frequency and intensity of unusual weather events, including floods and droughts. In the context of flooding, interest centres on changes in the amount and intensity of rainfall, changes in snowpack and temperature regime, insect infestations, forest fires and SLR. These factors need to be considered in certain combinations in flood estimation.

APEGBC (2014) has published a position paper entitled *A Changing Climate in British Columbia*, identifying potentially increasing flood risks and underlining its registrants' responsibilities to stay abreast of climate change science and incorporate appropriate resiliency into the design of infrastructure projects.

The *National Principles, Best Practices and Guidelines – Flood Mapping Guidelines* (AECOM 2017; the National Guidelines) include some discussion on climate change. These guidelines suggest that, while the practice of incorporating SLR in climate change trends is "robust and generally well accepted," prediction of wave hazards is "less mature." The same term is applied to changing precipitation patterns, with different global circulation models (GCMs) sometimes showing opposite trends. Best practice must therefore include a combination of outputs from different simulations.

In BC, the Pacific Climate Impacts Consortium (PCIC) predicts that by mid-century (2050s), mean annual temperatures will be 1.4°C to 3.7°C higher, on average. Extremely high temperatures will become more frequent. At the same time, in winter, most of BC will likely receive more precipitation (up to 26 percent more in some locations). In summer, northern BC may be up to 15 percent wetter, while southern BC may be up to 20 percent drier. In winter and spring, snowfall may decrease (Zwiers *et al.* 2011). Other assessments of future climate change and impacts are available through PCIC (Rodenhuis *et al.* 2009 and PCIC 2016).

The anticipated impact of climate change on Fraser River floods has also been assessed by PCIC (Shrestha *et al.* 2015). Both temperatures and precipitation for December through May are projected to increase significantly over the next 85 years. Despite decreasing snow accumulation at lower elevations, combinations of increased melt rates and more rainfall during the freshet period provide possible mechanisms for higher flood flows. The study results indicate that peak flows in the Fraser River should be expected to increase by a significant amount in the next few decades, with further increases to 2100. While the ranges of results from different GCMs are quite broad, the median increase to the 1:500 *annual exceedance probability* (AEP) flood for a moderate emission scenario for the 2041–2070 period is approximately 10 percent. This aligns with the APEGBC (2012) recommendation for incrementing design floods in the absence of more detailed information.

Climate change during the 21st century is expected to result in more frequent fires in many parts of Canada's boreal forest, with severe environmental and economic consequences (Natural Resources Canada 2016). In the context of flooding, forest fires alter catchment characteristics with regard to infiltration, retention and overland flow processes in such a way as to increase peak rates of runoff (Ministry of Forests and Range 2011).

Mountain pine beetle infestations are another manifestation of climate change that have been shown to increase the frequency and intensity of flooding (Winkler *et al*. 2008; EDI 2008). This results from reduced interception, increased snowpacks, reduced times of concentration and altered timing of snowmelt runoff.

In Section 3.5.3 of the *APEGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (APEGBC 2012), an approach is recommended to address the uncertainties associated with climate change.

Thomson *et al.* (2008) examined a number of causes of SLR in BC, including vertical land movements and thermal processes, and recommended low, mean and extreme high SLR estimates for different areas in BC (see also Sustainability Solutions Group 2013). The report also addresses the impact of climate change on storm surge and El Niño–Southern Oscillation (ENSO) events. Planning for a 1-m SLR from 2000 to 2100 and for a further 1-m to 2200 is recommended.

In the United States, AECOM (2013) published a report for the Federal Insurance and Mitigation Administration (FIMA) and the Federal Emergency Management Agency (FEMA) on the impact of climate change and population growth on the National Flood Insurance Program. According to this study, by 2100 the average size of riverine and coastal flood hazard areas may increase by 40–45 percent, and the population within these areas is expected to increase by 130–155 percent.

The implications of projected climate change with regard to flooding in BC are:

- an increase in frequency and intensity of severe rainstorms, including "pineapple express" events and increased snowmelt rates, causing greater peak discharges for a given AEP
- an increase in the frequency and magnitude of floods due to phenomena such as insect infestations and forest fires
- higher storm surges in combination with SLR causing increased flooding and erosion in low-lying coastal areas

All of the above could result in expanded areas vulnerable to flooding.

3.3 DATA REQUIREMENTS

As indicated in the National Guidelines (AECOM 2017), free, open and trusted data is a prerequisite for flood mapping. The following types of data are regarded as essential components of flood mapping:

- elevation data (topographic and bathymetric)
- base map features (streams, waterbodies, roads, etc.)
- infrastructure
- land cover
- land tenure
- geomorphology
- climate data
- aerial or satellite imagery
- hydrometric (streamflow and water level) data

The above data can be usefully supplemented by historical data, such as high water marks (for specific floods, indicated by silt deposits or debris), media reports of flooding, traditional knowledge, anecdotal information and paleoflood analysis. All data sources should be noted.

In any flood mapping exercise, design discharges of various AEPs are essential input data. These should be developed from a hydrological study involving frequency analysis of local or regional data, or hydrological modelling, or both. Note that peak discharge data available from Environment Canada can, in some locations, be supplemented by discharge data collected under local government flow monitoring programs.

British Columbia's DataBC portal (data.gov.bc.ca) provides access to iMapBC as part of the Canadian Geospatial Data Infrastructure (CGDI) database (to be adopted in 2018), also referred to as Canada's Spatial Data Infrastructure (SDI). iMapBC provides access to mapping and metadata such as administrative boundaries, contours and many other layers. The contour interval of 20 m is not adequate for floodplain mapping work, but the base maps are useful. Google Earth provides imagery that can be invaluable in the production of base maps. Others sources need to be tapped for higher resolution topographic data, such as Light Detection and Ranging (LiDAR) or ground-based surveys.

Bathymetric survey data need to be of sufficient resolution to pick up changes in channel slope, cross-sectional area and roughness.

When preparing a flood map for a *municipality*, all relevant provincial legislation and local government regulations and policies should be reviewed, particularly the technical basis for flood levels incorporated into any existing floodplain bylaws.

3.4 TOPOGRAPHIC MAPPING

3.4.1 Mapping Standards

Best practices in the generation of all types of flood maps should adhere to certain standards to ensure consistency and a level of utility that serves the users. For example, the European Exchange Circle on Flood Mapping (EXCIMAP 2007a) has produced the *Handbook on Good Practices for Flood Mapping in Europe*, which is shared by 24 countries. In the United States, FEMA (2016) maintains a series of standards for flood risk analysis and mapping.

3.4.2 Map Accuracy

Greater base map accuracy leads to greater flood map accuracy and utility. At present there are no Canadian guidelines for flood mapping accuracy. The National Guidelines (AECOM 2017) make reference to the FEMA accuracy requirements, which in turn depend on the flood risk. For example, the highest specification level is for a consolidated vertical accuracy of 36.3 cm, which corresponds to an equivalent contour accuracy of 0.6 m.

In rural, sparsely populated areas, a lower degree of accuracy is acceptable, while in dense urban areas, higher accuracies are recommended, such as those obtained through LiDAR surveys. For the greatest utility, flood maps should be at the cadastre level, unless mapping is done on a river basin scale.

Vertical accuracy of LiDAR is in the 0.05 to 0.1 m range for smooth or hardened surfaces, while that from orthoimagery is in the 0.1 to 0.2 m range (Boyd *et al.* 2015). This may be hard to achieve where vegetation is dense. Therefore it can be advantageous to acquire LiDAR data in "leaf-off" conditions. LiDAR surveys can have gaps in locations where there is ponding water.

Minimum requirements for digital elevation models (DEMs) are considered to be 10 m by 10 m horizontal resolution (5 m by 5 m preferred) and 0.5 m vertical resolution (0.3 m preferred).

Datum, coordinate system and projection
The conventions in BC are currently North American Datum of 1983 (NAD83) for horizontal control and Canadian Geodetic Vertical Datum of 1928 (CGVD28) for vertical control. The latter is in the

process of being replaced by CGVD2013, which was released in November 2013. More discussion on the implementation of the new datum and the Canadian Height Modernization Initiative, including approximate changes in benchmark elevations in different areas of BC, can be found on the GeoBC website (Government of BC 2016b). Care is required to ensure that flood maps make reference to the appropriate datum and note the conversion correction to the other datum.

The projection used for topographic mapping in BC is Universal Transverse Mercator (UTM), and coordinates are expressed in metres as northings and eastings within the UTM grid.

3.4.3 Mapping Technologies

Various technologies are available to generate the data required to construct DEMs required for flood mapping.

Ground surveys still provide the greatest accuracy. Global positioning system (GPS) surveys can be used to collect a large amount of data relatively quickly, with differential GPS overcoming the problem of vegetation obscuring the view of GPS satellites.

Photogrammetry can be used to provide high accuracy data.

LiDAR is becoming the preferred method for obtaining accurate data at competitive costs. It can be combined with orthorectified digital imagery.

Synthetic aperture radar (SAR) and its variations (IFSAR, GeoSAR, AIRSAR) use radar signals from aircraft to measure ranges to the ground.

3.5 INUNDATION MAPPING

Inundation (or flood extent) maps are topographic maps showing the extent of floodwater in plan, under defined flood events. The flood event is usually modelled across a floodplain area using one-dimensional or two-dimensional models. Inundation mapping from coastal flood events is also addressed in this section.

3.5.1 River Floods

Design floods

In most of BC, the design floods for traditional (formerly "designated") floodplain maps have been those with return periods of 20 and 200 years. The 20-year flood levels have been used to apply *Health Act* requirements for septic systems, while the 200-year flood levels have been used to establish design elevations for flood mitigation works and FCLs. The exception to this is the lower Fraser River, where the 1894 flood of record is used.

For the wide spectrum of flood types addressed in the *APEGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (Table E-1, APEGBC 2012) return periods of recommended design rainfall and snowmelt-generated floods and ice jam floods range from 20 to 2500 years. The lower return periods (20 and 200 years) are suggested for lower flood risk situations, while the higher ones (500, 1000 and 2500 years) are recommended where there is moderate, high or very high loss potential.

There is increasing discussion (e.g., APEGBC 2012) on the merits of using a risk tolerance–based approach rather than the present hazard- or standard-based approach. Such an approach is applied in the dam safety community, where the classification of a dam is a function of the consequences (in turn a function of the risk) that would be caused as a result of a dam failure. A dam spillway capacity is required to be able to convey a design flood corresponding to the downstream consequence as defined in the *Dam Safety Guidelines* (CDA 2007). Return periods for reservoir inflow design floods range from 100 years where there is no population at risk to the probable maximum flood in cases where incremental (over the "no dam" situation) loss of life would be greater than 100. The probable maximum flood has no associated AEP.

The risk-based approach is also widely used for landslide risk management in BC and is the approach adopted in the EU Floods Directive (European Commission 2016).

A risk-based approach leads to considerations of the areal extent over which protective works are required to be effective and the problem of mitigation works upgrades if the risk changes (e.g., as a result of further development).

In addition to rainfall and snowmelt flood events, floods can be generated by geomorphological processes, such as failures of landslide dams. The implications of this are discussed in Appendix E5 in the *APEGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (2012). It is suggested that design flood return periods should be increased to reflect the approximate return period of the geohazard. For example, it is suggested that flood hazard maps for the Fraser River including the 1000-year and 2500-year return period events may be warranted, as there have been several occurrences of rock avalanche dam outbreak floods originating in the Fraser Canyon. The same guidelines suggest that 200-year and 2,500-year flood maps would be appropriate for the Pemberton Valley and the Upper Squamish River Valley on account of the possibility of debris flows or landslide dam breaches. It is the responsibility of the QP to make the client aware of all potential flood-generating processes. In the absence of detailed provincial standards at present, reference should also be made to the *Flood Hazard Area Land Use Management Guidelines* (MFLNRO 2016a). The QP should recommend the design flow, but the client should make the final decision regarding design flow and may opt, for example, not to proceed with 2,500-year flood maps.

For some BC Interior rivers, ice jams may result in higher flood levels than normal flood conditions. While anecdotal information on past events remains important, analytical tools are available to help estimate river stages due to backup caused by ice jams. For example, Lindenschmidt *et al.* (2015) used a dynamic model to generate stage frequency curves for open water, ice-cover breakup and ice jam events for the Peace River at the Town of Peace River. Similar work has been done on the Red River (Lindenschmidt *et al.* 2011). Beltaos *et al.* (2012) describe ice jam modelling on the Saint John River. Secondary to backwater flooding caused by ice jams, but potentially equally damaging, are floods downstream caused by the sudden release of ice jams. An approach to estimating ice jam flood levels is provided in the Prince George floodplain mapping case study in Appendix B.

It is the responsibility of the QP to ensure that ice jam floods are considered as part of determining the appropriate design flood.

If a design event is anticipated to contain a large amount of debris (a debris flood), it may be appropriate to apply a bulking factor to account for the increased volume of flow.

Hydraulic modelling

Hydraulic modelling of flood conditions in rivers ranges from simple steady-state one-dimensional modelling to dynamic two-dimensional modelling. Three-dimensional modelling is rarely used in this context. The simplest topographic and bathymetric input to hydraulic models is a series of channel and valley cross-sections at short enough intervals to describe the variation in terms of geometry, slope and hydraulic characteristics. More complex models require input in the form of digital elevation models. Such information should reflect local variations in topography caused by dikes, roads, buildings and other potential impediments to flow, as well as flow conduits such as culverts and bridges. Future development scenarios should also be considered, including complete build-out, if policies are in place regarding infill development.

Boundary conditions reflect hydraulic conditions at the computational boundaries and will normally consist of known discharges and water levels or, for dynamic models, variations over time of these parameters. The output of one-dimensional models can be used as boundary conditions for two-dimensional models where more detail is required.

Standard practice for hydraulic modelling includes calibration of a model to a known data set, if available, such as a river profile or observed high water marks, by adjustment of model parameters, such as friction factors and other loss coefficients. In the absence of suitable calibration data, engineering judgment must be applied to estimate the required parameters. It also includes validation of a model by verifying that a calibrated model successfully simulates a second flood event.

Note that hydraulic modelling in this context does not normally include any representation of scour, erosion or deposition, which alter the channel geometry.

Freeboard

A freeboard allowance is a vertical distance typically added to calculated flood levels to account for uncertainty in the hydrological and hydraulic components of the analysis. In some cases (generally in riverine situations), it may be selected to accommodate phenomena such as waves and surges as well. In coastal situations, freeboard is applied on top of wave, surge and SLR allowances.

In the regulatory context, freeboard is used to determine the FCL by providing an allowance above the design flood level (see Section 3.8). Typical freeboard values for "water" floods that have been adopted in BC are 0.3 m above the maximum instantaneous design flood level or 0.6 m above the mean daily design flood level (whichever is higher). Larger freeboards are appropriate where there is potential for debris floods, debris flows, ice jams, debris jams, sedimentation and other phenomena that are harder to predict. In floodplain areas protected by dikes, freeboard is applied to flood elevations determined by dike breach analysis.

Traditional designated flood maps in BC have included freeboard when depicting flood extents and isolines. It is important to note whether a freeboard allowance is incorporated into an inundation map.

Encroachment analysis

The Alberta government requires that an encroachment analysis be performed to determine the extent of a floodway, where the water is 1 m deep or greater, the local velocities are 1 m/s or faster and, if the river were encroached upon, the water level rise would be 0.3 m or more (Alberta Environment 2011). This approach has not been adopted in BC.

3.5.2 Alluvial Fans

Alluvial fans pose a special challenge when it comes to assessing flood levels. By their very nature, they are subject to high flows embracing the full spectrum of geohydrological events from "pure" water floods to debris flows. The accuracy of any assessment of flood levels decreases considerably as one moves from the water-dominated events to those with high concentrations of sediment and debris. Furthermore, active alluvial fans are subject to channel avulsions, whereby a channel becomes choked with deposited sediment and/or wood debris, which causes flooding and erosion of a new channel (APEGBC 2012).

A distinction can be drawn between active alluvial fans, such as those found in the high-precipitation areas in coastal BC, and those in more arid areas such as the BC Interior, where fans were active in the post-glacial period but now have well-incised channels in the upper and middle reaches of the fan (APEGBC

2012). Such inactive fans are reasonably amenable to conventional hydrological and hydraulic analyses as applied to rivers and floodplains. Active fans, on the other hand, are subject to debris floods and debris flows.

Debris floods may contain between 4 percent and 20 percent sediment by volume. They can arise from water flood flows through entrainment of channel debris, but can also be generated by landslide, dam or glacial lake outbreak floods, other dam failures, hillslope and channel erosion and similar processes. Debris floods are highly erosive but can cause aggradation where channel slopes decrease, leading to avulsions and erosion.

Debris flows are landslide processes that typically can occur in creeks with an average channel slope of 15 degrees or more. Debris flows entrain channel debris at a rate that can produce peak discharges several times higher than a 200-year clear-water flood discharge.

Active fans therefore require consideration of inactive channels, sediment supply and potential sources, vegetation, and watershed condition in order to assess flood hazard. Clearly, former channels and anomalously low areas are more susceptible to flooding than surrounding areas of a fan, but no area may be immune. As active fans are aggrading features, conventional stage discharge relationships are of limited value, and the most pragmatic approach to hazard assessment is through detailed fieldwork to identify likely avulsion sites and routes down the fan. Erosion can be accounted for through allocation of setbacks for varying degrees of hazard. Hazard zones for flood mapping can be determined through identification of a combination of potential inundation areas and those subject to erosion.

For the purposes of these guidelines and their application to alluvial fans, it is recommended that a suitably experienced geoscientist be involved with assessment of the types of hazard that could occur. If this assessment suggests that geomorphic events (debris floods and debris flows) are predominant with the return periods of concern, the hazard and risk assessments should be completed by the geoscientist with input from a hydrotechnical engineer. On the other hand, if critical events are likely to be water-dominated flooding, conventional hydrological and hydraulic analyses can be conducted, with precautionary input from a geoscientist. As part of the hydraulic analysis, the QP should provide allowances for potential channel aggradation through adjustment of hydraulic model cross-sections to account for anticipated sediment deposition during the design flood event.

3.5.3 Coastal Floods

Coastal flood hazards can be grouped under three headings:

1. Storm surges in combination with high tides, waves and/or river flows
Design storm surges for different parts of the BC coast have been proposed in the *Coastal Floodplain Mapping Guidelines and Specifications* (KWL 2011). This document suggests deep water storm surges for various parts of the coast. These magnitudes are from the *Sea Dike Guidelines* (Ausenco Sandwell 2011c).

Site-specific hydraulic modelling may be required to provide refined estimates of deep water storm surge to account for regional coastline type, local characteristics such as shoaling and shallow water, and nearshore features such as estuaries, spits and seawalls.

Higher high water large tide (HHWLT) levels are published by the Canadian Hydrographic Service for a number of reference stations and can be determined for a network of secondary ports. Reference stations and secondary port locations are shown in the *Coastal Floodplain Mapping Guidelines and Specifications* (KWL 2011).

Wave effects can be assessed by a coastal engineering study, taking into consideration a designated storm, the local geometry and substrate of the shore, and sea state. For semi-protected and semi-enclosed coastlines, regional-scale two-dimensional wave propagation and wave transformation models should be utilized to determine localized effect on storm surge and wave climate. One-dimensional models may be adequate for sheltered coastlines (KWL 2011).

In estuarine locations, hydraulic modelling should take into consideration an appropriate flood flow in the river. This flow need not have the same return period as the storm surge, as this could lead to an unreasonable joint probability. However, there are situations in which a storm surge could coincide with a heavy rainfall event.

To avoid the difficulties of a direct statistical joint probability analysis, a continuous simulation approach may be helpful, whereby long-term simulations of the hydraulic performance of the system are conducted, and the simulated annual peak floodplain water levels are subject to conventional frequency analysis.

2. Tsunamis

Tsunamis can be caused by nearby or distant earthquakes and large landslides (above or below water). As tsunami wave heights are very dependent on site-specific conditions, detailed modelling is required to determine potential run-up at a given location (KWL 2011). Resonance may be a consideration in some circumstances (e.g., Port Alberni).

The Institute of Ocean Sciences has modelled tsunamis generated by Cascadia subduction zone earthquakes west of Vancouver Island (Fisheries and Oceans Canada 2016). However, the results are preliminary at this stage and are not intended as a basis for engineering design or policy. There are presently no tsunami criteria for flood mapping, and a comprehensive study to determine these has been recommended (KWL 2011). Design elevations for emergency planning were established by the former Provincial Emergency Program (now Emergency Management BC; EMBC), which when combined with ground elevations indicate areas for evacuation planning (KWL 2011). However, such levels do not appear in the more recent *Tsunami Notification Process Plan* (Government of BC 2013).

Natural Resources Canada has published a *Tsunami Hazard Assessment of Canada* (Leonard *et al.*, 2014) and various associated online resources. According to this study, the cumulative estimated tsunami hazard for potentially damaging run-up (more than 1.5 m) of the outer Pacific coastline is 40–80 percent in 50 years. For larger run-up with significant damage potential (over 3 m), this decreases to 10–30 percent in 50 years.

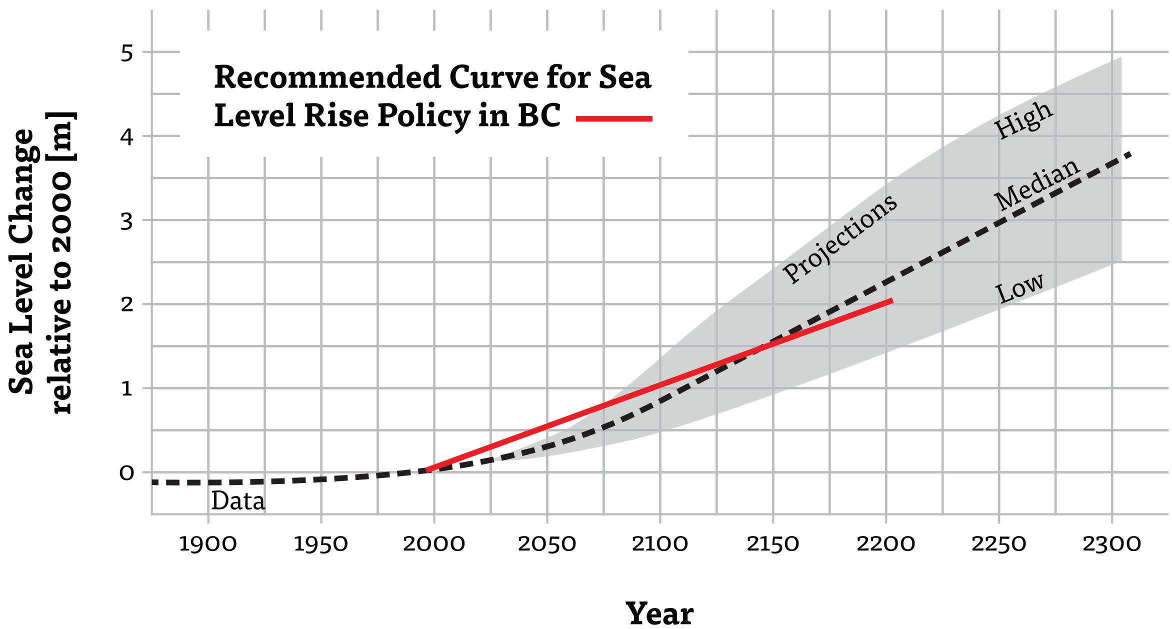
Ocean Networks Canada (2016), in collaboration with University of Rhode Island and the National Oceanic and Atmospheric Administration, has been developing new tsunami wave models for the area of Barkley Sound and the City of Port Alberni for emergency preparedness purposes.

3. Ongoing sea level rise

Rates of SLR for BC have been estimated based on the latest research (Ausenco Sandwell 2011a). Essentially a 1 m rise is suggested between 2000 and 2100 and a further 1 m by the year 2200 (Figure 3.1). Clearly these are subject to ongoing updates.

Site-specific adjustments to SLR are required to account for the uplift or subsidence of the land surface in the area of interest. The ground appears to be generally rising along the coast, with local areas of subsidence. Some uplift and subsidence rates for coastal BC are given by KWL (2011). This information is also subject to periodic updates. Local governments

Figure 3.1 Projections of Global Sea Level Rise



may have regional information based on recent research.

The FCLs required for preparation of coastal floodplain maps are derived from a combination of the components listed earlier (i.e., storm surge, HHWLT, wave effects and SLR) with an additional amount for freeboard. This combination requires specification of the design storm (for storm surge and waves) and the planning time frame (for the SLR). Freeboard of 0.6 m is recommended by KWL (2011). It is not necessary to factor tsunamis into this approach, as the probability of a tsunami occurring concurrently with the other components is considered remote. However, an estimate of tsunami elevation is required, as in some cases tsunami levels may govern the FCLs. In an exposed coastal context, the FCL is equivalent to the dike crest elevation, which is not the case in riverine situations. However, a short distance inland, wave effects are not an issue and FCLs can be reduced accordingly.

Amendments have been proposed to section 3.5 (The Sea) of the *BC Flood Hazard Area Land Use Management Guidelines* (MFLNRO 2016a). The fourth draft amendments suggest that local governments consider defining SLR planning areas for which flood protection (sea dikes) and flood hazard management tools would be developed. These areas should include those exposed to coastal hazards, diked areas and floodplains of tidally influenced rivers.

The fourth draft amendment describes two alternative approaches for determining the 2100 FCL for areas not subject to significant tsunami hazard. They are both based on an allowance for SLR to 2100, adjusted for regional uplift or subsidence. The resulting level is augmented by either:

- the 1:200 or 1:500AEP total water level as determined by probabilistic analyses of tides and storm surge

- estimated wave effects associated with the designated storm with an AEP of 1:200 or 1:500
- a minimum freeboard of 0.6 metres

or (a more conservative "combined method):

- HHWLT
- estimated storm surge for the designated storm with an AEP of 1:200, or 1:500 as per Table 6-1 in Ausenco Sandwell (2011a)
- estimated wave effects associated with the designated storm
- a minimum freeboard of 0.3 metres

With regard to building setbacks, the draft guidelines suggest the greater of 15 m from the future estimated natural boundary of the sea at Year 2100, or landward of the location where the natural ground elevation contour is equivalent to the Year 2100 FCL. More details can be found in Ausenco Sandwell (2011b). Where some protection is provided by a natural bedrock formation, the approving official may agree to modify setback requirements as recommended by a QP. All aspects of the coastal flood hazard associated with Year 2100 water levels should be considered, including waves, debris and related splash impacts. Any approval should be augmented through a restrictive covenant describing the hazard and building requirements, and including the QP's report and a liability disclaimer. The setback may be increased on a site-specific basis, such as for highly erodible areas.

3.5.4 Dike Breach Flood Levels

Where rivers have extensive diking systems, such as along the lower Fraser River, the modelled design flood water level can be much greater than the ground surface elevation at some locations. This is primarily because the dikes constrain the flow within the river channel, which results in a higher flood profile than if the dikes were not present. Use of the dike-constrained flood levels to develop flood mapping is impractical in some situations. More realistic flood elevations in floodplain areas can be calculated by simulating dike breaches and modelling the propagation of resulting flood waves over the floodplain. This approach also allows the development of flood hazard maps showing the variation in flow velocities across the floodplain.

Data on flood breach characteristics, primarily for BC and the Netherlands, has been compiled by Water Management Consultants (WMC 2004). The WMC report recommends an ultimate breach width of 200 m for larger rivers such as the Fraser River and 100 m for smaller rivers. Conservative assumptions are recommended for the timing of the maximum breach width at the peak of the hydrograph and for no reduction of the water surface profile in the river as a result of the breach.

Various breach locations should be assessed to establish the worst case scenario, and combinations of breaches should be included in the analysis. Floodboxes and pumpstations are weak points in a dike system, and a breach may be more likely at one of these structures. Malfunctioning of such components of a flood defence system is unlikely to be as significant as a dike breach.

Two-dimensional hydraulic modelling is now the standard for representing the propagation of the flood wave from a dike breach across the floodplain. Such modelling should take into account all structures influencing the flow, such as roads, bridges and culverts, existing and future development, remaining dikes and other embankments. Output from this modelling can be used to indicate areas subject to flooding in the event of a dike breach.

It is possible that a dike breach will cause a design flood level on the floodplain that is higher than the adjacent flood level in the river if water from a dike breach becomes trapped by a remaining dike farther downstream.

In some circumstances, breach modelling of coastal dikes may be warranted for flood mapping in coastal areas. Data compiled by WMC (2004) indicate an appropriate breach width of 200 m for coastal dikes. The approach described above using two-dimensional modelling should be applied with the additional considerations of timing of a breach relative to tide level variation and potential storm surges.

3.6 FLOOD HAZARD MAPPING

Hazard maps provide information on the hazards associated with defined flood events, such as water depth, velocity, and duration of flooding. Hazard maps typically indicate various degrees of hazard, such as low, medium and high, based on one or more parameters (e.g., depth or a function of depth and velocity).

3.6.1 Setbacks

Bank erosion can be a significant flood hazard, particularly in areas adjacent to mountain rivers. Flood hazard maps should include appropriate setbacks from rivers to indicate areas that are threatened by bank erosion. The BC *Flood Hazard Area Land Use Management Guidelines* address setbacks (MWLAP 2004) where a minimum of 30 m is required from major watercourses. For rivers with active bank erosion, larger setbacks should be established based on a fluvial geomorphological analysis. Consideration can be given to reduced setbacks where engineered and maintained bank protection exists. Setbacks can also be used as part of a floodway where part of the floodplain is allocated for conveyance of flood flows that are not impeded by man-made structures. Designation of a floodway can result in reduced flood construction levels on the rest of the floodplain.

British Columbia's *Riparian Areas Protection Act* calls on local governments to protect riparian areas during residential, commercial and industrial development. Setbacks established under the Act may be greater or less than flood hazard setbacks. Depending on the circumstances, flood hazard maps could include the location of riparian area setbacks in addition to flood hazard setbacks.

The issue of setbacks is also discussed in the *APEGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (2012).

3.6.2 Hazard Ratings

There are a number of different ways to characterize flood hazards. Maps can be prepared to show variations in flood depths and flow velocity. Maps showing the timing of arrival of flood waves from dike breaches are included in the *Flood Hazard Mapping Manual in Japan* to provide information for emergency response (Japan Ministry of Land, Infrastructure and Transport 2005). Colour-coding standards for flood depths have been developed in the Japan manual and were applied in coastal flood mapping for the City of Vancouver described as a case study in Appendix B. These are easier to distinguish than several shades of blue, and the colours are more distinguishable if the map is photocopied to greyscale, which can be common during an emergency event.

Hazard ratings combining both flood depth and flow velocity have been developed in the UK, Australia and Japan. The UK has adopted a hazard rating formula (HR Wallingford 2006) to characterize hazard intensity as a function of inundation depth, water velocity, and the potential for floating debris, primarily based on consideration of the direct risks to people exposed to floodwaters.

The UK formula is:

HR = d x (v + 0.5) + DF, where

HR = (flood) hazard rating;

d = depth of flooding (m);

v = velocity of floodwaters (m/s);

and DF = debris factor (= 0, 0.5, 1 depending on probability that debris will lead to a significantly greater hazard).

It is useful to use a hazard rating classification framework as a proxy for physical hazard to persons directly exposed to inundation. For example, a UK hazard rating classification framework from Surendran *et al.* (2008) is summarized in Table 1. This hazard rating classification system was used in the Squamish Integrated Flood Hazard Management Plan described as a case study in Appendix (B-2).

Table 1: Hazard to People Classification

Hazard Rating (HR)	Hazard to People Classification
< 0.75	Very Low Hazard (Caution)
0.75 – 1.25	Danger for Some (includes children, the elderly, and the infirm)
1.25 – 2.00	Danger for Most (includes the general public)
> 2.00	Danger for All (includes emergency services)

For hazard and risk mapping on alluvial fans, Jakob *et al.* (2011) developed a debris flow intensity index as the product of maximum expected flow depth and the square of the maximum flow velocity. The debris flow intensity index correlates with building damage, and four classes of building damage were considered, ranging from nuisance/flood/sedimentation damage to complete destruction.

Maps showing hazard ratings can be used to develop mitigation measures as part of land use planning at the local government level. These can be applied through official community plans, zoning bylaws and floodplain bylaws. Maps of hazard ratings can also be used to develop consequence assessments as a precursor to flood risk mapping.

3.6.3 Impacts of Flood Mitigation on Flood Hazards

Flood mitigation can impact others in the floodplain in two primary ways:

1. The construction of dikes can result in increases in adjacent and upstream water levels in the main watercourse. Dikes can also increase water levels within a diked floodplain when there is an upstream dike breach.
2. Floodproofing, particularly with extensive fill placement, can increase water levels and velocities near adjacent properties within the floodplain if there is no dike or in the event of a dike breach. This is a transfer of risk that can be addressed by including future development in the floodplain in two-dimensional modelling. Other topographic changes, such as future road fills, should also be included. Thus the mapped flood water elevations would account for the influence of future development.

It is the responsibility of the QP to ensure that flood mapping adequately represents these impacts.

3.7 FLOOD RISK MAPPING

Flood risk is the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment and economic activity associated with a flood event (EXCIMAP 2007a). Flood risk maps extend the information shown on flood hazard maps by quantifying the risk from a range of possible flood events and the consequences of each event.

Risk assessment is the process of estimating a range of hazards, determining the consequences for each hazard, and combining results to obtain an overall estimate of the expected risk. Benefit–cost analysis is one well-known application of risk assessment.

Estimating the consequences of flooding is often more difficult than estimating the flood hazards themselves. Consequence assessments begin with output from a hydraulic model and combine it with extensive spatial databases that characterize the elements at risk (e.g., people, buildings, infrastructure, natural environment, archaeological sites). Consequence assessments consider the vulnerability of each element using damage functions that relate probability of death or injury or amount of property damage to variables like water depth, water velocity or debris impact. Engineers must use their professional judgment to determine whether a damage function accurately represents the elements at risk. Guidelines for flood risk assessment are provided in Appendix F of the *APEGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (2012).

Flood vulnerability maps are simplified risk maps that provide inventories of elements at risk for a given flood hazard scenario. Flood consequence maps show the distribution of the economic, social and environmental damages from a given flood event.

A comprehensive flood risk map quantitatively combines a range of flood hazard scenarios with the likely flood consequences. Considerable judgment is required to estimate probabilities of dike breaches and other flood scenarios and to quantify the combined social, economic and environmental consequences.

3.8 REGULATORY MAPPING

All types of flood maps can be used for regulatory purposes, such as developing floodplain bylaws and informing official community plans. The most common regulatory application is where inundation mapping is incremented by a freeboard allowance to establish FCLs. The concept of FCL has a long history of use in BC. In floodplain mapping it is used to establish the elevation of the underside of a wooden floor system or top of a concrete slab for habitable buildings. In the case of a manufactured home, for example, the ground level or top of the concrete or asphalt pad on which it is located must be no lower than the above described elevation (MWLAP 2004). In a sense, therefore, inundation maps that include a freeboard allowance serve as simple hazard maps, although no measure of the relative hazard is provided in terms of depth or velocity.

In the absence of inundation mapping, an assessed height above the natural boundary of the waterway or above the natural ground elevation may be used (MWLAP 2004).

The appropriate freeboard to apply to inundation maps to obtain FCL values ranges between 0.3 and 1.0 m, depending on the uncertainties in the inundation mapping and the risk tolerance of the regulating jurisdiction. With knowledge of the uncertainties in the development of a flood map, the QP should provide recommendations to the client regarding freeboard. Including freeboard on a flood map will increase the potential inundated area shown on the map.

Ultimately it is the decision of the client whether to add freeboard and how much freeboard to apply. The economic and social impacts on the community must be taken into account in this decision.

Flood construction levels and setbacks can be shown on the mapping, but they only take effect if a local government adopts a floodplain bylaw, or uses another tool (e.g., development permit areas) to implement these conditions. Production of the maps is only an interim step in the process and the local government must adopt specific land use regulations for regulatory mapping to take effect.

Dike crest elevation
In the 1970s and 1980s, FCLs were also used in BC to establish minimum standard dike crest elevations. Dike design profiles that include freeboard are now determined independently from inundation mapping studies.

3.9 DELIVERABLES

Outputs from the various mapping technologies are generally exported in one of a variety of GIS formats, which can then be used to generate maps. It is standard for flood maps to be generated digitally, providing the option for hard-copy mapping with selected metadata appropriate to the needs of the users. The National Guidelines (AECOM 2017) provide principles and standards for geospatial data, metadata, geographic information and data encoding. The expectation is that flood maps will be made available online. Standards for web-based maps are discussed in Section 3.8.4.

3.9.1 Map Notations

Flood maps have limitations that should be clearly noted on each map. Typical notations, including disclaimers, are as shown below (WMC 2004). The sample floodplain map from the Prince George case study (Appendix, B-3) has similar disclaimers, and a disclaimer noting the quality of the base information might also be required.

- Flooding may still occur outside the defined floodplain boundary, and the local government does not assume any liability by reason of the failure to delineate flood areas on this map.
- The floodplain limits are not established on the ground by legal survey.
- Building and floodproofing elevations should be based on field survey and established benchmarks.
- The required or recommended setback of buildings from the natural boundaries of watercourses to allow for the passage of floodwaters and possible bank erosion may not be shown. This information may be available from the local government.
- Under the provisions of the *Local Government Act* (Sections 473, 488, 490, 491, 500 and 524), the Community Charter (Section 56) and the *Land Title Act* (Sections 86 and 219), local governments have the role of and responsibility for making decisions about local floodplain development practices, including decisions about floodplain bylaws within their communities. Information on floodplain management guidelines can be found in the *Flood Hazard Area Land Use Management Guidelines* (MLWAP 2004).

3.9.2 Specifications

According to the National Guidelines (AECOM 2013), a map sheet should include the following blocks:

- base map/photo and flood risk information block
- base map author and stamp block
- flood risk author and stamp block
- legend block
- north arrow and datum block
- scale and contour interval block
- map sheet index block
- client logo block
- title block
- sheet number block

Furthermore, the base map block should indicate the following:

- location of all benchmarks and monuments
- location and name of all dikes and major erosion protection works
- delineation of the floodplain area protected by specific dikes, so that the linkage between the protected (benefiting) area and the specific dike protection is clear
- location of all streamflow gauges and climate stations
- street names, park names, cultural information, etc.
- administrative boundaries (e.g., cities, municipalities, townships, counties)
- watercourse name and flow arrow
- name of major water control structures
- cross-section and cross-section labels
- water surface elevation at each cross-section
- gridded flood characteristic name and colour ramp categories
- upstream and downstream study limits and mapping limits
- match lines for overlapping map sheets
- topographic information

The *Coastal Floodplain Mapping Guidelines and Specifications* (WMC 2004) recommend the following mapping specifications:

- scale: 1:5000 minimum, 1:2000 preferred
- contour interval: 0.5 m
- DEM point spacing: 10 m minimum, 1.5 m preferred for hydraulic modelling; alternatively a triangulated irregular network (TIN) can enhance breakline features
- vertical accuracy 30 cm; horizontal accuracy 1.7 m, based on 95 percent confidence levels

The current coastal floodplain mapping guidelines (KWL 2011) provide similar specifications, but give 1:10,000 as a minimum scale, with 1:5,000 preferred. The horizontal accuracy required is somewhat less in the coastal guidelines.

3.9.3 Reporting

As part of the Floodplain Mapping Program delivered under the Canada/British Columbia Agreement Respecting Floodplain Mapping from 1987 to 1998, design briefs were prepared for each study. These are available on the BC MFLNRO website: env.gov.bc.ca/wsd/data_searches/fpm/reports/.

For each floodplain mapping project, the design briefs provide background information on historical flooding, assumptions made in the analysis, the method used to develop design floods, the hydraulic analysis used to determine flood levels and the limitations of the mapping data. More comprehensive reports would be required to document the analysis undertaken for flood maps that address dike breach modelling, ice jam floods and other complex flood scenarios.

Reports should be prepared to document all flood mapping studies, and they should be signed and sealed according to the procedures established by APEGBC (2013).

3.9.4 Geographical Information Systems Platforms

Flood maps can be made available on GIS platforms, which can be a significant advantage to the end-user. The core principles of the guidelines for the implementation of a geospatial platform are set out in the National Guidelines (AECOM 2017). The platform must be adaptable to new trends and approaches, and should:

- offer access to trusted geospatial data, services and applications

- increase information sharing across various levels of government and the private sector
- comply with national or international standards, as well as with policies
- be independent of specific software and hardware
- be interoperable, notably through the use of international encoding standards

The National Guidelines (AECOM 2017) provide details on federal standards for GIS platforms. Guidelines for the BC MFLNRO are available at for.gov.bc.ca/his/datadmin/spatproj.htm.

The National Guidelines (AECOM 2017) also provide a standard on a Geographic Information—Web Map Server Interface (WMS). A WMS dynamically produces maps of spatially referenced data from geographic information. The map is a portrayal of geographic information as a digital image file suitable for display on a computer screen. A map is not the data itself. Usually, WMS-produced maps are rendered in a pictorial format such as PNG, GIF or JPEG.

3.9.5 Updating

Flood maps should be reviewed about every 10 years and updated if any of the following have occurred:

- There is a change in the design flood because of changes to the criteria, change in climate, or a significant hydrologic change in the upstream watershed.
- There have been significant changes in the channel geometry as a result of a flood or other event.
- Significant local subsidence has occurred that changes the land elevation in relation to SLR.
- New flood hazards are identified.
- Significant diking works are constructed in the floodplain, particularly if the diking alignments are new.
- There are changes to the official community plan within a floodplain that would nullify the assumptions made in the hydraulic modelling (e.g., a development blocking a preferential overland flow route that was included in the model).
- There are significant changes in the floodplain, such as community growth and urbanization.

3.10 CASE STUDIES

Case studies are included in Appendix B of these guidelines to illustrate flood mapping methods that have been applied in BC. Three case studies were selected to show a range of flood mapping initiatives addressing different challenges:

1. Flood mapping was incorporated into the City of Vancouver Coastal Flood Assessment (2014). This study included SLR to the year 2200 combined with 1-in-500- and 1-in-10,000-year coastal storm events. Inundation and flood hazard maps were prepared, as well as maps showing flood vulnerability, displaced households and building losses. Included in these guidelines is an inundation flood map from this study.
2. Flood mapping was included as part of the Squamish Integrated Flood Hazard Management Plan (2016). This study addressed SLR, coastal storm events, dike breach flooding and impacts of flood mitigation works. Inundation maps, flood hazard maps and flood vulnerability maps were prepared.
3. Flood mapping for the City of Prince George in 2009 included assessment of both open water floods and ice jam events. The flood maps were incorporated in a city floodplain regulation bylaw.

QUALITY ASSURANCE/QUALITY CONTROL

A QP must carry out quality assurance/ quality control during all phases of flood mapping.

4.1 APEGBC QUALITY MANAGEMENT REQUIREMENTS

APEGBC members are obligated to abide by the quality management requirements set out in the APEGBC Bylaws. In order to meet the intent of those requirements, APEGBC members must establish and maintain documented quality management processes for their practices, including as a minimum:

- the application of the relevant APEGBC professional practice guidelines - *Engineers and Geoscientists Act,* s.4.1 (2)(b)
- authentication of professional documents by the application of the APEGBC professional's professional seal - *Engineers and Geoscientists Act,* s.20(9)
- direct supervision of delegated professional engineering/geoscience activities - *Engineers and Geoscientists Act,* s.1(1) and 20(9)
- retention of complete project documentation - Bylaw 14(b)(1)
- regular, documented checks using a written quality control process - Bylaw 14(b)(2)
- documented field reviews of engineering/geoscience designs/ recommendations during implementation or construction - Bylaw 14(b)(3)
- where applicable, documented independent review of structural designs prior to construction – Bylaw 14(b)(4)

4.1.1 Professional Practice Guidelines

APEGBC professionals are required to comply with the intent of APEGBC practice guidelines related to the engineering or geoscience work they undertake. One of the three objects of APEGBC, stated in the *Act* is "to establish, maintain, and enforce standards for the qualifications and practice of its members and licensees". Practice guidelines are one means by which APEGBC fulfills this obligation.

4.1.2 Use of Seal

APEGBC professionals are required to seal all professional engineering or professional geoscience documents that have been prepared by them or have been prepared under their direct supervision, and will be delivered to others who will rely on the information contained in the documents.

Failure to seal engineering or geoscience documents that they prepare and deliver in their professional capacity or have prepared and delivered under their direct supervision in any sector is a breach of the *Act*. Please refer to the *APEGBC Quality Management Guidelines* -Use of the *APEGBC Seal* (APEGBC 2013a).

4.1.3 Direct Supervision

Direct supervision means taking responsibility for the control and conduct of the engineering or geoscience work of a subordinate. With regard to direct supervision, the QP having overall responsibility should consider:

- the complexity of the project and the nature of the flood hazards and/or flood risks
- training and experience of individuals to whom work is delegated
- amount of instruction, supervision and review required

Field work can be an important aspect of flood mapping. Therefore, careful consideration must be given to delegating field work. Due to the complexities and subtleties of flood mapping, direct supervision of field work is difficult and care must be taken to ensure that delegated work meets the standard expected by the QP. Such direct supervision could typically take the form of specific instructions on what to observe, check, confirm, record and report back to the QP. The QP should exercise judgment when relying on delegated field observations by conducting a sufficient level of review to be satisfied with the quality and accuracy of those field observations.

4.1.4 Retention of Project Documentation

APEGBC professionals are required to establish and maintain documented quality management processes that include retaining complete project documentation for a minimum of 10 years after the completion of a project or 10 years after the engineering or geoscience documentation is no longer in use.

These obligations apply to APEGBC professionals in all sectors. Project documentation, in this context, includes documentation related to any ongoing engineering or geoscience work, which may not have a discrete start and end, and may occur in any sector.

Many APEGBC professionals are employed by organizations that ultimately own the project documentation. APEGBC professionals are considered compliant with this quality management requirement when a complete set of project documentation is retained by the organizations that employ them using means and methods that are consistent with the APEGBC Bylaw and *APEGBC Quality Management Guidelines - Retention of Project Documentation*.

4.1.5 Checking and Review

As referenced in Section 4.1 of these guidelines, and consistent with the requirements of APEGBC Quality Management Bylaw 14(b)(2), as a minimum, flood mapping reports and supporting documentation must undergo a documented checking and review process before being finalized and delivered. This process would normally involve an internal review by another APEGBC member within the same firm. Where an appropriate internal reviewer is not available, an external reviewer (i.e., one outside the firm) must be engaged. Where an internal or external review has been carried out, this must be documented. The level of review is to be based on the professional judgment of the APEGBC member (the reviewer). Considerations should include the type of map; complexity of the area and of the underlying conditions; quality and reliability of background information, field data and elements at risk; and the APEGBC member's training and experience.

4.1.6 Field Reviews

Field reviews are reviews conducted at the site of the construction or implementation of the engineering or geoscience work. They are carried out by an APEGBC professional or his or her subordinate acting under his or her direction supervision. Field reviews enable the APEGBC Professional to ascertain whether the construction or implementation of the work substantially complies in all material respects with the engineering or geoscienceconcepts or intent reflected in the engineering or geoscience documents prepared for the work.

APEGBC professionals are required to establish and maintain documented quality management processes, which include carrying out documented field reviews of their domestic projects or work during implementation or construction.

Domestic works or projects include those located in Canada and for which an APEGBC professional meets the registration requirements for the engineering or geoscience regulatory body that has jurisdiction. Please refer to the *APEGBC Quality Management Guideline – Documented Field Reviews During Implementation or Construction* (APEGBC 2013b).

4.1.7 Independent Review

An independent review is an additional level of review beyond the minimum requirements of APEGBC Bylaw 14(b)(2) that may be undertaken for a variety of reasons by an independent APEGBC member not previously involved in the project. At the discretion of the QP, and in consultation with the reviewer(s) involved in the regular checking/review process outlined above, this additional level of review may be deemed appropriate. Alternatively, a *regulatory authority* or the client may request an independent external review to support project approval. An independent review may be undertaken by another APEGBC member employed within the same firm or with an external firm.

An independent external review process should be more formal than the checking/review process carried out under Bylaw 14(b)(2). An independent external reviewer should submit a signed, sealed and dated letter or report that includes the limitations and qualifications with regards to the independent external review and the results of the independent external review.

The independent external review discussed here is not the same as an independent review or advisory service provided by an APEGBC member who is retained by the regulatory authority or sometimes by the client.

PROFESSIONAL REGISTRATION; EDUCATION, TRAINING AND EXPERIENCE

5.1 PROFESSIONAL REGISTRATION

It is the responsibility of the professional engineer or professional geoscientist to determine whether he/she is qualified by training and/or experience to undertake and accept responsibility for the carrying out of flood mapping in BC (APEGBC Code of Ethics Principle 2).

With regard to the distinction between professional engineering and professional geoscience, the following is an excerpt under Principle 2 of the Code of Ethics guidelines (APEGBC 1994, amended in 1997):

> The professions are distinct and registration in one does not give a member the right to practice in the other; however, the association recognizes that there is some overlap of the practices of engineering and geoscience.

Nothing in this principle authorizes a professional engineer to carry on an activity within the area of professional geoscience that goes beyond the practice of professional engineering, and nothing in this principle authorizes a professional geoscientist to carry on an activity within the area of professional engineering that goes beyond the practice of professional geoscience.

The APEGBC member who investigates or interprets complex geological conditions including geomorphic processes, in support of flood mapping is typically registered with APEGBC as a professional geoscientist in the discipline of geology or environmental geoscience, or as a professional engineer in the discipline of geological or civil engineering.

5.2 EDUCATION, TRAINING AND EXPERIENCE

Flood mapping, as described in these guidelines, requires minimum levels of education, training and experience in many overlapping areas of geoscience and engineering. The QP taking responsibility for flood maps must adhere to the APEGBC Code of Ethics (to undertake and accept responsibility for professional assignments only when qualified by training or experience) and, therefore, must evaluate his/her qualifications and must possess the appropriate education, training and experience to provide the services.

The level of education, training, and experience required of the QP should be commensurate with the complexity of the project. Typical qualifications for the QP or a team of professionals may include education and experience in:

- hydrodynamic modelling
- watershed hydrology
- groundwater geology
- extreme value statistics and trend analysis
- ice effects
- air photograph and satellite imagery interpretation
- bathymetric and land based surveying
- hydrological studies, including flood frequency analysis
- climate change and its effects on hydrological processes
- geomatics
- knowledge of fluvial and coastal geomorphology principles and applications

The academic training for the above skill sets can be acquired through formal university or college courses, or through continuing professional development. There may be some overlap in courses, and specific courses may not correlate to specific skill sets. A QP should also remain current, through continuing professional development, with the evolving topics of flood mapping. Continuing professional development can include taking formal courses; attending conferences, workshops, seminars and technical talks; reading technical publications; searching the Internet; and participating in field trips.

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APPENDIX A: FLOOD MAPPING ASSURANCE STATEMENT

To: The Client Date:______________________

____
Name (print)

____

____
Address (print)

Flood Mapping Project:

____

The undersigned hereby gives assurance that he/she is an APEGBC registered professional and the Qualified Professional for the project identified above.

I have signed, sealed and dated the attached report in accordance with the *APEGBC Professional Practice Guidelines – Flood Mapping in BC*. The report supports and accurately reflects the assurances made in this Assurance Statement.

I have completed the following activities:

(Check the applicable items)

	Activity
	Reviewed the relevant provincial legislation and local government regulations, policies, and floodplain bylaws
	Reviewed available and relevant background information, documentation and data
	Visited the site and reviewed the conditions in the field that may be relevant
	Considered the need for, and scale of, investigations that address future land use changes and climate change
	Developed and executed the flood mapping in accordance with the criteria established by the client
	Addressed any significant comments arising from internal or peer reviews
	Prepared a flood mapping report along with the accompanying digital information

I hereby give assurance that the attached flood mapping report and supporting digital documentation have been produced in accordance with the *APEGBC Professional Practice Guidelines – Flood Mapping in BC*.

Name (print)

Signature

Date

Address (print)

(Affix Professional Seal here)

Telephone

(email)

If the APEGBC Qualified Professional is a member of a firm, complete the following:

I am a member of the firm ______________________ (Print name of firm),
and I sign this letter on behalf of the firm.

APPENDIX B: CASE STUDIES

B-1: CITY OF VANCOUVER COASTAL FLOOD ASSESSMENT

Sea level has increased over the last century and is expected to rise at an accelerated rate over the next century. This study assessed the potential for present and future flooding along four shoreline zones in the City of Vancouver to reflect the projected sea level rise (SLR). Detailed hydrologic–hydraulic modelling investigations were carried out for five scenarios, including simulating the base case (2013) and conditions in 2100 and 2200. Of particular interest was defining the floodplain extents, flood depths and flood construction levels (FCLs) to assess vulnerable areas and the consequences to people, property and infrastructure. The study was the first step in an overall strategy to explore options for mitigating and adapting to the flood risk across the city. Detailed information on the study can be found at vancouver.ca/green-vancouver/sea-level-rise.aspx

Five scenarios were developed that encompass possible future SLR conditions to 2200 combined with design storm events:

- Scenario 1, Year 2013, 0.0 m SLR, 1:500-year storm hazard
- Scenario 2, Year 2100, 0.6 m SLR, 1:500-year storm hazard
- Scenario 3, Year 2100, 1.0 m SLR, 1:500-year storm hazard
- Scenario 4, Year 2100, 1.0 m SLR, 1:10,000-year storm hazard
- Scenario 5, Year 2200, 2.0 m SLR, 1:10,000-year storm hazard

A continuous simulation (joint probability) approach was taken to establish the ocean levels affected by meteorological and oceanographic conditions corresponding to the selected return periods for each scenario. Ocean levels were then used as the boundary conditions for the overland flood models. The city was divided into four modelling zones, each having similar exposure and characteristics. Modelled flood levels were found to be relatively consistent across each zone for each scenario. Maps were developed to show the flood extents and flood depths spatially under each scenario.

Flood construction levels were set based on Scenario 3, and a freeboard of 0.6 m was added to modelled flood levels to give an FCL of 4.6 m Geodetic Datum (GD), consistent across the four flood-prone zones. A wave boundary was delineated and an additional 0.3 m wave effect allowance is to be applied seaward of the boundary to form the FCL in the wave zone (or, alternatively, a site-specific study is to be completed). As a point of comparison, an FCL of 3.5 m GD, assumed to have a return period of 1 in 200 years, was used by the city prior to the recognition that SLR will affect future conditions.

Depth map colours for the City of Vancouver were based on the Japanese Flood Control Division, River Bureau, Ministry of Land, Infrastructure and Transport standard, which uses shades of yellow, green, blue and purple (Japan Ministry of Land, Infrastructure and Transport, 2005). These are easier to distinguish than several shades of blue. The colours will also be more distinguishable if the map is photocopied to greyscale, which can be common during an emergency event. See Map B-1 for an example of an inundation flood map from the Vancouver study.

Areas within the city that are vulnerable during a Scenario 3 coastal flood event were assessed and “hot spot” maps produced.

The mapping showed that emergency routes such as Main Street and Pacific Boulevard will be partly inundated.

Important transportation hubs such as Waterfront Station could potentially be vulnerable. Current planned gathering areas in the downtown core will have to be redefined, as some will be flooded. Cultural and historic sites in Gastown and Chinatown will flood. Community services and housing centres in the Downtown Eastside, particularly between Carrall Street and Main Street, as well as school and childcare spaces in the Olympic Village and International Village and near Terminal Avenue are vulnerable, assuming no flood mitigation measures are taken. Maps were also produced showing locations of displaced households and building losses.

MAP B-1: FLOOD MAP FROM VANCOUVER STUDY

B-2: SQUAMISH INTEGRATED FLOOD HAZARD MANAGEMENT PLAN

The Integrated Flood Hazard Management Plan (IFHMP) for the District of Squamish considered a range of hazards in the area:

- flood hazards from the Squamish, Mamquam, Cheakamus, Cheekeye and Stawamus rivers
- debris flow hazards from the Cheekeye River and smaller local creeks
- coastal flood and tsunami hazards from Howe Sound

Detailed information on the Squamish IFHMP can be found at squamish.ca/yourgovernment/projects-and-initiatives/floodhazard/resources/.

The coastal design flood level for Howe Sound was based on a combination of tide, external storm surge, subsidence, local effects, and allowances for sea level rise of 1 m to the year 2100. The combination of tide and external storm surge was based on a joint probability analysis, and an annual exceedance probability AEP of 1 in 200 years was selected. Wave effects were modelled using a 1-in-200-year storm. An inundation flood map of downtown Squamish was prepared, showing the extent of inundation from the coastal design flood (see Map B-2a).

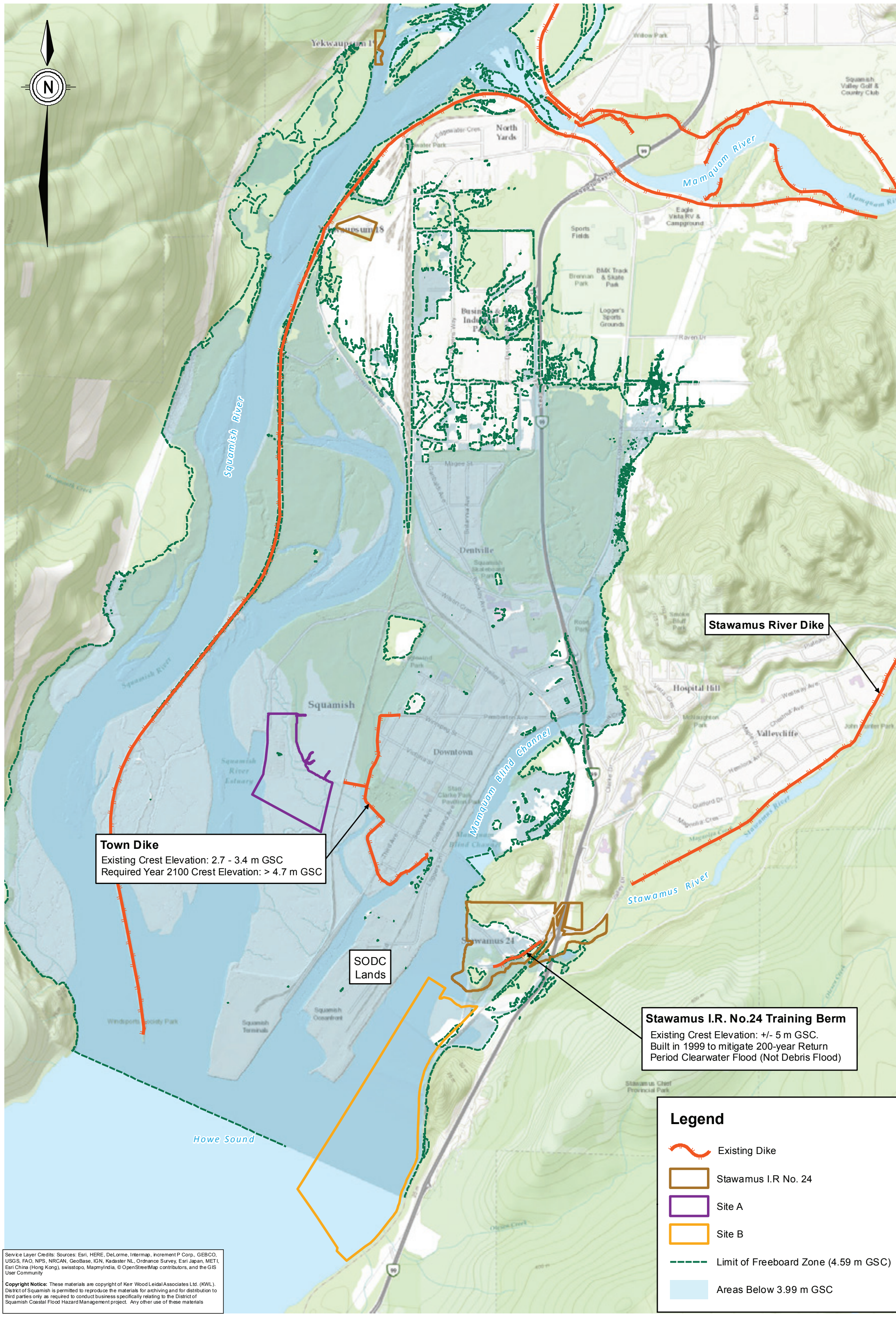
The Mamquam River naturally divides the Squamish River floodplain into an upper floodplain area and a lower floodplain area. Existing dikes at the south end of the upper floodplain will stop inflow from a dike breach from returning to the river, resulting in internal ponding. In this situation, water levels within the floodplain would rise higher than the river level, allowing water from the floodplain to flow over the dike back to the river. The sea dike around downtown Squamish will create a similar situation for the lower floodplain south of the Mamquam River.

At the District of Squamish's request, the two-dimensional floodplain modelling focused exclusively on assumed Year 2100 development conditions. A focus on Year 2100 conditions means that the results of the modelling will remain relevant as a target throughout the implementation of a long-term mitigation plan. However, results may not provide an accurate picture of flood hazard under present-day conditions.

Implementing Year 2100 assumptions involved modifying existing topography to account for new development and floodproofing. The resulting changes affect internal flood levels and the determination of corresponding flood construction levels (FCLs). In addition, by Year 2100, each city block is assumed to have experienced infill development to the maximum footprint for its corresponding primary land use. The increase in building density is represented as a proportional increase in roughness for each city block. Floodways were incorporated by maintaining present-day ground elevations along selected corridors.

MAP B-2A: SQUAMISH COASTAL FLOOD INUNDATION MAP

Path: O:\0400-0499\463-278\430-GIS\MXD-Rp\Council Presentation Sea Dike Concept\20151009 UPDATE\Figure 2-3 Downtown Squamish Coastal Flood Inundation.mxd Date Saved: 30/04/2016 8:05:15 AM
Author: ASeuarz



KERR WOOD LEIDAL
consulting engineers

District of Squamish - Integrated Flood Hazard Management Plan
Coastal Flood Hazard Mitigation Strategy and Coastal Flood Protection Options

Project No.	Date
463-278	April, 2016

400 0 400 (m)

Downtown Squamish Coastal Flood Inundation Including Sea Level Rise to Year 2100

Figure 2-3

Flood hazards associated with dike breaches on the Squamish River/Mamquam River floodplain required specialized hydraulic modelling. The IFHMP dike breach model employed innovative approaches to account for the possibility of a breach at any point along the dike, preferential flow along roads and floodway corridors, and assumed Year 2100 development conditions. The model assumed that the dike breaches occur during the 1:200-year return period clear-water river flood. To support planning-level risk assessment and mitigation, results were presented as a maximum envelope of modelled conditions at any location in the floodplain. Mapping was prepared for maximum water surface elevation, water depth (under future development conditions), velocity and hazard rating.

Physical flood hazard was assessed using the concept of hazard rating. Hazard rating results capture the most critical combination of velocity and depth, and can be compared to established thresholds for risk to exposed individuals. Hazard ratings were mapped for floodplain areas north and south of the Squamish River. Predictably, maximum values occur adjacent to the dike, along constricted floodways, and in areas where water ponds to significant depth. See Map B-2b for an example of flood ratings.

Economic consequences were modelled using the HAZUS-MH model and were considered a lower bound estimate on expected damages.

Social consequences were mapped using a GIS-based process that considered displacement of residents, disruption of employment, and interruption of important community services. Social consequence intensity maps were provided for floodplain areas north and south of the Squamish River. Maximum intensities were governed by inundation of critical community facilities such as schools, wastewater treatment infrastructure and fire halls.

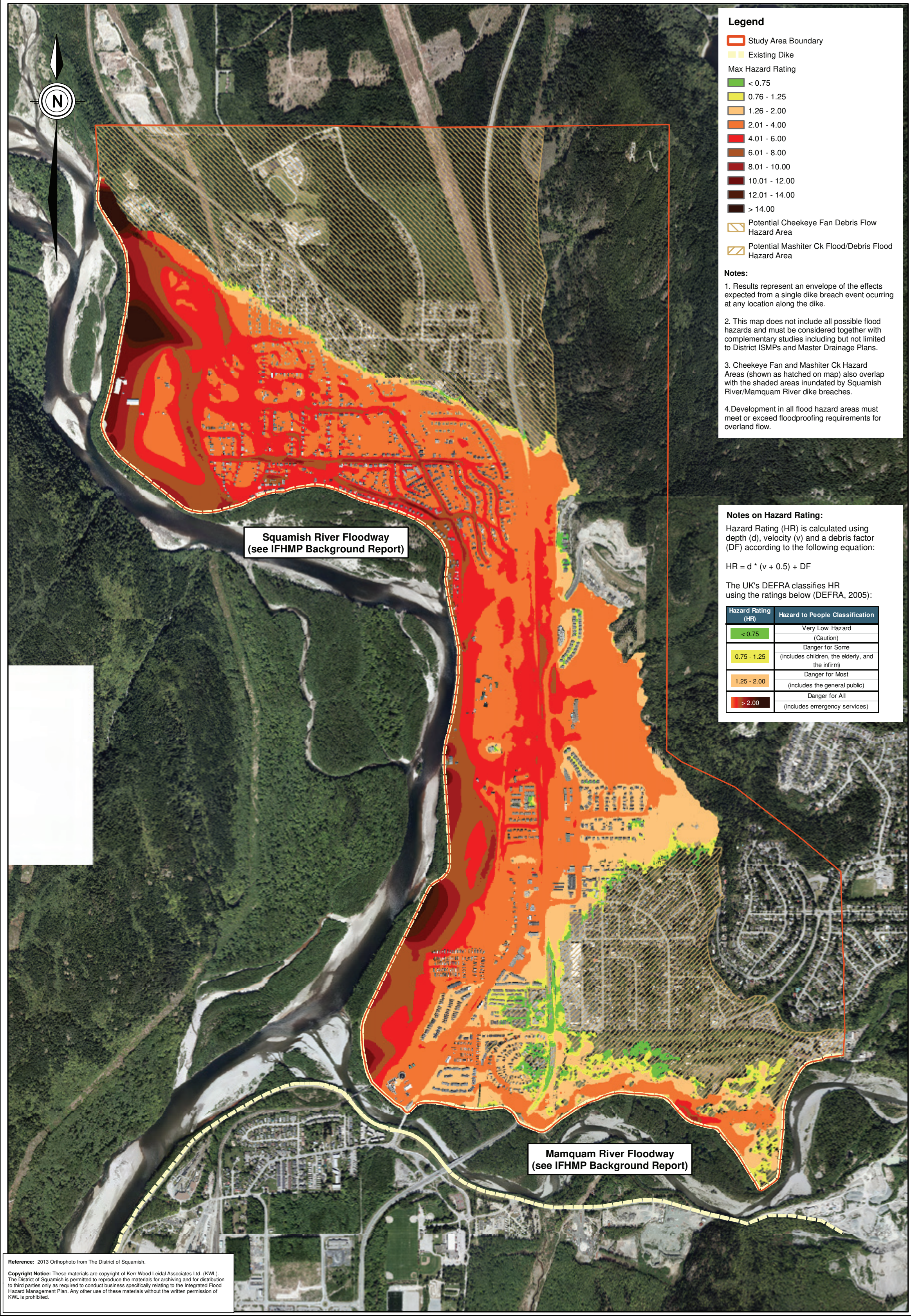
Environmental consequence mapping was completed using a similar GIS process that focused on environmentally sensitive areas as well as the potential mobilization of hazardous materials. Environmental consequence sites are distributed throughout both floodplains.

A one-dimensional Stawamus River hydraulic model was used to assess the 1:20-year return period clear-water flood as well as 1:200-year and 1:1,000-year return period debris flood hazards. Flood and debris flood hazard areas are concentrated along the lower reach of Little Stawamus Creek, near Highway 99, and along the downstream river estuary. The Valleycliffe community would be flooded only if excessive sediment deposition or a bridge blockage at the Mamquam FSR caused a river avulsion. See Map B-2c for a flood hazard map for the Stawamus River.

A one-dimensional model was also used for modelling and mapping on the Cheakamus River. The modelled flood levels were projected across the floodplain to develop flood hazard maps.

MAP B-2B: SQUAMISH RIVER HAZARD RATINGS

Path: O:\0400-0499\463-278\430-GIS\MXD-Rp\River Flood Risk Mitigation Options\Figure 2-8 Upper Floodplain_Year 2100_Q200_Maximum Hazard Rating.mxd Date Saved: 06/05/2016 2:38:07 PM
Author: ASeuarz



Reference: 2013 Orthophoto from The District of Squamish.

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consulting engineers

District of Squamish - Integrated Flood Hazard Management Plan
DRAFT River Flood Risk Mitigation Options Report

Project No. 463-278

Date May, 2016

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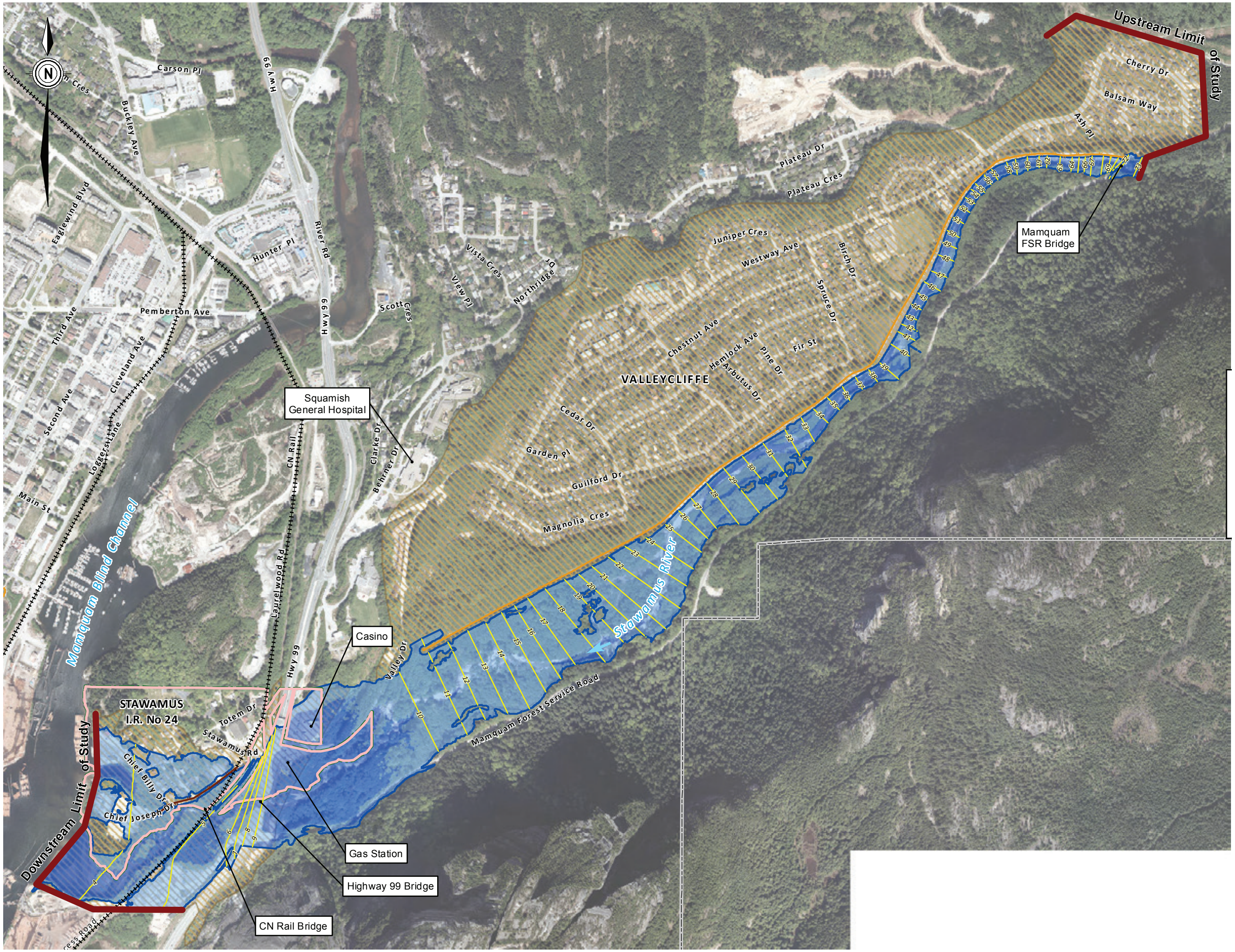
Preliminary Composite Maximum Hazard Ratings for Upper Floodplain Dike Breach Scenarios Year 2100 200-Year Return Period Flood

Figure 2-8

MAP B-2C: SQUAMISH RIVER FLOOD HAZARD MAP



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Author: ASeuarz

District of Squamish
Integrated Flood Hazard Management Plan
DRAFT
River Flood Risk Mitigation Options Report

Legend

- Municipal Boundary
- First Nations Reserve Boundary
- Railway
- District Dike
- Other Dike
- Flood Elevation Contours (1m Interval)

1:200 Flood Hazard Area

- Water depth less or equal to 2.5 m
- Water depth more than 2.5 m
- Potential Overland Flow Area

Notes:

1. Mapping represents areas expected to be inundated by lin 200-year return period debris flood Stawamus River peak flow with concurrent 200-year return period coastal flood.

2. Conservative inundation limits are shown in backwater areas to reflect hydraulic model uncertainty.

3. Water surface elevations shown on map do not include freeboard.

Reference: 2013 Orthophoto from the District of Squamish.

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200 0 200 (m)
1:10,000

Project No.	Date
463-278	May 2016

Preliminary Stawamus River 1:200 Year Return Period Flood Hazard Map

Figure 4-2

B-3: PRINCE GEORGE FLOODPLAIN MAPPING

The City of Prince George experienced severe ice-related flooding during the winter of 2007/2008, when inundation of lands along the lower Nechako River caused extensive damage. This ice event had an estimated return period of about 90 years. Just a few months before, in the spring of 2007, high water levels in the Fraser River had caused localized flooding of low-lying areas along the Fraser and in the area of the Nechako–Fraser confluence. This spring event had an estimated return period of about 20 years.

In the Fraser River, flooding normally occurs in the spring, caused by melting of large snowpacks combined with sudden rises in temperature and/or heavy rains. In the Nechako River, on the other hand, the most critical condition is ice-related flooding that occurs during fall freeze-up. When November/December flows in the Nechako exceed a certain threshold and there is a prolonged period of cold weather, ice-related flooding may occur. Since 1957, the Nechako flow at Prince George has been partly regulated by Rio Tinto Alcan's Kenney Dam, almost 300 km upstream. The current mode of operating the reservoir tends to reduce winter flows during freeze-up and to delay the summer peak until after the Fraser River has peaked, thereby reducing the risks of both open-water and ice-related flooding.

Floodplain mapping was prepared for Prince George, taking into account regulation of the Nechako River by Kenney Dam and the potential for ice jam events. The floodplain mapping was incorporated into an updated City of Prince George Flood Plain Regulation Bylaw, which was adopted in 2011. Information on the bylaw and the floodplain mapping analysis can be found at princegeorge.ca/citybusiness/currentplanning/floodplainbylaw/Pages/Default.aspx.

For the development of design flows, flood frequency analyses were conducted to determine the appropriate freshet design flows for the Fraser River above the Nechako River confluence, for the Nechako River at Prince George, and for the Fraser River below the confluence. The flood frequency results were used for calculating 200-year water surface profiles along the rivers.

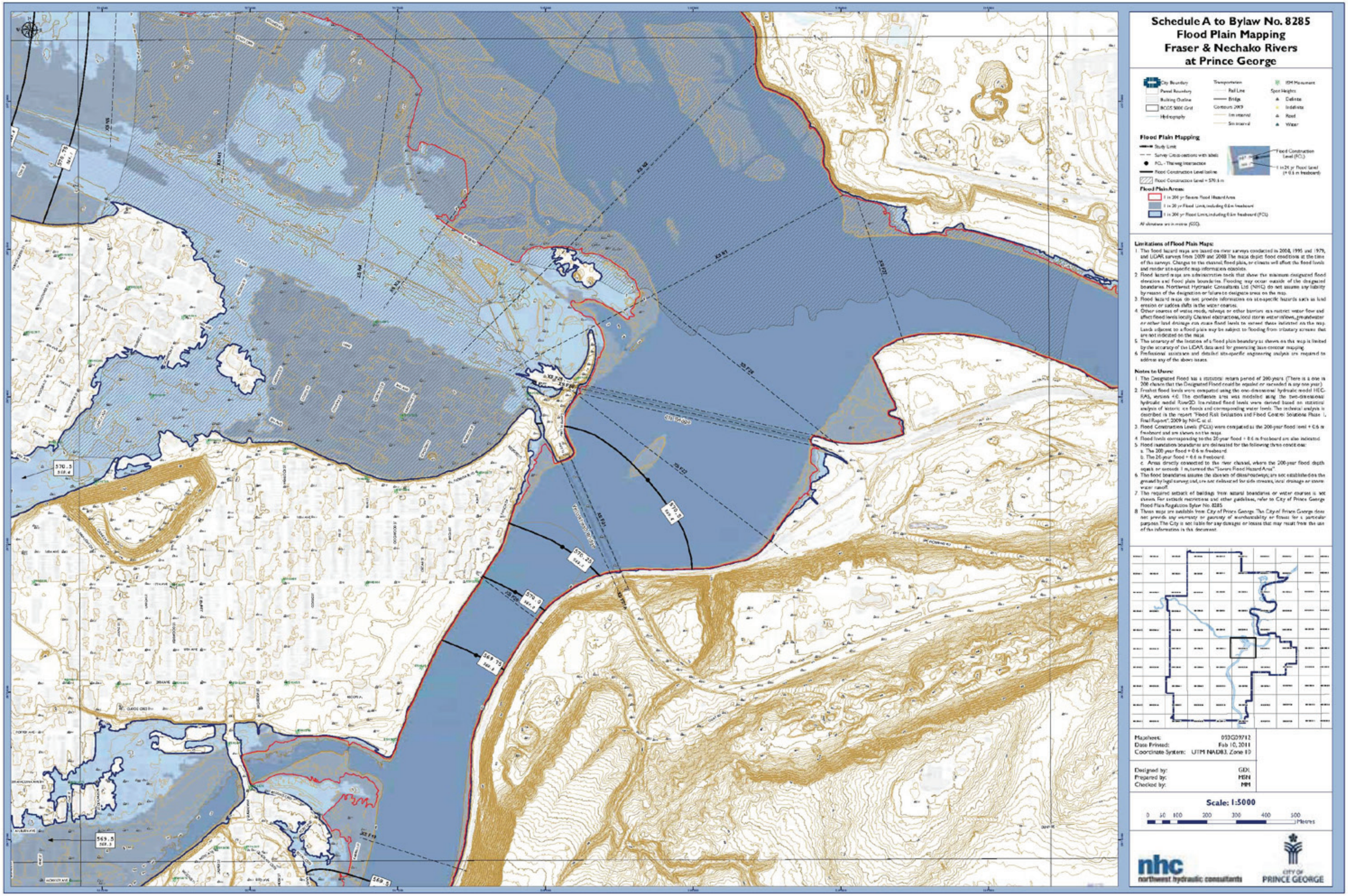
Hydraulic modelling was undertaken to simulate open-water (freshet) flood profiles corresponding to the estimated Nechako and Fraser River design flows, using HEC-RAS (Hydrologic Engineering Center River Analysis System, US Army Corps of Engineers). The developed model was calibrated and validated to observed water levels and then used to simulate design profiles. Its sensitivity to variations in roughness, flows and starting conditions was also assessed.

The ice-related profile was developed using probability analysis. The probability of experiencing a given freeze-up level at any location each year is a function of:

- the probability of experiencing a given flow at freeze-up
- the probability of experiencing the required amount of cold weather to allow an ice cover to form at that location
- the probability of a stable equilibrium ice cover forming at that location

These probabilities were combined using a Monte Carlo simulation to develop simulated frequency curves of annual peak freeze-up levels. For the floodplain mapping, the Nechako River 200-year open water flood profile was compared to the 200-year ice-related profile, and the higher of the two was taken as the design condition. Map B-3 is a sample floodplain regulatory map.

MAP B-3: PRINCE GEORGE FLOODPLAIN MAP



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