PROFESSIONAL PRACTICE GUIDELINES

NATURAL HAZARDS

LEGISLATED FLOOD ASSESSMENTS IN A CHANGING CLIMATE IN BC

VERSION 2.1
PUBLISHED AUGUST 28, 2018

ENGINEERS & GEOSCIENTISTS
BRITISH COLUMBIA

FUNDING PROVIDED BY:

BRITISH COLUMBIA
Ministry of
Forests, Lands, Natural
Resource Operations
and Rural Development

Natural Resources Canada
Ressources naturelles Canada

VERSION 2.1, AUGUST 28, 2018

PREFACE

These *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* were commissioned by the British Columbia (BC) Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD). They were written to guide professional practice for flood assessments, identify the circumstances when Risk Assessments are appropriate, and emphasize the need to consider climate change and land use changes in such assessments.

This update to these guidelines was undertaken to ensure consistency with the *Professional Practice Guidelines – Flood Mapping in BC* (Engineers and Geoscientists BC 2017a). Some general improvements in wording and updating of technical components was also undertaken at this time.

The goals of the MFLNRORD flood hazard management program are to reduce or prevent injury, human trauma, and loss of life and to minimize property damage from flooding events in BC. In its ongoing effort to achieve these goals, the MFLNRORD has played a leadership role in working with Engineers and Geoscientists BC (formerly the Association of Professional Engineers and Geoscientists of BC, or APEGBC) to develop these and other guidelines. The development of such guidelines is consistent with one of the primary objectives of Engineers and Geoscientists BC, which is to establish, maintain, and enforce good practice of professionals regulated by Engineers and Geoscientists BC.

These guidelines complement the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientist BC 2010).

MFLNRORD and Engineers and Geoscientists BC assembled a team of specialists from government and the engineering and geoscience community to prepare and review these guidelines. The goal is that the application of these guidelines will result in consistent and comprehensive Flood Assessment Reports being submitted to government authorities.

Specific objectives of these guidelines are to:

1. Outline the professional services that should generally be provided by Engineering/Geoscience Professionals conducting legislated flood assessments;
2. Describe the standards of practice that Engineering/Geoscience Professionals should follow in providing professional flood assessment services;
3. Specify the tasks that should be performed by Engineering/Geoscience Professionals to meet an appropriate standard of care when preparing Flood Assessment Reports, and which fulfill their obligations under the *Engineers and Geoscientists Act* (the *Act*). These obligations include Engineering/Geoscience Professionals' primary duty to protect the safety, health, and welfare of the public and the environment;

4. Describe the roles and responsibilities of the various participants/stakeholders involved in flood assessment work, and assist in delineating the roles and responsibilities of the various participants/stakeholders;
5. Identify various methodologies that can be used when dealing with Tolerable and Acceptable Risk;
6. Provide consistency in the Flood Assessment Reports and other documents prepared by Engineering/Geoscience Professionals when providing professional flood assessment services; and
7. Describe the appropriate knowledge, skill sets, and experience that Engineering/Geoscience Professionals should have who are working in this field.

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ABBREVIATIONS

ABBREVIATION	TERM
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
ALC	Agricultural Land Commission
ALR	Agricultural Land Reserve
BC	British Columbia
C	centigrade
FCL	Flood Construction Level
FEMA	Federal Emergency Management Agency
FHA	Flood Hazard Assessment
FRA	Flood Risk Assessment
ha	hectare
IDF	intensity duration frequency
INAC	Indigenous and Northern Affairs Canada
LiDAR	light detection and ranging
MBE	minimum building elevation
MFLNRORD	Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
MMCD	Master Municipal Construction Documents
MTI	Ministry of Transportation and Infrastructure
NRCan	Natural Resources Canada
PCIC	Pacific Climate Impacts Consortium
PICS	Pacific Institute for Climate Solutions
PMF	probable maximum flood
PMP	probable maximum precipitation
QP	Qualified Professional

DEFINED TERMS

The following definitions are specific to this guideline.

TERM	DEFINITION
Acceptable Risk	A Risk, which, for the purposes of life or work, we are prepared to accept as it is with no special management. Society does not generally consider expenditure to further reduce such Risks to be justifiable.
Act	*Engineers and Geoscientists Act* [RSBC 1996] Chapter 116.
Active and Inactive Alluvial Fan	An Active Alluvial Fan is a fan on which the surface is subject to periods of aggradation and channel incision, and avulsions may occur. An Inactive Alluvial Fan can be defined as a fully trenched (from fan apex to distal section) fan on which fluvial processes are limited to the present channel and its banks. Avulsions on the fan surface are considered extremely unlikely.
Alluvial Fan	An accumulation of sediment where a steep stream channel flows out onto a valley floor of reduced gradient, which is often fan-like in shape and subject to further additions of sediment. Strictly, an Alluvial Fan is the product of sediment transported and deposited by water floods (including debris floods), but the term is often also applied to debris flow fans, which are those constructed from the deposits of debris flows. Many fans incorporate deposits of both types.
Approving Authority	A local or provincial government, which could include First Nations, with the authority to authorize a Proposed Development.
Approving Officer	An official who is appointed under the *Land Title Act* (Section 77) and acts independently to (1) ensure subdivisions comply with provincial acts and regulations and local bylaws; and (2) protect the best interests of the public. There are four jurisdictions of Approving Officers in BC: 1. Municipal Approving Officers ▪ Appointed by: municipal councils ▪ Jurisdiction: subdivision approvals within municipal boundaries 2. Regional District and Islands Trust Approving Officers ▪ Appointed by: Regional District boards or the Islands Trust Council ▪ Jurisdiction: subdivision approvals within the boundaries of those local governments that have assumed the rural subdivision Approving Authority* 3. BC Ministry of Transportation Approving Officers ▪ Appointed by: provincial cabinet ▪ Jurisdiction: subdivision approvals outside municipal boundaries and within those Regional Districts and the Islands Trust boundaries that have not assumed the rural subdivision Approving Authority* 4. Nisga'a Lands Approving Officers ▪ Appointed by: Nisga'a Lisims Government ▪ Jurisdiction: subdivision approvals within Nisga'a Lands, including Nisga'a village lands NOTE: * No Regional District, nor the Islands Trust, has assumed responsibility for rural subdivision approvals; therefore, that authority is still held by the Ministry of Transportation and Infrastructure.

TERM	DEFINITION
Association	The Association of Professional Engineers and Geoscientists of the Province of British Columbia, also operating as Engineers and Geoscientists BC.
Bylaws	The Bylaws of Engineers and Geoscientists BC made under the *Act*.
Client	An individual or company who engages a Qualified Professional (QP) to conduct a flood assessment.
Code of Ethics	A higher standard of ethics and integrity, in addition to other legal and regulatory requirements and standards, that places on Engineering/Geoscience Professionals the paramount duty to uphold the values of truth, honesty, and trustworthiness, and to safeguard human life and welfare, and to protect the environment. (See https://www.egbc.ca/About/Governance/The-Act,-Bylaws-and-Code-of-Ethics.)
Consequence	The outcomes or potential outcomes arising from the occurrence of a flood, expressed qualitatively or quantitatively in terms of loss, disadvantage or gain, damage, injury, or loss of life.
Construction	Either new Construction of a building or structure, or the structural alteration of or addition to an existing building or structure. Construction does not include the repair of an existing building or structure.
Covenant	A registered agreement, established by the *Land Title Act* (Section 219), between a land owner and the local or provincial government that sets out certain conditions for a specific property with regards to building use, building location, land use, property subdivision, and property sale.
Design Flood	A hypothetical flood representing a specific likelihood of occurrence (for example the 200-year or 0.5% annual probability flood). The Design Flood may comprise two or more single source dominated floods.
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*.
Elements at Risk	The population, building or engineering works, economic activities, public services, utilities, infrastructure, and environmental features in the area potentially affected by floods or landslides.
Engineering/Geoscience Professional(s)	Professional engineers, professional geoscientists and licensees who are licensed to practice by Engineers and Geoscientists BC.
Engineers and Geoscientists BC	The Association of Professional Engineers and Geoscientists of the Province of British Columbia, also operating as Engineers and Geoscientists BC.
Flood Assessment Report	A report that is written by a Qualified Professional (QP) to outline the result of the flood assessment work that was completed. It may be a Flood Hazard Assessment, a Flood Risk Assessment, a flood mitigation assessment, or some combination of these.
Flood Assurance Statement	The statement for submission, along with the Flood Assessment Report, to the Approving Authority, confirming that an appropriate assessment has taken place and that the Qualified Professional (QP) has taken responsibility for the work.

TERM	DEFINITION
Flood Hazard	The potential for loss of life or injury and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.
Flood Hazard Map	A map that displays the extent of historic as well as potential future flood events of variable probability, illustrating the intensity and magnitude of the hazard at an appropriate scale. A Flood Hazard Map forms the basis of considerations and determinations in land use control with respect to potential flooding, Mitigation Measures for Construction, and flood awareness and preparedness.
Flood Intensity	A set of spatially distributed parameters related to the destructive power of a flood. The parameters may be described quantitatively or qualitatively, and may include the area inundated, the maximum flow velocity, total channel scour, sedimentation, and impact force.
Flood Risk	The combination of the probability of a flood event and the potential adverse Consequences to human health, the environment, and economic activity associated with a flood event.
Flood Risk Map	A map that combines the Consequences of a flood with a Flood Hazard. For example, a Flood Risk Map can show the likely economic losses for a 500-year return period event under a given Hazard Scenario (Dike overtopping or Dike breaches). A Flood Risk Map could also show the population at Risk for a given return period flood, or show likely fatalities for evacuated and non-evacuated Hazard Scenarios.
Freeboard	A vertical distance added to the actual calculated flood level to accommodate uncertainties (hydraulic and hydrologic variables), potential for waves, surges, and other natural phenomena.
Hazard Scenario	A specific scenario that could lead to an undesirable Consequence (flooding, boulder impact, scour). For example, a Hazard Scenario can be a Dike breach for a specified return period or a glacial lake outburst flood.
Hydroclimatic Event	A rainstorm, snowfall event, or rain-on-snow event that is temporally limited (typically to one or a few days); also referred to as a synoptic event.
Hydrogeomorphic Process	Any process in which flowing water leads, by erosion, transport, and deposition of earth materials, to the modification of a landform.
Individual Risk	The Risk of fatality or injury to any identifiable individual who lives within the zone impacted by the flood or who follows a particular pattern of life that might subject him or her to the Consequences of the flood.
Inspector of Dikes and Deputy Inspector of Dikes	Appointed provincial employees with the statutory authority to oversee maintenance of Dikes by diking authorities, set diking standards, and approve new Dikes and changes to existing Dikes.
Mitigation Measures	The alteration of land or buildings to reduce flood damage, including the use of building setbacks from water bodies to maintain a floodway and allow for potential erosion. Mitigation Measures may be achieved by either or both of the following: • Building on structural fill, provided such fill does not interfere with flood flows of the watercourse and is adequately protected against floodwater erosion and scour • Building raised by foundation walls, columns, or piles
Municipality	A corporation into which the residents of an area are incorporated under the *Local Government Act* or another act, or the geographic area of the municipal corporation.

TERM	DEFINITION
Official Community Plan	A statement of objectives and policies to guide decisions on planning and land use management within the area covered by the plan, respecting the purposes of the local government (*Local Government Act*, Part 14, Division 4).
Orphan Dikes and Works	Orphan works are flood protection works that are not being maintained by an owner or diking authority. Orphan Dikes are Orphan Works that are considered by the Inspector of Dikes to be regulated under the *Dike Maintenance Act*.
Private Dike	A Private Dike is defined in the *Dike Maintenance Act* as “a dike built on private property that protects only that property.” While Private Dikes are not regulated by the province under the *Dike Maintenance Act*, these professional practice guidelines still apply.
Professional of Record	The Engineering/Geoscience Professional or licensee taking direct professional responsibility for the engineering or geoscience work and any related engineering or geoscience documents produced.
Proposed Development	A development for which a flood assessment is being performed, including institutional, commercial, industrial, resource development, infrastructure, and Residential Development.
Qualified Professional (QP)	A professional engineer, professional geoscientist, or licensee with the appropriate level of education, training, and experience to conduct flood assessments for Proposed Development as described in these guidelines and licensed to practice by Engineers and Geoscientists BC. Each QP may practice professional engineering and/or professional geoscience if duly registered in such profession. Within the professions, a QP may practice in disciplines if qualified by education, training, and experience.
Regional District	A district incorporated under the *Local Government Act*, or the geographic area of the district, that has authority to enact subdivision servicing and zoning bylaws.
Residential Development	As defined by various pieces of provincial legislation, either (1) the subdivision of property; (2) the new Construction of a building or structure; or (3) the structural alteration of, or addition to, an existing building or structure.
Risk	A measure of the probability and severity of an adverse effect to health, property, or the environment. Risk is often estimated by the product of probability and Consequence. A more general interpretation of Risk involves a comparison of the probability and Consequences in a non-product form.
Risk Analysis	The use of available information to estimate the Risk to individuals or populations, property, or the environment, from hazards. Risk Analyses contain scope definition, hazard identification, and Risk estimation.
Risk Assessment	The process of Risk Analysis and Risk Evaluation.
Risk Evaluation	The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated Risks and the associated social, environmental, and economic Consequences, in order to identify a range of alternatives for managing the Risks.

TERM	DEFINITION
Standard Dikes	Those Dikes considered by the Inspector of Dikes to meet minimum provincial standards including the following: • Design and Construction to contain the designated flood • Design and Construction completed under the supervision of a Qualified Professional (QP) • An effective Dike management and maintenance program by a local diking authority (typically local government) • Legal access (rights of way or land ownership) for the diking authority to maintain the Dike Note that new Dikes or major upgrades to existing Dikes may need to meet additional standards, e.g., seepage, seismic, and sea level rise.
Structural Mitigation Works	Dedicated engineering works that reduce the impacts of floods, including dams, Dikes, training berms, floodwalls, seawalls, bank protection works, flood retention basins, sediment basins, river diversions, floodways, channel modifications, sediment management, debris barriers, pump stations, and floodboxes, but not including building Mitigation Measures such as structural fill and erosion/scour protection works to raise and protect building foundations (see definition of Mitigation Measures).
Tolerable Risk	A Risk that society is willing to live with in order to secure certain benefits in the confidence that the Risk is being properly controlled, kept under review, and further reduced as and when possible.
Vulnerability	The degree of loss to a given element or set of elements within the area affected by the Flood Hazard. Vulnerability is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons it will be the probability that a particular life will be lost given that the person is subject to the flood, debris flood or debris flow.

1.0 INTRODUCTION

By the year 2035, the population of British Columbia (BC) is predicted to grow from the current 4.5 million to approximately 6 million, with the greatest growth and highest population densities likely occurring in Greater Vancouver, in the Fraser Valley, on Vancouver Island, and in the Okanagan Valley. Lack of urban affordability in the future will increase development pressure in areas that are potentially subject to flooding.

Over time, the frequency and magnitude of floods on some rivers may also increase, due to factors that include riverbed aggradation, river channel alterations, land use change, insect infestation, wild fire, and climate change.

To date, BC's flood management has been largely standard-based, with a focus on particular flood magnitudes (the 200-year return period flood in general, and the flood-of-record for the Fraser River).

The role of the provincial government has lessened in the area of development approvals in Flood Hazard areas, with an increasing role for local governments and consultants.

Some guidance for professionals is provided by the 2004 *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the 2018 *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018), but there remains a need to provide direction that promotes consistency and also incorporates Flood Risk management, climate change, and land use.

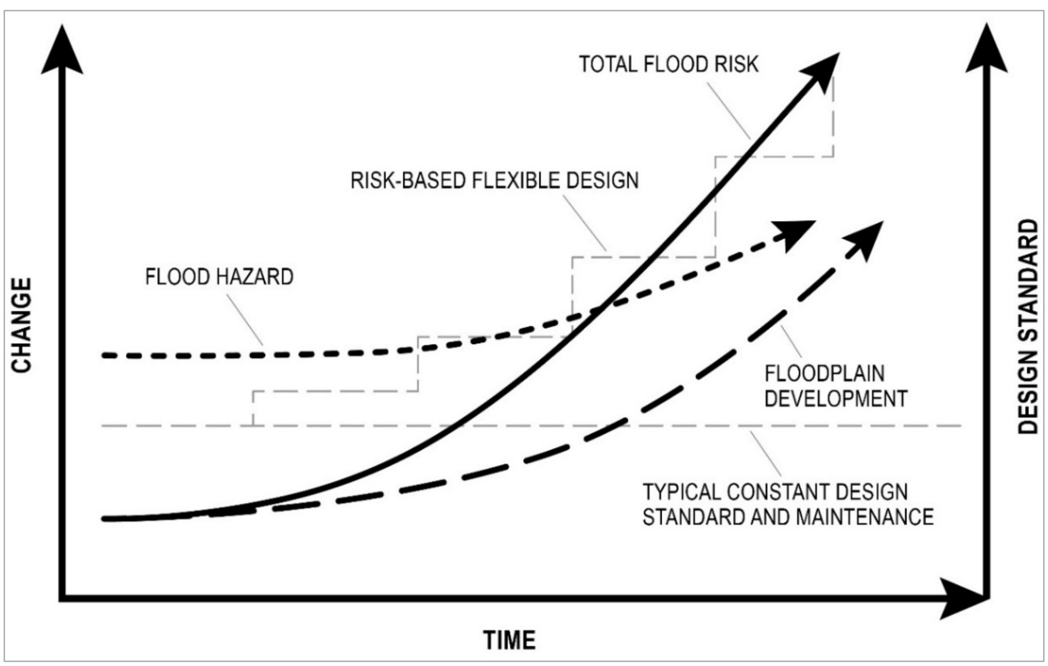

Figure 1: Changes in Flood Hazard and Risk over time (adapted from Jakob and Church 2012).

Figure 1 above illustrates the apparent conflict of the constancy of the design standard against an increase in Flood Risk due to increasing floodplain development, climate change leading to higher peak flows, or river channel bed aggradation (Jakob and Church 2012). A Risk-based flexible mitigation approach could therefore be considered.

Global climate change that is also affecting BC presents further challenges. Increasingly, non-stationary data series invalidate the traditional statistical analysis of flood frequency.

1.1 PURPOSE OF THESE GUIDELINES

The intention of Engineers and Geoscientists BC professional practice guidelines is to provide a framework for professional practice that will result in a high level of professional practice that serves the public interest and meets the requirements of all levels of government. These guidelines are primarily intended to provide direction to the Qualified Professional (QP) regarding professional practice for flood assessments.

In summary, the QP should:

- undertake flood assessments consistently and transparently;
- undertake appropriate consultation with Approving Authorities;
- use a level of effort and approach that is appropriate for the nature of the Elements at Risk;
- provide recommendations to suit existing regulations and the level of protection provided by Structural Mitigation Works;
- increasingly consider "Risk management" and "adaptation" as opposed to solely "protection" and "defence";
- consider a broad range of issues and a broad range of analytical techniques to help achieve improved social and environmental outcomes as part of development;
- include predicted changes in the hydroclimate, as well as natural and anthropogenic changes to channel morphology and watersheds in the flood assessment; and
- identify situations that require expert input.

Flood assessments may be relevant to residents, property and land owners, development consultants, planners, Approving Authorities, and local governments, as well as provincial and federal government ministries. Many of these parties require and rely on flood assessments that have been prepared by a QP. These guidelines may also assist these parties.

By necessity, there is some overlap between these guidelines and the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010) and other guidelines produced by the provincial government (see **Appendix C: Current Flood Management Legislation and Guidelines in BC**).

Flood assessments may have to address other engineering, forestry, fishery, and/or other related issues. For example, some landslide processes affect channel changes, which can impact flood characteristics, while other landslide processes such as landslide dams may directly be the cause of a flood. If other relevant guidelines exist, they should also be considered.

1.2 ROLE OF ENGINEERS AND GEOSCIENTISTS BC

These guidelines have been formally adopted by the Engineers and Geoscientists BC Council and form part of the Association's ongoing commitment to maintaining the quality of services that Engineering/Geoscience Professionals provide to their Clients and the general public. Engineering/Geoscience Professionals are professionally accountable for their work under the *Act*, which is enforced by Engineers and Geoscientists BC. An Engineering/Geoscience Professional must exercise professional judgment when providing professional services. As such, application of these guidelines will vary depending on the circumstances.

Engineers and Geoscientists BC supports the principle that Engineering/Geoscience Professionals should receive fair and adequate compensation for professional services, including services provided to comply with these guidelines. Insufficient fees do not justify services that fail to meet the intent of the guidelines. These guidelines may be used to assist in establishing the objectives, type of flood assessment to be carried out, level of effort, and terms of reference of an Engineering/Geoscience Professionals' agreement with his/her Client.

By following these guidelines, a QP should fulfill his/her professional obligations when preparing flood assessments, especially the Engineers and Geoscientists BC Code of Ethics Principle 1 (hold paramount the safety, health, and welfare of the public, the protection of the environment, and promote health and safety in the workplace). Engineering/Geoscience Professionals who do not follow the provided guidance should document their decisions and reasons. Failure of an Engineering/Geoscience Professional to meet the intent of these guidelines could be evidence of unprofessional conduct and lead to disciplinary proceedings by Engineers and Geoscientists BC.

A summary of the roles that Engineers and Geoscientists BC has relevant to these guidelines is as follows:

- Regulates the engineering/geoscience professions under the authority of the *Act*, Bylaws, and Code of Ethics
- Establishes the boundaries of practice for professional engineers and professional geoscientists
- Develops, maintains, and updates practice standards including professional practice guidelines
- Supports Engineering/Geoscience Professionals and Approving Authorities in relation to work undertaken pursuant to professional practice guidelines
- Addresses professional practice issues as they arise (up to and including investigation and discipline)

1.3 SCOPE AND OVERVIEW OF THE GUIDELINES

These guidelines focus on flood assessments for Proposed Development (residential, institutional, commercial, industrial, resource development, and infrastructure). They do not address other potential natural hazards such as landslides, soil erosion, subsidence, or snow avalanches, except as related to flooding.

These guidelines contain the following sections:

- **Section 1** introduces and identifies the need and purpose of these guidelines, clarifies the role of Engineers and Geoscientists BC, introduces salient terms, and documents the applicability of these guidelines.

- **Section 2** guides the QP on how flood assessments can be organized and clarifies the responsibilities of the Client, the Approving Authority, and the QP when completing a flood assessment.
- **Section 3** is the backbone of these guidelines and provides guidance on flood assessment procedures and methods for accounting for climate change and land surface change. It also compares standard-based and Risk-based approaches. Section 3 should be read in conjunction with Appendices D, E, and F (see below), which provide further guidance on the specifics of flood assessments.
- **Section 4** provides information on quality assurance and control, similar to the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010).
- **Section 5** explains the requirements for registration, education, training, and experience.
- **Section 6** provides references that correspond to in-text citations.

These guidelines also include a set of appendices that include the following complementary information:

- **Appendix A:** Floods and Flood-Related Hazards in BC
- **Appendix B:** Current Flood Management Approach in BC
- **Appendix C:** Current Flood Management Legislation and Guidelines in BC
- **Appendix D:** Flood Hazard Assessments
- **Appendix E:** Flood Risk Assessments
- **Appendix F:** Flood Assessment Considerations for Development Approvals
- **Appendix G:** Professional Practice in Light of Potential Climate Change and Land Surface Condition Impacts on Flooding
- **Appendix H:** Flood Management in Other Jurisdictions
- **Appendix I:** Flood Assurance Statement
- **Appendix J:** Case Studies
- **Appendix K:** List of Contributors

1.4 APPLICABILITY OF THE GUIDELINES

Notwithstanding the purpose and scope of these guidelines, an Engineering/Geoscience Professional's decision not to follow one or more aspects of the guidelines does not necessarily represent 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.

Although the Client is often a landowner or development consultant, flood assessments are usually carried out at the request of the local government or the provincial or federal government who may either specify requirements for a flood assessment or leave it to the QP to determine an appropriate approach. Following these guidelines, however, does not guarantee that the conclusions and recommendations contained within a QP's Flood Assessment Report will automatically be accepted by the Approving Authority.

These guidelines do not replace any guidelines provided by the federal, provincial, or local government, or an Approving Authority, but it is possible that the various guidelines may be used in conjunction with each other.

These guidelines reference, but do not replace, current legislation, regulations, and guidelines. The guidelines will be influenced by advances in knowledge, evolution of general professional practices, and regulatory changes. As such, this is a dynamic document and will require occasional updating.

These guidelines are not intended to provide step-by-step instruction on carrying out flood assessments.

1.5 INTRODUCTION OF TERMS

The **Defined Terms** section explains many of the terms used in these guidelines. This section introduces some common terms.

For the purpose of these guidelines, a QP is an Engineering/Geoscience Professional with appropriate education, training, and experience to conduct flood assessments as described in these guidelines (see **Section 3**). Typically, such a professional engineer or licensee will be practising civil or geological engineering[1], and such a professional geoscientist or licensee will be practising environmental geoscience[2].

A flood is a condition in which a watercourse or body of water[3] overtops its natural or artificial confines and covers land not normally under water. When a flood becomes a source of potential harm it becomes a hazardous flood.

In BC, high water levels of creeks, rivers, streams, ponds, lakes, reservoirs, and the ocean can result from a number of different causes. Typical causes include rainfall, snowmelt, ice jams, ice runs, log jams, beaver dams, landslide dams, extreme tides, storm surges, and tsunamis.

In addition to the conventional floods described above, there are several other flood-related hazards in BC, including the following:

- Debris flows and debris floods or hyperconcentrated flows
- Channel avulsions
- Bank erosion
- Sediment deposition
- Breaching of ice jams, log jams, beaver dams
- Breaching of landslide dams and moraine dams, and glacial lake outburst floods
- Breaching of earth embankments such as dams and tailings impoundments

In these guidelines, both conventional floods and other flood-related hazards are collectively referred to as floods or hazardous floods. Floods can affect floodplains, Alluvial Fans, shorelines and coastlines, or any other riparian land.

Floods and flood-related hazards can be predictable or may occur without warning. Apart from inundating land with all the associated Consequences, other Consequences not directly associated with flood inundation are bank erosion and sediment deposition.

The different types of floods and flood-related hazards in the province, their typical causes and effects, and their basic characteristics are summarized in **Appendix A: Floods and Flood-Related Hazards in BC**.

[1] Geological engineering and civil engineering are disciplines of engineering registration within Engineers and Geoscientists BC.

[2] Geology and environmental geoscience are disciplines of geoscience registration within Engineers and Geoscientists BC. Until 2000, Engineers and Geoscientists BC referred to the discipline of environmental geoscience as geotechnics.

[3] Watercourses include creeks, streams, and rivers; bodies of water include ponds, lakes, reservoirs, and oceans.

The term “Flood Hazard” as used in these guidelines refers to the probability, likelihood, or frequency of a hazardous flood event occurring, but sometimes also refers to a physical condition. The term “Flood Risk” combines the probability of a hazardous flood occurring and the potential Consequences to Elements at Risk.

Flood management refers to mitigation that may be considered or implemented to reduce the effects of a hazardous flood, either by changing the probability, likelihood, or frequency of a hazardous flood occurring or by effecting change to the Consequences.

The term “flood assessment” is used throughout the guidelines and can include Flood Hazard Assessments (FHAs), Flood Risk Assessments (FRAs), and/or Flood Risk mitigation assessments.

Development, as defined by various pieces of provincial legislation, includes the following:

- Subdivision of property
- Land use designation and zoning
- Construction, including Construction of new buildings or structures
- Structural alteration of, or addition to, existing buildings or structures

1.6 ACKNOWLEDGEMENTS

These guidelines were prepared on behalf of Engineers and Geoscientists BC by a committee of QPs and was reviewed by several diverse parties and stakeholders as members of an Engineers and Geoscientists BC Review Task Force. The authors and reviewers are listed in **Appendix K: List of Contributors**. Engineers and Geoscientists BC and the authors thank the reviewers for their constructive suggestions. Authorship and review of these guidelines does not necessarily indicate the individuals and/or their employers endorse everything in these guidelines.

Engineers and Geoscientists BC thanks Natural Resources Canada (NRCan), the BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD), and the Fraser Basin Council for their support. NRCan and the MFLNRORD funded the preparation of these guidelines and facilitated the review process. The Fraser Basin Council administered the funding and facilitated project coordination between NRCan and the MFLNRORD.

The current update of these guidelines was prepared on behalf of Engineers and Geoscientists BC by an original author, with input from the authors and some reviewers of the *Professional Practice Guidelines – Flood Mapping in BC* (Engineers and Geoscientists BC 2017a). The changes were brought forward to various Engineers and Geoscientists BC Professional Practice Committees and Divisions for an additional level of review.

2.0 PROJECT ORGANIZATION AND RESPONSIBILITIES

2.1 COMMON FORMS OF PROJECT ORGANIZATION

Flood assessments for building permits, subdivision approvals, and other land development activities are typically initiated by either a local government or by the provincial government, requesting the project proponent to retain a QP to carry out a flood assessment and prepare a Flood Assessment Report. The project proponent then submits the Flood Assessment Report in support of a land development application. This report may be reviewed by the Approving Authority, occasionally with assistance from an independent QP.

Typically, the landowner or development consultant is the Client, and the QP establishes an agreement for professional services with that party. The QP should be aware, however, that any Flood Assessment Report submitted will ultimately be reviewed by an Approving Authority and possibly by another QP.

The Client should be aware that the findings and recommendations of the QP could result in a number of actions being required: the development could require modification, the Approving Authority could require a Covenant, or the development could be disallowed. Consequently, it is prudent that a flood assessment be commenced early in the development planning process and include consultation with the Approving Authority.

The role of the QP and his/her relationship with the Client and the Approving Authority should be clearly defined. The QP should inform the Client about land development approval processes and these guidelines, especially if the Client has not previously engaged a QP or been involved in land development or flood assessments. The QP should consider reviewing the typical responsibilities listed below with the Client, in order to establish an appropriate agreement for professional services and inform the Client of the expectation of appropriate and adequate compensation (according to the Engineers and Geoscientists BC Code of Ethics, Principle 5).

2.2 RESPONSIBILITIES

Sections 2.2.1 to 2.2.3 of these guidelines describe some of the typical responsibilities of the Client, QP, and Approving Authority. Section 2.2.3 also describes some of the typical responsibilities of a QP who is asked by an Approving Authority or Client to review a Flood Assessment Report prepared by another QP.

2.2.1 CLIENT

The Client may be the landowner, a development consultant, the local government, the provincial government, a First Nation, or the federal government. Before undertaking a flood assessment, and to manage the cost of professional services, the Client should be knowledgeable about and provide the QP with the following information:

- Process, procedures, and requirements for the applicable land development application within the area of jurisdiction
- Legal description of the property, as registered with the Land Title and Survey Authority of BC
- A copy of the current land registration including any relevant Covenants
- A survey plan of the property and the location of the legal property boundary markers on the ground (this may require a BC Land Surveyor)
- Plans of existing buildings or structures, location of the Proposed Development, and drawings of the Proposed Development
- Proposed and anticipated land use changes (for example forestry activities, insect infestations, forest fires, mining) on and beyond the property
- Information on past or existing flooding and related issues (for example, bank erosion, riverbed aggradation, channel migration)
- Relevant background information (written or otherwise) related to the property and the existing and Proposed Development, including previous Flood Assessment Reports conducted for the Client or available to the Client
- Unrestricted access to the property and, if possible, access to relevant areas beyond the Proposed Development property

The Client should recognize that the flood assessment is based on the Proposed Development and subsequent changes to that development may require changes to, or invalidate, the assessment.

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 – 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 appropriate limitations of liability.
- The agreement should confirm the scope of services 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 dictate that the Flood Assessment Report may only be relied upon for the project for which it was prepared.
- The agreement should establish a budget estimate, either 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.

The agreement should also include a clause that addresses potential disclosure issues due to the obligation of the QP under Engineers and Geoscientists BC Code of Ethics Principle 1 (hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety in the workplace). In certain circumstances, the QP may have to convey adverse assessment findings to parties who may not be directly involved but who have a compelling need to know. Following is suggested wording for such a clause:

> "Subject to the following, the Qualified Professional (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 Engineers and Geoscientists BC'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, the QP shall notify the client as soon as practicable of this information and the need that it be disclosed to the appropriate parties. If the client does not take the necessary steps to notify the appropriate parties in a reasonable amount of time, the QP shall have the right to disclose that information to fulfill his/her ethical duties, and the client hereby agrees to that disclosure."

After the assessment, the Client should consider completing the following activities:

- Review the Flood Assessment Report and understand the limitations and qualifications that apply
- Discuss the Flood Assessment Report with the QP and seek clarification, if desired
- Discuss the need for the QP to complete a Flood Assurance Statement (**Appendix I**), in view of Approving Authority requirements
- Provide the Flood Assessment Report, and if applicable, the Flood Assurance Statement to the Approving Authority
- Allow the QP to confirm that his/her recommendations have been followed, so the applicable Letters of Assurance (Schedules A, B, C-A, and C-B) under the *BC Building Code* or other applicable codes can be prepared if necessary
- Notify the QP if land use, site development, or other conditions change or vary from those described in the Flood Assessment Report

The Flood Assessment Report and any Flood Assurance Statement should be the property of the QP until the Client fully pays the QP's outstanding invoices.

2.2.2 QUALIFIED PROFESSIONAL

The QP is responsible for carrying out the flood assessment and, if required by the Approving Authority or if the QP deems appropriate, for outlining proposed measures to protect the Proposed Development.

Prior to carrying out a flood assessment, the QP should complete the following actions:

- Be knowledgeable about any applicable approval processes for the Proposed Development project
- Confirm that he/she has appropriate training and experience to carry out the assessment in view of the terrain characteristics, the type of potential Flood Hazard, and the type of Mitigation Measures potentially needed
- Appropriately educate the Client regarding pertinent aspects of flood assessments
- Consult with the Approving Authority to determine whether there is an impediment to the Proposed Development in view of regulations, planning considerations, and local issues
- Consult with the Approving Authority regarding applicable regulations, available information, application of these guidelines, role of Structural

Mitigation Works, applicability of Risk Assessment, and requirements for development approval

- Determine whether the scope of work should include an FHA, an FRA, a flood mitigation plan, and/or design of Structural Mitigation Works
- Consider the need for and scale of investigations to address land use changes and climate change
- Consider the need for the involvement of other specialists
- Establish an appropriate mechanism for internal checking and review
- Consider the need for independent peer review
- Obtain a copy of any bylaws, guidelines, or regulations that are pertinent to carrying out a flood assessment
- If applicable, obtain the level of Flood Hazard or Flood Risk tolerance, or other assessment approval criteria, for the Proposed Development adopted by the Approving Authority (otherwise, seek direction from the Approving Authority as to whether it would be appropriate to apply a standard-based approach versus a Risk-based approach in the flood assessment)

QPs must recognize the differences between the practice areas of professional engineering and those of professional geoscience and work only within their licensed area of practice. While there is some overlap in the professions (such as hydrology), there are other areas that are solely within the practice area of one of the professions (for example, specification and design of Structural Mitigation Works is only within the practice area of professional engineering). If there is any confusion regarding areas of professional practice, a QP should consult Engineers and Geoscientists BC.

The QP should comply with the requirements of Engineers and Geoscientists BC Bylaw 17 regarding professional liability insurance.

During preparation of the flood assessment, the QP should follow the guidance provided in Section 3 of these guidelines and the relevant appendices. Furthermore, the QP should undertake the following activities:

- Assist the Client in obtaining relevant information such as listed in Section 2.2.1
- Make reasonable attempts to obtain from the Client and others all relevant information related to Flood Hazards on and beyond the property
- Notify the Client as soon as is reasonably possible if the project scope and/or budget estimate requires modification
- Write the Flood Assessment Report clearly, concisely, and completely to conform to applicable guidelines and regulations
- Outline appropriate steps to effectively implement recommendations (such as those pertaining to design and Construction of any Structural Mitigation Works, as well as preparation of an operation and maintenance manual for any Structural Mitigation Works)
- Identify any final review or certification that may be required prior to the development being occupied
- Ensure that the Flood Assessment Report and all related work are appropriately checked and reviewed in accordance with Section 4.1.5
- Where appropriate, obtain an independent peer review (see Section 4.2)
- If required by the Approving Authority or if the QP deems appropriate, review the draft Flood Assessment Report with the Client, Approving

Authority, and technical advisory staff of the Approving Authority

- When a Flood Assessment Report recommends a significant variance from an applicable requirement (for example, variance from a bylaw or from municipal/provincial bulletins or directives), discuss that variance with the Approving Authority prior to final submission
- Address any significant comments arising from any of the above reviews

Where flood assessments are complex, one QP may function as the lead QP, whose Flood Assessment Report relies on one or more supporting subject matter expert reports that are independently prepared, reviewed, signed, and sealed by others. Examples of these cases include the following:

- A complex hazard that warrants in-depth review by a specialist other than the lead QP
- A multiple-Hazard Scenario with related hazards (for example, floods and debris flows) with at least one hazard type that is not within the expertise of the lead QP and requires a specialist assessment
- A flood assessment where some detailed aspect requires a specialist assessment

If the hazards are completely independent (for example, floods and rock fall), the QP reports could be kept separate with two independent QPs.

If the QP delegates any aspect of the flood assessment, that work should be carried out under the QP's direct supervision. It is the QP who assumes responsibility for the delegated work and ensures that appropriate checking and review take place (see Section 4.1.3 and Section 4.1.5).

When the flood assessment is complete, the QP must sign, seal, and date the final Flood Assessment Report prior to delivery to the Client or submission to the Approving Authority, if required. The Flood Assessment Report should clearly indicate the reviews that were performed. If directed by the Client or the Approving Authority, the report should be supplemented with the Flood Assurance Statement in Appendix I of these guidelines. The QP should not use the assurance statement from the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010) for purely Flood Assessment Reports. Even if the Flood Assurance Statement in Appendix I does not need to be submitted to the Approving Authority, the QP should review the Flood Assurance Statement items to check that all appropriate steps were undertaken in preparing the Flood Assessment Report.

The QP should specify the time limitation or condition statement which identifies the period and/or condition for which the Flood Assurance Statement and Flood Assessment Report are valid, and when resubmission is recommended. Should the time limitation expire or the condition statement become relevant, the Approving Authority must contact the QP to determine if the Flood Assurance Statement should be resubmitted to reflect current physical and regulatory conditions.

After delivery of the Flood Assessment Report and submission of the Flood Assurance Statement, if submitted, the QP should:

- clarify questions the Client and/or Approving Authority may have about the assessment that was done, the Flood Assessment Report, and/or the Flood Assurance Statement; and
- carry out follow-up work regarding implementation of findings of the Flood Assessment Report, if agreed with the Client.

If the Flood Assessment Report is followed by design and Construction of Structural Mitigation Works, the professional engineer carrying out the design and field reviews for the Structural Mitigation Works must follow the quality management guidelines as outlined in **Section 4**. Final completion should be appropriately documented, usually with record drawings and an operation and maintenance manual.

Pursuant to the Engineers and Geoscientists BC Code of Ethics Principles 1, 8, and 9, an Engineering/Geoscience Professional should:

- hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety in the workplace;
- clearly advise his/her Client of the possible Consequences if recommendations are disregarded; and
- report to Engineers and Geoscientists BC or another appropriate agency any hazardous, illegal, or unethical professional decisions or practices by others.

If a Client fails or refuses to accept the findings and recommendations of a Flood Assessment Report, the QP should:

- advise the Client in writing of the potential Consequences of the Client's actions; and
- consider whether the situation warrants notifying Engineers and Geoscientists BC, the landowner (if different from the Client), and/or appropriate authorities.

2.2.3 APPROVING AUTHORITY

For flood assessments, the Approving Authority is usually a local government that is represented by an Approving Officer, building inspector, or other representative. Within Regional Districts, the role of Approving Officer is with the provincial government, but the building inspector is from the Regional District. For the sale or lease of Crown lands, land officers from the MFLNRORD act as the Approving Authority.

Where a Flood Assessment Report proposes Structural Mitigation Works, whether or not in and around a stream, other provincial and federal authorities may become involved including the Inspector of Dikes and environmental agencies. Such situations are outlined in **Appendix B: Current Flood Management Approach in BC**.

As of the adoption of this revision of these guidelines by Engineers and Geoscientists BC, the legislative environment in BC gives local and regional governments the authority to implement bylaws and other measures for natural hazard mitigation, with due consideration of any applicable provincial guidelines or standards. However, while some local government and Regional Districts have adopted bylaws with simple setback and elevation requirements, very few have adopted advanced bylaws to address steep mountain creeks, debris-flow hazards, and Flood Risk considerations.

2.2.3.1 Approving Authority Regulation of Land Development Projects

As a prerequisite for development in a flood-prone area, the Approving Authority may require the proponent to obtain a Flood Assessment Report by a QP. The report may be required for the following purposes:

- To determine whether there is a potential Flood Hazard on the subject property
- To meet the requirements of a local government bylaw

- To confirm appropriate implementation of conditions in an existing Covenant
- To ensure that the land is suitable for the intended use in the absence of a bylaw, Covenant, or other applicable regulation

Few local governments currently have comprehensive bylaws to guide flood assessments. Over time, it is expected that many local governments will adopt such bylaws that consider these and other guidelines. In the absence of a national or provincial standard, it is also expected that local governments will establish an appropriate local standard (adopted level of flood safety) to guide preparation of QP Flood Assessment Reports. This may include some or all of the following (for various types of hazards and/or development types):

- Minimum design return periods
- Risk Assessment criteria (such as discussed in **Appendix E: Flood Risk Assessment**)
- Direction on when a QP may apply a standard-based approach versus a Risk-based approach

Such local standards may provide more stringent criteria for new developments, as opposed to redevelopments or infill developments.

The Approving Authority may help the Client define the terms of reference for the study. Before the flood assessment is initiated, the Approving Authority should undertake the following actions:

- Inform the Client why a flood assessment is required
- Inform the Client, if applicable, of the adopted level of flood safety (level of tolerable Flood Hazard or Flood Risk) in the approving jurisdiction (or in the absence of such level, identify flood assessment approaches that may be acceptable)
- Provide the Client with any applicable guidelines and regulations for carrying out a flood assessment and/or preparing a Flood Assessment Report
- Identify known Flood Hazard information and reports relevant to the project (such as flood reports and maps) and describes how to access the documents
- Provide the Client with information regarding existing Structural Mitigation Works and input on the need for additional works
- Advise the Client of any key policies or procedures that potentially affect the outcome of the assessment (for example, at least one Regional District has a policy that states that it will not assume the role of a Diking Authority)
- Ensure the Client is aware of the implications of the *Dike Maintenance Act* and the *Water Sustainability Act*
- Indicate any desired interaction with the QP during preparation of the Flood Assessment Report
- Advise whether a Flood Assurance Statement (**Appendix I**) must accompany the Flood Assessment Report

In considering the possible use of a Flood Assurance Statement as part of its regulatory program, Approving Authorities may use the generic version included in **Appendix I**. Approving Authorities may not make changes to this generic version without authorization from Engineers and Geoscientists BC. Approving Authorities may also work with Engineers and Geoscientists BC to customize the statement for improved local relevance.

After the assessment has been submitted, the Approving Authority should:

- review the Flood Assessment Report;
- if necessary, discuss the Flood Assessment Report with the Client and/or QP; and
- outline any applicable next steps in the land development process.

The Approving Authority may act to implement any recommended mitigation strategy. This will typically include registration of a Covenant pursuant to Section 219 and 221 of the *Land Title Act*. Where the mitigation strategy includes Structural Mitigation Works, the Approving Authority should ensure that appropriate arrangements are made for design, Construction, operation, and maintenance (where appropriate, in consultation with other jurisdictions).

2.2.3.2 Approving Authority Issues Related to Structural Mitigation Works

The QP may recommend a mitigation strategy that includes upgraded or new Structural Mitigation Works. In this case, approvals must be obtained from various federal and provincial government agencies. For Structural Mitigation Works to proceed, the Client must ensure the following approvals and measures have been obtained or addressed:

- Local government approval, acting both as development reviewer and the local authority who will likely operate and maintain the works
- Applicable local, regional, provincial, or federal environmental approvals
- Approval from Fisheries and Oceans Canada if in-stream or riparian Construction could result in a Harmful Alteration, Disruption, or Disturbance (HADD) of fish habitat
- Approval from the Inspector of Dikes as the provincial regulator for flood protection works pursuant to the *Dike Maintenance Act* (for the Construction or alteration of Dikes)
- Approval from the provincial MFLNRORD (*Water Sustainability Act*) if Construction will involve works in or about a stream, or if a water licence is required
- Confirmation that the project is compliant with the *Heritage Act*
- Evidence that First Nations have been consulted, if applicable
- Approval from the Transport Canada, Navigable Waters Protection Division if the works could impact a navigable watercourse

At the project outset, all of the above should be considered as potential requirements, and input from the appropriate Approving Authorities and government agencies should be sought at the earliest possible opportunity. Any or all of the above requirements may have regulations or other prescriptions concerning scope, extent, timing, design, operation, maintenance, compensation, and/or reporting.

In addition to technical design criteria, any Structural Mitigation Works that are constructed must meet applicable administrative criteria (i.e. be located on a right-of-way and under the jurisdiction of an Approving Authority, and have an operation and maintenance manual provided).

2.2.3.3 Approving Authority Reviews of Flood Assessment Reports

The Approving Authority may use in-house personnel or directly retain an independent QP to provide advisory services before or during a flood assessment, or to review a submitted Flood Assessment Report. Such a QP may provide advice regarding the type of flood assessment that would be appropriate, review documents submitted by another QP, advise on improving the local flood management approach, and develop new local guidelines and regulations.

If a Flood Assessment Report submitted by a QP does not meet the requirements of the Approving Authority or has an obvious deficiency, such as lack of checking and review, the Approving Authority should return the report to the QP with a suitable explanation. Before submitting a revised Flood Assessment Report, the QP should consult with other expert professionals, review these guidelines, and possibly consult Engineers and Geoscientists BC. In some cases, the Approving Authority may wish to bring the matter to the attention of Engineers and Geoscientists BC.

An Approving Authority or Client may use the independent QP retained to provide advisory services to review the Flood Assessment Report submitted by a QP. The need for this advisory review on behalf of the Approving Authority is determined on a case-by-case basis, and may depend on the following:

- The credentials and experience of the QP who authored the Flood Assessment Report
- The presence (or lack) of scientific consensus in understanding the relevant hazards
- The capability of the Approving Authority to review and respond to a Flood Assessment Report
- Past precedent and/or the present state of local practice
- The complexity of the subject matter
- The degree of judgment incorporated in the flood assessment
- The apparent sufficiency of checking and review in preparation of the Flood Assessment Report
- The concept and scale of any Structural Mitigation Works proposed for mitigation
- The size of the at-Risk population, the nature of the Elements at Risk, and the extent of potential Consequences for the spectrum of Flood Hazard Scenarios being considered

For a QP to undertake advisory services that include reviewing another QP's work, the requesting Approving Authority should:

- be aware of the Engineers and Geoscientists BC Code of Ethics Principle 7, specifically item (c) from the *Code of Ethics Guidelines*, which states that an Engineering/Geoscience Professional should not, except in cases where review is usual and anticipated, evaluate the work of a fellow professional without the knowledge of, and without communicating with, that professional where practicable;
- provide the reviewing QP with any applicable bylaws, guidelines, and regulations for carrying out a flood assessment and/or preparing a Flood Assessment Report;
- explain the purpose of the review;
- define the scope of the review;
- provide relevant background information and reports;
- define any intended interaction the reviewing QP will have with the QP responsible for the Flood Assessment Report;

- review any documents prepared by the reviewing QP;
- if necessary, discuss any review documents with the reviewing QP; and
- adopt an appropriate means of communicating the work of the reviewing QP to the QP responsible for the Flood Assessment Report.

A QP undertaking advisory services should also enter into an appropriate professional services agreement with the requesting Approving Authority or the Client, as described in Section 2.2.1.

Before accepting the review assignment, the reviewing QP should consider whether there may be a conflict of interest and act accordingly (Engineers and Geoscientists BC Code of Ethics Principle 4), and if retained, conduct the review with fairness, courtesy, and good faith towards colleagues and provide honest and fair comment (Engineers and Geoscientists BC Code of Ethics Principle 7).

Following Principle 7, item (c) of the Guidelines to the Code of Ethics, the reviewing QP should, if appropriate and authorized,

- inform the QP who was responsible for the Flood Assessment Report of the review and the reasons for the review, and document in writing that the QP was informed;
- ask the QP who was responsible for the Flood Assessment Report if the reviewing QP should know about unreported circumstances that may have limited or qualified the flood assessment and/or the Flood Assessment Report; and
- contact the QP responsible for the Flood Assessment Report if the results of the review identify safety or environmental concerns, in order to allow this QP an opportunity to comment prior to further action.

The reviewing QP who provides the advisory service to the Approving Authority should submit a signed, sealed, and dated review letter or corresponding report that includes the following information:

- Limitations and qualifications with regards to the review
- Results and/or recommendations arising from the review

See Section 4.2 for more information on this additional level of review.

A QP review performed for an Approving Authority, as described above, does not constitute checking and review of the original Flood Assessment Report. Each Flood Assessment Report is to have appropriate checking and review prior to being submitted (see Section 4.1.5).

Occasionally, a QP is retained by an Approving Authority to provide a second independent flood assessment. This role goes beyond that of reviewing the work of the original QP. In such cases, the second QP should carry out sufficient office work, field work, analyses, and comparisons, as required, to accept full responsibility for his/her independent flood assessment.

3.0 GUIDELINES FOR PROFESSIONAL PRACTICE FOR FLOOD ASSESSMENTS

3.1 GUIDING PRINCIPLE

QPs are required to carry out activities to meet their obligations under the *Act*, including their primary duty to protect the safety, health, and welfare of the public and the environment.

3.2 OBJECTIVES

The objectives of a flood assessment may be guided by legislated requirements for subdivision approval, development permits, building permits, or floodplain bylaw variance or exemption. This section offers a practical approach to prepare flood assessments for the following:

- Obtaining building permits
- Subdivision developments
- Rezoning applications
- The sale or lease of Crown lands

These guidelines not only provide guidance to the Engineering/Geoscience Professional with regard to conducting such assessments, but also inform Approving Authorities so regulatory approaches may be improved over time.

3.3 OVERVIEW

This section provides guidance for meeting professional obligations for a QP commissioned to carry out flood assessments. The section closely follows the flow chart below (**Figure 2**). It is structured chronologically into the phases of the study including project initiation, regulatory considerations, consideration of Structural Mitigation Works, development review and Risk Assessment, and reporting. Generalities of the approach are presented in this section and specifics on the execution of the work are summarized in **Appendix D: Flood Hazard Assessments**, **Appendix E: Flood Risk Assessment**, and **Appendix F: Flood Assessment Considerations for Development Approvals.**

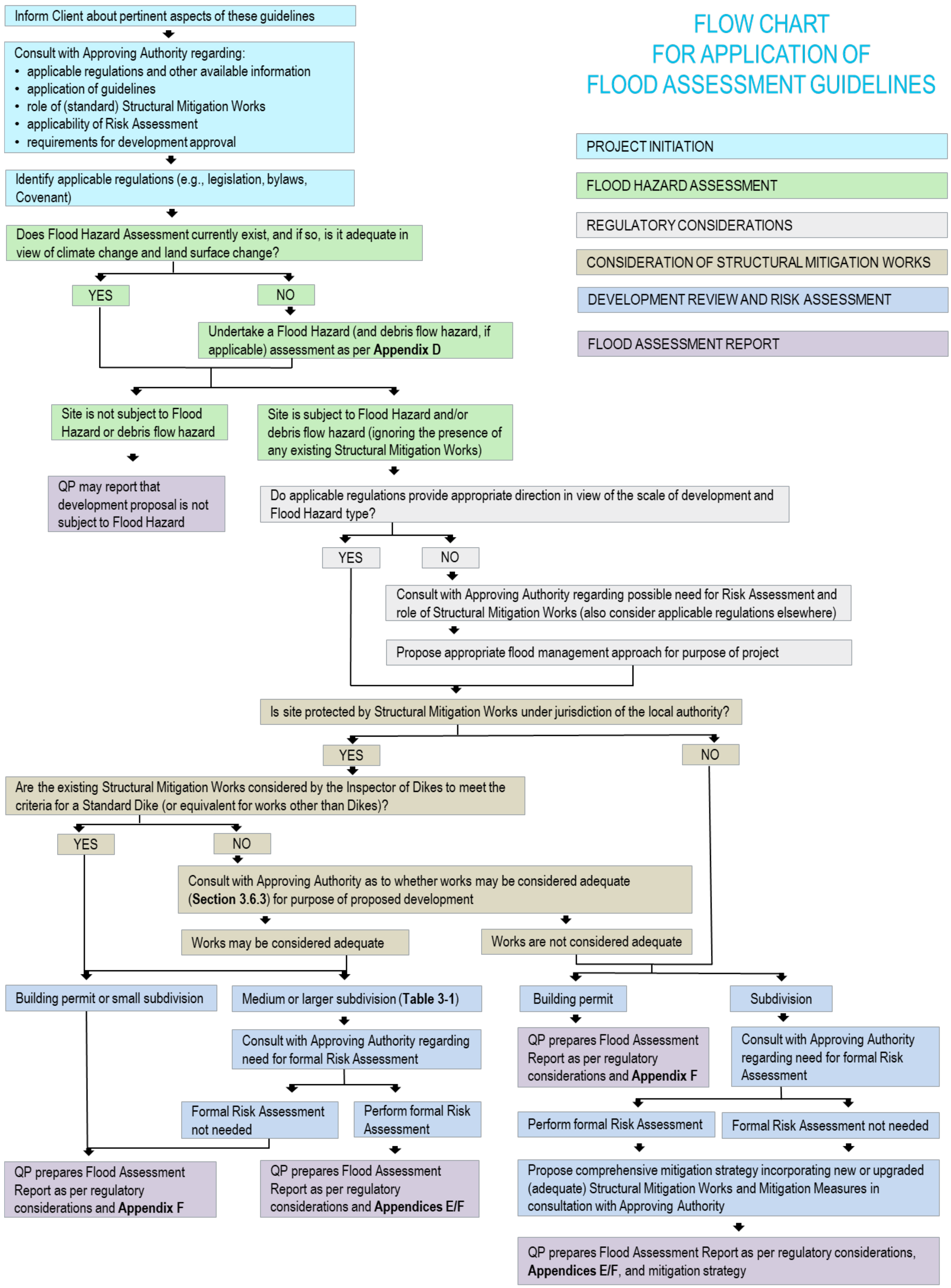

Figure 2: Flow chart for application of flood assessment guidelines

3.4 PROJECT INITIATION

At the onset of any flood assessment, the Client should be informed about these guidelines and how they apply to the desired development project. The role of the Approving Authority is defined in **Section 2.** The QP should consult with the Approving Authority at this stage to:

- confirm that the proposed project may be considered for approval;
- define the study area;
- obtain background information;
- clarify the application of these guidelines;
- clarify the role of Structural Mitigation Works (Standard Dike or otherwise);
- determine whether a level of flood safety (or any related standard) has been adopted;
- clarify the suitability and applicability of either a standard-based or Risk-based approach and consider the "Considerations for Development Approvals" in **Appendix F**; and
- clarify the requirements for a development approval.

3.4.1 STUDY AREA

The study area should be determined by the study objective, the Proposed Development area, existing and proposed assets to be protected, and the nature of the flood processes involved. The study area should not be limited to the Proposed Development area, and may include other sites, properties, or watershed areas that could potentially contribute to the Flood Hazard or be affected as a result of any changes to the flooding condition that may be created by the Proposed Development. Where deemed relevant, consideration should be given to the potential impact of Flood Hazard issues that cross jurisdictional boundaries. The QP should also consider hazards associated with flooding from all adjacent hydraulically-linked sources. All of these issues will determine the extent of the study area.

3.4.2 BACKGROUND INFORMATION

It is the responsibility of the QP to obtain and review the available background information. Prior to field work, the QP should collect, possibly with the help of the Client or Approving Authority, existing information associated with the study area. The QP should consider the items in **Table 1** as possible sources of information.

Previous Flood Assessment Reports from neighbouring areas can be useful to the QP, and local and provincial governments are encouraged to make such reports available to the QP since they are not always publicly accessible. In using such reports, it is important to respect any expressed limitations of use (typically, previous reports by others are to be used only for the project purpose at the time of preparation and are not to be relied upon for other projects and purposes).

The QP should check whether there is a Covenant pertaining to flooding registered against the land title. It may also be beneficial to check whether Covenants are registered against other land titles in the vicinity.

Information can also be obtained from published and non-published sources from federal and provincial agencies, local governments, and other local sources. Newspaper archives may provide valuable information on past flooding, but the credibility of such sources will need to be scrutinized.

Table 1: Background Information for Flood Assessments

CATEGORY	SOURCES OF INFORMATION
PREVIOUS ASSESSMENTS	• Flood Hazard maps and reports, terrain maps • Floodplain maps and Alluvial Fan maps • Other resource inventory maps and reports • Previous Flood Assessment Reports • Relevant geological and geotechnical reports • Sedimentation records and reports • Hydrogeology reports
MAP INFORMATION	• Large- and small-scale topographic and cadastral maps • LiDAR maps • Channel, lake/ocean bathymetry • Maps that show existing and proposed land use, infrastructure such as transportation routes, utilities, surface drainage, in-ground disposal of stormwater, and in-ground disposal of wastewater • Air photos from different years (historical to present) and scales • Bedrock and surficial geology • In forested areas of the watershed: forest cover maps, forest development/stewardship plans, watershed assessments, past and proposed forest road Construction and logging, and other relevant logging-related information
LEGAL DATA, ELEMENTS AT RISK	• Locations and characteristics of existing development, including residential and non-residential, and associated infrastructure locations and characteristics of Proposed Development (if relevant)
HISTORIC DATA	• Evidence and history of flooding in the area • Newspaper articles • Historic information available from local libraries • Data from Water Survey of Canada hydrometric stations and Meteorological Service of Canada climate stations • Hydrometric and climate data collected by municipalities, BC Hydro, Ministry of Forests, mining companies, and others • Evidence and history of wildfires and insect infestations in the area

For flood assessments of larger areas, obtaining project-specific information, in addition to existing background information, may be useful. Examples are air photos, high-resolution satellite imagery, and LiDAR images that can be used for topographical mapping and geomorphological or geological mapping. Regional flood frequency curves, intensity-duration-frequency (IDF) rainfall graphs and other existing information on flood and rainfall frequencies should also be obtained.

Background information should be reviewed prior to undertaking subsequent phases of the flood assessment, and the QP should consider the reliability of such information. If information is known to be available and the QP did not (or was not able to) obtain it, the circumstances should be included in the Flood Assessment Report.

In or near urban centres, a wealth of information is available that can help the QP. This information can span diverse fields such as climatology, meteorology, geology, and flora, and can include information on fire history, land use, previous flood reports, media reports, and mapping of different variables at a variety of scales.

These guidelines include references that can be used when checking the reliability of the relevant background information. The references can be used to confirm that the background information gathered is sufficiently comprehensive for the specific flood assessment being completed.

3.4.3 LEVEL OF EFFORT

The level of effort for a flood assessment depends largely on the size of the development and the scale/complexity of the potential Flood Hazard (that is, whether there is Risk of injury or death).

At the low end of the development spectrum scale, an example could be a request to relax a bylaw floodplain setback for a house located adjacent to a small creek or a river channel. In this case, the level of effort would be very site-specific, and possibly limited to a short field visit by the QP followed by a qualitative flood assessment. Details on what such an assessment may involve are provided in Appendix D: Flood Hazard Assessments and Appendix F: Flood Assessment Considerations for Development Approvals.

At the middle of the development spectrum scale, an example could be a study of a steep creek. Here, the contributing study area may be a 2 km^2 size watershed, while the local study area may be a small number of buildings situated on the creek fan. Peak flows would need to be determined for floods and/or for debris floods and debris flows, as well as total debris volumes for the latter two processes if they are considered a possible hazard. The watershed would be examined for land use changes, forest road stability, hydrologic effects of ski area developments, and perhaps the potential effects of insect infestations or stand-replacing forest fires. The fan area would need to be studied with respect to the effects of the Hydrogeomorphic Process in terms of hazard frequency, magnitude, and intensity, and, where appropriate, the potential Consequences and Risk to people and infrastructure on the fan.

At the high end of the development spectrum scale, an example could be a study of Flood Hazard for a new community of several hundred homes. The study area can be categorized into a contributing study area and the local study area or consultation zone (the designated development zone). The contributing area would need to be considered for flood frequency analysis and would need to account for long-term changes in the watershed and, where applicable, the adjacent ocean. The former involves an analysis of changes in snow distribution and snow-water equivalents, synoptic weather pattern, and land use. The latter requires a review of anticipated sea level rise, changes in the frequency or magnitude of storm surges, and, where applicable, possible submarine delta front landslides and potential for bore generation.

3.5 ANTICIPATING CLIMATE CHANGE AND LAND SURFACE CHANGE

These guidelines acknowledge that global climate change is affecting the hydrologic regime in BC, and encourage the QP to include climate change considerations together with land surface changes in flood assessments, where appropriate.

3.5.1 THE PROBLEM

Global and regional climates are now changing on time scales typical for many engineering and land use projects. Since climate and hydrology are closely linked, the prospect for changed hydrological conditions must be incorporated into estimates of future Flood Hazards. Furthermore, the changeable condition of the land surface may influence runoff formation and flood potential in significant ways. Design for protection against future flooding must consider these factors.

Natural and anthropogenic causes of climate change are complex and difficult to determine, so predictions of change are subject to significant uncertainty. For this reason, the term "projection" is favoured in these guidelines. It is even more difficult to predict the changes in factors that can affect flooding at the watershed scale, because local factors (for example, land use change, insect infestations, stand-replacing forest fires, widespread windthrow) are superimposed on regional estimates of climate change.

Appropriate professional practice requires that the effects of climate change be considered when carrying out FHAs and/or FRAs, and that significant potential changes in land surface conditions be considered as much as is foreseeable. Consideration of such factors will allow Approving Authorities and other provincial and federal environmental agencies to ensure that appropriate climate change effects are incorporated into Flood Hazard and land development decisions.

This section identifies various methodologies and resources that can be accessed for incorporating the specific effects of climate change into Flood Hazard and/or Risk Assessments. A more detailed discussion is provided in **Appendix G: Professional Practice in Light of Climate Change and Land Surface Condition Impacts on Flooding**.

The following summarizes the principal climate change effects relating to hydrology and hydro-geomorphic processes currently expected to be experienced in BC by the end of this century:

- Average temperatures are expected to increase by approximately 2.8°C, warmer than most of the warmest years in recorded history (Rodenhuis et al. 2009).
- The average annual precipitation is expected to increase between 6% and 17%, with the increase primarily occurring during winter months and in the mountains (Province of BC 2007).
- For larger watersheds, surface runoff is expected to increase in the winter months, an earlier spring freshet is expected, and drier conditions are expected in the summer months.
- For smaller watersheds, rain-dominated floods are expected (Schnorbus et al. 2010) with potentially higher peak flows due to increased storm precipitation intensity.
- A net sea level rise of as much as 1 m is projected to occur along the BC coast (Province of BC 2007; Ausenco Sandwell 2011).

- Warmer winters are expected to raise winter snowlines; however, high elevation snowpacks may increase in depth because of wetter conditions.
- Increases in winter precipitation and precipitation intensities will result in increases in the likelihood of shallow landsliding in coastal BC, although this effect will remain significantly below that of, for example, clearcut logging (Jakob and Lambert 2009).
- Glaciers will continue to reduce their mass, in the northwest mostly by thinning, and in central and southern BC dominantly by frontal retreat (Moore et al. 2009); high-elevation snowpacks may maintain many glaciers in a new equilibrium but with reduced area (Moore et al. 2009).
- A changed climate is expected to shift the ranges of forest species and result in an increased incidence of pest infestation.
- Increases in temperature, lightning strikes, and summer droughts will increase the potential for forest fires (Province of BC 2007).

Some climate change effects lead to land cover changes such as increased frequency or severity of forest fires or insect infestations. However, increased urbanization and sealing of pervious ground, as well as diking, can lead to significant changes in the runoff regime that need to be incorporated in flood assessments.

Additional details are provided in **Appendix G: Professional Practice in Light of Climate Change and Land Surface Condition Impacts on Flooding**, Sections G2 and G3.

It is expected that these changes will result in an increase in the frequency of floods in small- and medium-drainage basins that will be dominated by rainfall runoff. Flood events will typically be more intense (higher peak flows, flow velocities, flow depths, areas inundated) and of a larger magnitude (flow volume). Large drainage basins in which the hydrology is dominated by the spring snowmelt freshet may experience diminished flood magnitude in many years and more frequent low flows. However, the potential for a historically high flood will remain, since an exceptionally large winter snow accumulation followed by a sudden spring heat wave might still create extremely high runoff.

Climate change means that hydrometeorological and hydrological data sequences will continue to change, so traditional methods of predicting the frequency of floods and levels of flood flows based on historical records (assumption of data stationarity) are increasingly unreliable (Milly et al. 2008). Hydro-climatological model-based forecasting of flood flows will become more important, but its appropriate use will require a better understanding of the processes causing climate change.

Hydro-climatological modelling is an expert activity; the responsibility of the QP is to be familiar with current model-based projections, including the specified precision of those projections. Professional judgment must be exercised to extract the most appropriate design parameters for particular projects from currently available climatic projections. Results should be compared with the historical record to determine whether they are plausible for the project site.

3.5.2 SOURCES OF INFORMATION ON CLIMATE CHANGE

The Pacific Climate Impacts Consortium (PCIC) is a government-supported research group based at the University of Victoria that is tasked with continuing study of climate change in BC. The mandate of the group includes projecting future trends in runoff. Their reports are archived online (Table 2) and should be consulted before making estimates for future flood flows.

The PCIC and MFLNRORD, along with the Ministry of Transportation and Infrastructure and the Ministry of Agriculture, are working with BC Hydro and Rio Tinto Alcan under a formal agreement to make long-term meteorological data available for professional users involved in climate change analysis and adaptation. The mandate of this program is to collaborate on collection of climate data in BC, discussing everything from monitoring technologies and data quality to data sharing. PCIC is developing a data portal, which will provide access to observed time series of temperature, precipitation, and other climate variables for BC extending more than a century into the past, and including stations operated by all the partners in the program. An overview of the Climate Related Monitoring Program is available online (Table 2).

The Pacific Institute for Climate Solutions (PICS) is a useful technical resource focussing on climate issues and solutions, with an emphasis on economic and social implications of climate change. The PICS News Scan provides a weekly summary of the major climate-change related science, technology, and policy advances of direct relevance to BC and Canada and, more generally, to businesses, government, and civil society. QPs engaged in Flood Hazard and Risk analyses should regularly refer to the PICS website (Table 2).

The University of Washington Climate Impacts Group is an interdisciplinary research group studying the impacts of natural climate variability and global climate change (“global warming”) in the western United States, with most work focused on the Pacific Northwest. Reports from this group are relevant to the heavily populated areas of southern BC and can be found online (Table 2).

Ouranos is a consortium of scientists and organizations based in Quebec with a mandate to study climate change and social and economic adaptations. Ouranos has resources that can be found online (Table 2).

The Compendium of Forest Hydrology and Geomorphology in British Columbia (Pike et al. 2010) provides an authoritative review of forest hydrology, including expected effects of climate change.

Table 2 below and Section 6 include online links to the above information and other useful sources of information and reports.

Table 2: Sources of Information on Climate Change

ORGANIZATION	WEBSITE ADDRESS
Environmental Reporting BC	www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/reporting/environmental-reporting-bc
Climate Related Monitoring Program (CRMP)	www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/climate-related-monitoring
Environment and Climate Change Canada	canada.ca/en/environment-climate-change
Ouranos: Consortium on Regional Climatology and Adaptation to Climate Change	ouranos.ca/en
Pacific Climate Impacts Consortium (PCIC)	pacificclimate.org
Pacific Institute for Climate Solutions (PICS)	pics.uvic.ca
University of Washington Climate Impacts Group	cig.uw.edu

3.5.3 ANALYTICAL CONSIDERATIONS

Current climatic projections for future precipitation are mainly expressed in terms of expected changes in its amount. However, precipitation intensity is the critical input for making flood projections, especially in smaller drainage basins with short response times. IDF curves are a standard method to estimate the probability that a given average rainfall intensity will occur at various event return periods. IDF curves are based on historic precipitation at a particular climate station and, like flood frequency analyses, depend on the statistical principle of data stationarity. Given that such data stationarity may no longer be valid under consideration of climate change scenarios, IDF curves based on past conditions should be interpreted with caution when used as design inputs for long-term (>30-year design life) infrastructure.

Currently, the short-term and local precipitation data required to construct IDF curves cannot be discerned by regional climate models, which typically report results at monthly or longer time and regional spatial scales. Methods to overcome this problem include the use of weather scenarios (Prodanovic and Simonovic 2007) and correlation of rainfall intensity with monthly rainfall totals (BGC 2006; 2010). A basis for adjusting IDF curves is presented by Burn et al. (2011) in an analysis of rainfall totals for 1 to 12 hours for long-term recording stations in BC. See **Appendix G: Professional Practice in Light of Climate Change and Land Surface Condition Impacts on Flooding** for further details.

Most projections of future hydroclimate are couched in terms of changes in mean conditions and, possibly, expected extremes. If one expects only a shift in the mean, forecasts based on past experience might be used if consideration is given to changing frequencies of events, but if variance also changes, then future distributions of events will be quite unlike those of the past. Given the uncertainty associated with model projections, models are run repeatedly with small perturbations of input conditions to determine the range of sensitivity of the model. Projections of future climate or runoff are best assessed in terms of the mean and range of outputs from an ensemble of model runs. Such results must be obtained from climatologists who specialize in model analysis, from the sources listed in **Section 3.5.2** or from specialized consultants. In the absence of applicable hydroclimate model results, magnitude-frequency analyses based on recent experience (approximately 30 years) may remain valid for short-term (<30 years) projections, provided no trend is evident in the historical sequence of flood flows.

Practitioners should recognize that the effect of changes in land use, hence storm runoff, may have to be superimposed on projections of hydroclimatic change, to arrive at the most appropriate estimates of future flood flows. This is particularly important in urbanizing areas, where dramatic changes in storm runoff accompany land use conversion. Extensive knowledge has been generated on this topic in urban, agricultural, and forest environments, and it should be considered as an additional adjustment to be made to the hydroclimatic projection. It is also important in areas where extensive changes are occurring in forest conditions, such as widespread insect or fungus-induced die-off and extensive forest harvest.

Historical records should continue to be examined as a source of valuable information. Analysis of the record for trends in magnitude and frequency of flood events should be the first procedure in determining a Design Flood for future protection measures (see Appendix G).

The following procedures are recommended when it is necessary to project expected flood magnitudes for design of protective works or mitigation procedures:

- By time series analysis of historical precipitation and flood records, determine whether any statistically significant trend is currently detectable in storm precipitation and in flood magnitude and/or frequency.
- If the subject water course has limited or no record, analyze nearby records from drainage basins of similar character.

If no historical trend is detectable, follow one of these recommended procedures:

- When IDF curves are to be applied, review current IDF curves and apply results of stormwater runoff modelling appropriate for expected land surface conditions.
- When local or regional streamflow magnitude-frequency relations are used, apply a 10% upward adjustment in design discharge to account for likely future change in water input from precipitation.

In the analyses described above, it should be recognized that, while climatological forecasts are couched in terms of expected changes in total or seasonal precipitation, it is storm-period inputs that are of paramount importance for flood planning. However, simple correlations can be constructed, using historical data, between precipitation totals (such as monthly precipitation) and the variable of interest, such as short-period rainfall intensity; these could become the basis for some estimates of possible future conditions.

If a statistically significant trend is detected, follow one of these recommended procedures:

- In large (seasonally driven) basins, adjust expected flood magnitude and frequency according to the best available regionally downscaled projections of annual precipitation and snowpack magnitude, assuming that the precipitation increment will all be added to peak runoff. For snowpack, compare projections with historical records of runoff from snowpacks of similar magnitude. Consider potential effects of plausible land use change. Combine the various effects if considered necessary.

- In smaller basins, adjust IDF curves for expected future precipitation climate and apply the results of stormwater runoff modelling appropriate for expected future land surface conditions.
- Adjust expected flood magnitude and frequency according to the projected change in runoff during the life of the project, or by 20% in small drainage basins for which information of future local conditions is inadequate to provide reliable guidance. Consider potential effects of land use change in the drainage basin.

The QP must be aware that all estimates of climate and hydrological trends are tentative and changes must be expected. It is the responsibility of the QP to be aware of current best projections.

3.6 FLOOD ASSESSMENT PROCEDURES

3.6.1 FLOOD HAZARD ASSESSMENT

Regardless of whether a standard-based approach and/or a Risk-based approach is used in a flood assessment, it is important to undertake an appropriately detailed FHA.

An FHA characterizes the flood process, identifies the existing and future Elements at Risk, and determines the Flood Intensity characteristics that may damage the Proposed Development.

Provincial, regional, or local standards or bylaws may specify a flood return period for which mitigation should be designed. **Appendix D: Flood Hazard Assessments** provides supplemental information in this regard. A Freeboard allowance is typically added to account for uncertainties in the analysis.

Appendix D provides details as to the requirements and applications for different development types. It differentiates between conventional floods and unconventional floods, including debris flows, landslide dam, and glacial outbreak floods.

The FHA will determine whether the Proposed Development is subject to flood, debris flood, debris flow, or other hazards. If it is not, the QP may summarize a finding of “no Flood Hazard” in the Flood Assessment Report. In general, sites on fan or floodplain landforms would not be considered “no Flood Hazard” areas.

3.6.2 REGULATORY CONSIDERATIONS

Flood assessments that pertain to development approval must comply with legislative requirements (federal and/or provincial). Flood Assessment Reports must also comply with local bylaw requirements (recognizing that they typically include a formal process for variance or relaxation). Legislative and local bylaw requirements may evolve over time, requiring that the QP remains informed of changes and updates.

Flood assessments must also comply with existing Covenants registered against a land title, unless discharge or modification of the Covenant can be achieved through a formal process (this will involve a lawyer, and consultation with the parties to the Covenant).

While legislation and bylaw requirements provide some guidance for flood assessments, the QP should consider the sufficiency and appropriateness of such requirements according to the type and scale of the proposed project, as well as the nature, frequency, intensity, and potential Consequences of the Flood Hazard. In cases where appropriate regulations are absent or are considered insufficient, the QP should consult with the Approving Authority to determine an appropriate approach for the Proposed Development.

During such a consultation, the QP should complete the following actions:

- Confirm that the Approving Authority is aware of these guidelines
- Encourage the Approving Authority to conduct work that may lead to an appropriate bylaw or land use regulation
- Encourage the Approving Authority to consider establishing a tolerable limit for flood safety (which could be standard-based and/or Risk-based)
- Inform the Approving Authority of some standards from elsewhere that may be applicable
- Try to obtain direction for the flood assessment to be performed

Definitions of different development types as used in **Figure 2** and elsewhere in these guidelines are provided in **Table 3**.

Table 3: Definitions of Different Development Types

DEVELOPMENT TYPE	EXAMPLES
Building Permit	Renovations, expansions, new single house, new multi-family house
Small Subdivision	Subdivision into separate lots (3 to 10 single family lots)
Medium Subdivision	Subdivision into ≥10 to 100 single family lots, new subdivisions
Large Subdivision	>100 single family lots, new subdivisions
Very Large Subdivision (new community)	>100 single family lots, new subdivisions

3.6.3 CONSIDERATION OF STRUCTURAL MITIGATION WORKS

Structural Mitigation Works may include Dikes, bank protection works, debris barriers, and other works. The presence of a Standard Dike or other Structural Mitigation Works protecting a property for which a flood assessment is being undertaken is a key consideration for development approval. Protection of a development by a Standard Dike implies that the local authority is responsible for Dike maintenance, upgrading, and repair. This provides a high level of assurance to property owners and residents that the Dike protection is to a high standard. However, it is important for QPs to recognize in flood assessment work that a Standard Dike can potentially be breached or overtopped during extreme events. Therefore, Mitigation Measures remain important, and Risk Assessment principles may still be warranted.

In some cases, existing Structural Mitigation Works may not meet all applicable standards, but may still be considered adequate for the project purposes. In the event of uncertainty, a QP should consult with the Approving Authority and/or the Inspector of Dikes to determine whether existing Structural Mitigation Works meet current MFLNRORD or local government standards.

The flow chart in **Figure 2** above illustrates alternative procedures, depending on whether the existing Structural Mitigation Works are considered to meet the criteria of a Standard Dike. **Appendix F: Flood Assessment Considerations for Development Approvals** outlines a range of approaches that can be undertaken, depending on the scale of development and whether Structural Mitigation Works can be classified as standard or adequate.

For building permit or small subdivision developments that are protected by a Standard Dike, the approach outlined in **Appendix F** may be used in a Flood Assessment Report. In most cases, Mitigation Measures will be defined without the need for a formal Risk Assessment.

For a medium or larger subdivision that is protected by a Standard Dike or other Structural Mitigation Works, the QP should consult with the Approving Authority regarding the applicability or need for a formal Risk Assessment and proceed accordingly (see **Appendix F**). If no direction is received, a QP may propose a standard-based approach or a Risk-based approach that is appropriate to the situation. A proposed approach should be submitted to the Approving Authority for consideration and approval. In the event of a Risk-based approach, it is important to note that many of the provisions described in **Appendix F** will remain applicable.

For a development project on a fan or floodplain that is not protected by a Standard Dike or equivalent Structural Mitigation Works, the QP may advise the Client to construct Structural Mitigation Works. Some recommendations for flood protection measures for building permits in the absence of Structural Mitigation Works are described in **Appendix F**.

For a subdivision on a fan or floodplain that is not protected by a Standard Dike or equivalent Structural Mitigation Works, the QP should consult with the Approving Authority regarding the applicability or need for a formal Risk Assessment and proceed accordingly (see **Appendix F**). Some limited provision is made for subdivision approval in such areas in the absence of standard works. However, unless it is acceptable to the Approving Authority, a subdivision requires a comprehensive mitigation strategy that incorporates standard Structural Mitigation Works as part of the development. Unless it is acceptable to the Approving Authority, this provision for standard works is not conditional on the results of a Risk Assessment.

3.6.4 COMPREHENSIVE MITIGATION STRATEGY

The preferred components of a comprehensive mitigation strategy are as follows:

1. Outline a comprehensive approach to mitigating flood-related hazards appropriate to the nature and scale of the proposed project.
2. Provide engineering designs and specifications for any Structural Mitigation Works or non-structural strategies proposed as a primary level of protection.
3. Identify an appropriate maintenance authority (generally the local government) for any proposed Structural Mitigation Works.
4. Define secondary Mitigation Measures within the Proposed Development area.
5. Consider the potential for impacts to neighbouring properties and transfer of Risk.
6. Document the need for land tenure in favour of the maintenance authority.
7. Outline future operation and maintenance measures by the maintenance authority in order for the works to be effective over the long-term.

Flood assessments that propose Structural Mitigation Works should follow the approach outlined above.

3.7 STANDARD-BASED AND RISK-BASED APPROACHES

3.7.1 STANDARD-BASED APPROACH

A standard-based approach for flood mitigation typically involves selection of an appropriate design return period. For floods, the 200-year return period (Q_{200}) is traditionally used in BC (**Appendix F: Flood Assessment Considerations for Development Approvals**). For debris flood and debris flow hazards, higher return periods are typically selected. There are no such criteria for the assessment of erosion hazards.

A typical application is the use of flood frequency analysis to determine the Q_{200} flood magnitude on a river. This is followed by numerical analysis of the cross-section of the river. If the results find that the cross-section is not sufficient to carry the Design Flood plus Freeboard, the design may have to be upgraded or Dikes may have to be constructed to meet the required standard. After such an upgrade or Construction, and after implementation of the appropriate Flood Construction Level (FCL), it is assumed that safety requirements (up to the design level) have been met. By considering additional provisions for Mitigation Measures (**Appendix F**), the development is typically may be deemed approvable on the basis of a Flood Assessment Report and on acceptance by the Approving Authority.

The adoption of a standard-based approach includes an element of Risk. For example, the 200-year return period Design Flood assumes that the residual Risk of a higher magnitude flood, even one that would most likely overcome existing or proposed flood mitigation strategies, is a Risk that is tolerable to the Client, Approving Authority, and society at large. A standard-based approach also includes implicit Risks from the possibility that the magnitude or frequency of the Design Flood is uncertain, that the frequency-magnitude relation may change during the lifetime of the Proposed Development, and even that different Hazard Scenarios might incorporate different levels of residual Risk. Therefore, all flood assessments, even the standard-based approach, include the element of Risk evaluation, whether explicitly analyzed or implicitly assumed.

3.7.2 RISK-BASED APPROACH

In contrast to the standard-based approach, a formal Risk-based approach systematically quantifies flood Consequences, which are combined with Hazard Scenarios to estimate Flood Risk. Human safety and economic and environmental losses are typically the most important Consequence categories, but loss of cultural values and mental stress associated with property loss can also be included.

The resulting Risk estimates are then evaluated by comparing them with existing local or provincial Risk tolerance criteria or, in the absence of those other criteria, with applicable international criteria.

Figure 3 summarizes how hazard and Consequences are combined in a comprehensive Risk Assessment.

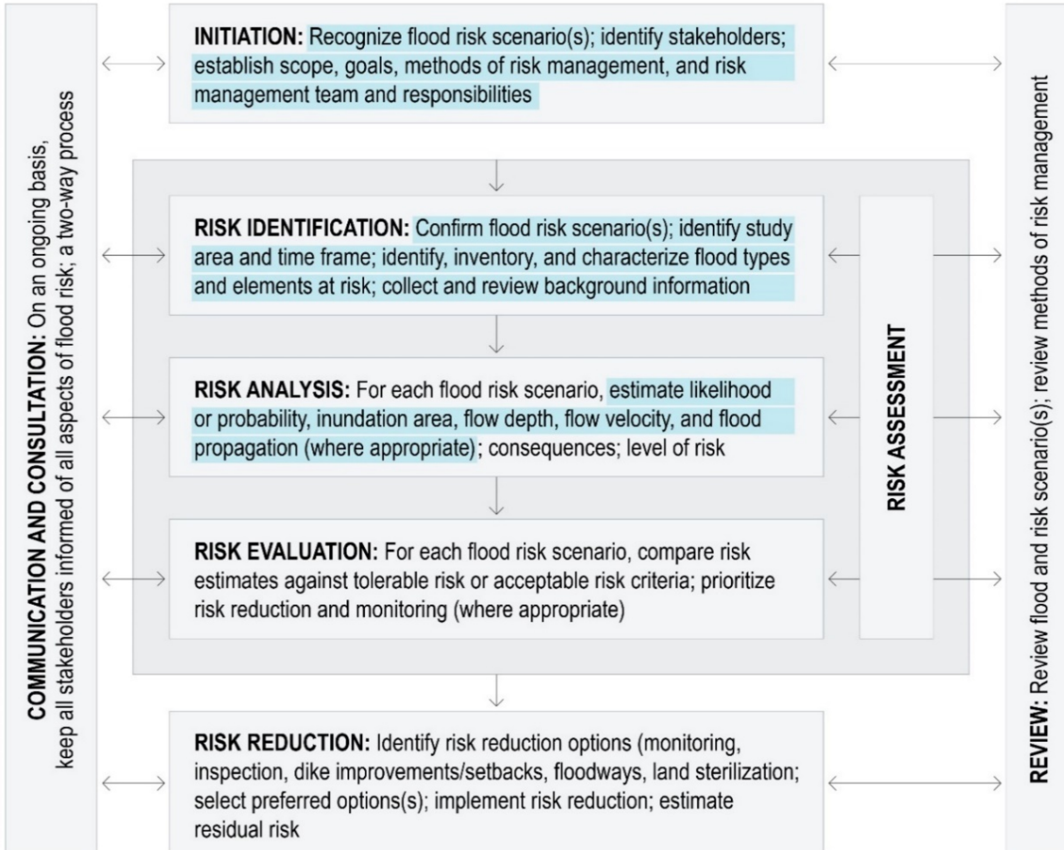

Figure 3: Generalized Risk-based approach for Flood Risk management (modified from CAN/CSA-Q850-97). Elements of Flood Hazard Assessment (FHA) are highlighted in blue.

3.7.2.1 Risk Tolerance

At this time, BC has not developed formal Flood Risk tolerance criteria. As noted above, professional practice standards have emerged that imply some level of Risk tolerance. These have been codified in existing guidelines (Province of BC 2004). However, those standards make little provision for changes in either hazard or Consequence, and may not be suited to environments where total Risk is increasing due to upward trends in either Flood Hazards or flood Consequences (Jakob and Church 2012).

Risk tolerance must be viewed over varying spatial scales. For example, significant flood damage to a single home in an extreme flood may be tolerable to society, as this constitutes hardship mainly to the owner and may not have a significant effect on society at large. However, if many homes are impacted, losses are increasingly deferred to taxpayers. For extreme losses (in the billions of dollars), the total Risk for all flood Consequences may become intolerable to individuals and society alike, particularly when flood Consequences directly or indirectly affect a large portion of the population. An example would be a catastrophic flood on the lower Fraser River.

Current flood (Risk) management in BC does not account systematically for cumulative losses, as flood management has largely been transferred to municipalities or Regional Districts. Within the provincial government, only Approving Officers from the Ministry of Transportation and Infrastructure and lands officers from the MFLNRORD still regulate land use. Currently, economic Risk to the individual and local governments is addressed through the flood damage compensation program with Emergency Management BC. If the local government and/or individual builds to a Q_{200} FCL and meets minimum erosion setbacks, and a flood larger than Q_{200} occurs, then disaster financial assistance is available from the provincial and federal governments.

This issue is a regulatory one that cannot be addressed by a QP. However, this discussion should be considered when defining the area of the flood assessment and the potential effect on the overall Flood Risk for the larger region. This concept has been used for landslides (Hungr and Wong 2007).

The geographic area considered for a FRA is the consultation zone, which is defined as "a zone that includes all existing and Proposed Development and that contains the largest credible area potentially affected by a flood or related phenomenon." Application of this definition would at least allow approving agencies to consider total Risk in their assessments.

Further information on Risk tolerance and Risk Evaluation is provided in Appendix E: Flood Risk Assessment. At the end of a flood assessment, the QP may be required to state that "the land may be used safely for the use intended." With this statement, the QP declares that the Risks and Consequences of a given Hazard Scenario are tolerable or acceptable[4]. This presents a significant paradox: a statement of Risk tolerance or acceptance cannot be made by a QP but only by the regulatory agency, unless the owner wishes to design and construct to higher safety standards. This statement is required through current regulations (see Appendix C: Current Flood Management Legislation and Guidelines in BC). Engineers and Geoscientists BC recommends that "safety" be clearly defined by the QP in the flood assessment.

3.7.3 CONSIDERATIONS FOR DEVELOPMENT APPROVALS

Appendix F outlines a practical approach for development approvals in Flood Hazard areas. These provisions may apply for both for the standard-based approach and the Risk-based approach, or may be the only provisions required in the flood assessment.

3.7.4 SELECTION OF APPROACH FOR FLOOD ASSESSMENT REPORT

Preferably, Flood Assessment Reports should follow either the published requirements of an Approving Authority or directives received from Approving Authority staff. If no such requirements or directives exist, a QP should consult with the Approving Authority to determine whether a standard-based or Risk-based approach should be implemented and proceed accordingly. If direction is not received, a QP may propose an appropriate approach that may be standard-based and/or Risk-based.

If a QP proposes a standard-based approach in the absence of an Approving Authority's requirement or directive, some general guidance is as follows:

- A standard-based approach should not incorporate less than a 200-year design return period for any flood-related hazard.

[4] "Tolerable" risks are those that society can live with given the perceived or real benefit that emerges by developing in a hazardous area. However, these risks require monitoring and usually call for further reduction. "Acceptable" risks are those that are broadly accepted by society and typically do not require further reduction.

- Debris flow and debris Flood Hazards should be subject to greater than a 200-year design return period (at least a 500-year return period, preferably a 2,500-year return period, as discussed further in **Appendix D: Flood Hazard Assessments**).
- Creek-related hazards having greater than a 10,000-year return period can generally be considered sufficiently improbable to not require mitigation.
- It is important to recognize that some level of residual Risk will remain after mitigation, regardless of which design return period is adopted.

If a QP proposes a Risk-based approach in the absence of an Approving Authority's requirement or directive, some general guidance is as follows:

- Risk tolerance and Risk acceptability criteria for life loss Risk should be based on those from another comparable jurisdiction, as considered appropriate to the circumstances.
- Hazard probabilities having greater than a 10,000-year return period may be excluded from the Risk Assessment and appropriately considered a residual Risk.
- For subdivision and new community developments, standard Structural Mitigation Works should be provided to the satisfaction of the Inspector of Dikes and the Approving Authority, in addition to any measures to meet the Risk tolerance standards from the Risk Assessment.

In either case, appropriate secondary Mitigation Measures (such as building elevation) should be proposed on the basis of local considerations, the flood assessment and the considerations in **Appendix F: Flood Assessment Considerations for Development Approvals**.

While the QP may propose these two approaches in the absence of an Approving Authority's requirement or directive, it remains prudent to appropriately work with the Approving Authority during preparation of the Flood Assessment Report, so the final Flood Assessment Report is likely to be acceptable to the Approving Authority.

3.8 FLOOD ASSESSMENT REPORTS

This section contains a list of issues that may be included in a Flood Assessment Report. A Flood Assessment Report may be an FHA, a Risk assessment, a flood mitigation assessment, or some combination of these. The points below provide guidance on the key elements of reporting on these different assessments.

The QP is responsible for conveying the level of effort to be applied, which will ensure the Approving Authority understands the basis for choosing a particular analytical method. The level of documentation in a Flood Assessment Report should be sufficient to ensure repeatability of the work. In addition, sufficient documentation must be provided in the report so reviewers can understand how the QP arrived at his/her conclusions.

Flood Assessment Reports should be accompanied by drawings, figures, sketches, photographs, model results, test hole or test pit logs (where applicable), laboratory test results, other tables, and other supporting information, as required. Graphic information should be consistent with the information in the text. Maps or plans should delineate the contributing area and the consultation zone in relation to existing and Proposed Development.

The Flood Assessment Report should be clearly written and contain sufficient detail to allow non-expert readers, including the Client, Approving Authority, and others reviewing the report to understand the methods, information used, and supporting rationale for conclusions and recommendations, without necessarily visiting the property or site. Flood Assessment Reports are frequently included as part of a Covenant on the land title, and should be written accordingly.

All work incorporated in a Flood Assessment Report must be appropriately checked and reviewed in accordance with Section 4.1.5 of these guidelines. Note the requirement for this review to be performed by another appropriately qualified QP. See Section 4.2 for a discussion of additional levels of review that may apply.

3.8.1 FLOOD HAZARD ASSESSMENT

A Flood Assessment Report outlining an FHA could be structured in the following way (see also Appendix D: Flood Hazard Assessments):

1. Introduction and objectives, definitions of qualitative terms, technical terms, concepts and variables, information as specified in the agreement with the Client, or as required in jurisdictional guidelines
2. Study area with a legal description of the subject property (consultation zone) and a listing of all Elements at Risk and location map or description of the consultation zone relative to floodplains, alluvial/colluvial fans and relevant geomorphic features, terrain or physical description of the contributing area, existing flood/erosion protection, structures, roads, businesses, infrastructure and surface drainage
3. Description of background information available, collected and reviewed, and its relevance
4. Recognition and characterization of flood processes (e.g., rainfall/snowmelt generated floods, ice related floods, debris floods, debris flows, glacial lake outburst floods, composite processes) within and, if required, beyond the development boundaries (see Appendix A: Floods and Flood-Related Hazards in BC for descriptions of flood types)
5. Description of methods of FHA and level of effort
6. Reporting of results of the FHA with Flood Hazard maps showing, for example, area inundated, flow depths and flow velocities for different Hazard Scenarios
7. Conclusions including, if applicable, a local level of partial Risk tolerance
8. Recommendations, if requested and as required, to mitigate the Flood Hazards and for further work
9. References including maps and air photos, reports, manuals, guidelines, and scientific papers
10. Limitations and qualifications, assumptions, error limits and uncertainties of the hazard assessment, and time limitation or a condition statement which would stipulate criteria for establishing when the assessment is no longer valid
11. Consideration of land use and climate change

3.8.2 FLOOD RISK ASSESSMENT

Typically, a Flood Assessment Report outlining an FRA should include the following elements, in addition to those listed above for an FHA; however, this depends on the level of Risk Assessment being undertaken (see also Appendix E: Flood Risk Assessment, Table E-2):

- A local, provincial or federal level[5] of Flood Risk tolerance for comparison with determined Risk values
- Results of the FRA presented in numeric format and as Vulnerability and/or Risk maps
- Recommendations, if requested and as required, to reduce the Flood Risks
- An estimate of the associated residual Risks if the recommendations are implemented
- Limitations and qualifications, assumptions, error limits, and uncertainties of the Risk Assessment, and time limitation or a condition statement which would stipulate criteria for establishing when the assessment is no longer valid
- Determination of the changes in Risk in a changing climate

3.8.3 FLOOD MITIGATION ASSESSMENT

A Flood Assessment Report that includes provision for Structural Mitigation Works may typically include the following information:

- The objectives and basis for determining the proposed concept for hazard mitigation (if applicable, and referencing the established Risk tolerance criteria)
- References to any applicable local standards or provincial guidelines pertaining to hazard mitigation (for example, MFLNRORD Dike design and *Dike Maintenance Act* approval guidance documents)
- Reference to any relevant standards or guidelines for hazard mitigation from an outside jurisdiction (particularly where there are no local standards or guidelines)
- Identification of any potential or suspected natural hazard types that are not addressed in the mitigation plan
- An overview of the proposed concept for hazard mitigation (potentially including primary flood defence measures and on-site secondary Mitigation Measures)
- Discussion of possible Risk-transfer issues (and counter-measures if applicable)
- Design and specifications of proposed Structural Mitigation Works (in some cases, this would be in a separate report) with consideration to applicable standards for such works
- Measures to be considered in Construction of Structural Mitigation Works, including the issuance of an assurance statement at the completion of Construction
- Construction and maintenance cost estimates
- Identification of a proposed maintenance authority for any proposed Structural Mitigation Works (generally local government)
- Identification of operation and maintenance measures that will be required for the Structural Mitigation Works (an operation and maintenance manual will ultimately be required for this purpose)
- Attention to land tenure and other such operational issues
- Limitations and qualifications, assumptions, error limits, and uncertainties of the mitigation assessment, and time limitation or a condition statement which would stipulate criteria for establishing when the assessment is no longer valid

5 Note that as of the date of publication no formal flood risk tolerance criteria have been defined locally, provincially, or federally.

The specific effort spent on each of the bulleted items may be reduced in relation to the objective and spatial scale of the individual assignment.

Differences exist in how results are aggregated in the analysis and reporting stages. For assignments covering small areas, potential damage may be reported for individual buildings. For large areas, aggregating results within larger spatial units (for example, census blocks) may provide a more reasonable approach given uncertainties of hazard data, characteristics of Elements at Risk, and estimated relations between Flood Intensity and levels of damage or loss. This approach is taken by the United States Federal Emergency Management Agency's (FEMA) Hazus loss estimation program (FEMA 2017), which has been adapted for Canadian use (see **Appendix E: Flood Risk Assessment**, Section E2.1).

3.9 LIMITATIONS AND QUALIFICATIONS OF FLOOD HAZARD, FLOOD RISK, AND CLIMATE CHANGE IMPACT ASSESSMENTS

The limitations and qualifications of FHAs and FRAs can be based on numerous factors, including the data available, the record length of data received, insufficient resolution of climate change impacts, sources of error stemming from field or analytical techniques, as well as others. Each Flood Assessment Report should describe such limitations, to avoid giving the impression of exactness. Sensitivity analyses are recommended to stress these limitations and assess the worst-case scenario. This is particularly important for formal FRAs in which a series of Hazard Scenarios should be included in the Risk Assessment to provide a spectrum of possible Risk scenarios and their respective losses.

3.10 SPECIALTY SERVICES

Complex Flood Hazard and Risk assignments increasingly require a multi-disciplinary approach to meet their objectives. It is unlikely that a single QP will have a broad enough background to address every specialty service required for a flood assessment. Following are a number of specialty services that may be required in a complex flood assessment.

- **Quaternary science** can be used for dating certain flood, debris flood, or debris flow events. The dating of hydrogeomorphic events can be carried out using absolute dating methods such as varve chronology, radiometric dating of organic materials, and dendrochronology. Each of these techniques requires specialized knowledge and cannot be completed without prior training.
- **Fluvial geomorphology** is inseparably linked with Flood Hazard studies. Channel evolution, sediment transport mechanisms, and river bank stability at various temporal and spatial scales must be linked to the channel hydraulics. An understanding of these concepts is required to determine how a Flood Hazard has evolved in parallel with river and floodplain changes.
- **One, two, and three-dimensional numerical simulations** are increasingly applied to assess Flood Hazard. In most consulting firms, modelling is completed by those specialized in this task and managed by others. Both the modeller and the managing QP must understand the model's best applications and limitations. With ever-increasing model sophistication, intense collaboration between the hydraulic modeller, the Hydrogeomorphic Process

specialists, and those who will apply the output in Risk studies is crucial.

- **Risk Assessments** require a different skill set than hazard assessments. The QP responsible for determining economic losses must have access to high-quality data on housing and infrastructure and be able to comprehend the various losses associated with different flood stages and flow velocities. Furthermore, losses to the local and regional economies may need to be evaluated. This task may lie outside the expertise of the QP completing the FRA. In this case, additional qualified specialists should be retained, such as economists or government institutions such as BC Stats (BC Stats 2017).
- **Cost-benefit analyses or multi-criteria analyses** must be undertaken by someone with a background in economics. For more sophisticated Flood Risk studies, cost-benefit or multi-criteria analyses should be carried out by economists in collaboration with professional geoscientists or professional engineers.
- **Loss of life calculations** also require specialized skills with a strong background in the various methods being proposed. These methods rely on very different input and are structured around different levels of sophistication, starting at basic mortality statistics that are based on water depth only, and ending with computing the loss-of-life potential for individuals living or working in the potentially flooded area. Jonkman (2005) includes a summary of various loss-of-life estimating methods. Previous studies have shown that there are order-of-magnitude differences in the likely outcomes of loss-of-life studies. Sensitivity analyses and probabilistic assessment may be required to extract the most plausible scenarios that would be incorporated into a Class 3 Risk Assessment (see **Appendix D: Flood Hazard Assessments**, Table D-2).

3.11 FLOOD ASSURANCE STATEMENT

An Approving Authority may require a QP to submit a Flood Assurance Statement (**Appendix I**) or another form developed by an Approving Authority. Note that a different form of assurance statement is provided in the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010) and is not generally applicable to flood assessments. These guidelines evolve over time and may be updated, so a QP should ensure that he or she obtains and uses the most appropriate and most recent form of Assurance Statement for the particular situation.

When completing the Flood Assurance Statement, a QP should:

- ensure that the specific requirements discussed with the Approving Authority at project initiation have been achieved;
- where the Approving Authority has not established a level of flood safety (Flood Hazard or Flood Risk tolerance), ensure that the alternative approaches, explored in consultation with the Approving Authority at an early stage in the work, have been achieved;
- complete all relevant items on the Flood Assurance Statement; and
- ensure the Flood Assurance Statement is consistent with the Flood Assessment Report.

Even if it is not explicitly stated on the Flood Assurance Statement, a QP should ensure the statement has been appropriately reviewed, ideally by the same QP who reviewed the Flood Assessment Report.

4.0 QUALITY MANAGEMENT IN PROFESSIONAL PRACTICE

Engineering/Geoscience Professionals must adhere to the applicable quality management requirements during all phases of a flood assessment, in accordance with the Association's Bylaws. It is also important to be aware of whether additional quality management requirements exist from the Approving Authority or through service contracts. A QP should carry out quality assurance/quality control for all phases of a flood assessment. This section outlines some key points and responsibilities, in addition to those noted in **Section 2: Project Organization and Responsibilities**.

4.1 QUALITY MANAGEMENT REQUIREMENTS

To meet the intent of the quality management requirements, Engineering/Geoscience Professionals must establish and maintain documented quality management processes for the following activities:

- The application of relevant professional practice guidelines
- Authentication of professional documents by the application of the professional seal
- Direct supervision of delegated professional engineering/geoscience activities
- Retention of complete project documentation
- Regular, documented checks using a written quality control process
- Documented field reviews of engineering/geoscience designs/recommendations during implementation or Construction
- Where applicable, documented independent review of structural designs prior to Construction

4.1.1 PROFESSIONAL PRACTICE GUIDELINES

Pursuant to the *Act*, s.4(1) and Bylaw 11(e)(4)(h), Engineering/Geoscience Professionals are required to comply with the intent of any applicable professional practice guidelines related to the engineering or geoscience work they undertake. One of the three objectives of the Association, as 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 the Association fulfills this obligation.

4.1.2 USE OF SEAL

According to the *Act*, s.20(9), Engineering/Geoscience Professionals are required to seal all professional engineering or professional geoscience documents they prepare or deliver in their professional capacity to others who will rely on the information contained in the documents. This applies to documents that Engineering/Geoscience Professionals have personally prepared and those that others have prepared under their direct supervision.

Failure to seal these engineering or geoscience documents is a breach of the *Act*.

For more information, refer to *Quality Management Guidelines – Use of Seal* (Engineers and Geoscientists BC 2017b).

4.1.3 DIRECT SUPERVISION

According to the *Act*, s.1(1) and 20(9), Engineering/Geoscience Professionals are required to directly supervise any engineering or geoscience work they delegate. When working under the direct supervision of an Engineering/Geoscience Professional, unlicensed persons or non-members may assist in performing engineering and geoscience work, but they may not assume responsibility for it. Engineering/Geoscience Professionals who are limited licensees may only directly supervise work within the scope of their licence.

With regard to direct supervision, the Engineering/Geoscience Professional having overall responsibility should consider:

- the complexity of the project and the nature of the Risks;
- which aspects of the work should be delegated;
- the training and experience of individuals to whom work is delegated; and
- the amount of instruction, supervision, and review required.

Careful consideration must be given to delegating fieldwork. Due to the complex nature of fieldwork, direct supervision is difficult and care must be taken so delegated work meets the standard expected by the Engineering/Geoscience Professional with overall responsibility. Typically, such direct supervision could take the form of specific instructions on what to observe, check, confirm, record, and report to the supervising Engineering/Geoscience Professional. Engineering/Geoscience Professionals with overall responsibility should exercise judgment when relying on delegated field observations, and they should conduct a sufficient level of review to have confidence in the quality and accuracy of the field observations.

For more information, refer to *Quality Management Guidelines – Direct Supervision* (Engineers and Geoscientists BC 2018a).

4.1.4 RETENTION OF PROJECT DOCUMENTATION

Pursuant to Bylaw 14(b)(1), Engineering/Geoscience Professionals are required to establish and maintain documented quality management processes that include retaining complete project documentation for a minimum of ten (10) years after the completion of a project or ten (10) years after engineering or geoscience documentation is no longer in use.

These obligations apply to Engineering/Geoscience 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 Engineering/Geoscience Professionals are employed by organizations, which ultimately own the project documentation. Engineering/Geoscience 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 Association's Bylaws and guidelines.

For more information, refer to *Quality Management Guidelines – Retention of Project Documentation* (Engineers and Geoscientists BC 2018b).

4.1.5 DOCUMENTED CHECKS OF ENGINEERING AND GEOSCIENCE WORK

As per Bylaw 14(b)(2), Engineering/Geoscience Professionals are required to undergo documented quality checking and review of engineering and geoscience work appropriate to the Risk associated with that work.

Regardless of sector, Engineering/Geoscience Professionals must meet this quality management requirement. In this context, 'checking' means all professional deliverables must undergo a documented checking and review process before being finalized and delivered. This process would normally involve an internal review by another Engineering/Geoscience Professional within the same organization. Where an appropriate internal reviewer is not available, an external reviewer (i.e., one outside the organization) must be engaged. Where an internal or external review has been carried out, this must be documented.

Engineering/Geoscience Professionals are responsible for ensuring that the checks being performed are appropriate to the level of Risk. Considerations for the level of review should include the type of document and the complexity of the subject matter and underlying conditions; quality and reliability of background information, field data, and Elements at Risk; and the Engineering/Geoscience Professional's training and experience.

For more information, refer to *Quality Management Guidelines – Documented Checks of Engineering and Geoscience Work* (Engineers and Geoscientists BC 2018c).

4.1.6 DOCUMENTED FIELD REVIEWS DURING IMPLEMENTATION OR CONSTRUCTION

As per Bylaw 14(b)(3), 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 Engineering/Geoscience Professional or a subordinate acting under the Engineering/Geoscience Professional's direct supervision. Field reviews enable the Engineering/Geoscience Professional to ascertain whether the Construction or implementation of the work substantially complies in all material respects with the engineering or geoscience concepts or intent reflected in the engineering or geoscience documents prepared for the work.

Engineering/Geoscience 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 Engineering/Geoscience Professional meets the registration requirements for the engineering or geoscience regulatory body that has jurisdiction.

For more information, refer to *Quality Management Guidelines – Documented Field Reviews during Implementation or Construction* (Engineers and Geoscientists BC 2018d).

4.2 INDEPENDENT PEER REVIEW/ADVISORY SERVICES

An independent peer review or advisory service review is an additional level of review beyond the minimum requirements of Bylaw 14(b)(2) that, for a variety of reasons, may be undertaken by an independent QP not previously involved in the project.

At the discretion of the QP who performed the flood assessment, and in consultation with the reviewer(s) involved in the regular checking/review process outlined above, an additional level of independent peer review may be deemed appropriate. This may be triggered by a complex flood assessment. Alternatively, a local government or other Approving Authority may request another QP to provide advisory services to support project approval. Independent peer review or advisory service review may be undertaken by another QP within the same firm or by an external QP. This type of review is additional to the normal degree of checking and review that is to be conducted for a Flood Assessment Report.

For both the independent peer review and the advisory service review, the review process should be more formal than the checking/review process carried out under Bylaw 14(b)(2) and described in **Section 4.1.5** above. The reviewing QP should submit a signed, sealed, and dated letter or report that includes the limitations and qualifications with regard to the review and the results of the review.

In cases where an independent peer review is triggered by the original QP, such review should generally be appended to the Flood Assessment Report. Regardless of this additional level of review, the QP who signed the Flood Assessment Report remains the Professional of Record.

5.0 PROFESSIONAL REGISTRATION & EDUCATION, TRAINING, AND EXPERIENCE

5.1 PROFESSIONAL REGISTRATION

As summarized in **Appendix C: Current Flood Management Legislation and Guidelines in BC**, following are the professional registration requirements for legislated flood assessments for Proposed Developments in BC:

- The *Local Government Act*, Section 491(5) indicates that, for a development permit, the local government may require a report from a professional engineer "with experience relevant to the applicable matter."
- The *Local Government Act*, Section 524(7) indicates that, for floodplain bylaw exemption, a professional engineer or professional geoscientist "experienced in geotechnical engineering" is required.

Various legislation and guidelines exist in BC that reference professionals performing flood assessment work such as geotechnical engineers, civil engineers, hydrotechnical engineers, and geoscientists. Regardless of these, Engineers and Geoscientists BC's interpretation of professional requirements is described in this section.

A professional engineer in this context is typically registered with Engineers and Geoscientists BC in the discipline of geological engineering or civil engineering and has developed expertise in hydrotechnical engineering, which includes hydrology.

A professional geoscientist in this context is typically registered with Engineers and Geoscientists BC in the discipline of geology or environmental geoscience[6]. Although the *Land Title Act* and the *Local Government Act* refer to a professional geoscientist as being "experienced in geotechnical engineering," by definition a geoscientist is not experienced in engineering. Engineers and Geoscientists BC interprets the *Land Title Act* and the *Local Government Act* to mean a "Professional Geoscientist experienced in geotechnical study," similar to that expressed in the Community Charter.

Not all professional engineers registered in the disciplines of geotechnical engineering or civil engineering are appropriately knowledgeable about geohazard assessments, river engineering, hydrology, and/or debris flow processes. Similarly, not all professional geoscientists registered with Engineers and Geoscientists BC in the disciplines of geology or environmental geoscience are knowledgeable about geohazard assessments including debris flows and

[6] Until 2000, Engineers and Geoscientists BC referred to the discipline of environmental geoscience as geotechnics.

floodplain assessments. It is the responsibility of the professional engineer or professional geoscientist to determine whether he/she is qualified by training or experience to undertake and accept responsibility for FHAs and/or FRAs for Proposed Developments (Engineers and Geoscientists BC Code of Ethics Principle 2).

As noted previously, as the complexity of Flood Hazards increases, site characterization and a sound understanding of the geology and hydrogeological processes at work becomes more critical.

With regard to the distinction between professional engineering and professional geoscience, Engineers and Geoscientists BC Code of Ethics Principle 2 indicates that professionals shall "undertake and accept responsibility for professional assignments only when qualified by training or experience." 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 Principle 2 authorizes a professional engineer to carry on an activity within the area of professional geoscience which 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 which goes beyond the practice of professional geoscience.

Accordingly, the QP who recommends, designs, and oversees the Construction of Structural Mitigation Works to mitigate the impact of Flood Hazards and/or mitigate Flood Hazard Risks must be registered with Engineers and Geoscientists BC as a professional engineer. The QP who investigates or interprets complex hydrogeological conditions and geomorphic processes in support of FHAs is typically registered with Engineers and Geoscientists BC as a professional geoscientist in the discipline of geology or environmental geoscience, or as a professional engineer in the discipline of civil engineering.

5.2 EDUCATION, TRAINING, AND EXPERIENCE

Flood Hazard and Risk Assessments, as described in these guidelines, require minimum levels of education, training, and experience in many overlapping areas of geoscience and engineering, as well as in economics and biology. A QP must adhere to the Engineers and Geoscientists BC Code of Ethics Principle 2 (to undertake and accept responsibility for professional assignments only when qualified by training or experience), and therefore must evaluate his/her qualifications and possess appropriate education, training, and experience consistent with the services being provided.

Education, training, and experience can vary, depending on the QP's background and whether specialty services are being provided. It also depends on the level of study as shown in **Appendix D: Flood Hazard Assessments**. Each higher level will require a larger skill set that is typically achieved by increasing the study team with the respective specialists. Whether carrying out a Flood Hazard and Risk Assessment or providing specialty services, appropriate experience can only be gained by working under the direct supervision of a suitably knowledgeable and experienced professional engineer or professional geoscientist.

Typical qualifications for a QP or for a team of professionals who carry out FHAs may include education and experience in the following areas:

- 1-D and 2-D hydrodynamic modelling
- Knowledge of fluvial geomorphology principles and applications
- Watershed hydrology
- Groundwater geology
- Extreme value statistics and trend analyses
- Understanding of the effects of climate change on the watershed in question, which involves appropriate training, education, and experience
- Ice effects
- Flood Hazard mitigation structure design and operation
- Air photograph interpretation
- Stream channel hydraulics
- Absolute dating methods

Typical qualifications for a QP or a team of professionals who carry out debris flood and debris flow hazard assessments may include education and experience in the following areas:

- Air photograph and satellite imagery interpretation
- Absolute dating methods (dendrochronology, radiometric dating, varve chronology)
- Relative dating methods, where applicable (for example, lichenometry, soil development)
- Modelling techniques for landslide dam outbreaks
- Basics of hillslope geomorphology and hillslope processes
- Understanding of frequency-magnitude analyses of Hydrogeomorphic Processes
- Sedimentology
- Basics of soil mechanics
- Calculations of impact forces for infrastructure and houses
- Design of debris flood and debris flow mitigation structures

For formal FRAs, appropriate qualifications may include the following:

- Database management
- Cost-benefit analyses
- Risk Analysis
- Environmental surveying techniques
- Aquatic resource inventory techniques

Where Structural Mitigation Works are contemplated, appropriate qualifications may include the following:

- Current Dike design guidelines and requirements
- Right-of-way requirements for Structural Mitigation Works
- Engineering design requirements for a Standard Dike
- Operation and maintenance requirements for Structural Mitigation Works
- Environmental requirements for design, Construction, and operation
- Principles of seismic design
- Principles of tsunami science

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 Hazard and Risk Assessments and specialized services offered (refer to Engineers and Geoscientists BC Code of Ethics Principle 6). Continuing professional development can include taking formal courses; attending conferences, workshops, seminars and technical talks; reading new texts and periodicals; doing web research; and participating in field trips.

6.0 REFERENCES AND RELATED DOCUMENTS

Documents cited in Sections 1 to 5 appear in **Section 6.1: References**; documents cited in appendices appear in the reference list at the end of each corresponding appendix.

Related documents that may be of interest to users of this guideline but are not formally cited elsewhere in this document appear in **Section 6.2: Related Documents**.

6.1 REFERENCES

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7.0 APPENDICES

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APPENDIX A: FLOODS AND FLOOD-RELATED HAZARDS IN BC

A1 INTRODUCTION

A flood is a condition in which a watercourse or body of water[7] overtops its natural or artificial confines and covers land not normally under water. When a flood becomes a source of potential harm it becomes a hazardous flood. In these guidelines, we address two types of floods: conventional and unconventional floods. The former refers to recurring floods that are either meteorologically or tidally driven. The latter addresses floods that are typically unexpected and poorly predictable and include river avulsions and dam breaches.

In British Columbia (BC), high water levels of creeks, rivers, streams, ponds, lakes, reservoirs, and the ocean can result from a number of different causes. Typical causes include:

- rainfall;
- snowmelt;
- ice jams, ice runs, log jams, and beaver dams;
- extreme ocean tides;
- storm surges; and
- tsunamis.

In addition to the conventional floods listed above, there are several other flood-related hazards in BC including:

- debris flows and debris floods/hyperconcentrated flows;
- channel avulsions;
- breaching of ice jams, log jams, and beaver dams;
- landslide dams;
- breaching of landslide dams and moraine dams, and glacial lake outburst floods; and
- breaching of anthropogenic Dikes, dams, and tailings impoundments.

In these guidelines, both conventional floods and other flood-related hazards are collectively referred to as "floods" or "hazardous floods." Conventional floods can affect floodplains, Alluvial Fans, shorelines, and coastlines, and all floods may, exceptionally, affect land outside the reach of normally expected water levels.

Floods and flood-related hazards can be either predictable or occur without warning. Besides inundating land, other common effects include erosion of land adjacent to the watercourse or body of water and deposition of sediment.

A2 FLOOD HAZARDS

A2.1 METEOROLOGICAL/CLIMATIC PRECEDENTS FOR CONVENTIONAL FLOODS

There are various common meanings of the word "flood." For our purposes, a flood will be considered to occur when the volume of water exceeds the bankfull capacity of the stream channel or water body to accommodate the water, so that water flows

[7] Watercourses includes creeks, streams, and rivers; bodies of water includes ponds, lakes, reservoirs, and oceans.

outside the channel or overflows the water body. However, a river is often said to be in flood when flows are sufficiently large and powerful to effect substantial erosion of the river banks in a short period of time. This condition has important practical Consequences even though it does not conform to the definition for flood just suggested.

River banks are not uniform, so a river does not go overbank everywhere along its course at the same time. However, once outside its banks at some point, downstream flooding may ensue because the floodplain topography prevents water from getting back into the channel.

River channels adapt their form over time to accommodate the range of normally experienced flows, so that hazardous floods are relatively exceptional events. Many efforts have been made to define the frequency with which floods may be expected to occur; that is, to define the frequency or return period for overbank flow. It has been supposed that some relatively frequently recurring flow, such as mean annual flood, might index flood frequency, but no consistent correlation has been found in western North America (see Williams 1978, who found overbank return periods to vary from less than 1 year to more than a century in the region). Reasons for this are found in the history of individual rivers. In BC, many rivers are slightly incised into glacial period sediments; hence, the return period for overbank flows may vary between a few years and many decades. However, many streams are sufficiently deeply incised that the valley fill is a true terrace and overbank flooding does not occur.

A related concept of relevance to river management is the idea of channel-forming discharge: that flow is capable of effecting significant erosion and sedimentation so as to modify the form of the channel. In mainly sand-transporting alluvial channels, this event may occur frequently and correspond approximately with mean annual flood, but in many upland channels with cobble and boulder beds, bed-mobilizing flows are much rarer.

The most common causes of flooding, and the causes often exclusively considered in water resources management, are high runoff resulting from extreme precipitation and/or snowmelt. In small- to medium-sized drainage basins (<10,000 km^2 in BC is a representative figure, but this is not an absolute limit), the runoff from individual meteorological events usually dominates the flood record. In the largest drainage basins in the province, however, the flood regime is dominated by seasonal snowmelt. There are regional variations: larger basins on the coast and in the eastern mountains are apt to be affected by severe synoptic events, while on the subhumid plateaus of the central portion of the province, seasonal snowmelt-generated flooding continues to dominate somewhat smaller rivers than on the coast. Some rivers have mixed regimes in which both seasonal and synoptic events may be important. In the long term, synoptic events create the most extreme flows in such basins because the amount of water that may be delivered by storm precipitation exceeds potential maximum daily snowmelt. Church (1988) reviews flood-generating mechanisms.

The area over which significant runoff may be generated at any one time conditions the dominant runoff-generating mechanism. Synoptic storms rarely produce their heaviest precipitation over more than a few thousand square kilometres at a time (although if the storm drifts along the axis of a large drainage basin it may have severe effects), whereas snowmelt may simultaneously occur over a very large area in regionally warm weather. In both regimes, however, complex events may produce the most extreme flows.

In smaller drainage basins, rain and rain-on-snow events produce extreme flows. In large basins, the occurrence of a major cyclonic storm during a period of strong regional snowmelt creates extreme runoff. In a warmer future, extreme flows in mid-winter due to rain-on-snow events may become more common and may significantly affect larger drainage areas.

A2.1.1 Rainfall Flood Regime

Rainfall floods are generated by discrete weather events, or by a linked set of such events (such as a sequence of North Pacific storms impinging in rapid succession on coastal BC). The effect of such events depends not only on the precipitation they deliver, but also on the prior state of the drainage basin. If soils are already near saturation from previous events, the effect of an individual storm is more severe than if the storm is a seasonal first or isolated occurrence.

In small drainage basins (<50 km^2), the most severe events consist of heavy rainfall from convection cells incorporated into squall lines on cold fronts. There is no apparent scale dependence of the runoff since rainfall may be delivered at a simultaneously high rate to areas of up to 50 km^2 (cell diameter <10 km). In larger drainage basins, precipitation is rarely equally severe over the entire basin and a scale effect is evident for maximum runoff. In the absence of a long gauge record, the magnitude of extreme runoff can be estimated on a regional basis and provides a first-order estimate for the maximum rainfall flood to be expected from a given drainage area.

A2.1.2 Seasonal Flood Regime

The most severe floods in larger drainage basins are produced by spring snowmelt. This is most particularly the case for larger rivers draining the plateaus of central BC where relatively uniform elevation produces maximum snowmelt over extensive areas at the same time.

Flood frequency curves in snowmelt-dominated drainage basins are relatively flat (i.e., record flows do not exceed relatively common high flows by more than a modest factor) because there is a limit imposed on how much snow may be melted in one day and contribute to runoff (with a fully water-primed snowpack), a limit imposed by solar radiation intensity and daylight length. Therefore, even in drainage basins of up to 100,000 km^2 (which covers most drainage basins in the province), an exceptionally large cyclonic storm might eventually produce the record flow (e.g., the June 1990 storm in the upper Peace River basin, a severe cyclonic depression that moved along the axis of the basin).

A2.2 OTHER FLOOD TYPES

A2.2.1 Alluvial Fans/Avulsions

Active Alluvial Fans (and some river floodplains, deltas, and montane river channels) are subject to channel avulsion, a process in which the main channel of the river switches position when the former main channel becomes choked with deposited sediment and/or wood debris. There usually follows a short period of general flooding and then the establishment of a new channel. The new channel is very often a former channel that previously was abandoned. However, the most dangerous avulsions are ones that take the river entirely outside its former (or recent) channel zone. Avulsion frequency may be roughly periodic because it is driven by sedimentation rate, but the sequence of floods in the stream modulates the inter-event period because it determines sedimentation.

Alluvial Fans are also produced by the deposits of debris flow. There is an important distinction in BC between Alluvial Fans in the humid mountains and those found in the subhumid interior of the province. Many of the latter are debris flow fans or fans built from mixed processes that were active in early postglacial times but have not experienced active sedimentation for a long time. On many such fans, the active stream is well-incised through the upper and middle reaches of the fan, so much of the fan surface clearly is not subject to flooding. In other cases, the activity of the fan may be difficult to ascertain. On active fans, topography, distribution of active and inactive channels, sediments, vegetation, and watershed condition must all be appraised to characterize the Flood Hazard. Most avulsions reoccupy former channels or divert water into anomalously low areas on the fan. These circumstances aid in the identification of hazard zones.

Because Active Alluvial Fans are aggrading systems, stream channels are inherently unstable so that traditional stage-frequency Flood Hazard Assessments (FHAs) are of very limited value. The active channel zone and all recently occupied channels should be regarded as hazardous. The most effective ways to identify former channels likely to be reoccupied and to forecast the likelihood for an avulsion to occur are to prepare a detailed morphological map of the fan surface and to inspect the channel regularly to note the occurrence of significant sediment deposition in-channel.

Guidelines for Flood Hazard management on Alluvial Fans have been presented by Thurber Consultants (1983) and a discussion of Flood Hazard management on fans is given by Kellerhals and Church (1990). A hazard zoning system is advocated to identify zones of current and potential hazard. Morphological methods for estimating Design Floods on mountain streams are presented by Jakob and Jordan (2001), while Wilford et al. (2005) have discussed Alluvial Fan characteristics in BC forest environments.

A2.2.2 Debris Flows

Debris flows are perhaps the most hazardous process in steep (>~15° average channel slope) mountain creeks. By definition, debris flow is a landslide process. However, since debris flows occur in stream channels subject also to fluvial processes, it is appropriate to include them here. There is a close link between hillslope processes and the fluvial regime. Debris flows are most often triggered by shallow (<1 m thickness) debris avalanches on hillslopes that run into channels and lead to fluidization of the channel debris. Debris flows can entrain channel debris at a rate that can produce final event volumes orders of magnitude higher than the initiating debris avalanches. Peak discharge of debris flows can be up to three orders of magnitude higher than the 200-year return period flood discharge that forms the design basis of many in-stream or stream-spanning structures (Jakob and Jordan 2001). For this reason, the recognition and quantification of frequency-magnitude characteristics is very important, to avoid under-design of bridge or culvert crossings and floodplain or fan protection structures. Jakob and Hungr (2005) is a basic reference for debris flow phenomena.

Debris flow hazards are not always easily recognized, particularly on fans or along channels that are subject to high-magnitude, low-frequency events. A discriminating criterion for initial reconnaissance identification of drainage basins that may be subject to debris flow in the BC mountains is $H/\sqrt{A_d} > 0.3$, where H is drainage basin relief, A_d is contributing drainage area, and L_d is drainage basin length (Jackson, Jr. et al. 1987; confirmed by D. Boyer, pers. comm., 2012). For $0.2 < H/\sqrt{A_d} < 0.6$, debris flood (see below) may occur instead (e.g., Wilford et al., 2004). For $H/\sqrt{A_d} < 0.2$, ordinary flooding is normally to be expected, but may still lead to rapid aggradation within channels. Exceptions exist: the Quaternary volcanoes of the province yield debris flows from channels with low ratios because of weak rock composition and fine textured debris. Furthermore, drainage basins that originate on plateau surfaces but have steep intermediate reaches where they plunge into incised valleys may give rise to debris flows despite a low overall ratio. Where development is anticipated, field inspection of fan stratigraphy by an experienced geoscientist must be undertaken to confirm any initial diagnosis.

Assigning debris flow potential to a given creek changes the way a hazard assessment is to be conducted. A debris flow hazard analysis requires a special set of diagnostic and analytical skills because of the uniqueness of each individual debris flow situation. A general treatment of debris flow hazard analysis can be found in Jakob (2005). Special skills are required to conduct frequency-magnitude assessments because statistical analysis of annual runoff data or regional analysis of peak flows does not yield sufficient or adequate data for a sound hazard assessment. Jakob (2010) summarizes the application of dendrochronology for debris flow science and Chiverrell and Jakob (2013) describe radiocarbon dating of debris flow deposits on fans. Jakob (2013) discusses the requirements to produce reliable frequency-magnitude relationships on fans. Hungr et al. (2005) and Iverson (2010) address the issue of debris entrainment. See Jakob et al. (2005) for discussion of channel recharge rates, Vallance (2005) for volcanic debris flows, and Rickenmann (2005) for debris flow prediction models.

Debris flow Risk Assessment is still in its infancy as few studies have been conducted that attempted to quantify Risk for loss of life or economic losses. Such studies required very detailed frequency-magnitude analyses (i.e., Jakob and Friele 2009), numerical modelling, and specialized Risk Assessment techniques.

A2.2.3 Debris Floods/Hyperconcentrated Flows

Debris floods or their rheologically better defined equivalent hyperconcentrated floods form a transition between purely water floods and debris flows. Debris floods may contain between approximately 4% and 20% sediment by volume (Waananen et al. 1970; Pierson 2005). They can be triggered by a variety of processes including landslide dam and glacial lake outbreak floods, beaver dam breaks, tailings or water retention dam failures, water pipeline ruptures, snow avalanche dams, hillslope and channel erosion, dilution and selective deposition at the heads and tails of debris flows, and inputs of large sediment volumes by landslides. Debris floods, though typically not as destructive as debris flows, have some characteristics that are distinctly different from clear water floods and debris flows, the potential of which needs to be recognized to quantify the hazard and provide for Risk reduction measures.

Debris floods are not necessarily a singularly-acting Hydrogeomorphic Process but can devolve from debris flows through water dilution. Debris floods can also evolve from purely flood flow through entrainment of debris. Debris floods can therefore be viewed as a spatially and temporally transient flow type. A reconnaissance criterion for identifying channels potentially prone to debris flood is given above (Section A2.2.2). Discrimination between processes post-event is possible only through an interpretation of sedimentary deposits and is best done by experts. For information on interpretation of sedimentary deposits associated with debris floods, see Pierson (2005) and Cronin et al. (2000).

Some distinguishing characteristics of debris floods are:

- high erosivity, particularly along steep channels through scour, which will at least partially depend on sediment concentration;
- potential for excessive riverbed aggradation in places where channel gradients decrease or channels widen, which in turn can lead to avulsion, reduction of flood conveyance capacity, and burial of low-lying areas and structures; and
- potential for avulsions that can lead to riverbank erosion well after the debris flood has passed.

Debris Flood Hazard Assessments (FHAs) will therefore need to account for a series of processes, few of which can be reliably modelled using commercially available software. A good portion of expert judgment will be required in assessing the various Consequences of a debris flood, as illustrated in Jakob and Weatherly (2007). In almost all cases it will require a multi-disciplinary approach that combines geomorphology, Quaternary dating methods, and hydrodynamic modelling to arrive at reasonably reliable results.

A2.2.4 Log Jam and Beaver Dam Outbreak Floods

Log jams are pervasive features along forest streams in BC. Many log jams are the product of landslide entry into the channel or debris flows incorporating a high volume of woody debris. Log jams may be classified into two types: (1) in channels confined by adjacent hillslopes, jams build vertically and may reach elevations of 5 to 10 m; the stream must flow over the jam; (2) in streams with an adjacent valley flat, the jams build horizontally and the stream commonly outflanks the jam, so that the jam creates a channel avulsion. Log jam formation is usually associated with abundant sediment movement, so the upstream area rapidly fills with sediment. If there are in-channel or channel bank installations, this may pose severe problems both of siltation and water stage. Jams are, however, sometimes permeable, so that there is only modest interference with normal water flows. Jams have high integrity for periods of a decade or two, but by 30 years wood decay and channel adaptation render the jam less effective in trapping sediment and diverting water flow. Debris flows can then erode such jams in one event, leading to a sudden release of stored sediment that may then bulk the debris flow to very high volume.

Beaver dams are found on low gradient streams. The animals use mud to reduce dam permeability leading to their intended effect; the inundation of a more or less extensive area upstream may pose a significant inconvenience to adjacent landowners.

In extreme circumstances, log jams and beaver dams may fail quickly. In the case of log jams, this is most likely to create a downstream surge of sediment stored behind the dam with a modest surcharge of flood water. In the case of beaver dams, water flows may increase in proportion to the size of the draining pond (see **Section A2.2.5** for reconnaissance assessment methods). Beaver dam failures are more widespread than realized (Butler and Malanson 2005).

A2.2.5 Landslide Dams, Moraine Dams, and Small Earthen Dams

Landslides may block the course of a river or stream. Cases in BC vary from small forest streams that have been temporarily blocked by a debris slide, up to the historic blockage of the Thompson River and the prehistoric blockage of the Fraser River. The flooding hazard associated with landslide dams is twofold:

1. Flooding in the upstream impoundment; and
2. Outburst flooding downstream if the dam fails rapidly.

Glacial moraines commonly impound lakes after the glacier retreats from the moraine. Small earthen dams have been built on many streams in BC to provide domestic or irrigation water supplies or industrial water supply. In addition, tailings dams at many mine sites can hold substantial decant water and much under-consolidated sediment of potentially toxic composition.

All of these dam types might possibly fail rapidly. Old earthen dams, in particular, may be susceptible to failure due to low design standards at the time of Construction, lack of engineering inspections, and progressive deterioration. Landslide dams are prone to fail because they are irregularly placed with no consolidation. In many steep mountain creeks, naturally caused or human-caused landslides (most often the Consequence of road-building activities) are a frequent occurrence, and many of these have the potential to dam creeks, albeit sometimes for only minutes or hours.

Upstream inundation after the formation of a major landslide dam may pose a hazard if the valley is settled or constitutes an essential communications or transport route. Rates of inundation depend on the discharge of the inflowing stream and, for a large dam, may vary from hours to months; that is, there will usually be time for emergency evacuation of people and securing of resources not affected by the initial landslide.

Moraine-dammed lakes are common in many glacierized mountainous regions of the world and in the Cordillera of western Canada. Clague and Evans (2000) illustrate the principal features of moraine-dammed lakes and phenomena associated with their failure. The geotechnical characteristics of moraine dams make them prone to rapid incision and failure. Some moraines are ice-cored or within permafrost zones characterized by interstitial ice. These are of particular interest in a changing climate, as the ice core or the interstitial ice may melt, resulting in a drop of the moraine crest elevation with respect to the impounded waterbody and likely destabilization of the moraine. McKillop and Clague (2007a, 2007b) have presented a statistical criterion for estimating the probability that a moraine dam will fail. Recent developments associated with forestry, mining, independent power projects, and recreational activities have increased the need to understand the processes involved.

Landslide, moraine, and earthen dams most frequently fail by overtopping during an extreme runoff event, although they may also fail by piping. Seismic shaking might also cause dam failure if portions of the dam are partially or fully saturated. Waves set up by a landslide into the impoundment or, in the case of moraine dams, by an ice-fall into the lake from an overhanging glacier may, in some instances, initiate erosion in the outlet channel leading to dam failure. Kershaw et al. (2005) provide a detailed description of one such failure. In many cases, failure begins relatively slowly and then accelerates rapidly to reach peak discharge immediately before exhaustion of the water supply. This is the Consequence of progressive erosion caused by the continually increasing outflow. Downstream, the flood wave is modified by channel and overbank water storage. If the lake discharges into a sufficiently steep channel, failure may be succeeded by a debris flow or debris flood.

Reconnaissance estimates of possible flood magnitude immediately downstream from the dam may be made by simple scaling relations based on historical floods. The most comprehensive collection of data for this purpose has been made by Walder and O'Connor (1997). They quote envelope relations (see **Table A-1** below) for various dam types. Moraine dam failures are more sensitive to lake volume than the other two types, probably because the usually rather narrow base is conducive to rapid breach enlargement. It should be noted, however, that there is no strictly physical basis for these scaling relations. They are useful insofar as they provide a first estimate of the potential hazard that the dam presents. A more elaborate analysis, based on the erosion rate in the dam breach is presented by the same authors, while Fread (1989) and Singh (1996) have summarized numerical simulation models of dam breach floods. Comprehensive reviews of dam breaches in earth and rock materials are provided by O'Connor and Beebee (2009) and by the ASCE/EWRI Task Committee on Dam/Levee Breaching (2010).

Assessments of lake outbreaks and subsequent debris flows and debris floods require that the following steps be considered:

1. Definition of the study area and remote sensing of existing lakes and locations where lakes may form as a Consequence of glacier retreat.
2. Definition of Hazard Scenarios based on remote sensing techniques.
3. Field work to determine the stability of the dam itself. The level of effort for such study would hinge on the downstream Elements at Risk.
4. Once the likelihood of a trigger mechanism and the likelihood for dam failure have been assessed and probability estimates developed for different Hazard Scenarios, an evaluation can be made of the downstream effects.

Table A - 1: Envelope Relations for Estimated Peak Discharge Following Dam Failure

DAM TYPE	COEFFICIENT	EXPONENT	N
Landslide	46	0.46	15
Moraine	0.22	0.66	32
Constructed	8.5	0.46	9

NOTE:
Adapted from Walder and O'Connor (1997), Table 1. Relations are based on upward displacement to envelope position of best-fit regression equations of the form $Q_P = aV_o^b$, in which Q_P is the peak discharge (m^3s^{-1}) and V_o (m^3) is the initial volume of the impoundment.
N = number of cases

A2.2.6 Glacial Lake Outbreak Floods

Glacial lake outbreak floods include breaches of ice-dammed lakes and drainage of so-called supraglacial lakes, which are defined as lakes that form on top of glacial ice, often dammed by a larger trunk glacier. Occasionally, subglacial reservoirs also drain rapidly, but their volume is usually relatively small. Drainage of such lakes occurs either by surface channels over or, more frequently, along the edge of ice or via subglacial passages. Supraglacial lakes usually drain via crevasses to the glacier bed before discharging from the glacier front. The pattern of drainage is similar to that of earthen dams, beginning slowly and continuously accelerating to a peak just before exhaustion of the impoundment. The erosive mechanism in this case is thermal erosion of ice, which occurs along the extended drainage route rather than at a specific outlet. Consequently, the peak flow may be preceded by a long period (weeks) of developing drainage. Peak discharge exceeds flows estimated by traditional hydrological methods. The lake must, of course, have a normal drainage path, usually along the ice margin or sub-marginally; that is, under ice but along the glacier margin. This is sometimes but not invariably the route for rapid drainage. Often, these routes are difficult or impossible to assess for lack of access.

The outlet of some glacially dammed lakes, after drainage, reseals by ice movement, so that the lake refills and eventually drains again. One such extended history in BC is summarized by Mathews and Clague (1993) for Summit Lake at Salmon Glacier. In other cases, drainage occurs only once (see an example by Clague and Evans 1997) or perhaps twice.

In many respects, the hazard assessment for glacially dammed lakes is similar to that for landslide and moraine dams, except that specialist knowledge of glacial hydrology may be required. As for landslide and moraine dams, scale relations have been developed for glacial dam failures. Data of Walder and Costa (1996) led to envelope relations:

$$Q_P = 0.014V_o^{0.66}$$

for fully subglacial drainage (Q_P in m^3s^{-1} and V_o in m^3), and

$$Q_P = 3.5V_o^{0.46}$$

for surface drainage, probably including marginal cases. Again, more physically rigorous relations are pursued by Walder and Costa that require more comprehensive data.

Future decades will likely see significant retreat of alpine ice in BC. It is conceivable that glacial lake drainage events may increase and, combined with increased extension of settlement and economic activity into the mountains, may pose a substantially increased hazard compared with the past.

A2.2.7 Ice Jams and Ice Runs

In rivers that are subject to significant winter ice formation, high water levels may be created by ice jams. While some features of ice jams exhibit a degree of regularity (e.g., the places along a river where jams tend to develop, which is related to the channel morphology), the progress of an individual jam is a singular event so that water levels are difficult to forecast. On rivers subject to significant ice jams, the highest water levels usually are associated with ice jam floods independent of the river discharge. Hence, a historical stage-frequency analysis, not the usual (flow) magnitude-frequency analysis, is the basic statistical tool to gauge hazard.

Ice runs (or ice drives) may do significant damage along riverbanks and to instream installations (such as bridge piers). Driven ice may be piled up metres above water level, so damage may extend to high elevations. An important aspect of ice jam floods is the rapidity with which they develop. On a large river, a stage rise of up to several metres may develop in less than an hour.

The ice regime of a river comprises three periods: (1) freeze-up; (2) mid-winter; and (3) break-up. Freeze-up and break-up are relatively short periods that can produce significant flooding and riparian damage due to the effects of moving ice and fluctuating water levels. In comparison, mid-winter tends to be a time of relatively stable low flows and stable ice cover. On regulated rivers, however, fluctuating flows may destabilize the ice cover, producing damaging mid-winter ice runs. Occasional thaws in mid-winter can also result in ice jams.

Freeze-up begins with the formation of frazil ice in the water, which are disc-shaped millimetre-scale ice crystals that grow and stick together to form slush pans. Frazil ice may also stick to the riverbed and banks, forming anchor ice. Slush pans agglomerate into larger units that grow out from the channel edge to the point that they lodge across the channel and bridge. In cold conditions, they then freeze to form a juxtaposed ice cover. The cover stops downstream running pans, and the ice cover progresses upstream. This process is relatively quiet and produces only a modest stage rise as the flowing water encounters the increased flow resistance posed by the ice cover. In fast water, however, frazil ice and slush may be drawn under the edge of the cover, where it sticks in a downward-growing hanging ice dam, which interferes with water conveyance to create significant stage rises. This, in turn, may break up the developing cover, which then runs into a larger jam downstream. This consolidated ice cover can cause significant flooding and damage along the channel margins.

At break-up, there are similarly two scenarios. A thermal break-up occurs when ice melts *in situ* and remaining ice floats out without obstruction. Little damage is done. Thermal break-ups occur when warm weather melts ice before the spring freshet. If, however, rising flows break a still competent ice cover, the resulting drive of large slabs may pile ice into large jams with accompanying extreme high stages. Jams eventually break under the force of oncoming water and ice, and then a surge of ice and water occurs downstream: a damaging ice run. Such a mechanical or dynamic ice break-up usually exhibits a series of jams and surges downstream, with the jams occurring at similar places each year where the channel geometry makes ice passage more difficult. Hence, the most extreme damage may be quite localized and the probable locations well known. In general, northward flowing rivers are more prone to significant ice jam flooding than southward flowing ones, since ice forms earlier and breaks up later downstream.

Observations of ice-scoured river banks, arrested riparian vegetation succession, and damage to riparian vegetation are important means to diagnose the characteristic levels of flooding associated with ice along rivers with few or no records. Importantly, damage to trees may be dated by dendrochronological means.

The 21st century prospect is for warmer winters, so that one may judge that, in general, ice will become a less pervasive problem along BC rivers. Mid-winter break-ups and flooding may, however, become more common on northern rivers that have an extended ice season. In this circumstance, historical information remains a useful guide for planning and forecasting purposes. Reviews on ice jams and ice jam flooding in the Canadian context have been given by Beltaos (1995; 2008). Forecasting potential ice problems can be aided by a model that predicts the advance and retreat of ice cover on a river (Chen et al. 2006).

A2.2.8 The Sea

Low-lying coastal areas may be subject to flooding from the sea, which is subject to astronomic tide cycles. Extreme high sea level can arise from storm surge, wind set-up, wave effects, and other local effects. Sea level is increasing over time due to sea level rise.

Determination of an appropriate design sea level should be subject to site-specific analysis, with addition of an appropriate Freeboard allowance. New development areas in BC are typically required to be designed for the Year 2100 sea level rise condition (Ausenco Sandwell 2011).

In addition to high water levels, coastal areas can be subject to significant erosion from waves and currents.

A2.2.9 Tsunamis

Tsunamis are waves created when a large body of water is rapidly displaced by processes such as earthquakes or landslides. Tsunamis have previously impacted the BC coast and adjacent coastlines with wave heights and runups that far exceed other processes such as storm surges.

The largest tsunamis impacting the BC coast have been triggered by submarine earthquakes originating around the tectonically unstable Pacific Rim. Although geologic evidence indicates that much larger tsunamis have occurred in the past, the most significant historical event was triggered by the March 27, 1964 Alaska earthquake, which caused about $10 million damage in BC (1964 dollars), mainly to communities on the west coast of Vancouver Island (Clague 2003). Landslide-triggered tsunamis have also been responsible for damage to BC communities, including an 8.8 m high tsunami that impacted Kitimat Village in 1975 (Campbell and Skermer 1975).

Earthquake-triggered tsunamis potentially affecting the BC coast are monitored by the Pacific Tsunami Warning Center (PTWC) located in Ewa Beach, Hawaii and the West Coast and Alaska Tsunami Warning Center in Palmer, Alaska. These warning centres use tide gauges to check if a tsunami has formed and then forecast the future of the tsunami, issuing warnings if needed. More information on the warning centres can be found on the PTWC website at ptwc.weather.gov.

A recent modelling study (Xie et al. 2012) based on the known 1700 event suggests that, for a major earthquake on the Cascadia fault—the subduction zone fault lying off the west coast of Vancouver Island—(a so-called mega-earthquake), the time for a tsunami wave to reach the west coast of Vancouver Island would be about 1 hour; propagation into the mainland shore along the Strait of Georgia would require 1.5 to 2 hours. Maximum wave height near Esquimalt Harbour is estimated to be about 25 m. However, experience of the 1964 Alaska earthquake in Alberni Inlet shows that extreme wave amplification may occur in coastal inlets. However, amplitude in the Strait of Georgia is expected to be reduced (Clague et al. 2003). Based on available evidence, a major Cascadia earthquake is thought to be a millennial event, but there is insufficient information to formulate a magnitude-frequency relation.

Tsunamis triggered by submarine landslides associated with liquefaction of collapsible sediment in submarine Fraser River delta deposits may represent a potential hazard. Locations where submarine landslides have been reported include Howe Sound (Terzaghi 1956; Prior et al. 1981) and the Fraser River delta (Hamilton and Wigen 1987; McKenna et al. 1992).

Assessment of riverine Flood Risk should include an assessment of potential tsunami hazard where the study area extends to ocean coastlines, but such study will require a different set of analytical skills. Regarding hazard assessment, a maximum probable event approach, based on historical or sedimentological evidence, can be implemented, whereas there is, at present, insufficient historical information to permit magnitude-frequency analysis for locations on the BC coast.

A2.3 EROSION AND SEDIMENTATION

A2.3.1 Erosion Susceptibility

The susceptibility of riverbanks, ocean shores, and lakeshore to erosion depends on local conditions best investigated in the field, and on the physiographic setting and longer term history of channel/shoreline changes at and near the subject site. In a river, erosion susceptibility depends upon the following local conditions:

- Site situation (outside of meander bend; opposite a developing gravel bar; downstream from bank-armoured reach or training structure)
- Strength of materials that make up the channel banks
- Bank vegetation cover and condition
- Direction and force of attack of the river current
- Bank geometry (bank angle; depth immediately offshore)
- Debris loading across the bank and/or at the base of the bank
- Seasonal ice effects
- Water seepage out of the bank, associated with bank stratigraphy
- Land use adjacent to the bank, especially livestock activity
- Rapid variations in flow (which promotes sloughing of the bank)

Longer-term factors that affect riverbank susceptibility to erosion include the following:

- Active aggradation or degradation
- Active braiding, meandering
- Effects of a dam or other control structure upstream
- Land use and stream management

These factors are investigated by studying the history of channel shifting by making use of historical air photography, which for most locations in the province, extends back at least 65 years. Air-photo inspection may also reveal distinct former channels of the river, indicating a propensity for avulsion, and it can reveal the recent trend of channel shifting that may permit reasonable forecasting of likely erosion in the near-term future (how far into the future will depend on the level of river activity and current channel form). For this work, specialist advice should be sought from a fluvial geomorphologist or river engineer.

A preliminary classification of places along a river where erosion susceptibility is high can be obtained from terrain mapping (to determine materials; Howes and Kenk 1997) and inspection of air photos to determine channel style and recent history.

On coasts, erosion susceptibility depends on local factors similar to those listed above except that the directions and strength of wave attack replaces factors associated with river currents. It remains possible, though, that strong long-shore currents may influence coastal stability since they promote systematic movement of sediments. Wave attack depends on fetch, which in turn depends on coastline orientation and coastal geography and on the local exposure. Headlands are subject to strongly focussed wave attack, but for that reason are usually composed of relatively erosion-resistant rock. Bays and inlets are more sheltered but wave attack may still be strong in steadily narrowing inlets. Specialized coastal classifications have considered erosion susceptibility. At site scale, field inspection is, again, the most effective indicator. The Consequences of coastal location and wave fields are studied by map analysis to determine wave climate.

It should be recognized that on sandy shores at many locations there is significant seasonal movement of sand onshore and offshore, so apparent shore zone condition may depend on the time of year at which inspection is made.

A2.3.2 River Erosion and Sedimentation

Erosion and deposition of sediment influences water levels along rivers, hence the incidence of floods. This is particularly obvious on Active Alluvial Fans—sites of chronic accumulation of sediment at the base of steep mountain channels. On larger rivers, the processes are much more subtle and may escape notice for substantial periods.

Sedimentation style and attendant flooding problems vary systematically through the drainage network. In mountain headwaters, steep channels that accumulate sediment are prone to mass movement in a debris flow. Debris flows may be triggered in channels steeper than about 15 degrees, although many initiation zones are much steeper. Debris flows may run out onto gradients of order 10% in the case of relatively coarse, easily drained debris, but 1% or 2% for muddy flows. Sediment deposition on the colluvial or Alluvial Fan at the slope base fills channels and promotes diversion of the debris flow outside the current channel. Debris floods, often associated with the onward transport of material initially mobilized in a debris flow, may similarly spread sediment outside channel limits, even farther than debris flow deposits because of their highly fluid nature (see Section A2.2.3). The fans are the product of persistent sediment deposition from debris flows and debris floods.

Rivers in the mountain valleys of BC normally have gravel beds and carry gravel as bedload. The gravel is staged downstream from bar to bar during successive high flows. The river currents cannot lift gravel to a very high level, so sediment deposited in the channel is stacked laterally on bar edges, which grow outward into the channel. The river current is pushed against the opposite bank and, to maintain conveyance, the river erodes that bank (so that sediment is moved on downstream). The rivers consequently have an irregular lateral style of instability and bank erosion, which is a common problem. Bank erosion is a normal part of the natural sediment transfer process along the river. The problem is particularly severe in the uppermost part of the main trunk valleys, where many upland tributaries converge to produce significant sediment influx.

In contrast, rivers flowing in finer-grained sediments gain bank strength as the result of sediment cohesion. They adopt a more regular meandered style where the erosive attack of waters is more systematically applied on the outside of successive bends and is more predictable, at least in the short to intermediate term.

Vegetation roots form a critical reinforcement mechanism (sometimes called root cohesion) for riverbank stability. However, many tree species in BC, including most conifers, have a laterally spreading root development and lack a strong, deep taproot. Hence they are effective only along the banks of relatively shallow streams. In BC, it is widely observed that root cohesion is effective to a depth of about 0.5 to 1 m below the surface. Deeper streams can undercut the banks in unreinforced sediment and topple trees. Turf and peat banks provide effective surface cohesion but may be undercut, leading to block failure of the bank.

It usually is possible to estimate a channel zone within which normal processes of lateral channel shifting occur. In meander-form channels, the width of the meander belt gives such a measure. In wandering or braided gravel-bed rivers, a width of two to three times current channel zone width is a common range for lateral activity. Within this zone, the bar surfaces and floodplain should be recognized as part of the channel zone, eventually to be reclaimed by the river through lateral erosion; that is, the proper channel zone of a bed-sediment transporting river should be recognized to extend beyond the limits of the currently occupied channel. This would not preclude development near apparently stable channels (ones with strong or strongly defended banks and no recorded history of significant lateral movement).

Rivers do not normally aggrade uniformly; sediment is deposited in preferred places along the channel where currents slacken. Hence aggradation may occur locally for some time, to be followed by degradation as sediment moves along the channel. Over time, these positions change because the deposits themselves influence the evolution of the channel and the river currents. Aggradation in certain places along the channel creates upstream backwater and rising flood levels. The upstream distance over which this phenomenon persists depends upon the size of the river, the general gradient of the channel and the severity of the aggradation, but can be several kilometres on a large river.

Persistent aggradation/degradation, accompanied by a definitive change in water levels, occurs only if there is ongoing net loss or gain of sediment in the reach. Extreme aggradation leads to channel avulsion. The latter case is particularly important on Alluvial Fans. Conversely, degradation leads to incision of the river channel and to reduced water levels for a given flow, thus reducing Flood Hazard. Degradation may nevertheless cause local problems such as the undermining of bridge piers and isolation of water intakes.

A special circumstance in mountain valleys is that Alluvial Fans deposited by tributaries sometimes spread across the valley floor and constrict the main river, so that backwater and rising water levels occur upstream in the main river, even though it may not be primarily aggrading. In some places, these back-watered reaches have given rise to ecologically valuable wetlands because of chronic inundation of the valley floor. The phenomenon creates a stepped profile along the rivers of mountain valleys, with backwater upstream of successive tributary fans, and spill over the fan toe on a locally steeper gradient. This may induce systematic variation in Flood Hazard along the valley that may be identified by morphological evidence in the field, by historical reports of flooding extent, or by a numerical model that encompasses both river channel and floodplain.

There are two principal means by which to detect water level effects of erosion and sedimentation:

1. Specific gauge analysis at a stream gauging station
2. Repeated survey of cross-sections

The former method is restricted to places on a river with a substantial history of gauging. Furthermore, once trends are established at the gauge point, it remains to interpret the result in terms of causes and probable effect along an extended reach of channel. Repeated surveys are expensive and apt to be restricted to reaches known to be aggrading or degrading. In BC, for example, this includes the lower Chilliwack/Vedder River. Qualitative indications of sedimentation trends can be gained from examination of river morphology. Furthermore, observant local citizens (river guides, fishers, boaters) may possess useful knowledge.

A3 REFERENCES AND RELATED DOCUMENTS

Documents cited in this appendix appear here. Related documents that may be of interest to users of this guideline but are not formally cited elsewhere in this appendix appear in the Related Documents subsection below.

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APPENDIX B: CURRENT FLOOD MANAGEMENT APPROACH IN BC

B1 INTRODUCTION

Flood management refers to mitigation strategies considered or implemented to reduce the effects of a hazardous flood, either by changing the likelihood of a flood occurring, or by effecting change to the Consequences. Measures can be broadly divided into non-structural and structural measures. These are discussed in the following sections.

Regardless of the measures used, flood management has a number of limitations arising from design, implementation, and performance. Failure to acknowledge these limitations can lead to increased development in flood-prone areas.

B1.1 NON-STRUCTURAL MEASURES OF FLOOD MANAGEMENT

Non-structural measures include avoiding development in flood-prone areas by means of land use planning and zoning, Covenants on land titles, enforcement of Flood Construction Levels (FCL) and minimum building elevations, and Mitigation Measures. Typically, non-structural measures are the preferred means of flood management.

Over time, the regulation of floodplain development has evolved to include awareness of floods and the management of proposed development on floodplains. Unfortunately, existing development on floodplains limits policy options for changing inappropriate land use.

Throughout the province, several formal land use planning programs have been implemented to manage proposed development on floodplains. These include the following:

- The Lower Mainland Regional Planning Board and its 1966 Official Regional Plan
- The provincial Agricultural Land Commission (ALC) created in 1973
- The provincial Floodplain Development Control Program, which operated between 1975 and 2003, and subsequently has been delegated to local governments
- The Floodplain Mapping Program, funded by the provincial government from 1974 to 1998, and subsequently delegated to local governments

B1.2 STRUCTURAL MEASURES OF FLOOD MANAGEMENT

Structural measures of flood management typically refer to dedicated structures that separate watercourses or bodies of water from areas to be protected, otherwise known as Structural Mitigation Works. Examples of Structural Mitigation Works include Dikes and training berms, floodwalls and seawalls, bank protection works, flood retention basins, sediment basins, river diversions, floodways, meander Construction, debris barriers and basins, and dams. Structural measures can also include integral infrastructure such as pump stations and floodboxes. Despite their temporary nature, in-stream sediment management and removal activities are often considered a structural approach because they represent a physical intervention within the natural fluvial system.

Most Structural Mitigation Works are regulated by the province under the *Dike Maintenance Act*, which defines a Dike 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 flooding of land. 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*. 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.

The 1948 flood on the Fraser River resulted in the establishment of the federal-provincial Fraser Valley Diking Board that coordinated an emergency Dike rebuilding program. The Board ceased operations in 1950.

Also following the 1948 Fraser River flood, the Dominion-Provincial River Board (changed to the Fraser River Board in 1955) was established to recommend development of water resources and options for flood control and hydroelectric power generation on the Fraser River. The Fraser River Board concluded in 1963, and was succeeded in 1968 by the Fraser River Flood Control Program, established under a new Canada/British Columbia (BC) agreement. A number of government cost-sharing programs have evolved since the conclusion of the Fraser River Flood Control Program in 1995. Examples of such programs include the Flood Protection Assistance Program (1999-2005) and Urgent Mitigation Works completed in 2007.

In 2007, the Flood Hazard Protection Fund, a provincial cost-sharing program, was created and is managed by Emergency Management BC under the Ministry of Justice.

The provincial Dike Safety Program was established in the 1950s, following the experience of the 1948 floods, with the adoption of the *Dike Maintenance Act*. The office of the Inspector of Dikes, through administration of the *Dike Maintenance Act* oversees maintenance of Dikes by local diking authorities, sets diking standards, and approves changes to existing Dikes and new Dikes.

Structural measures on First Nations lands are owned and operated by First Nations, and have been funded primarily by Indigenous and Northern Affairs Canada (INAC). In addition, there are over 100 historic orphan structural flood protection works that are currently not being operated or maintained by a local diking authority. These Orphan Works comprise a variety of structures including berms, erosion protection, and other works of varying Construction standards, including approximately 60 that are considered to be Dikes under the *Dike Maintenance Act* (i.e., any changes to these Orphan Dikes would require a *Dike Maintenance Act* approval).

The length of Orphan Works totals over 85 km and these works provide a measure of protection for at least 6,000 hectares of land in 75 communities around the province. These works have been constructed typically as a response to the threat of immediate flooding. As many of the works were constructed under emergency conditions, they generally lack adequate planning and engineering design. These structures are not inspected or maintained and many have deteriorated with time. Sudden failure of these works could exacerbate flood damage and increase Risk of injury and loss of life.

The following sections describe various aspects of the flood management approach in BC.

B2 HISTORY OF FLOODPLAIN MANAGEMENT IN BC

BC's rugged terrain promoted the early development of flat floodplain areas. Over time, public policy regarding floodplain development has evolved to include awareness of Flood Hazards and the need for Risk management. Unfortunately, in many cases historical development still limits the ability of authorities to drive policy changes in land use planning. This section describes some of the formal programs that have evolved to manage development in Flood Risk areas.

B2.1 LOWER MAINLAND REGIONAL PLANNING BOARD

The Lower Mainland region was a leader in the early adoption of floodplain Risk management practices in BC. In August 1966, the Lower Mainland Regional Planning Board's Official Regional Plan (covering the area from Hope to the Georgia Strait) was approved. This plan included a policy that floodplains were to be kept free of urban uses, save where urban development was already present. Further urban development was to include Mitigation Measures. Future development on floodplains was to be limited to uses that would not be highly susceptible to flood damage. The Lower Mainland Regional Planning Board was dissolved in 1969 and its planning functions divided amongst four Regional Districts.

B2.2 AGRICULTURAL LAND COMMISSION

Some floodplain areas of BC are classified as part of the Agricultural Land Reserve (ALR), a provincial zone where farming is recognized as the primary use. The Agricultural Land Commission (ALC) is an independent provincial agency created in 1973, which governs the use of ALR land for other purposes. Past and present pressures to develop floodplains for uses other than agriculture have meant that the ALC has had a considerable effect in preventing development within agricultural floodplains.

The ALC remains an active agency and continues to exercise control over development in floodplain areas within the ALR.

B2.3 FLOODPLAIN DEVELOPMENT CONTROL PROGRAM

The large Fraser River flood of 1972 and resulting damage in the BC Interior (particularly on the North Thompson River near Kamloops) was a catalyst for new legislation, policies, and procedures at the provincial level. These initiatives were aimed at controlling development on the floodplain and reducing potential damages. From 1975 to 2003, the province managed development in designated floodplain areas under the Floodplain Development Control Program.

The Floodplain Development Control Program fulfilled a key term of the Fraser River Flood Control Program Agreement between BC and Canada, which committed the province "to a program of land use zoning and flood proofing to diminish potential losses in the area covered by [the] Agreement."

Central to this program was a requirement that Ministry of Transportation and Infrastructure (MTI) Subdivision Approval Officer was required to refer all subdivision plans for lands subject to Flood Hazards to the Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD), and the MFLNRORD was involved in assisting local governments with the preparation of floodplain bylaws. This authority has since been delegated to local governments, and the MTI no longer refers subdivision applications to the MFLNRORD, although the MFLNRORD still provides guidance in the form of the *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018) (see **Appendix C: Current Flood Management Legislation and Guidelines in BC**).

B2.4 FLOODPLAIN MAPPING PROGRAM

BC's floodplain mapping program commenced in 1974 as a provincial initiative aimed at identifying Flood Risk areas. The program was accelerated considerably in 1987 with the signing of the Canada/BC Agreement Respecting Floodplain Mapping (the Agreement). The Agreement provided shared federal-provincial funding for the program through 1998 and included provisions for termination of the Agreement as of March 31, 2003.

The floodplain mapping program was responsible for identifying designated floodplain areas so that development in these areas could be controlled appropriately. Under the Agreement, both governments were restricted from further under-takings in designated floodplain areas. Measures were also provided to encourage local authorities to reduce their exposure. Throughout its tenure, the program designated 89 floodplain areas throughout the province and produced over 560 map sheets.

On January 1, 2004, the responsibility for developing and applying floodplain mapping tools was transferred to local government as part of the legislative changes described below. The terms of the Agreement were not renewed and are no longer in effect.

The MFLNRORD worked with consultants to develop *Coastal Floodplain Mapping – Guidelines and Specifications* (Province of BC 2011) that provide a methodology to determine FCL considering storm surge, wave action, and sea level rise.

B2.5 2003/2004 LEGISLATIVE CHANGE

A major shift in policy occurred in 2003, corresponding with the end of the Floodplain Development Control Program. This policy change involved a significant change in how the MFLNRORD participated in land use regulation in flood-prone areas. Post-2003, each local government has the authority to exercise a degree of discretion in developing its own policies for zoning, development permits, subdivision approvals, bylaws, and building permits through the statutory authority described in **Appendix C: Current Flood Management Legislation and Guidelines in BC**. The MTI Subdivision Approval Officer continues its role as the approval authority for subdivisions in flood-prone areas in rural areas without the benefit of MFLNRORD referrals, and they still address Flood Hazard in their approval process.

B2.6 HAZARD MAPS

Steep mountain creeks and creek fans are subject to hazards beyond clear-water flooding such as debris flows, debris floods, and avulsions (see **Appendix A: Floods and Flood-Related Hazards in BC** for descriptions of these phenomena). In such areas, hazard maps are an appropriate means of summarizing information critical to making good floodplain management decisions.

Hazard maps are a more general tool than floodplain maps. While floodplain inundation will typically be shown on a hazard map, the map may also address a broader range of hazards and may provide complementary information (such as hazard likelihood and/or key Risk parameters such as velocity).

Hazard maps are useful for understanding the balance of Risk in a multi-hazard area, and can identify other external processes that need to be considered by a local government developing a Risk management strategy. Hazard maps are highly site-specific and as such, no comprehensive program has been developed for hazard mapping at the provincial level.

Flood Hazard maps developed by the provincial government under the BC Floodplain Development Control Program (discontinued in 2003) represent an existing and useful set of hazard maps. These remain publicly available as unsupported legacy documents. In light of ongoing environmental change, a Qualified Professional (QP) who consults such legacy documents must always be aware of their date of production and consider changes to the indicated conditions that may have occurred since.

In addition, active floodplains were systematically identified on terrain analysis maps produced by the former Resource Analysis Branch, BC Ministry of Environment (ca.1975-1990) and on maps commissioned by Forest Renewal BC. These maps may identify many smaller floodplains not covered by the provincial flood mapping program, but the basis for identification is restricted to landform interpretation, often only from air photography.

B3 NON-STRUCTURAL MEASURES TO REDUCE FLOOD AND EROSION RISKS

Non-structural flood protection refers to measures that mitigate Flood Risk without the use of a dedicated flood protection structure, otherwise known as Structural Mitigation Works. The most effective means of non-structural flood protection is to avoid development in flood-susceptible areas. However, non-structural flood protection can also include elevation and design of a building, often also referred to as Mitigation Measures. Erosion protection is sometimes necessary to safeguard Mitigation Measures such as fill and/or building foundations during an inundation event, and should be considered an integral part of non-Structural Mitigation Works.

Requirements and development controls for Mitigation Measures (such as setbacks, no-build areas, FCL, and minimum building elevations [MBE]) are typically identified in an engineering report and adopted by local government. Common tools for implementing non-Structural Mitigation Works include land use zoning, development permits, bylaws, and/or Covenants on land title.

Non-Structural Mitigation Measures provide a common secondary defence against Flood Risk in areas protected by primary structural works such as Dikes. In such cases, routes to convey water away from the Dike in the event of a breach (floodways) can also be part of the non-Structural Mitigation Works portfolio.

The section below provides additional information for some non-Structural Mitigation Works.

B3.1 LAND USE PLANNING AND ZONING

Land use planning and zoning, commonly through bylaws or development permits implemented under the local Official Community Plan, represent a local government's primary tool for controlling development and managing Flood Risk in their community. These tools are supported by a variety of legislation discussed in **Appendix C: Current Flood Management Legislation and Guidelines in BC**.

The goal of the process is to manage Risk by limiting the extent to which development is exposed to the Flood Hazard. Local governments, developers, and constituents must all recognize that Flood Hazards are not necessarily static and public policy including established FCL and MBE may need to be adapted to changing conditions. For example, the potential for sea level rise is currently driving extensive changes in local Flood Risk management policies in coastal communities around BC. Some communities are attempting to incorporate the time-dependent evolution of sea level rise into their plans for successive cycles of community redevelopment.

B3.2 COVENANTS ON LAND TITLE

Covenants on land title, primarily administered under Section 219 of the *Land Title Act*, outline conditions regarding development and are permanently attached to the legal title of a property parcel. Typical clauses in a Section 219 Covenant may include specification of permanent no-build areas (e.g., flood setbacks from a watercourse), MBE or FCL for the lowest finished floor or habitable space, and/or exemptions allowing Construction of certain elements below the MBE or FCL (e.g., garages without electrical equipment). Covenants also typically include an indemnification for the local authority and/or the Crown against any future claims for flood damages.

The Covenant is attached to the land title in perpetuity and is transferred along with title during sale, subdivision, or other dispensation. Long-term Consequences must always be considered when preparing a Covenant, and legal review by all named parties is strongly recommended.

B3.3 FLOOD CONSTRUCTION LEVELS AND MINIMUM BUILDING ELEVATIONS

The FCL is defined as the Design Flood level plus an allowance for Freeboard. In BC, the standard Design Flood for flood protection purposes is the flood with a 0.5% chance of being exceeded in any given year (the 200-year flood). Some local jurisdictions may specify a different (typically more conservative) Design Flood condition. Examples of this include the Fraser River, where the Design Flood is the 1894 flood of record, and other areas where geohazards (debris flows or debris floods) coexist with clear-water Flood Hazards. The minimum allowance for Freeboard is typically 0.3 m above the instantaneous Design Flood level or 0.6 m above the daily average Design Flood level, whichever results in the higher FCL. However, for many BC rivers, Freeboard has been set higher than these minimum values to account for sediment deposition, debris jams, and other factors.

Where the Design Flood level cannot be determined or cannot be reasonably used to set flood protection standards, an assessed height above the natural boundary of the water body or above the natural ground elevation may be used.

MBE has a less formal definition and simply refers to the minimum required elevation for a habitable area. MBE is typically used in areas where the Flood Hazard is not defined by a Design Flood event. This can include areas protected by primary structural flood protection works (i.e., Dikes) but also includes creek fans where the possibility of avulsion (rapid change in channel geometry) means that Flood Hazards may not be limited to the existing channel.

For areas with primary flood protection, MBE is typically determined through a Dike breach analysis. The MBE will also depend to some degree on the size and extent of floodways and the drainage characteristics, if any, for the protected area. The MBE may or may not include a specified allowance for Freeboard.

Both MBE and FCL elevations are commonly referenced to the underside of a wooden floor system or the top of a concrete slab—those areas that are used for habitation or storage of goods damageable by floodwaters.

Some local jurisdictions provide exemptions from MBE or FCL Construction requirements for special-use (non-habitable) buildings; however, practicing professionals should be aware that some of these exemptions might not be consistent with the exemptions provided in the *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018).

A higher standard of protection should be considered where critical infrastructure (e.g., hospitals, fire halls, and schools), population centres (e.g., shopping malls), or areas with difficult evacuation procedures (e.g., correctional centres) must be situated in a floodplain.

B4 HISTORY OF STRUCTURAL MITIGATION WORKS

B4.1 DIKING PROJECTS IN THE EARLY 1900S

Following the Fraser River flood of 1894, early diking works were constructed to protect farmland from routine spring flooding. Works were also established in other prime agricultural valleys. These earliest flood protection works were generally built by local landowners and were not subject to design standards or a controlled Construction program. Over time, the first diking and drainage improvement districts began to emerge as agricultural efforts expanded. The provincial office of the Inspector of Dikes was established in the early 1900s to oversee the operation and maintenance of Dikes by local diking authorities.

B4.2 FRASER RIVER DIKING BOARD

The 1948 flood on the Fraser River caused Dike failures and inundated widespread areas of the Fraser Valley, Kamloops, Quesnel, and Prince George. In response, the federal and provincial governments created the Fraser River Diking Board to coordinate an emergency Dike rebuilding program.

Between 1948 and 1950, the Board reconstructed over 200 km of Dikes and added about 45 km of new Dike works. This is generally acknowledged as the first coordinated large-scale Construction program for flood protection works in BC. The Fraser River Diking Board effectively ceased operations in 1950.

B4.3 FRASER RIVER BOARD

Established following the 1948 Fraser River flood, the Dominion-Provincial Board was set up to recommend options for water resources development and flood control in BC. At the beginning of its tenure, the Board recognized a widespread lack of data and worked for several years to fill gaps in the knowledge base.

In 1955, the federal and provincial governments replaced the Dominion-Provincial Board with the more focussed Fraser River Board, with the goal of evaluating options for flood control and hydroelectric power generation on the Fraser River. The Board studied several options for upstream storage as well as improvements to the diking system.

The work of the Fraser River Board formally concluded with a final report in 1963 recommending five storage reservoirs and one diversion for both flood management and power.

B4.4 THE FRASER RIVER JOINT ADVISORY BOARD AND THE FRASER RIVER FLOOD CONTROL PROGRAM

In 1968, the Fraser River Flood Control Program Agreement was signed between the provincial and federal governments. The scope of the agreement included rehabilitation of existing Dikes, Construction of new Dikes, extensive bank protection, and improvement of internal drainage facilities. Of the 44 projects initially proposed, 19 were completed and 3 were partially completed on the basis of cost-benefit analysis. Many of the unsuccessful candidate projects were on First Nations reserves, where projects were found to provide insufficient benefits to justify the proposed expenditures.

Between 1968 and 1994, the Fraser River Flood Control Program constructed over 250 km of Dikes and related works to the 1894 Design Flood levels (plus Freeboard) at a cost of about $300 million (1994). The federal and provincial governments provided 50/50 cost-sharing for capital works, while local governments were required to provide rights-of-way and accept ongoing responsibility for operation and maintenance.

Under the 1968 Agreement, the Joint Advisory Board also agreed to review a program of upstream storage to provide further flood protection. The Board's final Fraser River Upstream Storage Review Report, dated December 1976, concluded that:

- the completion of the current diking program (Fraser River Flood Control Program) will only increase the reliability of protection up to the 1894 level and that greater floods can and will occur; and
- additional flood protection by upstream storage or diversion is essential.

The report recommended Construction of the Lower McGregor River Diversion as well as further implementation of flood forecasting and floodplain management. The McGregor Diversion (to the Peace River watershed) did not proceed due to fisheries impact concerns. The BC *Water Protection Act* currently prohibits such large-scale water transfers between major watersheds.

B4.5 DIKE SAFETY PROGRAM

The office of the Inspector of Dikes administers the provincial Dike Safety Program. Through this program, the Inspector of Dikes is responsible for approving all new Dikes and modifications to existing Dikes, monitoring and auditing Dike management programs, and issuing orders under the *Dike Maintenance Act* to protect public safety. The authority of the Inspector of Dikes applies to all Dikes and appurtenant works except Private Dikes and those located on First Nations reserves. The intent of the program is to set design standards for Dike upgrades and new Dike Construction, provide oversight for the management of existing structures, and approve the design and Construction of new flood-protection works. The program also provides technical information and support for major multi-jurisdictional flood issues (e.g., Fraser River Hydraulic Model, Nooksack River, Vedder River). The program itself does not fund operation and maintenance or capital spending on any flood protection structures.

The Dike Safety Program worked with consultants to develop the *Seismic Design Guidelines for Dikes* (Province of BC 2014) and the *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* (Ausenco Sandwell 2011).

B4.6 ORPHAN FLOOD PROTECTION WORKS

Throughout BC, there are over 100 historic flood protection works that do not have a designated local authority responsible for operation and maintenance. The provincial government continually seeks opportunities to have these structures adopted by a local authority where they are found to provide benefit to a new or existing community.

The office of the Inspector of Dikes will not issue a *Dike Maintenance Act* approval for a major upgrade of an Orphan Dike, except where the local government has acquired the necessary legal access to land and has agreed to own and maintain the Dike.

See also Section B1.2: Structural Measures of Flood Management.

B4.7 RECENT BC FLOOD PROTECTION INITIATIVES

Often, local diking authorities lack the necessary capital resources to pursue significant upgrades and expansions. A number of government cost-sharing programs have evolved since the conclusion of the Fraser River Flood Control Program. Examples of such programs include the BC Ministry of Environment’s Flood Protection Assistance Program (1999-2005) and Urgent Mitigation Works completed prior to the 2007 freshet.

In the fall of 2007, the province announced the Flood Hazard Protection Fund, which will provide $100 million over 10 years to help local governments complete capital projects for flood protection. The program does not fund FHAs, Risk Assessments, or other technical studies, but does fund detailed engineering design. The Flood Hazard Protection Fund is managed through Emergency Management BC under the Ministry of Justice.

Under the current program, the local authority is responsible for cost sharing up to 33% of capital costs as well as providing rights-of-way and ongoing funding for operation and maintenance activities. As a result, not all local authorities have had the resources to allow them to participate. Nonetheless, project proposals have significantly exceeded the available funding in each year of the program to date.

B4.8 RECENT CANADA FLOOD PROTECTION INITIATIVES

In recognition of increasing disaster Risks and costs, the 2014 budget earmarked $200 million over 5 years to establish the National Disaster Mitigation Program (NDMP) as part of the Government's commitment to build safer and more resilient communities. The NDMP will address rising Flood Risks and costs, and build the foundation for informed mitigation investments that could reduce, or even negate, the effects of flood events.

The NDMP fills a critical gap in Canada's ability to effectively mitigate, prepare for, respond to, and recover from flood-related events by building a body of knowledge on Flood Risks in Canada, and investing in foundational flood mitigation activities. Knowledge that is up-to-date and accessible will not only help governments, communities, and individuals to understand Flood Risks and employ effective mitigation strategies to reduce the impacts of flooding, but will also further discussions about developing a residential flood insurance market in Canada.

B4.9 STRUCTURAL MITIGATION WORKS FOR FIRST NATIONS

Structural Mitigation Works owned and operated by First Nations vary significantly in importance and condition. Most First Nations works are not eligible for the senior government funding programs open to other local authorities. Rather, funding applications must be made through INAC, typically in the form of a Capital Funding Submission. Capital Funding Submissions are considered on the merits of each project, compared to other critical infrastructure initiatives (e.g., potable water, schools, or wastewater systems).

INAC can and does fund flood-protection works as required on an emergency basis; for example, extensive Urgent Mitigation Works programs were undertaken prior to the 1999 and 2007 floods.

Flood mitigation projects on First Nations reserves can have social and cultural benefits that are very important to local residents. These benefits are often difficult to represent in terms of the cost-benefit accounting typically used to screen and evaluate candidate projects.

B5 STRUCTURAL MITIGATION WORKS

Structural flood protection involves a dedicated linear structure such as a Dike or training berm that separates a watercourse from a protected area. The structure is designed such that water levels along the watercourse can exceed the local ground elevation inside the protected area. In some situations, structural measures may include integral appurtenant infrastructure such as pump stations and floodboxes. This section provides an overview of different approaches to Structural Mitigation Works.

B5.1 DIKES AND BERMS

A Dike is commonly a linear, compacted earthfill structure intended to protect a designated area from inundation caused by high water conditions on an adjacent watercourse or floodplain. These Dikes typically tie in to high ground at both the upstream and downstream ends and must be geotechnically stable under long-duration hydrostatic conditions associated with a protracted Design Flood event, without allowing seepage to overwhelm internal drainage capacity. To this end, many Dikes include impermeable core materials, seepage cutoffs, landside toe berms, relief wells, and other works to promote stability and control seepage.

Training berm Dikes are typically used to confine shorter and more transient flood, debris flood, and debris flow events within a designated channel. As such, training berm design poses lesser challenges with regard to seepage. Erosion protection is usually critical, since shorter flood events are typically associated with higher flood velocities and debris transport. These structures may also be tied in to high ground only at the upstream end.

Earth embankment Dikes are designed to the local FCL (described above) such that they will preserve a Freeboard allowance during the Design Flood. There is growing concern about the behaviour of major Dike systems during a major earthquake. Many local authorities, particularly in potential liquefaction areas around the Lower Mainland, have undertaken seismic studies and seismic upgrading programs. Design of new structures must consider relevant seismic standards before obtaining approval from the Inspector of Dikes. Climate change, discussed elsewhere in these guidelines, is also an area of significant concern, particularly with regard to the potential for sea level rise and/or increased climate variability to increase the FCL.

Historically, Structural Mitigation Works have isolated watercourses from their floodplains in an attempt to preserve the maximum amount of land for development. This approach has a number of effects, including:

- increased water levels associated with the loss of floodplain storage;
- increased peak discharge due to the loss of storage attenuation; and
- increased velocity within the confined channel.

More recent mitigation projects have recognized these Flood Hazards and the many environmental benefits associated with preserving a wider natural corridor. New Dikes and berms are usually set back from the current creek or river channel. Nonetheless, the design must protect the structural works against erosion hazards that are both direct (against the slopes) and indirect (through undermining or outflanking).

B5.2 FLOODWALLS AND SEAWALLS

In some special cases, for closure sections, or where there is insufficient space to construct an earthen embankment between a potential Flood Hazard and an existing development, a floodwall may be appropriate for a short section of the Dike. A typical form is to have fill on one side of a vertical, near-vertical, stepped, or angled structural face composed of erosion-resistant materials. Like Dikes and berms, seawalls and floodwalls are typically constructed to the FCL.

Because these structures are unique, it is not appropriate to provide a detailed description. However, free-standing floodwalls have several design limitations (high basal seepage gradients; inflexible with regard to future height increases; cannot be raised during floods; susceptibility to differential settlement or ground movement; may require erosion protection at base) and should only be used where it is impractical to use a conventional earth embankment. The Inspector of Dikes will generally not authorize a free-standing floodwall or seawall where land can be acquired to accommodate a Standard Dike.

B5.3 BANK PROTECTION WORKS

Many of BC's rivers and creeks follow relatively steep, high-energy channels and can be laterally unstable. In their natural state, most river channels change slowly over time through gradual bank erosion. Higher velocities during flood events can increase the energy of the river, leading to increased potential for bank erosion and, in some cases, rapid channel change referred to as avulsion. Debris transport can be significant during major floods, creating potential impact hazards that can accelerate local erosion.

Where erosion is a threat, bank protection works may be used to reduce property damage and Risk to the public. The most common form of bank protection is the riprap revetment, which is a flexible apron of angular rock that is sized to resist disturbance under Design Flood conditions. A filter material used behind the revetment will prevent the finer Dike, berm, or bank material from being washed out between the riprap voids. A toe is required to protect the revetment against undermining if the channel downcuts during high flows.

By definition, Construction of bank protection creates a relative "hard point" along the riverbank. This raises flow velocities past the protected bank, which, in turn, sweep sediment that was formerly deposited on the opposite bar downstream to the next bend, where the problem repeats itself. Some erosion protection works are later threatened by outflanking as this process changes the channel alignment, profile, or planform. In some cases, there is little option but to extend the hard point of erosion protection further along the stream; however, there is a growing recognition of the potential impacts of this approach on both environmental and channel morphology processes. Caution must be taken that bank protection works do not simply relocate problems to a location farther downstream.

B5.4 BIOENGINEERED BANK PROTECTION WORKS

High environmental values sometimes conflict with conventional bank protection works (e.g., installation of a permanent inorganic blanket through a valuable riparian zone). Alternatives to conventional bank protection works can include planting with resilient native vegetation species (usually for lower-velocity river systems) or a range of bioengineering alternatives.

Bioengineering refers to the use of natural materials and vegetation in an engineering design framework, which is sometimes integrated with more typical engineering techniques and materials. While bioengineered bank protection works offer environmental benefits, the Risks associated with this approach often involve a shorter project life span, more intensive maintenance requirements, and possible mobilization and/or downstream displacement of protective structures. Without careful consideration of the complete life-cycle of these alternatives under all conditions, bioengineered works have the potential to compromise public safety and affect other properties.

Bioengineered works must be implemented with due regard for their mitigation context. For example, soft timber-type structures should not be considered as primary bank protection for critical assets such as homes. However, the same approach may be acceptable in another context, such as protecting productive farmland.

B5.5 APPURTENANT STRUCTURES (PUMP STATIONS AND FLOODBOXES)

Structural flood protection works interrupt the natural hydraulic connectivity between the protected floodplain area and the adjacent watercourse. Provision must be made to allow natural runoff to drain out of the protected area through the structure, usually in the form of culverts through an earthfill Dike.

During a flood event, water levels outside the protected area are higher than those inside, and gravity drainage of internal runoff is not possible. Backflow protection is typically required on drainage culverts to prevent water ingress.

The most common form of culvert backflow protection is a flapgate, which is a free-swinging gate hinged at the top or side that is held closed by differential water pressure during a high-water event. An automatically-controlled hydraulic or mechanical gate that allows controlled inundation during moderate high water but closes during floods is referred to as a tide gate. Some manufacturers have developed duck-bill type rubber check valves that can replace a conventional flapgate. Manual gates (e.g., slide gates) are also used in some systems but are less common due to their reliance on human intervention to function during a flood.

A culvert combined with a flapgate, tide gate, or duck-bill check valve or manual gate system is referred to as a floodbox. When water rises outside the Dike system, the floodboxes close and gravity drainage ceases for the duration of the flood event.

If there is significant internal drainage to a low point within the protected area, a pump station is required to evacuate water and avoid internal flooding. Pump stations have the potential for mechanical or electrical failures and are normally inspected frequently during a flood. The discharge capacity of a pump station will vary throughout a flood due to changes in internal and external water levels.

Both floodboxes and pump stations involve pipes and other elements that pass through or reside within the Dike cross-section. Therefore, floodboxes and pump stations are an integral part of the associated Structural Mitigation Works. Care must be taken that drainage works do not create preferential seepage pathways through the structure that could lead to internal erosion.

B5.6 DESIGN OF BUILDINGS BEHIND DIKES AND BERMS

Notwithstanding the provision of primary structural flood protection, buildings in Flood Hazard areas should be designed with secondary Mitigation Measures, including elevation to the applicable FCL or MBE, erosion protection/foundation treatments, and the appropriate placement of key services and utilities.

B5.7 FLOODWAYS

Floodways play a key role in conveying floodwaters that have circumvented primary flood protection defences. This is generally achieved by providing an intentional flow path that avoids critical areas and limits inundation. A local government may designate floodways as part of ongoing development in the floodplain. A distinction is made between floodways within a Dike-protected area and dedicated bypass channels used in other jurisdictions (e.g., Red River Floodway in Winnipeg, Manitoba), which in BC would be considered a river diversion. Key considerations in defining floodways should include the definition of FCL and MBE for adjacent development, as well as emergency access routes while the floodways are in use.

B5.8 SEDIMENT REMOVAL

Aggradation of an active creek bed due to natural sediment transport and deposition can increase Flood Hazards on fans and floodplains, promote avulsion, and compromise the standard of protection provided by Structural Mitigation Works. Where riverbed aggradation is an ongoing issue, an environmentally appropriate in-stream sediment management program can be an important part of a local authority’s Flood Hazard mitigation program. Local authorities should monitor sediment accumulation in the river channel to determine whether deposition has reduced discharge capacity as a prerequisite to the planning and consultation process.

In select situations where there are no economically and/or environmentally superior alternatives for reducing Flood Risk, environmental agencies may permit the local government or engaged provincial agency to remove some of the gravel accumulating within the channel. Removals are considered more favourably when the sediment balance is well-known (so that the amount necessary to remove can be determined) and when the benefit can effectively be demonstrated. An ongoing program of river surveys, sediment budget reviews, and flood profile modelling is usually required. The permitting process for such removals will involve both the provincial government (represented by the MFLNRORD) and federal government (represented by Fisheries and Oceans Canada).

Sediment transport is a natural process. Human interference (in the form of sediment removal) can result in unintended Consequences, such as erosion or sediment deposition in inconvenient places, siltation or degradation that threatens river-oriented facilities, and destruction of aquatic habitat. Consideration should be given to the scale of intended actions in the planning and design process. For example, removal of riverbed sediments in smaller amounts that, over several years, equal the bed material influx can be considered as a strategy for maintaining the river's flood profile at an acceptable level. Conversely, removing sediments in quantities sufficient to immediately adjust the flood profile typically entails much larger excavations with greater environmental impact and more potential for unintended Consequences.

The temporary nature and high environmental disturbance associated with in-stream sediment management makes it a practice best left to situations where historical development patterns preclude other options for Flood Risk management. Where sediment management is an integral and ongoing part of a Flood Risk management strategy, it should be incorporated into the applicable operation and maintenance manuals for related structural flood protection works.

B5.9 RIVER DIVERSIONS AND MEANDER (RE)CONSTRUCTION

Historically, river diversions have been implemented to promote efficient hydroelectric power production, facilitate drainage, or shorten navigation routes. Diversions of large rivers can also decrease Flood Risk by cutting off meanders, thereby increasing channel slope and conveyance. Diversions are also used to supply water to fish hatcheries and irrigation projects.

Diverting water from a channel can cause an initial reduction in the Flood Hazard. However, if the diversion fails to capture a comparable proportion of the sediment load, aggradation may cause Flood Hazards to redevelop.

The diverted water may increase erosion potential in the receiving channel, with corresponding aggradation problems emerging farther downstream as the river seeks to adjust to the new flow regime.

In recent decades, research has provided a growing understanding of the ecological impacts of river diversions. River diversions have also been noted to result in flood waves proceeding more rapidly downstream. In many jurisdictions, focus has shifted to restoring old channels, reactivating old cutoff meanders, and reclaiming lost ecological spaces wherever feasible.

A common practice in river restoration or channel realignment projects is to specify a regularly meandering channel, designed to pass expected flood flows. The viability of this solution will depend on how the channel performs given the actual charge of both water and sediment. In general, some sediment of bed material calibre will be deposited, at least initially, within the channel, which may destabilize the channel if the banks remain erodible, and will, in any case, raise flood water levels.

B5.10 DAMS

Dams modulate the flow regime and interrupt sediment transport down a river. Modulation of the flow regime commonly reduces downstream Flood Hazards, but can also increase Flood Hazards in areas inundated by the upstream reservoir. In general, dams make the definition of a designated "design" flood for downstream areas more complex. BC's *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018) require that the designated flood below the dam be established on a site-specific basis. Hydrologic and hydraulic modelling is often required, as the Design Flood can be affected by reservoir operation and available storage as well as natural inflow. Certain operating regimes might exacerbate ice run problems and ice jam flooding in winter.

In some cases, the QP will have an obligation to consider the dam classification in the context of development issues, particularly with regard to whether a new development might change the Consequence classification of the upstream facility.

The interruption of sediment transfer by a dam often results in clear-water releases from the dam, promoting scour and degradation in the downstream channel. On some of BC's gravel-bed rivers, the regulated peak flows are incapable of moving the bed sediment and natural scour is reduced. Sediments entering the main stream from tributaries can create fans that move into the main channel, creating raised backwater levels upstream. The net effect of these changes may increase or decrease Flood Hazards.

Emergency releases from the dam into a river that has been regulated for many years, and has consequently adjusted its channel morphology to the regulated regime, may cause flooding onto surfaces where it is no longer expected, typically onto former bar surfaces and lower floodplain areas.

B5.11 OTHER STRUCTURAL MEASURES

BC's environment of steep mountain creeks creates the potential for debris floods and debris flows. Existing or Proposed Development in some at-Risk areas has resulted in the development of specialized Structural Mitigation Works generally referred to as debris barriers. The goal of a debris barrier is to dissipate the energy associated with debris mass movement and retain all or part of the transported debris. A debris barrier can take a variety of forms and serve a range of functions. Debris breakers, deflection berms, and retention basins can all help to reduce debris flow or debris Flood Risk. Debris barriers should be designed by a team of professionals with experience in geohazard mitigation.

On smaller channels carrying high sediment loads—for example, channels on Alluvial Fans—sediment traps may be constructed to focus sediment management activities at a particular location. These sediment basins typically take the form of channel expansions, which cause a slackening of the current and deposition of the coarser part of the sediment load. The retained sediment is excavated periodically under controlled conditions, usually by implementing dedicated flow diversion or bypass works. Environmental agencies should be involved as stakeholders at the feasibility stage and throughout the design process.

Flood detention and retention features (e.g., ponds, swales, ditches, basins, wetlands, and rain gardens) are commonly employed as part of urban stormwater management strategies. As a result, these features can also have a mitigating effect on Flood Hazards where urban areas comprise a significant portion of the upstream watershed area. Flood detention features attenuate runoff and release it slowly over time, but do not alter the volume of runoff. Flood retention features permanently retain all or a portion of the runoff, which eventually infiltrates into the ground. Features may be designed to incorporate both retention and detention characteristics, and can also help to improve water quality when constructed in the form of semi-natural wetlands.

B5.12 LIMITATIONS OF STRUCTURAL MITIGATION WORKS

Structural Mitigation Works have limitations in both design and performance. Failure to acknowledge these limitations can lead to increased development in flood-susceptible areas. Consequences can include damage such as was observed in New Orleans after Hurricane Katrina. Closer to home, Dike failures on the Fraser River (Chilliwack) in 1948, North Thompson (Kamloops) in 1972, and Coal Creek (Fernie) in 1995 caused major damage. Other near misses include Michel Creek (1995) and Squamish (2003). The Fraser River and Skeena River freshets of 1999 and 2007 represented runoff from large snowpacks, which could have resulted in very severe and extensive flooding under different weather conditions. These failures and near-misses have brought the potential limitations of Structural Mitigation Works into public focus.

Structural Mitigation Works can fail due to overtopping during a flood in excess of the design event. Mitigation structures can also fail due to erosion, such as the 1995 failure on Coal Creek, internal erosion (piping), or slope instability. Structural failure of primary works can expose development to the full range of hazards associated with the design event, or in some cases, a greater degree of hazard. In contrast, non-structural measures like Mitigation Measures continue to mitigate damage regardless of event size, since the development would be impacted by a reduced depth of inundation above the Design Flood level.

In general, non-structural measures are preferred as a means of mitigating Flood Risk.

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APPENDIX C: CURRENT FLOOD MANAGEMENT LEGISLATION AND GUIDELINES IN BC

This appendix introduces the main legislation and guidelines that govern Flood Hazard management in BC.

C1 OVERVIEW

Land use in flood-prone areas is regulated under the following acts and regulations:

- *Local Government Act* (for development permits and floodplain bylaws, variances, and exemptions)
- *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)

The Construction and maintenance of many of the Structural Mitigation Works in BC are regulated by the *Dike Maintenance Act*. There are approximately 100 diking authorities throughout the province, which are charged with the responsibility to operate and maintain these works. The majority of diking authorities are local governments designated under the *Local Government Act* or the Community Charter. In the past, a number of other entities have been recognized as diking authorities, including improvement districts, diking districts (under the *Drainage, Ditch and Dike Act*), strata corporations, ratepayers associations, government agencies, non-government organizations, private corporations, and private individuals. However, approvals for new structures, as defined by the *Dike Maintenance Act*, will only be authorized where local government has agreed to be the diking authority.

Development and/or flood protection works proposed for Construction in riparian areas[8] or within a watercourse may require approvals pursuant to the following environmental legislation:

- Provincial *Riparian Areas Regulation* under the *Riparian Areas Protection Act*
- Provincial *Water Sustainability Act*
- Federal *Fisheries Act*
- Provincial *Environmental Assessment Act*
- Federal *Canadian Environmental Assessment Act*
- Federal *Navigation Protection Act* (formerly the *Navigable Waters Protection Act*)

Any works or activities proposed for Construction on or for the use of Crown land, including the removal of gravel from a channel or foreshore requires authorization under the *Land Act*.

Lands Officers from the Integrated Land Management Branch of the Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD) may require flood assessments as a

[8] A riparian area is the interface between land and a watercourse or water body. Specifically, it is the land area directly adjacent to the watercourse or water body, the character of which is directly influenced by the presence of the water course or water body.

requirement for applications to lease and purchase Crown lands.

Flood management is guided at the local government level through Official Community Plan*s*, bylaws, development permits, building permits, zoning restrictions, and other types of documents. Local governments may have additional requirements concerning public access to watercourses.

Development of floodplains on First Nations land can be subject to regulation by local First Nations as well as Indigenous and Northern Affairs Canada (INAC). Local governments may be required to consult with local First Nations when developing floodplains adjacent to First Nations land; however, there is no legal framework for such consultations.

C2 ENVIRONMENTAL MANAGEMENT ACT

Sections 5(f) and 138(3)(e) of the *Environmental Management Act* provide the Minister of the MFLNRORD with broad flood management powers, including the authority to establish guidelines and regulations. The Minister may also require local governments and diking authorities to prepare plans with respect to flood protection Dikes and the development of land subject to flooding. While no regulations have been established under this statute to date, the MFLNRORD has published the *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018) (discussed in **Section C8**) that must be considered by local governments when adopting floodplain bylaws under Section 524 of the *Local Government Act*. These guidelines are periodically updated by the MFLNRORD.

C3 LAND TITLE ACT – SUBDIVISION APPROVALS

Section 86 of the *Land Title Act* allows the Approving Authority to address natural hazards issues during the subdivision application process. It contains provisions for "refusing to approve" a subdivision plan if the Approving Authority reasonably expects that the land could be subject to "flooding, erosion, land slip [landslide] or [snow] avalanche."

If the Approving Authority reasonably expects that the land may be subject to flooding, Section 86 allows the Approving Authority to require either or both of the following as condition(s) of approval:

- A report certified by a professional engineer or professional geoscientist experienced in geotechnical engineering that the land may be used safely for the use intended
- One or more registered Covenants under Section 219 of the *Land Title Act* in respect of any lots created by the subdivision.

A Covenant is attached to the property title. The Covenant will typically specify conditions to which the development must adhere to reduce Flood Risk and to indemnify the Crown and the Approving Authority against future flood damages.

C4 LOCAL GOVERNMENT ACT – DEVELOPMENT PERMITS

The *Local Government Act* (Section 488) states that a local government Official Community Plan can establish a Development Permit Area to protect development from "hazardous conditions."

According to the *Local Government Act*, hazardous conditions include "flooding, mud flows, torrents of debris [debris flows], erosion, land slip [landslide], rock falls, subsidence, tsunami, [snow] avalanche or wildfire."

In a Development Permit Area, an owner must obtain a Development Permit from the local government before subdividing or altering the land, including constructing, adding to, or otherwise altering a building or other structure. A Development Permit may set out requirements, conditions, or standards regarding the development itself or the sequence and timing of Construction. In particular, a Development Permit can establish flood-prone areas that must remain free of development.

Before issuing a Development Permit, the local government may require the applicant to provide a report "certified by a professional engineer with experience relevant to the applicable matter, to assist the local government in determining the conditions or requirements."

A Development Permit precedes a related building permit. Both may be required in jurisdictions that have an Official Community Plan and where development may be exposed to flooding.

C5 BARE LAND STRATA REGULATIONS, STRATA PROPERTY ACT – STRATA PLAN APPROVALS

A Bare Land Strata Plan must be reviewed and found acceptable by a local government Approving Authority. The Approving Authority can refuse to approve the strata plan if it is considered that the land could reasonably be subject to "flooding, erosion, land slip [landslide] or [snow] avalanche." Alternatively, the Approving Authority can approve the plan "if the owner-developer agrees in writing to enter into such Covenants registerable under section 182 of the *Land Title Act* as the Approving Authority considers advisable."

For Strata Title applications other than bare land strata, floods may be addressed through the Official Community Plan, re-zoning, and Development Permit process documented elsewhere in this appendix.

C6 COMMUNITY CHARTER – BUILDING PERMITS

The Community Charter (Section 56) contains provisions governing the ability of a building inspector to issue a building permit for land that is likely to be subject to "flooding, mud flows, debris flows, debris torrents, erosion, land slip [landslide], subsidence, rock falls, or [snow] avalanche."

In areas where a bylaw exists regulating the Construction of buildings and other structures, the building inspector may require an applicant proposing Construction on flood-prone land to "provide the building inspector with a report certified by a QP that the land may be used safely for the use intended."

If the Qualified Professional (QP) does not include the statement "that the land may be used safely for the use intended," the building inspector may not issue the building permit.

Conditions noted in the Flood Assessment Report that are necessary to render the land safe for the intended use are incorporated in a Covenant registered under Section 219 of the *Land Title Act*. Usually, the Flood Assessment Report itself is registered in the Covenant, making the document publicly available.

C7 LOCAL GOVERNMENT ACT – FLOODPLAIN BYLAWS, VARIANCES, AND EXEMPTIONS

The *Local Government Act* (Section 524) addresses Construction requirements in relation to floodplains. Specifically, this section of the *Local Government 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, often the flood protection measures are not required if the renovation does not exceed 25% of the building footprint.)

In developing its bylaws, the local government must consider provincial guidelines as well as 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 have been developed under regulation. However, the provincial document *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018) (see **Section C8**) provides guidance for developing bylaws under Section 524 of the *Local Government Act*. Through Section 524, local governments may, by bylaw, designate specific floodplain areas.

Section 524 also indicates that a local government can grant a bylaw exemption if:

- the exemption is consistent with the provincial guidelines; or
- a report exists that the land may be used safely for the intended use, as certified by a professional engineer or professional geoscientist experienced in geotechnical engineering and expertise in river engineering and hydrology.

Historically, some jurisdictions have enacted bylaws under Part 14, Division 5 of the *Local Government Act*, which governs zoning bylaws. However, it is preferable that a Section 524 bylaw be used

C8 FLOOD HAZARD AREA LAND USE MANAGEMENT GUIDELINES

The *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018) are published by the MFLNRORD under the *Environmental Management Act* to assist local governments in developing and implementing management strategies for flood-prone areas. These guidelines are considered a key resource for implementing management practices at the local level, are referenced under Section 524 of the *Local Government Act*, and must be considered by local government in developing bylaws under that Section.

The *Flood Hazard Area Land Use Management Guidelines* and the *Amendment Section 3.5 and 3.6* have five general sections, organized to address administration, floodplain mapping, application by natural hazard type, application by specific land use, and implementation measures.

The QP should also be familiar with the *Coastal Floodplain Mapping Guidelines and Specifications* (Province of BC 2011a), the Flood Hazard Map User Guide (Province of BC and Fraser Basin Council 2004), the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* , and the *Professional Practice Guidelines – Flood Mapping in BC* (Engineers and Geoscientists BC 2010 and 2017).

As an important complement to the *Flood Hazard Area Land Use Management Guidelines* and the *Amendment Section 3.5 and 3.6*, the provincial government has developed a set of Flood Hazard maps and a registry of Flood Hazard reports based on information accumulated by the BC Floodplain Development Control program (discontinued in 2003). These maps and reports registry are available from the Approving Authority. Some Approving Authorities update the maps. However, for the most part, these maps remain as unsupported legacy documents that represent the state of knowledge and understanding of known hazards at the time the maps were initially produced. In light of ongoing environmental change, a QP who consults such legacy documents must always be aware of their date of production and consider changes to the indicated conditions that may have occurred since.

C9 PROFESSIONAL PRACTICE GUIDELINES: LEGISLATED LANDSLIDE ASSESSMENTS FOR PROPOSED RESIDENTIAL DEVELOPMENTS IN BC

Engineers and Geoscientists BC has a comprehensive suite of guidelines aimed at assisting QPs retained to undertake landslide assessments in areas subject to rock falls, slumps, slides, avalanches, or creep; debris falls, slides, flows, or floods; earth falls, slumps, slides, flows, and creep; and flow slides. Where Flood Hazards overlap with areas subject to one or more of these hazards, the *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010) must be consulted in conjunction with these guidelines.

C10 PROFESSIONAL PRACTICE GUIDELINES: FLOOD MAPPING IN BC

With funding support from Emergency Management BC, Engineers and Geoscientists BC developed the *Professional Practice Guidelines – Flood Mapping in BC* (Engineers and Geoscientists BC 2017). Those guidelines are intended to provide guidance and information suitable for uses related to Flood Risk management, land use planning and management, emergency planning, and flood insurance.

The *Flood Mapping in BC* guidelines support the development of flood maps in a consistent manner, incorporating best practices. These guidelines outline a common approach to be followed when carrying out a range of professional activities including data requirements and input, appropriate use and interpretation of data and flood modelling, typical hazard assessment methods, and climate and environmental considerations.

C11 DIKE MAINTENANCE ACT

The *Dike Maintenance Act* gives authority to the provincial Inspector of Dikes. Under the *Dike Maintenance Act*, the Inspector of Dikes may:

- access and inspect designated flood protection structures;
- require that a local authority repair, replace, renew, alter, add to, improve, or remove all or part of a flood protection or appurtenant structure; and
- require a diking authority to provide routine or special reports on the Construction or maintenance of Dikes for which the diking authority is responsible.

The Inspector of Dikes must give authorization in writing before a person or diking authority can:

a) lower, or cause or allow to be lowered, the elevation of a Dike or decrease, or cause or allow to be decreased, the width or cross-section of a Dike;
b) install, or cause or allow to be installed, any culvert, pipe, floodbox, or any structure through a Dike;
c) construct, or cause or allow to be constructed, any works on or over a Dike or Dike right-of-way;
d) alter, or cause or allow to be altered, the foreshore or stream channel adjacent to a Dike; or
e) construct a new Dike.

Specialized Structural Mitigation Works, such as debris barriers, may or may not be subject to the *Dike Maintenance Act*. Flood protection works located on private property that protect only that property may not be subject to regulation under the *Dike Maintenance Act*.

Interference with a flood protection structure and failure to cooperate with the Inspector of Dikes are defined as offences under the *Dike Maintenance Act*.

Although the Inspector of Dikes sets design standards as a regulatory and enforcement authority, responsibility for designing, constructing, monitoring, and maintaining flood protection works remains with the designated local authority.

To obtain an approval under the *Dike Maintenance Act*, the following application requirements must be met:

- The application conforms with the Dike Design and Construction Guide: Best Management Practices for British Columbia (Province of BC 2003) as amended from time to time, and with other published guidelines.
- The design, Construction, and as-constructed drawings are certified by a suitably QP engineer.
- Works are planned and scheduled to ensure that the protection is not diminished during potential flood periods.
- The raising of Dikes or the Construction of new Dikes or other works (e.g., bridge constrictions on Diked channels) must not impact the safety of other Dikes or increase the Flood Risk to others.
- Depending on the scope of works involved, an Operations and Maintenance (O&M) manual may be required.

New Dikes will only be approved where the local government has agreed to act as the diking authority. Among other things, the diking authority must ensure ongoing inspections, operation, and maintenance, and permanent legal access to the lands on which the new Dike is to be constructed.

C12 OTHER LEGISLATION RELATED TO STRUCTURAL MITIGATION WORKS

The *Drainage, Ditch and Dike Act* and the *Local Government Act*, Part 17, have enabled the creation of autonomous diking and improvement districts for purposes such as drainage, ditching, and diking. The improvement districts can design, construct (subject to approval from constituents), operate, and maintain flood protection and drainage works, and raise money to support these activities through a tax levy on protected properties.

Improvement districts were historically created in rural areas where there was no alternative form of local government. Where a suitable local government exists, an improvement district is encouraged to transfer drainage and diking assets and responsibilities to that local government. Over time, it is expected that services currently provided by improvement districts will be assumed by local governments.

Where Structural Mitigation Works are constructed on or within a watercourse channel, authorization must be obtained under the provincial *Water Sustainability Act* as well as the federal *Fisheries Act* and, if applicable, under the federal *Navigable Waters Act*. Major projects may be subject to review under the provincial or federal *Environmental Assessment Act*. Structural Mitigation Works that occupy Crown land require some form of land tenure under the *Land Act*. The *Land Act* also provides authority for removing sediment from channels.

C13 KEY GUIDELINE DOCUMENTS

The MFLNRORD and its predecessors, through the office of the Inspector of Dikes, has prepared a number of guideline documents to assist experienced professional engineers in the design and implementation of Structural Mitigation Works.

A QP should be thoroughly familiar with the following guidelines:

- *Guidelines for Management of Flood Protection Works in British Columbia* (Province of BC 1999a)
- *Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment* (Province of BC 1999b)
- *Flood Protection Works Inspection Guide* (Province of BC 2000a)
- *Riprap Design and Construction Guide* (Province of BC 2000b)
- *Dike Design and Construction Guide – Best Management Practices for British Columbia* (Province of BC 2003)
- *General Guidelines – Hydrologic/Hydraulic Design Report* (Province of BC 2008a)
- *General Guidelines – Comprehensive Geotechnical Investigation and Design Report* (Province of BC 2015)
- *Seismic Design Guidelines for Dikes* (Province of BC 2014a)
- *General Guidelines – New Dikes and Upgrades to Existing Dikes* (Province of BC 2011b)

- *General Guidelines – Dike Maintenance Act Approval for Pipe Crossings of Dikes* (Province of BC 2014b)
- *General Guidelines – Rip Rap Erosion Protection for New and Existing Dikes* (Province of BC 2008b)
- *General Guidelines – Exploratory Geotechnical Testing Within a Dike or Dike Right of Way* (Province of BC 2009)

Other relevant guidelines include the following:

- *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018)
- Professional practice guidelines *Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010)
- *Coastal Floodplain Mapping Guidelines and Specifications* (Province of BC 2011a)
- *Flood Hazard Map User Guide* (Province of BC and Fraser Basin Council 2004)
- Professional practice guidelines *Flood Mapping in BC* (Engineers and Geoscientists BC 2017)

While not yet adopted as provincial policy, the province has commissioned and released the report *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* (Ausenco Sandwell 2011).

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APPENDIX D: FLOOD HAZARD ASSESSMENTS

This appendix should be read in conjunction with **Section 3: Guidelines for Professional Practice for Flood Assessment** in the main guidelines. It provides additional information on how to execute Flood Hazard Assessments (FHAs). FHAs provide the basis for Flood Risk Assessments (FRAs), in that they quantify the likelihood and intensity of a potentially damaging event. The Risk Assessment (**Appendix E: Flood Risk Assessment**) combines the results of the hazard assessment with estimation of Consequences.

D1 INTRODUCTION

FHAs, by definition, determine the probability of floods of variable magnitudes and assess their intensities. Both of these considerations need to be addressed when carrying out an FHA. Magnitude, for example, can be indexed by one summary measure of flood size (usually river discharge) or, in the case of coastal Flood Hazard, wave height or storm surge elevation. Flood extent can be expressed as the area inundated and the duration of the flood, while Flood Intensity is typically expressed as flow velocities and flow depths. These variables are not simply related. For example, river floods may be caused by high flows or by high stage due to backwater (as in ice jam or landslide dam backwater). It is arguable that, for rivers, stage should be the basic measure of flood magnitude.

Traditionally, in Canada, floods in Diked river sections are simulated with one-dimensional steady or unsteady state models that focus on the stream channel and overbank areas and provide stage and average flow velocities. As described in the *Floodplain Mapping Guidelines and Specifications* (Province of BC 2011), for Diked rivers, flood levels in the floodplain are estimated by applying the computed water surface profile values within the river channel across the floodplain. This is a conservative approach, as it not only assumes the Dike is essentially ineffective but also constrains the water surface profile by the presence of the Dike, which results in floodplain water levels that are often higher than would occur if a Dike is breached. For undiked rivers, one-dimensional models normally include the entire cross-section of the river and floodplain and no extrapolation is required. Two-dimensional models simulate the flow depth and area inundated and allow the user to examine the propagation of the flood wave across and downstream in the floodplain when Dikes are overtopped. Such models, while still the exception rather than the rule, are encouraged as they provide crucial variables for FRAs. However, they are generally more costly and likely to be limited to the assessment of large developments that would have distinctly two-dimensional flow patterns.

These methodologies are well-established and a large number of numerical models exist that fulfill the same functionality by using similar equations of flow. A comprehensive FHA, however, creates different Flood Hazard Scenarios beyond a purely flood stage approach. For example, the implicit assumption in Flood Hazard studies in British Columbia (BC) is that floodplain inundation will occur whether or not Dike elevations are exceeded and, as noted above, designated flood levels are often higher than what would actually occur if a Dike is breached. Detailed

Dike breach modelling studies have been carried out on some rivers with large floodplains, which has resulted in reduced designated flood levels in some areas in the floodplain (for example, Agassiz, Matsqui Prairie, and Squamish). In some cases, these modelling studies have shown that the presence of a Dike results in higher floodplain water levels than the river water surface profile at locations where water flows out of a floodplain over a Dike and back into the river.

Dike breach analyses should be considered in areas of high potential Risk (i.e., heavily urbanized areas or areas containing critical infrastructure where potential losses could be economic and social). Such breach analysis could allow for flood warning near strategic breach locations and preparation of emergency planning in the event of a breach.

Particularly for small-scale development cases, the Qualified Professional (QP) may be uncertain as to what level of effort is appropriate to determine if a proposed subdivision is "safe for the use intended." These guidelines are designed to answer some of these questions without providing a precise manual on flood assessment.

D2 IDENTIFICATION / CHARACTERIZATION OF ALLUVIAL FANS AND FLOODPLAINS

Floodplains and Alluvial Fans are surfaces constructed by the deposition of stream-borne sediments that are subject to normal flooding. Their identification is a key step in any FHA or FRA.

An Alluvial Fan is a conical accumulation of sediment deposited where a steep channel flows onto a much lower gradient so that much of the sediment load of the tributary is deposited. Alluvial Fans typically occur where a mountain tributary enters a main valley. As such, they are widespread in BC mountain valleys, though they may be overlooked where they are covered in dense forest.

A floodplain is, by definition, an area of flat terrain bordering a river that is composed of sediments transported and deposited by the river, and subject to flooding by the river (in the absence of flood defences). Floodplains should be distinguished from the valley flat, which is the essentially flat surface in a valley bottom (a purely morphological definition) that may or may not be an active floodplain. How frequently a surface must be inundated in order to be classified as an active floodplain is a matter of debate. Williams (1978) found that recurrence intervals for bankfull or overbank flow in a sample of floodplains in western North America defined as active varied from 1 year to more than 25 years.

For practical management, it is worthwhile to distinguish floodplains according to their degree of activity. For example, floodplains that are apt to be inundated with a return period of 10 or fewer years might be designated as "frequently active," while those that are apt to be inundated with a return period of 10 to 30 years (that is, in the period of a generation) might be termed "episodically active." Floodplains inundated with a return period of 30 to 200 years might be termed "infrequently active." Flood inundation exceeding 200-year return periods might be called "exceptional." The distinction is important in BC, where many floodplains and Alluvial Fans were formed at the end of the last glacial period and the streams that cross them are, today, mildly incised by subsequent degradation, so that they rarely or never overtop their banks. Surfaces that flood relatively rarely may be relatively exposed because, unless the likelihood of flooding has been firmly established, defences may be neglected. If it can be shown that a valley flat is unlikely to be flooded at all by normal streamflows, then it is designated as a terrace. Many terraces are obvious features in BC valleys, but the transition from infrequently active floodplain to terrace is sometimes difficult to establish.

Floodplains and Alluvial Fans form distinctive landforms that can be delimited using geomorphological and sedimentological criteria. For example, they are distinct units in the BC Terrain Mapping Code (Howes and Kenk 1997), hence are displayed on terrain maps. Criteria to identify an active floodplain include knowledge of historical inundation, the presence of (geologically) recent flood deposits, including cumulic soils, the occurrence of inundation-tolerant plants, and the presence and condition of drainage channels within the floodplain. In many sparsely settled areas, these indicators may be essential to confirm even frequently or episodically inundated surfaces. Howes and Kenk (1997) do not define activity level (active or inactive) in quantitative terms because the assessment of the frequency of most geomorphological processes (e.g., floods, landslides) is beyond the scope of the BC Terrain Mapping Code.

In an alternative approach, numerical models to predict water levels, driven by hydrologically derived estimates of flood flows and using bathymetry of channels and detailed topographical maps of the valley flat, may be used to predict limits of inundation. This method, which may be said to define a hydraulic floodplain is employed according to regulation in BC (see **Appendix B: Current Flood Management Approach in BC**). It avoids the difficulty that sometimes attends the interpretation and dating of genetic indicators of flooding, but numerical models are unlikely to be perfect representations of the physical truth so that the availability of both techniques constitutes a critical combination for site investigation. Most numerical models cannot model channel change, ice jamming, bank erosion, or other hazards, so significant expert judgment is needed in addition to numerical modelling. This is increasingly important because with more and increasingly sophisticated models non-critical reliance on models is increasing.

As an additional normal Flood Hazard factor, the likelihood for channel avulsion must be considered. This is particularly important in upper montane valleys where rivers often are aggrading due to the deposition of sediment flushed from steep tributaries, and on Alluvial Fans. The presence of large secondary channels is an indication of this phenomenon. Active Alluvial Fans are aggrading sediment bodies so that channel avulsion is the principal problem. Floods in anastomosed rivers and river deltas may share the characteristics of floods on Alluvial Fans; that is, avulsions or channel splitting are apt to occur. More generally, a change of flow division amongst anastomosed channels may increase Flood Hazard along one branch.

D3 METHODS OF FLOOD HAZARD ANALYSIS

A typical FHA may be structured as follows.

Introduction

- Definition of the study area that includes the local region (consultation area) with a listing of the Elements at Risk and the contributing region (often the river's watershed)
- A literature search to obtain all relevant information such as land use, hydroclimatic variables, historical floods, and geology

- If flood mitigation structures are already in place, examination of their state of maintenance and performance

Methods

- A formulation of Flood Hazard Scenarios (i.e., flood due to rainfall, snowmelt or both, sewers, groundwater, reservoirs, canals, and other artificial sources)
- A frequency-magnitude analysis of the Flood Hazard
- An assessment of the capacity of any pump stations, flap gates, drains or sewers, existing or proposed, on the site during various flood events
- An assessment of the volume of surface water runoff to be generated from a Proposed Development
- Modelling of the Flood Hazard at the desired return period(s) to obtain the following information:
  - Water depth
  - The velocity of surface water flow
  - The chronology in which various parts of the study area might flood
  - The event duration
  - Information on the extent and depth of previous flood events or on flood predictions

The above items can be addressed using standard techniques. The following additional considerations should be addressed where relevant:

- Are there any other processes acting on the stream channel in question (i.e., ice jams, debris flows, debris floods, hyperconcentrated flows, landslide dam/glacier dam outbreak floods)? If so, does the QP have the capacity to quantify those or does a specialist need to be consulted?
- Are there existing upstream structures that could fail and create a flood in excess of the Design Flood as determined by traditional methods? Could such structures be erected or dismantled during the timeframe considered for the study, and, if so, how would this change the frequency-magnitude relations of floods?
- Is the data time series long enough to provide reasonable answers for long-term prediction? Have the errors associated with long-term extrapolations of the time series been adequately quantified and included in the conclusions?
- What is the likelihood that the frequency-magnitude relations will change drastically over the design life of the structure(s) in question, due to anticipated land use changes, damming, climate change, urban development, densification, or others?
- What is the potential for water-repellent soils caused by fire leading to increased Risk of debris flows and flooding?
- If climate change is likely to imprint on the regional hydrology, how can it be included in the statistics to account for a drying or wetting trend; a change in rainfall amounts and/or intensities; and/or a change in the snowpack, its distribution, and/or snow water equivalent? How will this affect the frequency and magnitude of extreme runoff events?
- Have fluvial geomorphic aspects been adequately considered in this study? What are the dominant sediment inputs, how have they changed over time, and how will they likely change over time? Is there a long-term trend in river degradation or aggradation, and how is it distributed spatially and at what rates? How will net aggradation or net degradation affect Flood Hazard over time? Is bank erosion occurring and at what rates?

The need to address these additional considerations should be responded to at the proposal stage and either formalized in the scope of work as specified by the Client in conjunction with the Approving Authority, or as formulated by the practitioner. This requires some background work so the proposal can be properly developed. It also allows the lead QP to identify additional specialists where required. This facilitates the preparation of a realistic budget for the project.

Flood Hazard analysis can be approached in a number of ways. For streams with a history of gauging, statistical analysis of past extreme flows leads to estimates of the return period for flows of a specified magnitude. Historically this is the method used in planning flood protection. Where there is no history of gauging, a QP may consider regional flood frequency curves developed using data from nearby gauged basins. However, all approaches that refer to historical flood frequency curves carry two significant assumptions, which are not valid in the context of changing climate in BC:

1. The flood sequence is stationary (i.e., floods in the future will have characteristics similar to those in the past).
2. The flood sequence is homogeneous (all floods are generated by similar hydrometeorological mechanisms).

In BC, flood sequences vary demonstrably on time scales, which are as short as decades due to the occurrence of climate phases associated with the state of the adjacent North Pacific Ocean; furthermore, the climate is undergoing secular change.

Floods are generated by multiple mechanisms in many of the province's rivers (for example, rainstorm runoff and snowmelt; see Church 1988), necessitating the application of methods for analyzing mixed distributions and separating flood types based on antecedent weather. As a result, a modified approach to extreme flow analysis is required.

The estimation of extreme floods, with long recurrence intervals (greater than 200 years), requires professional judgment. Extrapolations from historical data can be used but are purely statistical in nature and do not necessarily represent what the experience will be.

A second method is to estimate the probable maximum flood (PMF) on the basis of precipitation history and drainage basin characteristics. This, however, is not appropriate for standard FHAs. The method is frequently used for small basins where there is no gauging history and where precipitation inputs can be assumed to be approximately constant over the basin (which, in BC, appears to be basins <50 km^2). This assumption no longer is credible for large basins, in which specific runoff clearly is scaled by area (Eaton et al. 2002). Application of the PMF methodology requires estimation of the probable maximum precipitation (PMP). It is standard practice to determine depth-area curves for the PMP that adjust for the fact that precipitation is not constant over large basins. The PMP/PMF methodology is applied in cases when it is imperative to obtain an estimate of an absolute safety criterion such as the design for dam spillways or sizing of tailings dam Freeboards.

A third method for appraising extreme Flood Hazards is to analyze morphological evidence of former floods on the ground. This method is particularly useful in small, steep basins subject to debris flow, and on Alluvial Fans. Flood deposits, vegetation damage (dateable using tree ring histories) and dateable organic deposits provide useful evidence. The resulting frequency-magnitude pairs, however, are difficult to analyze with standard frequency statistical methods. Data needs to be fitted to various extreme value distributions and the fit tested before credible relations can be used for Risk Assessments or design of Structural Mitigation Works.

The choice of which approach to use depends on a number of factors including those identified above, as well as the level of hazard and the Elements at Risk. The approach selected must provide results that are technically defensible. The Flood Hazard analysis should clearly state what assumptions underlie the analyses.

Generally, any Flood Hazard analysis method requires substantial professional judgment, and assumptions and uncertainties should be carefully considered and clearly stated in the Flood Assessment Report.

D4 FLOOD HAZARD ASSESSMENT – LEVEL OF EFFORT

The appropriate level of effort to be applied to a FHA is a function of the objectives. The type of assessment changes with the size of the study area and the potential Elements at Risk.

Recognition of the potential complexity of Flood Hazards suggests that a categorization of FHAs be considered as proposed in **Tables D-1** and **D-2**. These tables provide guidance on the appropriate level of effort to be applied depending on the objective of the assessment, including the issues that need to be addressed, the level of detail that needs to be included, and the types of analyses to be conducted so specialists can be engaged if required. **Table D-1** provides guidance on rainfall- and snowmelt-generated floods, while **Table D-2** focuses on unusual floods, including debris flows that are, by definition, a landslide process. These two tables split hazard assessments into six classes (0 to 4b); each class is associated with a set of hazard assessment methods, deliverables, applications, and return periods for Flood Hazard Maps. The guiding principle is that increases in loss potential necessitate increasing effort and increasing return periods to account for extreme flood events that could lead to catastrophic loss.

The tables reflect the experience gained to date by a group of practitioners within BC carrying out FHAs. They are not intended to stop a QP or an Approving Authority from selecting other procedures deemed to be appropriate when their use and application can be supported by a suitable level of analysis and relevant documentation.

Table D - 1: Types of Flood Hazard Assessments for Rainfall- and Snowmelt-Generated Floods and Ice Jam Floods

CLASS	TYPICAL HAZARD ASSESSMENT METHODS AND CLIMATE/ENVIRONMENTAL CHANGE CONSIDERATIONS	TYPICAL DELIVERABLES	APPLICATIONS	RETURN PERIODS FOR FLOOD HAZARD MAPS	APPLICATION FOR DEVELOPMENT TYPE
0	• Site visit and qualitative assessment of Flood Hazard • Identify any very low hazard surfaces in the consultation area (i.e., river terraces) • Estimate erosion rates along river banks	Letter report or memorandum with at least water levels and consideration of scour and bank erosion	Very low loss potential for rivers and floodplains; loss of life very unlikely		Building Permit: • Renovations, expansions, new single house, new duplex house
1	• All that was completed for Class 0 • Possibly 1-D modelling, qualitative description of fluvial geomorphic regime at the site and river stability, field inspections for evidence of previous floods • Identify upstream or downstream mass movement processes that could change flood levels (e.g., landslides leading to partial channel blockages, diverting water into opposite banks) • Conduct simple time series analysis of runoff data, review climate change predictions for study region, include in assessment if considered appropriate • Quantify erosion rates by comparative air photograph analysis	Cross-sections with water levels, flow velocity, and qualitative description of recorded historic events; estimation of scour and erosion rates, where appropriate, with maps showing erosion over time If significant watershed changes (logging, beetle infestations, forest fires) are detected, determine how this may affect watershed hydrology	Possible loss of life even for single homes; scoping level studies for linear infrastructures, mines, and urban developments	20-year 200-year 500-year (for Alluvial Fans)	Small Subdivision: • Subdivision into separate lots (3 to 10 single-family lots)
2	• All that was completed for Class 1 • 1-D or possibly 2-D modelling, modelling of fluvial regime and future trends in river bed changes, erosion hazard maps, possibly paleoflood analysis • Same as for Class 1 and add factors to adjust for changes in runoff or model effects of climate change	Maps with the area inundated at different return period, flow velocity, flow depth; delineation of areas prone to erosion and river bed elevation changes; estimates of erosion rates	Moderate loss potential for rivers and floodplains	20-year 200-year 500 to 1,000-year (where appropriate)	Medium Subdivision: • Subdivision into ≥10 to 100 single-family lots, new subdivisions

Table D - 1: Types of Flood Hazard Assessments for Rainfall- and Snowmelt-Generated Floods and Ice Jam Floods

CLASS	TYPICAL HAZARD ASSESSMENT METHODS AND CLIMATE/ENVIRONMENTAL CHANGE CONSIDERATIONS	TYPICAL DELIVERABLES	APPLICATIONS	RETURN PERIODS FOR FLOOD HAZARD MAPS	APPLICATION FOR DEVELOPMENT TYPE
3	• All that was completed for Class 1 • 2-D modelling of user-specified Dike breach scenarios, modelling of fluvial geomorphic processes using 2-D morphodynamic models and their respective effects on Flood Hazard • Same as for Class 2 and consider watershed environmental changes	Same as for Class 2 and formulation of decision tree	High loss potential for rivers and floodplains	200-year 1,000-year 2,500-year (where appropriate)	Large Subdivision: • >100 single-family lots, new subdivisions
4a	• All that was completed for Class 1 • 2-D modelling with probabilistic Dike breach routines, including breach width and breach outflow discharge scenarios, 2-D morphodynamic models and their respective effects on Flood Hazard • Same as for Class 3 and include findings from regional climate models	Same as for Class 3 but with documentation of breach discharge and flood propagation times	Very high loss potential for rivers and floodplains	200-year 1,000-year 2,500-year (where appropriate)	Very Large Subdivisions (new towns or townships): • >100 single-family lots, new subdivisions
4b	• All that was completed for Class 4a but including modelling of different Hazard Scenarios (i.e., different breach locations, multiple breaches, sequential breaches) for different Flood Risk reduction strategies • Same as for Class 4a	Same as for Class 3	Very high loss potential for rivers and floodplains	200-year 1,000-year 2,500-year (where appropriate)	

Table D - 2: Types of Flood Hazard Assessments for Debris Floods, Debris Flows, Glacial Lake/Moraine Dam Floods, Including Alluvial Fans

CLASS	TYPICAL HAZARD ASSESSMENT METHODS AND CLIMATE/ENVIRONMENTAL CHANGE CONSIDERATIONS	TYPICAL DELIVERABLES	APPLICATIONS	RETURN PERIODS FOR HAZARD MAPS	APPLICATION FOR DEVELOPMENT TYPE
0	• Site visit and qualitative assessment of Flood Hazard without modelling • Identify any very low hazard surfaces in the consultation area (i.e., inactive fan surfaces) • Consider watershed scale environmental changes	Letter report or memorandum with water levels, approximate flow velocities, and (where appropriate) loading conditions	Very low loss potential for rivers and floodplains; loss of life very unlikely	Typically not needed	Building Permit: • Renovations, expansions, new single house, new duplex house
1	• All that was completed for Class 0 • Qualitative description of process potential, preliminary estimates of process magnitude and frequency, mapping of hazard zones based on field evidence, separation into direct and indirect impact zones • Same as Class 0	Maps showing hazard zones, report with water levels, approximate flow velocities, and (where appropriate) loading conditions	Possible loss of life even for single homes; scoping level studies for linear infrastructures, mines, urban developments	20-year 200-year 500-year (for Alluvial Fans)	Small Subdivision: • Subdivision into separate lots (3 to 10 single-family lots)
2	• All that was completed for Class 1 • Qualitative failure mode assessment, frequency-magnitude assessment based on chronosequential air photograph assessment, judgment-based inundation mapping, empirically-based runout modelling, and inundation mapping • Same as Class 1, and consider how climate change could affect frequency/magnitude characteristics of hazard process	Maps with area inundated for design event, flow velocity, flow depth, delineation of areas prone to bank erosion and river/creek bed elevation changes	Pre-feasibility studies for linear infrastructures, mines, urban developments	10-year 200-year 500-year (where appropriate)	Medium Subdivision: • Subdivision into >10 to 100 single-family lots, new subdivisions

Table D - 2: Types of Flood Hazard Assessments for Debris Floods, Debris Flows, Glacial Lake/Moraine Dam Floods, Including Alluvial Fans

CLASS	TYPICAL HAZARD ASSESSMENT METHODS AND CLIMATE/ENVIRONMENTAL CHANGE CONSIDERATIONS	TYPICAL DELIVERABLES	APPLICATIONS	RETURN PERIODS FOR HAZARD MAPS	APPLICATION FOR DEVELOPMENT TYPE
3	• All that was completed for Class 1 • Qualitative failure mode assessment, detailed frequency-magnitude assessment using one or more absolute-dating methods, breach and or runout modelling for the design event as defined by return period and for the most likely failure scenario • Same as Class 2	Creation of frequency-magnitude graphs, mapping of area inundated for model run, flow velocity, flow depth, delineation of areas prone to bank erosion and river/creek bed elevation changes	Feasibility studies for linear infrastructures, mines, urban developments	200-year 1,000-year 2,500-year (where appropriate)	Large Subdivision: • >100 single-family lots, new subdivisions
4a	• All that was completed for Class 1 • Probabilistic failure mode assessment, geotechnical analysis of failure mechanisms, detailed frequency-magnitude assessment using all applicable absolute-dating methods, formulation of credible Hazard Scenarios and assigning of Hazard Scenario probabilities, breach modelling in 1-D and 2-D or 3-D runout modelling • Same as Class 2	Same as Class 3, with detailed reporting of geotechnical analyses, breach outflow hydrographs, and model assumptions and errors; hazard intensity maps for different Hazard Scenarios and return periods	Input for quantitative Risk Assessments; pre-design studies for large urban developments; design-level studies for high value/vulnerable industrial assets	200-year 1,000-year 2,500-year	Very Large Subdivisions (new towns and townships): • >100 single-family lots, new subdivisions
4b	• All that was completed for Class 4a assessment but for different Flood Risk reduction scenarios • Same as Class 2	Same as Class 4a for different Risk reduction scenarios	Same as Class 4	200-year 1,000-year 2,500 year	

D5 FLOOD INUNDATION AND FLOOD HAZARD MAPPING

The development, use, application, and interpretation of floodplain maps are professional activities that are crucial to the preparation of a quality FHA. The completion of these activities significantly and directly impacts the quality of Flood Assessment Reports.

Professional practice guidelines for preparation of flood maps are provided in Engineers and Geoscientists BC (2017).

Flood maps underpin urban development decisions. They can be used by many different stakeholders and serve at least one of the three purposes of Flood Risk management:

1. Prevent the creation of new Risks through planning or Construction
2. Reduce existing Risks
3. Adapt to changing Risks

Flood maps have very specific demands on content, scale, accuracy, or readability and should specify the scale of application. They are primarily used for the following activities:

- Flood Risk management strategy (prevention and mitigation)
- Land use planning and land management
- Emergency planning
- Raising public awareness
- Flood insurance

D5.1 FLOODPLAIN MAPS IN BC

In BC, the floodplain mapping program (1987-1998) was created as a joint initiative between the federal and provincial governments with the ultimate goal to minimize flood damage in BC (Province of BC and Fraser Basin Council 2004; Province of BC 2011). The maps identify areas susceptible to flooding and were designated as floodplains by the federal and provincial environment ministers. The maps are now largely out-of-date and referred to as legacy documents. However, the maps are still used as administrative tools that designate minimum elevations for Mitigation Measures that can then be incorporated into building bylaws, subdivision approvals, and local government planning and regulations. There are 140 sets of designated floodplain maps on the Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD) Floodplain Mapping website (Province of BC 2017). The floodplains are no longer considered to be "designated" by the Province.

On a BC floodplain map, a floodplain is defined as "the area that can be expected to flood, on average, once every 200 years or with an approximate annual probability of 0.5%." However, as flood mitigation structures alongside the river are meant to contain a flood within those structures, and the floodplain map extends well beyond those artificial boundaries, such floodplain maps more accurately delineate areas that would flood in the absence of flood Mitigation Measures or as a result of a Dike breach.

Floodplain maps show the location of the normal channel of a watercourse, surrounding features or developments, ground elevation contours, flood levels, and floodplain limits (the elevation and horizontal extent of the high-water marks of a computed 200-year flood). Within the floodplain, flood level isolines show the water elevation during a 200-year flood. The maps may also include the computed 20-year flood level, which is used in applying provincial *Health Act* requirements for septic tanks. A flood level isoline is a line that spans the floodplain, plotting the location at which the floodwater is expected to reach the indicated elevation. The elevation of floodwater between each isoline can be interpolated.

The following should be noted regarding the 1987-1998 BC flood mapping system and, if relevant, addressed in the Flood Assessment Report:

- Flood extents for flood return periods exceeding 200 years are not shown even though those floods will undoubtedly occur; the maps are thus instilling a false sense of safety.
- Only the 200-year return period level, and sometimes the 20-year level, may be shown even though the flood extent of other return periods may be associated with higher levels of Flood Risk.
- The accuracy of the base topography has a huge impact on the map's validity and accuracy.
- Information is not always provided on site-specific hazards such as bank erosion or channel avulsions.
- A map is usually applicable only for floods, defined as floods generated by rainfall, snowmelt, or a combination of those, but not debris floods or debris flows or floods due to ice or debris jams.
- A map provides a snapshot in time in terms of showing the potential flood extent at the time at which the input data were created (air photography, topographic mapping). Changes in floodplain development, channel planform, and the channel bed due to fluvial geomorphic processes are not included.
- A map is based on data stationarity assumptions and therefore does not include the direct or indirect effects of climate change, even though those effects are likely to change the return periods associated with map isolines.

An Approving Authority may require additional services in the development of Flood Hazard Maps, or a QP may recommend additional services to a Client. The following section provides guidance for when public safety issues or the Client's needs demand additional services related to the development and use of Flood Hazard Maps. Its contents advance beyond the approach presently used for flood management in BC so these methods are not referenced in current provincial or local legislation. Before proceeding with the application of advanced Flood Hazard mapping as discussed below, the Client and the QP should agree to the professional services to be provided.

Flood Hazard mapping has been conducted in a number of jurisdictions in BC (Province of BC and Fraser Basin Council 2004). For example, the Fraser Valley Regional District has developed hazard maps including for debris flow fans. The maps, which are updated regularly, are part of an information map where different layers including hazards can be selected (Fraser Valley Regional District 2017).

The advantage of these maps is that different map information layers can be turned on or off (i.e., topography, land use, zoning, hydrology). Furthermore, as of June 2011, a database of 690 geohazard reports accompanied such maps. However, the QP cannot solely rely on these maps because not all areas subject to flood, debris flow, and debris floods have been mapped to date. Therefore, the map only serves as a first orientation tool and provides data on work that has been completed to date.

Similar Flood Hazard Maps exist for the Kootenay Region at a scale of 1:50,000. These maps were prepared by the Fraser Basin Council and the (former) Ministry of Water, Land and Air Protection (MWLAP) to provide information originating from the Ministry's Floodplain Development Control Program files to local governments, land use managers, and Approving Officers, to help them begin the work of developing and implementing land use management plans and subdivision approvals for flood-prone areas, without referrals to MWLAP. The maps show Flood Hazard features including debris floods and debris flows, usually as delineations of the 200-year floodplain and fans. They do not replace detailed hazard maps for each fan, which require expert knowledge. Information for the use of these maps can be found in the Flood Hazard Map User Guide (Province of BC and Fraser Basin Council 2004). The Flood Hazard Map User Guide is also accessible through local governments. Each map contains a long section on qualifications and limitations and the QP is referred to those for further information.

Information on environmental protection in Flood Hazard zones is in Fraser Basin Council (2010).

In some areas of the province, flood profiles have recently been updated and detailed floodplain mapping produced. This new generation of floodplain maps contains information such as depth and velocity data, flood profiles corresponding to ice-related flooding, areas at Risk from groundwater flooding, floodway extents, inundation progression, avulsion, and erosion hazards. Where available, this information significantly reduces the effort required to assess Flood Hazards for a new development.

D5.2. PROPOSED FLOOD HAZARD MAPS

Following the European example, Flood Hazard Maps can follow at best three different probability scenarios: low (20 years), medium (100 and 200 years), and high (500, 1,000, and 2,500 years), which are reflected in Tables D-1 and D-2 and Table D-3. These probabilities will, at least to some degree, hinge on the available data for the river or stream in question, as well as the flood-producing process.

Table D-3 provides guidance on the range of return periods to be used for different flood-generating process and associated typical watershed sizes. For example, for Lillooet River in the Pemberton Valley, BC, work by Friele et al. (2008) has shown that lahars (i.e., volcanic debris flows) may reach the township of Pemberton, on average, every 2,000 years and that, measured by Risk tolerance standards developed elsewhere, Risk to inhabitants in Pemberton is currently considered unacceptable. For this reason, a 200-year and 2,500-year floodplain map may be considered a reasonable compromise. Similarly, for the Squamish River (watershed area: 2,330 km^2), large landslide dams from the Quaternary volcano Mount Cayley have been dated using radiometric methods. For developments in the upper Squamish River valley, a 2,500-year return period landslide dam breach would form a reasonable basis for floodplain mapping.

For the Fraser River, given the very high potential Consequences, Flood Hazard Maps including a 1,000-year return period event and a 2,500-year event may be warranted, as this river has been dammed by rock avalanches several times in the past in the Fraser Canyon. Outbreak floods from large landslide dams would likely result in greater flood depth than normal floods for some sections of the river. It is worthwhile comparing the 1,000-year and

2,500-year return period discussed here to return periods considered in the *Canadian Dam Safety Guidelines 2007 (2013 Edition)* (Canadian Dam Association 2013). For a High dam class with permanent population at Risk and loss of life of ≤10, the suggested return period for deterministic assessments of dam safety is defined as 1/3 between the 1,000-year return period flood and the PMF (**Table D-4**). The PMF has no associated annual exceedance probability (AEP). In the case of a landslide dam break and imperfect evacuation, given that there are currently no emergency management plans for such event, one could argue that the potential loss of life could be significantly higher (>100 people). In this case, the *Canadian Dam Safety Guidelines* proposed the PMF as the appropriate Design Flood level. Given these suggested design standards, the return period levels suggested above (1,000-year for snowmelt and rain-on-snow floods and 2,500-year for landslide dam outbreak floods) appear reasonable.

Table D - 3: Proposed Frequency Probability Scenarios for Different Watershed Areas

	LARGE RIVER SYSTEMS	MODERATE AND SMALL RIVERS AND LARGE STREAMS OR SMALL STREAMS WITH LOW GRADIENTS	SMALL STEEP STREAMS SUBJECT TO DEBRIS FLOODS AND DEBRIS FLOWS
Typical Length of Gauged Record	> 50 years	0–50 years	Rarely gauged record
Typical Watershed Area	> 1,000 km^2	10–1,000 km^2	0.1–10 km^2
Flood-Generating Process	• Rainfall • Snowmelt • Rain-on-snow • Ice-related floods	• Rainfall • Snowmelt • Rain-on-snow • Landslide dam outbreak floods • Volcanic debris flows • Log jams • Beaver dam failures • Ice-related floods	• Landslide dam outbreak floods • Debris flows • Lahars • Extreme rainfall
Proposed Flood Return Periods[a] Shown on Hazard Maps	• 20-year[b] • 100-year • 200-year • 1,000-year • 2,500-year [c]	• 20-year[b] • 100-year • 200-year • 500-year • 1,000-year	• 20-year[b] • 200-year • 500-year • 2,500-year[c]

NOTES

[a] The return periods serve as guides only and will need to be adjusted depending on the Elements at Risk on the floodplain to suit the objectives of the respective Flood Hazard or Risk Assessment. Also, the return period estimates beyond 200 years only make sense if a reasonably long gauged record is available from the river in question or from regional analysis.

[b] Should only be considered for areas where there are no flood defence structures or where the existing ones are likely to fail or be overtopped for an event of this return period.

[c] Peak flows, stages, or debris volumes (debris flows) for return periods exceeding 1,000 years are exceedingly uncertain and are in many cases at the limits of the available Quaternary dating methods. Such extrapolations also must contend with significant climate variability and thus variability in the geomorphic response. The 2,500-year return period will thus only apply to Class 3 and 4 (**Table D-2**) assessments.

Table D - 4: Dam Classification and Suggested Design Return Flood Return Periods (Adapted From the Canadian Dam Safety Guidelines 2013, Combined Tables 2-1 and 6-1B)

DAM CLASS	POPULATION AT RISK [Note 1]	INCREMENTAL LOSSES			
		LOSS OF LIFE [Note 2]	ENVIRONMENTAL AND CULTURAL VALUES	INFRASTRUCTURE AND ECONOMICS	DESIGN FLOOD RETURN PERIOD*
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services	100
Significant	Temporary only	Unspec.	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes	100 to 1,000
High	Permanent	≤10	Significant loss or deterioration of important fish or wildlife habitat Restoration on compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities	1/3 between 1,000 and PMF*
Very High	Permanent	≤100	Significant loss or deterioration of critical fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)	2/3 between 1,000 and PMF*
Extreme	Permanent	>100	Major loss of critical fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital major industrial complex, major storage facilities for dangerous substances)	PMF*

NOTES

Note 1: Definitions at Risk

- None – There is no identifiable population at Risk, so there is no possibility of loss of life other than through unforeseeable misadventure.
- Temporary – People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participation in recreational activities).
- Permanent – The population at Risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three Consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2: Implication for loss of life

- Unspecified – The appropriate level of safety required at a dam where people are temporarily at Risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the Design Flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

* PMF = probable maximum flood; PMF has no associated annual exceedance probability

On the lower spatial spectrum, consider a small (<10 ha) fan that is subject to infrequent debris floods as preliminarily determined through consideration of the watershed morphometry and fan gradient. The fan contains two homes and the owner of one of those wishes to double the square footage of his house with liveable space. An Approving Officer needs to determine if such development can be permitted and seeks the help of a consultant. In this case, the QP would orient himself/herself to the last column in Table D-3. A site visit would likely include some machine-aided test pitting to at least 2 m depth and perhaps some dendrochronology of impact-scarred trees. If buried organic materials are found, a few samples should to be taken to obtain an idea as to the frequency of debris floods on the fan. The methods should allow an interpretation of debris flood magnitude for at least a 500-year return period (0.2% annual probability of occurrence). The *Professional Practice Guidelines – Legislated Landslide Assessments for Proposed Residential Developments in BC* (Engineers and Geoscientists BC 2010) provide additional guidance on the requirements for conducting a debris flow or debris flood study.

For each of the above sample scenarios, the minimum requirement would be for the Flood Hazard Map to show the flood extent, water depth, and, where appropriate, maximum flow velocities. (This type of information is not provided in the floodplain maps previously published by the MFLNRORD.)

D5.3 PROPOSED BASIC INFORMATION

In order to be of use for planning processes and awareness campaigns, an Approving Authority or a QP may require the development of Flood Hazard Maps, which include the following information:

- Title of the map with reference to the map content such as flood extent, depth, flow velocity, past event, and flood probability
- Location of the map as part of the catchment or province, with a small inset map
- Legend with all parameters shown on the map, with easy to read symbols or colour schemes
- Name of the responsible authority or institute with address and website address (and/or telephone number)
- For digital maps, various data layers in GIS format
- The base date for the data and date of publication
- A disclaimer, including remarks on the quality of information can be added

For small-scale developments (single, multi-family housing), a precise hazard map does not necessarily need to be generated. An existing map base with well-labelled sketches that show the dominant features (e.g., channels, test pit locations, old debris lobes and levees, the existing house, and infrastructure) may suffice. For larger developments, including subdivision infills and new subdivisions, more sophisticated maps are highly recommended, including those generated by LiDAR that yield precise topographic information and allow recognition of paleochannels that are not evident on readily available government maps that are based on photogrammetry.

Freeboard is generally added to Flood Hazard Maps and is defined by each ministry/jurisdiction. BC government Freeboard criterion is discussed in Appendix B3.3: Flood Construction Levels and Minimum Building Elevations.

D5.4 PROPOSED MAP CONTENT

The following variables could appear in a Flood Hazard Map to maximize its use. The QP is required to use some judgment as to which features ought to be included given the scale of development. This section adds some details on the suggested elements of hazard maps.

Each map could show the dominant infrastructure and housing as well as all existing flood defence structures. Clarification should also be provided if the Flood Hazard Map addresses flood overtopping or Dike breach scenario(s) and, if so, the maps should indicate the likely locations of the Dike breach or overtopping scenario(s). Furthermore, the following information should be included in a Flood Hazard Map:

- **Flood depth:** Flood depth for a given recurrence interval, expressed in centimetres or metres, should be provided; the increments chosen will vary from floodplain to floodplain. Flood depth is used for the planning of flood defence measures. For example, a Flood Risk study in Chilliwack used 1-m increments for flood depth ranging from <1 m to 9 m. Where flood depth does not exceed a maximum of 2 m for the return period analyzed on the floodplain, increments of 0.3 m may be appropriate but need to be reconciled with the accuracy of the input topography.
- **Flow velocity and flood propagation**: Flow velocity estimates will require two-dimensional modelling. This is highly localized information that may need to be represented on a detailed scale for the development in question. Estimates should be shown as maximum velocities (adjusted from mean velocities that are the typical numerical model output) as those are likely to translate into the severest damage or loss of life. Flow velocities can be shown as vectors with the length or size of the vector symbolizing the flow velocity and flow direction. Alternatively, maximum flow velocities can be colour-coded and contours of equal velocity (isotach lines) drawn. Flood propagation can be shown as equal arrival times of the flood in appropriate intervals (isochron). For large rivers, these may be shown in 6-hour or 12-hour intervals, while for smaller rivers and streams, arrival times may best be presented in half hourly or hourly intervals. Flood propagation maps are an essential tool for floodplain emergency procedures. Flood propagation maps can be produced for different Hazard Scenarios (i.e., single or multiple Dike/dam breaches) or for different return periods. Flood propagation maps are typically presented at scales of 1:50,000 or larger (i.e., more detailed).
- **Hazard intensity maps**: These maps may include several intensity variables such as flow velocity, flow depth, or perhaps impact force, especially for debris flows or debris floods. They are best presented as multi-coloured maps in which areas of equal hazard intensity are in the same colour. Such maps are particularly useful for areas prone to debris floods or debris flows. Hazard maps should be shown for several return periods (see **Table D-3**) because the hazard intensity typically increases with larger floods. Hazard intensity maps are typically for areas at spatial scales of 1 ha to <10 km^2 and the appropriate mapping scale is likely to be between 1:1,000 and 1:10,000. Hazard maps should include houses and infrastructure, which will facilitate later Risk mapping.

- **Event maps**: These maps show the extent of previous floods or hydrogeomorphic events and thus provide an excellent tool for awareness-building in Flood Risk management. The event map could be overlaid on any or all of the previous three map types with either a single line indicating the aerial extent of the event, or as separate maps showing flood depth, flow velocity/propagation and intensity, although for most events such detailed data do not exist.

Many international jurisdictions have created interactive web-based maps that are accessible to the general public. Such interactive maps will allow the user to specify the return period of interest, flood depth, velocity, propagation, and various other measures of intensity. Problems may occur due to false interpretations, so a very clear explanation should be part of the interactive program. These maps could also include effects of climate change, for example for coastal areas, in which areas to be flooded by 2050 or 2100 could be delineated based on current understanding of rates of sea level rise. Guidelines for submission of digital data should be created separately to ensure consistency.

D6 REFERENCES

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APPENDIX E: FLOOD RISK ASSESSMENT

E1 INTRODUCTION

A Flood Risk Assessment (FRA) involves estimating the likelihood that a flood will occur and cause some magnitude and type of damage or loss. Following are the principal steps in the Risk Assessment:

1. Identify Flood Hazard Scenarios. These are defined as distinct outcomes from a given hazard that result in some direct Consequence (e.g., fatalities, damage to a building, environmental damage, intangibles such as human suffering) and are based on the results of the hazard assessment described in **Section D: Flood Hazard Assessments**. They can include different return periods for the same hazard, variable flood extent or Flood Intensity, multi-hazard chains of events, or different Consequence chains.
2. Estimate the probability of a Hazard Scenario resulting in some undesirable outcome. This is based on the estimated likelihood that the hazard will occur, reach the Element at Risk when it is present within the hazard zone, and cause the undesirable outcome. These may include a range of outcomes in categories such as economic loss, environmental damage, safety, and corporate or political reputation.
3. Estimate the Consequences of the unwanted outcome including economic losses; human health and loss of life; environmental losses; cultural/historic losses; and intangibles such as psychological distress. Details are described in **Section E2.2**.
4. Define Tolerable Risk criteria.
5. Prioritize Risk reduction strategies.

Flood Risk can be expressed as:

$$R = P_H * P_{S:H} * P_{T:S} * V * E$$

where:

- R = total Flood Risk;
- P_H = annual exceedance probability of a flood occurring;
- $P_{S:H}$ = spatial probability that the flood will reach the Element at Risk;
- $P_{T:S}$ = temporal probability that the Element at Risk will be present when the flood occurs (for fixed infrastructures and homes this is equal to 1);
- V = the Vulnerability, or probability of loss of life or the proportion of an asset loss to total loss; and
- E = the number of people at Risk or the homes and infrastructures at Risk.

The first three terms of this equation define the Flood Hazard, and the last two terms define the flood Consequences.

FRAs are an extension of Flood Hazard Assessments (FHAs) and rely on frequency-magnitude analyses and flood modelling. FRAs add a quantity of Consequence and combine it with the hazard. In this context, it is worthwhile to remember the Consequences of the 1948 flood on the Fraser River, during which 16,000 people were evacuated, 2,300 homes were damaged or destroyed, 1,500 residents were left homeless, 10 people died, and the recovery costs were approximately CAN $150 million (2010 dollars) (Watt 2006). The Consequences of a flood of similar or longer return period that would either overtop or breach Dikes would dwarf those of the 1948 flood (approximately a 200-year return period flood) because of the much higher development density.

E2 FLOOD CONSEQUENCES

Flood Consequences can be expressed in different categories. Commonly used flood Consequences include the following:

- Physical damage to buildings, utilities, roads, and other infrastructure
- Physical damage to agricultural assets such as crops and livestock
- Direct economic losses due to loss of jobs, business interruptions, and repair and reconstruction costs
- Social impacts including loss of shelter due to shelter damage or loss of essential services such as power, water, sewage, and communications
- Social impacts due to losses of facilities with historic or traditional value such as graveyards, celebration grounds, and holy sites
- Environmental impacts to terrestrial and aquatic habitat including contamination by hazardous materials

In addition to direct appraisal of these Consequences, resulting Flood Risk management could also involve the following:

- An assessment of the safety of access and exit for routine and emergency use under frequent and extreme flood conditions
- An assessment of the layout of development and its suitability for flood risk reduction
- Recommendations on how surface water could be managed to achieve effective drainage principles, including maintaining or reducing the runoff rate as a result of a development
- An assessment of the likely impact of any displaced water on third parties caused by alterations to ground levels or raising embankments for flood protection
- An assessment of a requirement of shelter for people displaced by flooding
- An assessment of the residual risks to the site after the construction of defences, as well as guidance as to their management

Of note is that Construction of flood defences often leads to a false sense of security and safety that may be followed by excessive investments that are disproportional to the added Risk. Safety cannot be guaranteed and is simply a matter of probabilities.

E2.1 ECONOMIC LOSSES

Economic losses can be broadly separated into loss of assets and losses to the local or regional economy. Assets can be homes as well as industrial complexes and infrastructure. Losses for residential buildings are usually evaluated by stage-damage curves that, for example, have been published by the Federal Emergency Management Agency (FEMA) in the USA. In its simplest application, economic loss assessments will sum the losses per house for the area studied. In most cases, it will be possible to homogenize areas with similar flood inundation depth if it can be shown that those will result in the same flood levels with respect to the building elevation. Economic losses for industry become more difficult to estimate, and such estimates have usually been done by the insurance industry which may not wish to share such information with third parties. Overland flood insurance is now available for Residential Developments, but it does not cover damage from coastal floods, tsunamis, or dam breaks. Previously Flood Risk insurance applied only to businesses and industries.

Significant difficulty and uncertainty are introduced when indirect economic losses are to be estimated, such as unemployment, loss of business due to business shutdown, and cost of rebuilding businesses. Furthermore, large floods can paralyze downstream economies particularly in cases where the flooded river valley also functions as the dominant economic artery of a region. In the Fraser River valley, major highways, oil and gas pipelines, the two national railways, power, and telecommunications run through the floodplain and are thus to varying degrees vulnerable. Similarly, the Skeena River valley carries a major highway and railway as well as power. Comprehensive economic analyses will be very laborious, specialized, and costly and may be applicable only to those rivers where anticipated losses are high.

E2.2 HUMAN HEALTH AND LOSS OF LIFE

Loss of life is very difficult to predict reliably because it largely depends on whether the flood or Dike breach was predicted, and whether the affected population had been warned and evacuated. Even in cases where warning has been given and a majority of the population evacuated, catastrophic loss is still possible, as amply shown by the 2005 hurricane Katrina that cost the lives of over 1,500 people. Life loss due to floods has been examined in detail by several researchers. Summaries can be found by Jonkman (2005) and Penning-Rowsell et al. (2005).

Tolerable Risks are Risks within a range that society accepts to secure certain benefits. The evaluation criteria for individual and societal Risk are different, but some common general principles can be applied (Leroi et al. 2005):

- The incremental Risk from a hazard to an individual should not be significant compared to other Risks to which a person is exposed in everyday life.
- The incremental Risk from a hazard should be reduced wherever reasonably practicable, i.e., the "as low as reasonably practicable" (ALARP)[9] principle should apply.
- If the possible number of lives lost is high, the likelihood that the incident might actually occur should be low. This accounts for society's particular aversion to many simultaneous casualties, and is enshrined in societal Risk tolerance criteria, which have a strong negative slope towards high loss numbers.
- Higher Risks are likely to be tolerated for existing developments and hazards than for planned or proposed projects, as mitigation against the former may exceed the financial capability of the jurisdiction.
- Tolerable Risks may vary from country to country, and within countries, depending on historic exposure to natural hazards, the intrinsic value that is placed on the life of an ordinary citizen, and the system of ownership and control of floodplains and other natural hazards areas.

Where the anticipated Consequences include the potential for loss of life, the decision-making process requires that Risks be compared against Risk tolerance criteria as a way to prioritize Flood Hazard Risk management activities.

For example, currently 350,000[10] people live on the Fraser River floodplain. In the Netherlands a 5% mortality is assumed for major floods (Jonkman, pers. comm. 2011). This would imply a potential life loss of 17,500 people, which is far in excess of what western societies currently consider Tolerable Risk.

E2.3 ENVIRONMENTAL LOSSES

Environmental losses include oil spills, spills of hazardous materials, flooding of farms that lead to uncontrolled release of manure and fertilizer, as well as secondary effects such as decomposing dead animals. It is again very difficult to quantify the monetary losses associated with such environmental hazards but they can be included in flood Consequence scenarios. This allows an improved planning approach to evacuate farm animals and provides impetus or

[9] The "as low as reasonably practicable" (ALARP) principle is also known as ALARA, with the last letter standing for "achievable." Their use is interchangeable.

[10] A 2006 census and calculation by Fraser Basin Council determined a total floodplain population of 324,465 for 2006. The 350,000 reported here is considered a reasonable estimate.

bylaws to store hazardous materials safely above a specified flood stage.

Environmental losses can also include damage to or destruction of aquatic or terrestrial habitat, but should be balanced with the benefits of habitat creation and the re-establishment of natural floodplain ecology.

E2.4 CULTURAL/HISTORIC LOSSES

Cultural and historic losses cannot be quantified monetarily. They can and should, however, be included in a comprehensive FRA, as they may be elements of considerable importance to some stakeholders.

Cultural or historic losses such as the flooding of graveyards, ancient buildings of historic value, or grounds of cultural value can be included in Risk Assessments by assigning a Consequence rating that can then be associated with a flood return period and included in a multi-criteria analysis that is based on a Risk matrix.

E2.5 INTANGIBLES

Human suffering is almost always associated with damaging floods, either through loss of assets or loss of life. Studies in the United Kingdom, for example, have shown that the suicide rate increased significantly in the aftermath of the 2002 floods. This observation indicates the high level of stress that is associated with floods and the post-flood period even in highly developed nations.

E3 FLOOD RISK ANALYSIS

Once a decision has been made through stakeholder consultation that a formal Risk Assessment may be warranted, **Table E-1** provides guidance as to the scope of a Risk Analysis. This can be done by examining the value of developments and vulnerable population exposed to Flood Hazards, based on the outcome of the FHA. In **Table E-1** the value of developments is annualized by multiplication with the chosen flood frequency. Economic loss and life loss have been included as the dominant factors that drive most FRAs in the Risk matrix shown in **Table E-1**. This table provides a screening tool to guide the level of Risk study as per **Table E-2**.

Life losses can be estimated rapidly using **Figure E-1** as well as rough scaling of expected losses in the development area affected by floods. It needs to be recognized that **Figure E-1** is suitable as an approximation of flood losses but will need to be adjusted for specific situations. Particular reference should be made if the flood is likely to be forecast and timely evacuation prescribed or if the process may occur without warning (for example debris flows, landslide dam, moraine dam, and glacial dam outbreak floods).

Economic losses can be determined as per methods outlined in **Section E2.1**.

Table E-2 then suggests the appropriate level of study. For example, a Very High rating as determined by **Table E-1** would suggest a study level of 4a or 4b, while for a High rating, a minimum study level of 3 may be appropriate. **Table E-2** summarizes the methods, deliverables and contents for the different study levels.

Figure E-2 provides guidance on data requirements for Flood Hazard and FRAs, as well as Flood Risk management, optimization of Flood Risk reduction options, decision-making, and Risk reduction option implementation.

An important consideration in determining the appropriate level of FRA is that the level of Risk Assessment and the level of effort for the FHA are related. For example, a Class 1 FHA cannot provide sufficient input for a Class 2 Risk Assessment.

Table E - 1: Matrix to Determine the Level of Risk Assessment Needed Based on the Exposure of a Development and Vulnerable Populations to Flood Hazards

POTENTIAL LOSS OF LIFE FOR APPLIED RETURN PERIOD	ANNUALIZED POTENTIAL BUILDING LOSS ($)				
	<1,000	1,000 to 10,000	10,000 to 100,000	100,000 to 1,000,000	>1,000,000
>100	VH	VH	VH	VH	VH
10 to 100	H	H	VH	VH	VH
2 to 10	H	H	H	H	VH
1 to 2	M	M	M	H	H
0	VL	L	M	M	H

NOTES:

VH = Very High; H = High; M = Moderate; L = Low; VL = Very Low

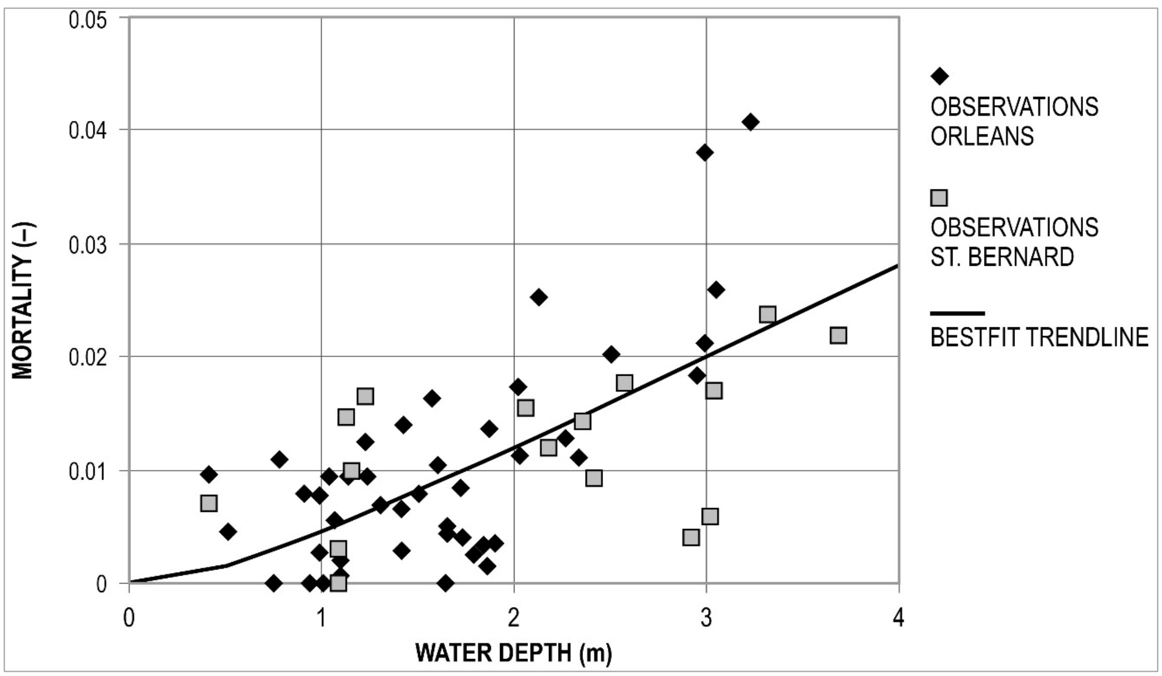

Figure E - 1: Relationship between water depth and mortality for the Orleans and St. Bernard areas in New Orleans for the 2005 Hurricane Katrina flood (Jonkman et al. 2009). The vertical axis is expressed as a fraction (multiply by 100 to obtain a percentage).

Table E - 2: Types of Flood Risk Assessments

RISK LEVEL	CLASS	TYPICAL RISK ASSESSMENT METHODS	DELIVERABLES	APPLICATIONS	FLOOD RETURN PERIODS (YEARS)
Very Low	0	• Include a short site survey with qualitative assessment of potential Consequences	• Memorandum or Letter • Sketch Maps	• Building permits	20 200 500[c]
Low	1	• Provide qualitative descriptions or tabulation of potential economic losses associated with various Consequence scenarios (see Figure E-4)	• Report • Maps	• Low loss potential for rivers and floodplains	
Moderate	2	• Estimate direct economic losses using homogenized stage-damage curves • Estimate mortality using empirical formulae under simplified assumptions • Assess total Risk via qualitative Risk matrix • Quantify Risk to individuals and societal Risk where required by local jurisdictions	• Method descriptions, maps of economic loss potential, inventory lists, lists of PDI[a] >tolerance threshold, FN[b] graphs	• Moderate loss potential for streams, rivers, and floodplains	
High	3	• Same as Class 2 for economic losses • Inventory environmental hazards and likely environmental losses, cultural and historic values, and intangibles (e.g., human suffering), • Assess Risk via a semi-quantitative Risk matrix (e.g., Figure E-4), • Compare Risk to local tolerance criteria or with stakeholder-developed Risk tolerance criteria • Quantify Risk to individuals and societal Risk where required by local jurisdictions	• Detailed method descriptions, maps of economic loss potential, maps of human loss potential inventory lists, lists of PDI>tolerance threshold, FN graphs	• High loss potential for rivers and floodplains	20 200 1,000
Very High	4a	• Same as Class 3 for economic losses plus determine direct and indirect economic losses for area affected • Model loss-of-life using one or more mortality models under different Hazard Scenarios • Quantify environmental losses through modelling or empirical study • Integrate all losses in semi-quantitative Risk matrix (e.g., Figure E-4) and compare to existing or developed Risk tolerance criteria	• Detailed method descriptions, maps of economic loss potential, inventory lists, lists of PDI>tolerance threshold, FN graphs	• Very High loss potential for rivers and floodplains	20 200 1,000 2,500
Very High	4b	• Same as Class 3 assessment for different Risk reduction studies • Provide cost-benefit analysis for selected Flood Risk reduction options	• Same as Class 3 with cost-benefit analysis (CBA)	• Same as Class 3	

NOTES:

[a] PDI stands for probability of death of an individual

[b] FN graphs exemplify group Risk with the number of potential deaths on the horizontal axis and the cumulative frequency of deaths plotted on the vertical axis

[c] Applies only to areas subject to debris floods and debris flows that may occur without warning

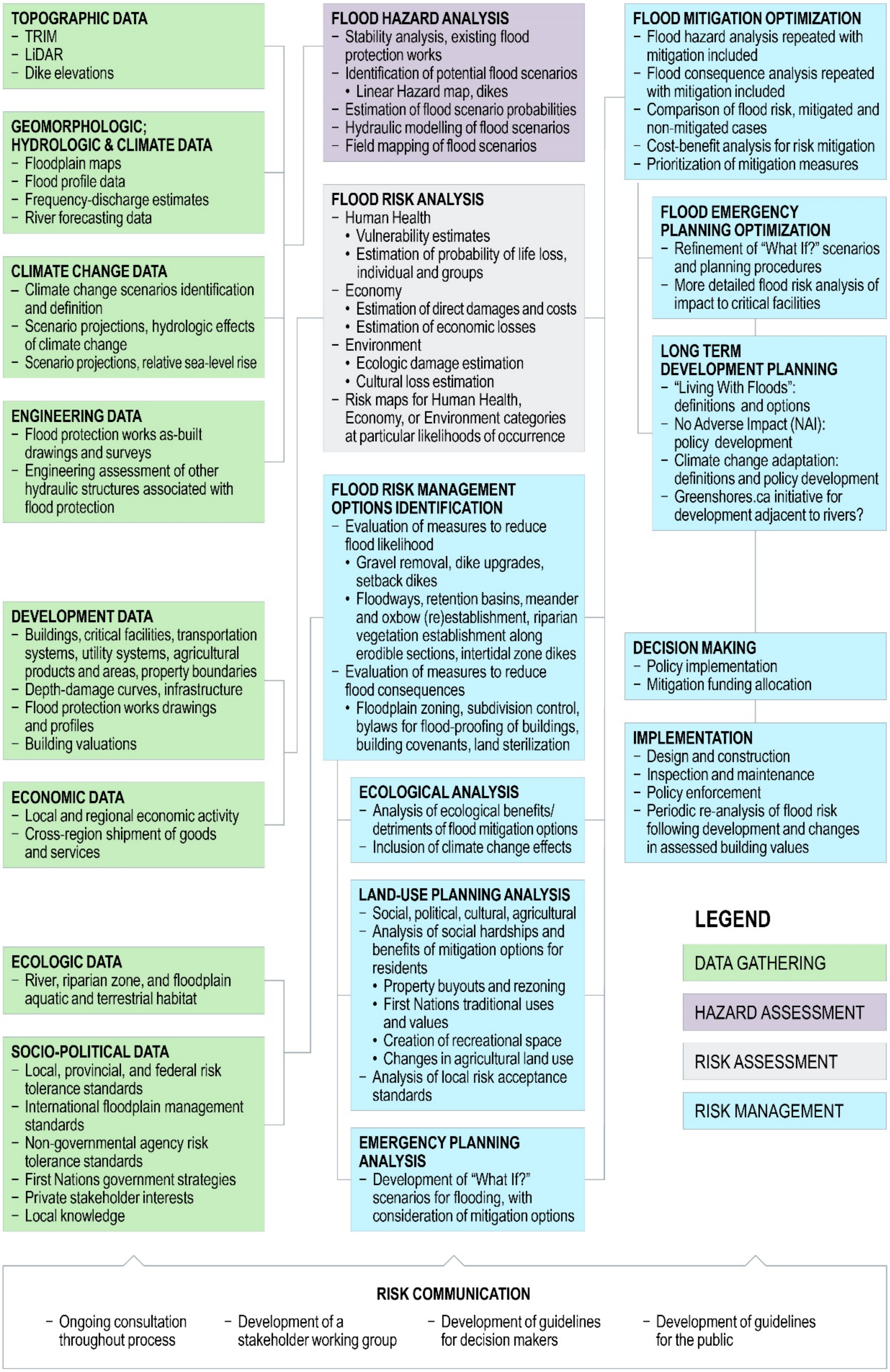

Figure E - 2: Flood Hazard and Risk Analysis embedded in the overall Flood Risk management approach. This chart applies mostly to Class 3 and 4 (High and Very High Risk) assessments.

E4 FLOOD VULNERABILITY AND RISK MAPS

Vulnerability and Risk maps are useful tools for determining damage potential and Risk, and can be applied by emergency managers to plan for evacuations. Flood experts use such maps for the planning of flood defence structures, and land use planners can base land management decisions on these maps.

Standardized Vulnerability or Flood Risk Maps do not yet exist in BC or Canada. The following section provides guidance for the Qualified Professional (QP) when public safety issues, or the Client's needs, require additional services that call for flood Vulnerability and Risk maps. The material presented reaches beyond the approach presently used for flood management in BC. It is, therefore, not referenced in the current provincial or local legislation.

E4.1 FLOOD VULNERABILITY MAPS

Flood Vulnerability maps can be defined as "maps that provide inventories of Elements at Risk for a given Flood Hazard Scenario."

Vulnerability maps can display the following variables:

- The number and location of floodplain inhabitants and users potentially affected
- The number and type of economic activity of the area potentially affected
- The location and type of facilities that may cause pollution in case of flooding, as well as areas potentially affected by those pollutants

For population, maps can be based on the following:

- The distribution of population per Municipality, address, building, average number of people per building, or block
- The distribution of particularly vulnerable groups (elderly, schools, hospitals, infrastructure with high density of population, or tourists)

For assets and economic activity, the following should be mapped and highlighted:

- Type of industries and products
- Type of agriculture
- Linear infrastructure (e.g., roads, railways, pipelines)
- Residential areas (metropolitan, urban, rural, recreation)
- Essential and sensitive infrastructures (roads, power, telephone, gas, sewer, water supply, hospitals, schools, fire brigade, railway, sports facilities)

For installations potentially causing pollution, environmentally sensitive areas, and areas of cultural value within the floodplain, the following contents could be included:

- Chemical industry facilities and warehouses
- Petroleum industry and storage facilities for oil products
- Thermo-electric power stations: oil, gas, coal
- Fuel/gas stations
- Agricultural warehouses for fertilizers, herbicides, pesticides, poisonous substances, nutrients, feed lots, and high-occupancy animal pens
- Special dump sites for chemical or industrial waste
- Wastewater treatment plants

For environmental assets and sites of known cultural value, the following contents could be included in flood Vulnerability maps:

- Burial grounds
- Celebration sites
- Heritage sites
- National parks and wildlife refuges
- Wetlands
- Fish spawning grounds
- Rare wildlife habitat areas and ecological reserves

E4.2 FLOOD RISK MAPS

Flood Risk Maps are defined in the United Kingdom as "maps that show the likely effects of floods on human health, economic activity, the environment, and cultural heritage." A more explicit definition emphasizes the combination of Flood Hazard and Consequences. A Flood Risk Map quantitatively or qualitatively combines the intensities of a given Flood Hazard Scenario with the likely flood Consequences. For example, an economic Flood Risk Map for a 500-year return period flood could show the likely direct monetary losses per unit area considered. The unit area will depend on the mapping scale, which hinges on the respective objectives of a Flood Risk study.

The following types of Flood Risk Maps could be considered:

- Maps of economic losses based on depth-damage statistics. Such maps would show homogenized zones in which damage is expressed as monetary value lost per unit area for the specified Flood Hazard Scenario (flood probability, Flood Hazard Scenario).
- Maps of the number of potential fatalities in a non-evacuated scenario based on mortality statistics. Such maps would display homogenized zones or contours that would allow the map viewer to identify areas of highest mortality as a function of inundation depth and flow velocity as well as habitation density. Such maps may have to be generated for different Hazard Scenarios (different Dike breaches, different return periods) because evacuation will drastically reduce likely mortality numbers.

Flood Risk Maps can be produced at different scales. For large areas, such as the Fraser River floodplain, maps at scales of 1:25,000 and 1:100,000 may be appropriate. For detailed information about individual buildings or facilities, scales between 1:5,000 and 1:10,000 may be more appropriate.

E4.3 FLOOD LOSS ESTIMATION AND HAZUS-MH

Estimation of potential losses due to flooding requires the management and analysis of geospatial information. This information includes hazard data, the position and attributes of Elements at Risk, and criteria to estimate losses based on the Flood Intensity at particular locations.

Geographic Information Systems (GIS) form a common platform for the management and analysis of these data. A free ArcGIS extension called HAZUS-MH has been developed by FEMA and the National Institute of Building Sciences (NIBS) and adapted for Canadian use by Natural Resources Canada to estimate losses due to flood and earthquake hazards at regional scale (Hastings et al 2016).

The HAZUS-MH flood module produces loss estimates applicable to Vulnerability assessments and development of flood mitigation plans, as well as emergency preparedness, response and recovery. The user can evaluate losses due to flood scenarios for a wide range of Elements at Risk including buildings, utilities, and essential facilities. The results are reported at a Canadian Census Tract level of study detail to account for uncertainty at particular building locations.

E5 FLOOD RISK TOLERANCE CRITERIA

E5.1 LOSS OF LIFE

The use of Risk of loss of life criteria originated in the United Kingdom and the Netherlands during the

1970s and 1980s in response to the need to manage Risks from major industrial accidents (Ale 2005).

In the United Kingdom, the maximum Tolerable Risk to an individual in a new development has been set by the Health and Safety Executive at 1:100,000 per annum. The maximum Tolerable Risk for workers, based on the assumption that the Risk faced by workers is somewhat voluntary, has been set at 1:1,000 per annum (Whittingham 2008).

In the Netherlands, maximum Acceptable Risk to an individual in a new development is 1:1,000,000 per annum. In practice, Ale (2005) has shown that the United Kingdom and Netherlands Risk tolerance criteria are very similar as a result of the different legal systems employed by the two countries.

The determination of tolerable life Risk can be expressed as:

- the Risk to the individual most at Risk; and/or
- the societal Risk.

Figure E-3 allows a direct evaluation of life loss from floods. The principal error source in applying this graph to Flood Risk scenarios is the assumption of timely and orderly evacuations well before the flood inundates the developed areas. Furthermore, in some cases, particularly for sudden unpredicted outbreak floods or debris flows or Dike failures, evacuation may not have been prescribed. Such error bands should be reported and ideally shown as two lines (upper estimate and lower estimate).

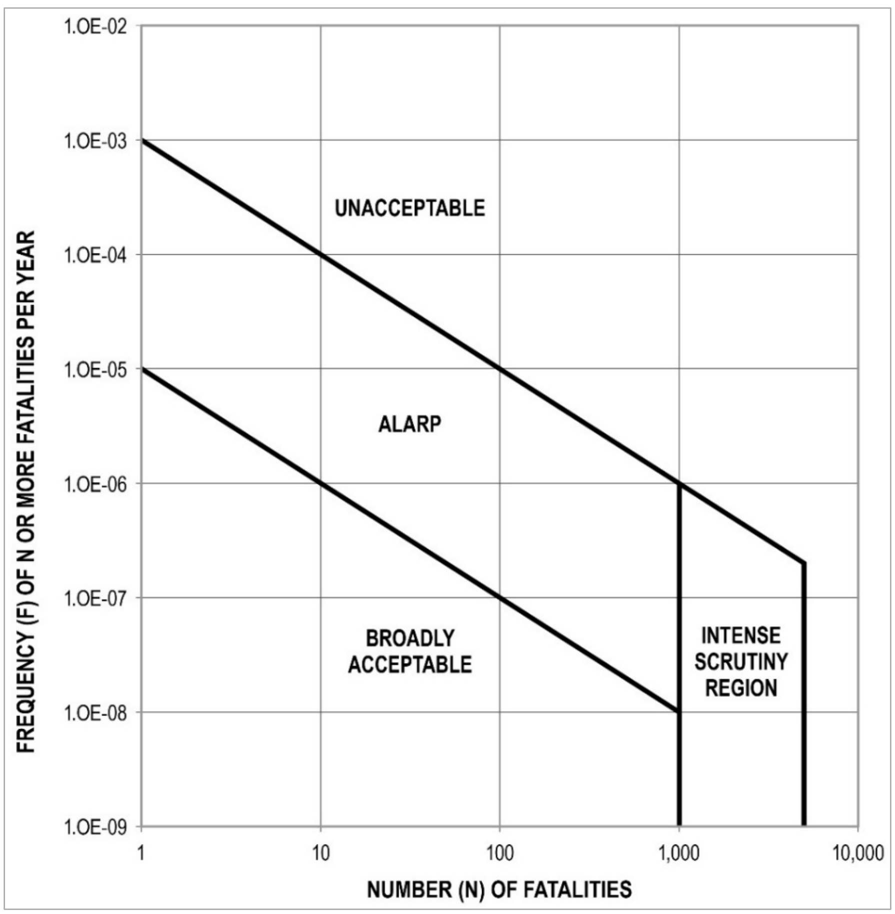

Figure E - 3: F-N curves to evaluate the Risk to life loss of groups (societal Risk) (Source: Kendall et al. 1977)

E5.2 ECONOMIC RISKS

The level of tolerable economic Risk from floods is a function of an individual's or organization's financial ability to absorb or survive the potential economic loss. Influencing factors include net worth or market capitalization, access to insurance, awareness of the Risks, and availability of suitable emergency response plans to help recover from the potential loss.

For example, large mining corporations and road, railway, and pipeline operators can plan for and recover from floods affecting their operations. Most local governments have much less experience and capacity to sustain economic losses. Most individual homeowners, who cannot insure against floods, may only be entitled to limited financial compensation from the government.

Because of these issues, it is difficult to establish economic Risk tolerance criteria for floods that apply across a range of subdivision sizes, industry and organizational types and sizes, and individuals.

Risk tolerance must be viewed over different spatial scales. For example, significant flood damage to a single home in an extreme flood may be tolerable to society, as this constitutes only hardship to the owner and does not affect society at large. However, if many homes are impacted, losses are increasingly deferred to tax payers. For extreme losses (in the billions of dollars), the total Risk for all flood Consequences may become intolerable to individuals and society alike, particularly when flood Consequences directly or indirectly affect a large portion of the population. An example would be a catastrophic flood on the lower Fraser River.

E5.3 OTHER RISKS

For other Consequence types, a purely quantitative approach is increasingly difficult because thresholds for what environmental and cultural losses are considered tolerable have not been set and are unlikely to be developed as a provincial standard. Furthermore, organizations and individuals have different levels of Risk tolerance. Risk associated with such Consequences will need to be evaluated on a case-by-case basis and through stakeholder and Approving Authority input.

Within some organizations, there may also be an aversion to discussing Flood Risk in quantitative terms. In these cases, qualitative methods are useful to communicate and evaluate Risks from floods and related phenomena. Risk management protocols can be assigned to a range of qualitative Risk ratings.

Figure E-4 provides an example of a semi-quantitative framework, developed by BGC Engineering Inc. (BGC Engineering Inc. 2010), for which Risks can be evaluated. The left side of the matrix provides a range of flood likelihoods. Implicit is that the flood will reach the Elements at Risk considered in the study in question. This section will need to be custom-tailored to each assignment and the ranges of return periods considered should be guided by Tables D-1, D-2, and D-3.

The portion of the table below the Risk ratings exemplifies a typical range of Consequences for floods but again can be adjusted depending on the project needs. For example, if the study relates to the City of Richmond, a different range in economic losses needs to be chosen with a highest category perhaps being >$10 billion.

The core of the Risk matrix is the rating from Very Low to Very High, which would govern the Risk response. Indicated on the Risk rating matrix are two lines that indicate three different Risk zones. First, the unacceptable zone is associated with High and Very High Risks. Tolerable Risk may be considered for Moderate and Low Risks. Acceptable Risk is associated with Very Low Risks for which no further mitigation may need to be considered.

The Approving Authority will need to review the Risk matrix in each case and determine if the suggested lines between acceptable, tolerable, and unacceptable Risk are applicable. In case of unacceptable Risk, the development will likely be rejected and a set of Risk reduction measures implemented before the development becomes approvable. In the case of a Tolerable Risk, the Risk reduction should be considered to lower Risk further.

FLOOD RISK EVALUATION

RISK EVALUATION AND RESPONSE		
VH	Very High	Risk is unacceptable short-term (before next flood season); Risk reduction required; long-term Risk reduction plan must be developed and implemented
H	High	Risk is unacceptable; medium-term Risk reduction plan must be developed and implemented in a reasonable (<5 years) time frame; planning should begin as soon as feasible
M	Moderate	Risk may be tolerable; more detailed review required; reduce Risk to low where reasonably practicable
L	Low	Risk is tolerable; continue to monitor if resources allow
VL	Very Low	Risk is broadly acceptable; no further review or Risk reduction required

LIKELIHOOD DESCRIPTIONS

Likelihood of Undesirable Outcome

LIKELIHOOD DESCRIPTIONS		PROBABILITY RANGE						
Scenario can be expected on average every other year	Very Likely	0.5 – 0.2	M	H	H	VH	VH	VH
Scenario typically occurs on average every 10 years	Likely	0.2 – 0.07	L	M	H	H	VH	VH
Scenario typically occurs on average every 50 years	Moderate	0.07 – 0.02	L	L	M	H	H	VH
Scenario occurs on average every 100 years	Unlikely	0.02 – 0.007	VL	L	L	M	H	H
Scenario occurs on average every 200 years	Very Unlikely	0.007 – 0.004	VL	VL	L	L	M	H
Scenario occurs on average every 500 years	Extremely Unlikely	0.004 – 0.0013	VL	VL	VL	L	L	M

unacceptable

tolerable

acceptable

CONSEQUENCE DESCRIPTIONS	INDICES	1	2	3	4	5	6
		Negligible	Minor	Moderate	Major	Severe	Catastrophic
	SAFETY (INJURY/LOSS OF LIFE)	Minor injuries of few individuals	Major injury of 1 person	Major injury of several persons	Single fatality	<10 fatalities	>10 fatalities
	ECONOMIC (MONETARY LOSSES)	Negligible; no business interruption; <$1,000	Some asset loss; <$10,000 damages	Serious asset loss; several days business interruption; <$100,000	Major asset loss; several weeks business interruption; <$1 million	Severe asset loss; several months business interruption; <$10 million	Total loss of asset; 1 year or more business interruption; >$10 million
	SOCIAL AND CULTURAL	Negligible impact	Slight impact; recoverable within days	Moderate impact; recoverable within weeks	Recoverable within months	Long-term (years) loss of social and cultural values	Complete loss of significant social and cultural values
	INTANGIBLES (PERSONAL SUFFERING)	Negligible impact	Slight impact; recoverable within days	Moderate impact; recoverable within weeks	Personal hardship; usually recoverable within months	Leaves significant personal hardship for years	Irreparable personal hardship
	ECOLOGICAL (FLORA AND FAUNA)	Negligible impact	Slight impact; recoverable within days	Moderate impact; recoverable within weeks	Recoverable within months	Severe species loss	Irreparable species loss

Figure E - 4: Example Risk matrix to determine the relative level of Flood Risk for Proposed Developments.

E6 REFERENCES AND RELATED DOCUMENTS

Documents cited in this appendix appear here. Related documents that may be of interest to users of this guideline but are not formally cited elsewhere in this appendix appear in the Related Documents subsection below.

E6.1 REFERENCES

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E6.2 RELATED DOCUMENTS

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APPENDIX F: FLOOD ASSESSMENT CONSIDERATIONS FOR DEVELOPMENT APPROVALS

F1 INTRODUCTION

F1.1 OVERVIEW

Qualified Professionals may be retained to prepare Flood Assessment Reports according to the statutes outlined in **Appendix B: Current Flood Management Approach in BC** (recognizing that these statutes will continue to evolve over time). With reference to the stages of land development, these can be generally categorized as follows:

- Building Permit
  - Renovation or expansion
  - New single family or duplex house
  - New multi-family building
  - New industrial/commercial/institutional building
- Subdivision
- Rezoning
- Crown Land Disposition

This appendix summarizes the flood assessment considerations and Mitigation Measures or Structural Mitigation Works that may be appropriate for such land development projects, and is intended to be consistent with the 2004 *BC Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018). Most of the numerical references in this appendix are extracted from these documents. It is important to recognize that legislative, local bylaw, and/or Covenants may be applicable and take precedence over the measures outlined in this appendix, and variances from them should only be in consultation with the appropriate parties.

A Flood Hazard Assessment (FHA) is a common component for flood assessments in each development category. In some cases, an existing FHA will suffice, but a Qualified Professional (QP) needs to be satisfied that it is appropriate in view of climate change, sea level rise, and land use change (see **Section 3.0: Guidelines for Professional Practice for Flood Assessments**). The flood assessment should document the full range of Flood Hazards to which the site may be subject and categorize the landform on which the site is located (e.g., floodplain, Alluvial Fan, fluvial terrace, bedrock). If the QP is aware of any potential hazards beyond flooding and erosion that are outside the area(s) of expertise of the QP, such hazards should be noted. The Approving Authority can then decide if such hazards warrant independent further investigation.

Flood Assessment Reports for Proposed Developments should consider the provision of flood protection in the form of Standard Dikes and other Structural Mitigation Works.

In all situations, transfer of Flood Hazard to other parties as a result of Construction of the proposed project and/or the protective works for the proposed project needs to be avoided or countered.

This appendix is a key component of implementing the flow chart (Section 3.3, Figure 2: Flow chart for application of flood assessment guidelines), and should be read in conjunction with that figure. This appendix should be considered for both standard-based and Risk-based Flood Assessment Reports.

F1.2 SPECIAL CONSIDERATIONS RELATING TO DIKE STANDARDS

If a development cannot practically be located outside an area subject to Flood Hazard, it is strongly preferred that it be located in an area protected by a Standard Dike (or an equivalent standard of protection for other types of Structural Mitigation Works). The Standard Dike level of protection represents a stringent standard in view of the high standard for design and Construction, the need for a maintenance program undertaken by a local diking authority (typically local government), and the provision of legal access in the form of rights-of-way or land ownership.

In British Columbia (BC), the Inspector of Dikes determines whether a Dike can be considered a Standard Dike. While a Standard Dike is the ultimate objective for protection of existing development and new development areas, this represents a standard that may not always be practically achievable. For example, the requirement of legal access (rights-of-way or land ownership) may represent a challenge for older Dikes that cross private property. In some cases, through consultation with a local authority, Dikes that are not fully standard according to the definition may nevertheless be considered adequate for the purpose of the proposed project.

If a Dike is to be considered adequate in the context of a flood assessment according to these guidelines, the following minimum standards must be met:

- A local diking authority (typically local government) accepts responsibility for the Dike
- While the Dike may not fully contain the designated flood, it should be reasonably close to doing so and be within the capability of the local diking authority to address such deficiency
- While the Dike may not fully meet all current design and Construction standards, any such deficiencies should be within the capability of the local diking authority to address
- Any deficiency in legal access must not unreasonably preclude the local diking authority from ensuring the overall integrity of the Dike
- The local diking authority accepts that the Dike is adequate for the purpose of the proposed project

The above criteria can also be extended to Structural Mitigation Works other than Dikes, if applicable.

All Flood Assessment Reports concerning Proposed Development must clearly describe both the existing and post-development level of protection provided by existing or proposed Dikes and other Structural Mitigation Works. If works are considered less than standard, the reasons for this determination are to be clearly noted in the report for the information of the Approving Authority, the developer, and future property owners. If works are less than standard, but are considered adequate, the reasons for this determination are also to be clearly noted, along with any relevant future Consequences. In general, significant new development should not be located in floodplain and fan areas in the absence of a standard/adequate Dike or other Structural Mitigation Works.

Where new Dikes or other Structural Mitigation Works are to be constructed, or where existing works are to be upgraded, prior approval from the Inspector of Dikes is required, along with any applicable environmental approvals. In general, such works should be constructed prior to the development being occupied.

F1.3 NEED FOR MITIGATION MEASURES IN AREAS PROTECTED BY STANDARD/ADEQUATE DIKES

The presence of Structural Mitigation Works in the form of a standard/adequate Dike (or other Structural Mitigation Works) alone is generally not sufficient to allow new development. In most cases, secondary Mitigation Measures should be undertaken. This may include some or all of the following:

- Elevation of buildings to a suitable Flood Construction Level (FCL)
- Determination of an appropriate method of achieving the FCL (landfill, structural means, or some combination)
- Protection against erosion
- Appropriate restriction of building use below the FCL
- Site-grading measures to direct overland flow

Specification of an FCL should be based on the flood level that would result in the absence of the standard/adequate Dike or other Structural Mitigation Works.

F2 BUILDING PERMIT

The conditions identified in this section apply to a building permit application for new Construction on an existing lot.

Regardless of any development approval requirements, it would be prudent for the QP to ask the local authority to make the Flood Assessment Report (in whole or in part) available to future landowners by registering an appropriate Covenant.

F2.1 RENOVATION OR EXPANSION

A building inspector may require a flood assessment for a building renovation or expansion in a potential Flood Hazard area.

Where local government bylaw provisions and/or Covenants exist that appropriately govern the project, those provisions should be followed. Any proposed variances to those provisions should be subject to consultation with the local and/or provincial government in consideration of the measures outlined below.

Where a renovation or expansion would result in the total floor space being increased by no more than 25% of the floor space existing at the time of the original building Construction, it is considered appropriate professional practice to implement the following measures when making submissions for renovation or expansion building permit applications:

- Where the building is subject to a Flood Hazard, the new floor area should be at or above the existing floor elevation.
- The method of achieving the required floor elevation (fill, structural, or any combination) may be the same as for the existing building.
- Where the building site is subject to a possible erosion hazard, any expansion must not intrude into the setback zone farther than the existing building.
- Any extension of the building foundation should consider hydraulic loading and scour.
- The Construction of additional or new erosion protection works may be required (such works must be suitably robust in view of the purpose of protecting a house), subject to environmental agency approval and with documentation of future operation and maintenance requirements for the owner.

- Where the building is subject to a Dike setback, any expansion must not be within 7.5 m of the Dike toe or Dike right-of-way, unless accepted by the local diking authority and the Deputy Inspector of Dikes.

Where applicable, the above measures must be incorporated into statements regarding the suitability of the land for the intended use. This will provide a practical approach to facilitate most building renovation and expansion projects.

If the local government requests a statement on the tolerability of Flood Risk, the local government should establish such a threshold. The QP may then determine Flood Risk in accordance with the guidelines in Appendix E: Flood Risk Assessment and report appropriately.

For building renovation or expansion where a potentially severe life-threatening hazard exists, the QP should consult with the local government regarding an appropriate approach, which may include a Risk Assessment and/or Structural Mitigation Works.

Where the renovation or expansion would result in the total floor space being increased by more than 25% of the floor space existing at the time of the original building Construction, the work shall be treated as a new building (see below).

F2.2 NEW SINGLE FAMILY OR DUPLEX HOUSE

A building inspector may require a flood assessment for a new house (single family or duplex) on an existing lot in a potential Flood Hazard area.

Where local government bylaw provisions and/or Covenants exist that appropriately govern the project, those provisions should be followed. In such cases, the local government may not require a Flood Assessment Report, but may require a QP to confirm adherence to bylaw and/or Covenant conditions. Any proposed variances to those provisions should be subject to consultation with the local and/or provincial government in consideration of the measures outlined below.

This section outlines principles and measures of appropriate professional practice when making submissions for building permit applications. Some common items that apply to each situation include the following:

- The building must be set back an appropriate distance from the creek or river in view of the potential for long-term erosion.
- The building must be elevated to an appropriate FCL.
- In addition to hydraulic considerations, the FCL must consider the implications of linear fills such as roads and railways.
- The FCL applies to the underside of a wooden floor system, or the top of a concrete floor system used for habitation or the storage of goods susceptible to damage by floodwaters.
- No area below the FCL must be used for habitation, business, the storage of goods damageable by floodwater, or the installation of fixed equipment.
- The method of achieving the FCL (fill, structural, or any combination) must be appropriately specified.
- Areas used solely for vehicular parking may be located below the FCL (subject to appropriate restrictions).
- The design of the building foundation should consider hydraulic loading and scour.
- Where the building is subject to a Dike setback, any expansion must not be within 7.5 m of the Dike toe or Dike right-of-way unless accepted by

the local diking authority and the Deputy Inspector of Dikes.

- The need for a future Dike right-of-way should be considered (if appropriate through consultation with the local diking authority), and recommendation for a Dike right-of-way may be made.

Where a lot has a suitable building site outside the hazard area, or in an area subject to a lesser hazard, a preferable approach is to require the building to be located in the non-hazard or lesser hazard area.

It is strongly preferred that standard creek or river setbacks be maintained. Only where a significant hardship exists should erosion protection measures be proposed as a justification for a reduced setback. Significant hardship may exist where comparative cost analysis indicates that Construction on the less hazardous site is impractical, prohibitively expensive, and/or results in environmental degradation. Any erosion protection works must be suitably robust in view of the purpose of protecting a house, subject to environmental agency approval, and with documentation of future operation and maintenance requirements for the owner.

F2.2.1 Alluvial Fan (No Dike)

Where a proposed building site is located on a creek or river fan that is not protected by a Dike or other Structural Mitigation Works, the need for both protective works and Mitigation Measures must be considered. In general, new buildings should only be considered for unprotected fans if:

- the local government has adopted an appropriate bylaw or land use regulation that provides for building Construction with knowledge of the Flood Hazard; or
- the QP concludes that the site may be suitable for the intended use.

A QP may conclude that the site may be suitable for the intended use if at least one of the following conditions applies:

- The fan is inactive
- A standard/adequate Dike or equivalent other Structural Mitigation Works is constructed with the pertinent approvals as part of the development
- The building site is not in a high hazard area of the fan (i.e., an avulsion or debris flow path, a Design Flood velocity greater than 1 m/s, and where safe access and egress is not possible)
- A Risk Assessment is undertaken whereby the local government establishes a tolerable level of Risk, and the QP assessment confirms that the Risk would not exceed this level

If the QP concludes that the land may be suitable for the intended use, the FCL should be a minimum of 1.0 m above the surrounding finished grade around the perimeter of the building. Particular attention needs to be given to specification of appropriate on-site Mitigation Measures such as foundation design, method of achieving the FCL, site grading, and building configuration.

F2.2.2 Flood Hazard Area (Not a Fan and No Dike)

Where a proposed building site is located in an area adjacent to a creek, river, lake, or ocean that is not protected by a Dike, the need for both Dike works and Mitigation Measures must be considered. In general, new buildings should be considered for unprotected floodplains only if:

- the local government has adopted an appropriate bylaw or land use regulation that provides for

building Construction with knowledge of the Flood Hazard; or
- the QP concludes that the site may be suitable for the intended use.

A QP may conclude that the site may be suitable for the intended use if at least one of the following conditions applies:

- A standard/adequate Dike or equivalent other Structural Mitigation Works is constructed with the pertinent approvals as part of the development
- The building site is not in a high hazard area of the floodplain (i.e., an avulsion path, a flood velocity greater than 1 m/s, a flood depth greater than 2.5 m, and where safe access and egress is not possible)
- A Risk Assessment is undertaken whereby the local government establishes a tolerable level of Risk, and the QP assessment confirms that the Risk would be within this level

If the QP concludes that the land may be suitable for the intended use, the FCL should be at the 200-year return period flood level plus Freeboard (0.3 m for instantaneous peak floods and 0.6 m for daily peak floods). Particular attention needs to be given to specification of appropriate on-site Mitigation Measures such as foundation design, method of achieving the FCL, and site grading.

F2.2.3 Fan or Flood Hazard Area with Standard/Adequate Dike

Where a proposed building site is located on a fan or floodplain that is protected by a standard/adequate Dike, the need for Mitigation Measures must be considered. In general, new buildings may be considered for protected floodplain and fans.

For fans, a minimum FCL may be 0.6 m to 1.0 m above the surrounding finished grade. For floodplains, the FCL should be at the 200-year return period flood level plus Freeboard (0.3 m for instantaneous peak floods and 0.6 m for daily peak floods), unless a lower FCL is prescribed by a local bylaw or justified on the basis of a Dike breach analysis. Where accepted by the local authority and in keeping with the character of the neighbouring area, the FCL for floodplains may be achieved by a ground-level basement with appropriate Mitigation Measures and building restrictions. The building must be set back an appropriate distance from any active internal drainage channels.

F2.2.4 General Considerations

Where, in the judgment of the QP, the proposed building would be subject to an unacceptable Flood Risk, the QP should not submit a Flood Assessment Report indicating that the land may be suitable for the intended use. The 2004 *Flood Hazard Area Land Use Management Guidelines* (Province of BC 2004) and the *Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines* (Province of BC 2018) provide the following examples of such situations:

- The site being in the floodway or an active erosional area
- The site being in an avulsion or debris flow path
- A flood depth greater than 2.5 m
- A flood velocity greater than 1 m/s
- Where safe access and egress is not possible

F2.3 NEW MULTI-FAMILY BUILDING

New multi-family buildings should not be located within fan or floodplain areas that are not protected by standard/adequate Structural Mitigation Works unless:

- the local government has adopted an appropriate bylaw or land use regulation that provides for building Construction with knowledge of the Flood Hazard; or
- the QP concludes that the site may be suitable for the intended use.

A QP may conclude that the site may be suitable for the intended use if at least one of the following conditions applies:

- The building site is on an Inactive Fan
- A standard/adequate Dike or equivalent other Structural Mitigation Works is constructed with the pertinent approvals as part of the development
- The building site is not in a high hazard area of the fan or floodplain (as noted above and where safe access and egress is not possible)
- A Risk Assessment is undertaken whereby the local government establishes a tolerable level of Flood Risk, and the QP assessment confirms that the Risk would be within this level

Standards for new multi-family houses should meet the standards for single houses, with a greater degree of conservatism in view of the greater number of inhabitants. Variance of the standards is discouraged.

F2.4 NEW INDUSTRIAL / COMMERCIAL / INSTITUTIONAL BUILDING

New industrial/commercial/institutional buildings should not be located within fan or floodplain areas that are not protected by standard/adequate Structural Mitigation Works unless:

- the local government has adopted an appropriate bylaw or land use regulation that provides for building Construction with knowledge of the Flood Hazard; or
- the QP concludes that the site may be suitable for the intended use.

A QP may conclude that the site may be suitable for the intended use if at least one of the following conditions applies:

- The building site is on an Inactive Fan
- A standard/adequate Dike or equivalent other Structural Mitigation Works is constructed as part of the development
- The building site is not in a high hazard area of the fan or floodplain (as noted above and where safe access and egress is not possible)
- A Risk Assessment is undertaken whereby the local government establishes a tolerable level of Risk, and the QP assessment confirms that the Risk would be within this level

Standards for new industrial / commercial / institutional buildings should consider the standards for single houses. Variance from the standards is discouraged.

Some specific considerations pertaining to industrial buildings are as follows:

- Water-oriented industrial buildings may be located outside the area protected by Standard Dikes.

- Relaxation of the FCL may be considered, especially for heavy industrial buildings behind Standard Dikes.
- In some cases, it may be appropriate to allow limited building use below the FCL if appropriate Mitigation Measures are incorporated into the building design.
- For proposed major industrial developments, a Risk Assessment may be considered as a basis to develop site-specific mitigative strategies.

Some specific considerations pertaining to commercial buildings are as follows:

- Commercial buildings should generally not be located outside the area protected by Standard Dikes.
- In some cases, it may be appropriate to allow limited building use below the FCL if appropriate Mitigation Measures are incorporated into the building design.
- The specification of Mitigation Measures must consider the potential for different building use in the future in accordance with the applicable land zoning.

Some specific considerations pertaining to institutional buildings (e.g., schools, universities, hospitals, fire halls, police stations, emergency response headquarters, churches, community centres) are as follows:

- Institutional buildings should not be located outside the area protected by Standard Dikes.
- Institutional buildings should be considered as potential places of local refuge during flood emergencies, so the FCL should not be relaxed.
- Institutional buildings should have appropriate access/egress in view of their potential use during flood emergencies.

In view of the wide variance of the sizes and types of industrial, commercial, and institutional buildings, it is recognized that Flood Hazard mitigation will be site-specific.

F3 SUBDIVISION

An Approving Officer may require a flood assessment for a new subdivision in a potential Flood Hazard area.

Regardless of any bylaw or development approval requirements, it would be prudent for the QP to ask the local authority to make the Flood Assessment Report (in whole or in part) available to future landowners through registration of an appropriate Covenant.

Where there are local government bylaw provisions and/or Covenants that appropriately govern the project, those provisions should be followed. In such cases, the local government may not require a Flood Assessment Report, but may require a QP to confirm adherence to bylaw and/or Covenant conditions. Any proposed variances to those provisions should be subject to consultation with the local and/or provincial government in consideration of the measures outlined below.

This section outlines some principles and measures that constitute appropriate professional practice when making submissions for subdivision applications.

At an early stage in the subdivision process, the QP should consult with the Approving Authority regarding the role of Dikes and other Structural Mitigation Works, as well as the need for a Risk Assessment. In general, unless the applicable regulations provide appropriate direction in view of the scale of development and Flood Hazard type, a

Risk Assessment is likely to be more appropriate for medium or larger proposed subdivisions (over 10 single family units as defined in **Appendix D: Flood Hazard Assessments**) in areas protected by standard/adequate works, and for any proposed subdivisions in areas not protected by standard/adequate works. A Risk Assessment can help determine the suitability of a site for the intended use, and refine proposed Flood Risk reduction measures to be incorporated as part of the Proposed Development.

Some common items that apply to each subdivision are as follows:

- The building area of the development must be set back an appropriate distance from the creek or river in view of the potential for long-term erosion (without the need for erosion protection works).
- Buildings must be elevated to an appropriate FCL.
- In addition to hydraulic considerations, the FCL must consider the implications of linear fills such as roads and railways.
- The FCL applies to the underside of a wooden floor system, or the top of a concrete floor system used for habitation or the storage of goods susceptible to damage by floodwaters.
- No area below the FCL must be used for habitation, business, the storage of goods damageable by floodwater, or the installation of fixed equipment.
- The method of achieving the FCL (fill, structural, or any combination) must be appropriately specified.
- Areas used solely for vehicular parking may be located below the FCL (subject to appropriate restrictions).
- The design of the building foundation should consider hydraulic loading and scour.
- Where the development is subject to a Dike setback, any expansion must not be within 7.5 m of the Dike toe or Dike right-of-way unless accepted by the local diking authority and the Deputy Inspector of Dikes.
- The need for a future Dike right-of-way should be considered (if appropriate through consultation with the local diking authority), and recommendation for a Dike right-of-way may be made.

Where a site has a suitable development area outside the hazard area, or in an area subject to a lesser hazard, a preferable approach is to require buildings to be located in the non-hazard or lesser hazard area. Alternatively, the land development density can be lowered within the hazard area, while compensating with an increase in development density outside the hazard area.

In general, new subdivisions should not be constructed on unprotected fans or unprotected floodplain areas. Unless otherwise regulated by the local authority, a preferable approach for such areas is as follows:

1. Undertake a comprehensive FHA.
2. Consider a formal Flood Risk Assessment (FRA) in consultation with the local authority.
3. Implement effective land use regulations through the local authority.
4. Protect a subdivision in a floodplain with a Standard Dike having a design return period of at least 200 years.
5. Protect a subdivision on a fan with standard Structural Mitigation Works.

6. Designate a local diking authority (typically local government) to be responsible for the works in perpetuity.
7. Ensure that all protective works are conservatively situated, located on a right-of-way, and designed in view of long-term fluvial geomorphological processes, land use, and climate change.
8. Prepare an operation and maintenance manual to facilitate the functions of the local diking authority in a manner that is consistent with provincial and federal environmental regulations.
9. Develop appropriate secondary Mitigation Measures for the development area.

The Standard Dike level of protection is strongly preferred for proposed subdivisions; however, as noted in Section F1.2, there may be situations where this level of protection cannot practically be provided, but where the works are considered adequate for the purpose of the Proposed Development.

F3.1 SUBDIVISIONS ON UNPROTECTED ALLUVIAL FANS

A new subdivision should only be considered for a fan that is not protected by standard/adequate Structural Mitigation Works if:

- the local government has adopted an appropriate bylaw or land use regulation that provides for subdivision with knowledge of the Flood Hazard;
- a standard/adequate Dike or equivalent other Structural Mitigation Works is constructed as part of the development (in which case, Section F3.3 of this appendix applies); or
- the QP concludes that the site may be suitable for the intended use.

A QP may conclude that the site may be suitable for the intended use if the local authority accepts that the proposed subdivision may proceed in the absence of a standard/adequate Dike or other Structural Mitigation Works, and at least one of the following conditions applies:

- The fan is inactive
- The subdivision would only nominally increase the development density on the fan, and is not in a high hazard area of the fan (i.e., an avulsion or debris flow path, a flood velocity greater than 1 m/s, and where safe access and egress is not possible)
- The subdivision site would only nominally increase the current development density on the fan, and a Risk Assessment is undertaken whereby the local government establishes a tolerable level of Risk and the QP assessment confirms that the Risk would be within this level

If the QP concludes that the land may be suitable for the intended use, the FCL should generally be a minimum of 1.0 m above the surrounding finished grade around the perimeter of the building. Particular attention needs to be given to specification of appropriate on-site Mitigation Measures such as foundation design, method of achieving the FCL, site grading, and building configuration. Provision should be made for safe access and egress during flood events.

F3.2 SUBDIVISIONS ON FLOODPLAINS NOT PROTECTED BY STANDARD DIKES

A new subdivision should only be considered for a floodplain that is not protected by a standard/adequate Dike if:

- the local government has adopted an appropriate bylaw or land use regulation that provides for subdivision with knowledge of the Flood Hazard;
- a standard/adequate Dike is constructed as part of the development (in which case, Section F3.3 of this appendix applies); or
- the QP concludes that the site may be suitable for the intended use.

A QP may conclude that the site may be suitable for the intended use if the local authority accepts that the proposed subdivision may proceed in the absence of a standard/adequate Dike, and at least one of the following conditions applies:

- The subdivision site is located on the flood fringe (i.e., its removal from the floodplain would not increase the designated flood level) and the ground is fully raised to the 200-year return period flood level plus Freeboard (with consideration of protection of the landfill slope against erosion).
- The subdivision site would only nominally increase the current development density on the floodplain, and is not in a high hazard area of the floodplain (i.e., an avulsion path, a flood velocity greater than 1 m/s, a flood depth greater than 2.5 m, and/or where safe access and egress is not possible).
- The subdivision site would only nominally increase the current development density in the floodplain, and a Risk Assessment is undertaken whereby the local government establishes a tolerable level of Risk and the QP assessment confirms that the Risk would be within this level.

If the QP concludes that the land may be suitable for the intended use, the FCL should be at the 200-year return period flood level plus Freeboard (0.3 m for instantaneous peak floods and 0.6 m for daily peak floods). Particular attention needs to be given to specification of appropriate on-site Mitigation Measures such as foundation design, method of achieving the FCL, prescribing building setback distances from water bodies, and site grading. Provision should be made for safe access and egress during flood events. The Construction of erosion protection works is not favoured as a means to reduce the building setback. Where necessary, erosion protection works may be appropriate, subject to environmental agency approval, and with documentation of future operation and maintenance requirements for the owner. Any Dikes should be subject to operation and maintenance by the local authority (with an appropriate land tenure). Bank protection works protecting more than three residential units should also be subject to operation and maintenance by the local authority (with an appropriate land tenure).

F3.3 SUBDIVISIONS ON FANS AND FLOODPLAINS PROTECTED BY A STANDARD/ADEQUATE DIKE

Where a proposed subdivision site is located on a fan or floodplain that is protected by a standard/adequate Dike (and/or other Structural Mitigation Works), the need for Mitigation Measures must still be considered. In general, new subdivisions may be considered for protected floodplain and fans.

For fans, a minimum FCL may be 0.6 m to 1.0 m above the surrounding finished grade. For floodplains, the FCL should be at the 200-year return period flood level plus Freeboard (0.3 m for instantaneous peak floods and 0.6 m for daily peak floods), unless a lower FCL is prescribed by a local bylaw or justified on the basis of a Dike breach analysis. Buildings must be set back an appropriate distance from any active internal drainage channels.

For medium or larger subdivisions (over 10 single family units as defined in **Appendix C: Current Flood Management Approach in BC**), the QP should consult with the local authority regarding the need for a formal FRA. If appropriate, such an assessment can be undertaken to help establish the development conditions.

F4 REZONING

A Flood Assessment Report may be required at the rezoning stage of a land development project. As rezoning typically results in increasing the development density, it should only occur in Flood Hazard areas where appropriate flood protection standards can be met. The requirements for a rezoning flood assessment should be clarified with the local authority.

The Flood Assessment Report should document any applicable legislation, bylaw requirements, and Covenants. Any proposed variances to these provisions should be subject to consultation with the local and/or provincial government in consideration of the measures outlined below. Appropriate bylaw measures or other land use controls should be implemented to guide subsequent development activities (subdivision and building permit).

Consultation with the Approving Authorities should occur regarding the benefit and need for a formal FRA. If appropriate, a formal FRA should be undertaken.

A proposed conceptual mitigation approach should be presented that is based on the concept of protecting the future development with standard/adequate Dikes (and other Structural Mitigation Works). Rezoning should not occur on an unprotected fan or unprotected Flood Hazard area unless an appropriate concept plan is developed to protect the development. Appropriate Mitigation Measures should also be proposed to fully achieve the applicable standards for building setbacks, flood Construction levels, and other measures.

F5 CROWN LAND DISPOSITION

Sale or lease of individual existing lots should be treated as a new building.

Sale or lease of raw land parcels should be treated as a subdivision.

F6 REFERENCES

Documents cited in this appendix appear here.

Province of BC. 2018. Amendment Section 3.5 and 3.6 – Flood Hazard Area Land Use Management Guidelines. [Effective January 1, 2018]. Victoria, BC: Province of BC. [accessed: 2017 Dec 05]. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/final_amendment_to_s_35_and_36_fhalumg_17-10-01.pdf.

Province of BC. 2004. Flood Hazard Area Land Use Management Guidelines. Victoria, BC: Province of BC. [accessed: 2017 Sep 28]. http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/flood_hazard_area_land_use_mgmt_guidelines-2011.pdf.

APPENDIX G: PROFESSIONAL PRACTICE IN LIGHT OF CLIMATE CHANGE AND LAND SURFACE CONDITION IMPACTS ON FLOODING

G1 INTRODUCTION

As noted in **Section 3.6: Flood Assessment Procedures**, it is now widely accepted that global and regional climates are changing on the time scale of a human generation. However, it remains difficult to quantify those changes, and it is even more difficult to predict the changes in factors, such as land surface condition, that can affect flooding at the watershed scale. As a result, appropriate professional practice requires that the effects of climate change and reasonably foreseeable changes in land surface condition be considered when carrying out Flood Hazard and/or Risk Assessments. **Section 3.5: Anticipating Climate Change and Land Surface Change** identifies various factors for consideration and outlines the steps to be taken in addressing the effects of climate and land surface change when completing flood assessments.

It is expected that the projected changes will result in an increase in the frequency of flooding in many drainage basins in the province, particularly small and medium drainage basins that are dominated by short-period runoff events, and that the flood events will typically be more intense and of a larger magnitude.

Climate change means that hydrometeorological and hydrological data will continue to change and that traditional methods of predicting the frequency of floods and levels of flood flows based on historical records (which entails the assumption of stationarity) will statistically not be valid (Milley et al. 2008) and will become increasingly unreliable. Model-based hydro-climatological forecasting of flood flows will likely become more important, but its appropriate use will require a better understanding of the underlying climate change model.

Engineers and Geoscientists British Columbia (BC) (formerly the Association of Professional Engineers and Geoscientist of BC, or APEGBC) has undertaken several initiatives to explore the impact of climate change on professional engineering and geoscience practice. This has involved Engineering/Geoscience Professionals of the Association, through the Climate Change Advisory Group, advising Council on these matters on an ongoing basis. In 2014, the Association published a position paper entitled "A Changing Climate in British Columbia: Evolving Responsibilities for APEGBC and APEGBC Registrants" (Engineers and Geoscientists BC 2014). In 2016, the Association published a position paper on Human-Induced Climate Change (Engineers and Geoscientists BC 2016).

Qualified Professionals (QPs) should anticipate future publications in this rapidly evolving area of practice.

G2 CLIMATE CHANGE SCIENCE – AN UPDATE

G.2.1 OVERVIEW

Successive reports of the Intergovernmental Panel on Climate Change (IPCC) have incrementally increased the level of scientific confidence in the fact of climate change. The physical processes driving climate change are complex. Climate models are simplifications of particular climate change scenarios that are subject to some level of uncertainty. Even more difficult are analyses of changes in flood frequencies, as these could be regarded as a third-order effect of climate change. Greenhouse gas emissions and changes in the condition of the earth's surface influence global temperatures and evaporation that, in turn, change tropospheric moisture fluxes. Changes in available moisture lead to trends in precipitation amounts, intensities, and timing on regional scales. These effects are influenced by topography, especially by mountain ranges that lie across the principal wind direction. Accordingly, broad regional generalizations need to be viewed with some skepticism. This is particularly the case for the relatively local spatial-temporal scales of most Flood Risk Assessments (FRAs), where climate variations may occur at topographic scales not considered within a regional or global model.

Nonetheless, climate model predictions, in combination with analyses of historic data for a particular site, are a useful tool when one is tasked with the assessment of Flood Risk in a changing climate. Historic data series in this context should be used to identify trends and deviances in mean and variance.

Over the past 25 years, global air temperatures have increased by approximately 0.2°C per decade. Globally, carbon dioxide emissions from fossil fuels in 2008 were 40% higher than in 1990. Assuming stable future emissions, it remains very likely that global temperatures will eventually increase by more than 2°C from the early 1990s—an outcome that many experts predict will cross a threshold to severe social and economic effects. It is further increasingly unlikely that the targeted upper limit CO_2 concentration of 450 ppm can be achieved given the globe's increasing appetite for fossil fuels. Global sea level rise over the past 20 years has averaged 3.4 mm/year, which is approximately 80% above prior IPCC predictions. Sea level rise is now forecast to reach and possibly exceed 1 m by the end of the century if emissions are not curtailed, with an upper empirically predicted limit of 1.4 m (Rahmstorf 2007). However, the Delta Committee (2008) in the Netherlands estimates an upper range of sea level rise of approximately 2.5 m by 2150 and 4 m by 2200, above 1990s levels. The currently recommended planning figures for BC are 1.0 m rise by 2100 and 2.0 m by 2200 (Ausenco Sandwell 2011).

Technical sources for tracking the continually developing analysis and projections of climate change, with particular reference to BC, are given in Section 3.6.2: Regulatory Considerations.

G.2.2 BC CLIMATE CHANGE

Climate change impacts the entire hydrologic system, including variables such as temperature, evaporation, the type and amount of precipitation, the balance between water storage as ice, snow, or liquid forms, and soil moisture levels. This section summarizes the pertinent findings (as of 2011) on climate change science for BC as they relate to hydrogeomorphic hazards.

- **Sea Level Rise**: Although post-glacial rebound and tectonic uplift partially mitigate global sea level rise in some locations, relative sea level rise on the BC coast is expected to be as much as 1 m by the end of the century (Province of BC 2007; Ausenco Sandwell 2011). Periodic increased sea level rise may also be associated with increased El Niño activity. Impacts of such sea level rise include reduced effectiveness of coastal defences, damage to coastal structures (e.g., marinas, docks, sewage outfalls), increased coastal erosion such as that observed on Haida Gwaii, and increased salinization of low-elevation aquifers such as those in the Gulf Islands.
- **Temperature**: By the end of the 21st century, BC's temperature is expected to be about 2.8°C warmer on average (Rodenhuis et al. 2009) with an important increase in winter temperatures. This means that projected temperatures for an average year will be warmer than almost all of the warmest years reported in historic data.
- **Precipitation**: Average annual precipitation is expected to increase by about 10% (6% to 17%) in BC by 2100, with the increase primarily occurring during winter months and in the mountains. Further description of potential impacts of rainfall changes is provided in Section G3.
- **Runoff**: For snowmelt-dominated large river systems, an increase in surface runoff can be expected during the winter months due to a greater proportion of precipitation falling as rain. There will be an earlier rise and peak in the spring freshet due to warmer spring temperatures, while drier conditions will occur in the summer (Schnorbus et al. 2010a). These conditions will produce characteristically lower spring freshets and summer flows, but the possibility for years with severe floods like those experienced in the past will remain.

For smaller coastal watersheds with a hybrid snowmelt and rainfall-dominated runoff regime, a trend towards purely rain-dominated floods can be expected. For example, in Campbell River, highest flows will likely switch from May/June to November, December, and January with decreasing summer flows (Schnorbus et al. 2010b).

The currently observed pine beetle kill may also increase the magnitude of peak flow events between 50% and 180% for combinations of pine kill plus a proportion of subsequent clear-cutting to remove dead standing timber from 25% to 100% (Schnorbus et al. 2010b). Such numbers relate only to relatively small watersheds (<10,000 km^2) and cannot be extrapolated because of the likely negative proportionality between increasing watershed area and area affected by pine beetle infestations. These changes will be modulated in subsequent decades by regrowth of the forests.

G3 CONSEQUENCES OF CLIMATE AND LAND USE CHANGES

G.3.1 CHANGES IN RAINFALL AMOUNTS AND INTENSITIES

The effects of precipitation on Flood Hazard vary over a wide range of temporal and spatial scales, from the cumulative effects of seasonal rainfall to the intensities encountered during a single storm. The projected approximately 10% increase in winter precipitation, combined with predicted higher temperatures during this same period, will influence the extent of winter snowpack and the timing and rate of melt. Increased temperatures may also influence the intensity of summer convectional showers and the frequency of strong southwesterly flows bringing particularly heavy rainfall to the coast in winter (the so-called “pineapple express”). For the practitioner, these changes have potential bearing on long-term estimates of the timing and magnitude of winter storms, including rain-on-snow events, the spring freshet, soil water balance, and effects of antecedent moisture on debris flow and debris flood triggering.

At shorter (e.g., sub–72-hour) time scales, intensity-duration-frequency (IDF) curves are a standard method to estimate the probability that a given average rainfall intensity will occur at various event return periods. They are routinely used in water management and form the basis for urban stormwater drainage calculations and sizing of culverts, drain pipes, and other wastewater infrastructure. Much of this infrastructure is designed to function for a half a century or more, a time scale comparable with that over which measurable changes in precipitation characteristics are expected.

IDF curves are based on historic precipitation at a particular climate station and depend on the statistical principle of data stationarity: that the mean and variance of data will not change significantly over time so that past precipitation patterns can be used to predict future events. However, given that such data stationarity is not expected to hold, IDF curves based on past conditions should be interpreted with caution when used as design inputs for long-term (>30-year design life) infrastructure. For flood assessments, a precautionary sensitivity allowance for climate change is recommended. The basis of such sensitivity analysis would likely be ensemble projections from regional climate models.

Currently, the short-term precipitation data required to construct IDF curves cannot be discerned by regional climate models, which typically report results at monthly or longer time scales. This poses a challenge for workers tasked with estimating rainfall intensities in a changing climate. Prodanovic and Simonovic (2007) generated simulated IDF curves for London, Ontario, based on existing, drier, and wetter climate scenarios. These authors used non-parametric weather generators to produce short-duration rainfall predictions. The weather generator combines historic information with Global Circulation Model output and produces climate information based on perturbation algorithms. A basis for adjusting IDF curves is presented by Burn et al. (2011) in an analysis of rainfall totals for 1 to 12 hours for long-term recording stations in BC.

G.3.2 CHANGES IN SNOWCOVER AND GLACIAL ICE COVER

Warmer winters will raise winter snowline (Cohen et al. 2012). However, high-level snowpack may increase, given the expectation for wetter winters. Glaciers, which sustain mid- and late-summer runoff in a significant number of BC mid-size drainage basins, are generally in retreat because of recent warm summers (Bolch et al. 2010). Changes are regionally variable: in northwestern BC, glaciers have dominantly been thinning, leading to increased summer runoff and sediment influx into streams, whereas in central and southern BC, glaciers have been in frontal retreat so that reduced area has led to lower late-summer flows (Moore et al. 2009).

High-elevation snowpacks may be expected eventually to sustain many of these glaciers in a new equilibrium with reduced area. As long as climate continues to change, however, glaciers will continue to change; larger ones will change more slowly than small ones because of their longer adjustment times to reach equilibrium with the prevailing climate.

G.3.3 CHANGES IN LAND USE, INSECT INFESTATIONS, AND WILDFIRES

Population in BC, in comparison with land area, is light. While population will continue to increase substantially, it is not expected to produce land use changes as severe as those experienced between 1850 and about 1980, except around the main foci of settlement. Urban land conversion will continue to be relatively rapid in the Lower Mainland, lower Vancouver Island, and the Okanagan Valley, with the first being largely urban by late in the century. This implies strongly changed patterns of runoff and streamflow in relatively small drainage basins in and immediately around these focal points of settlement. Stormwater management in small urban watersheds will be sufficiently important to merit concerted study at provincial scale.

Forest condition and forest hydrology are impacted over significant areas by fungal and insect infestations and by fire. The recent mountain pine beetle infestation demonstrates this. A future changed climate will induce ecological disequilibrium in many respects, including shifting the ranges of both forest species and their pests. The latter being more mobile, an increased incidence of infestation might reasonably be expected with a transient time scale of order a century (or more). This will influence runoff and the incidence of flooding in small- to medium-sized drainage basins. The pine beetle history provides valuable experience for anticipating such events. Pike et al. (2010) present an authoritative review of forest hydrology for BC (see, in particular, Chapter 6: Hydrologic Processes and Watershed Response, and Chapter 19: Climate Change Effects on Watershed Processes in British Columbia).

Increases in temperature and summer droughts will augment the potential for forest fires. An increased incidence of severe summer convectional storms will raise the incidence and severity of lightning strikes, hence the incidence of forest and grassland fire. Particularly hot (stand-replacing) forest fires can lead to formation of hydrophobic (water repellent) soils that can increase runoff and increase the probability of debris flows even at relatively minor (1 to 5 year) rainfall return periods for various intensities (Cannon and Gartner 2005).

G.3.4 CHANGES IN RUNOFF

The net result of the above factors is that runoff and flood flows will change in BC through the 21st century. Salient features include the following:

- An increased incidence of winter flooding in coastal BC, with the possibility for more extreme flows than in the past, due both to the increased proportion of winter precipitation that will fall as rain and a possible increased persistence of warm southwesterly flows that deliver particularly heavy and often long-duration rainfall.
- Spring floods associated with seasonal snowmelt may become more severe because of more rapid snowmelt, or when a major warm storm occurs over a rapidly melting snowpack. Possible increases of order 10% in extreme spring flood flows are envisaged.
- Increased likelihood of severe summer convectional showers inducing extreme floods in small- to medium-sized drainage basins. This applies everywhere in the province but is of greatest concern in the Interior.
- Increased precipitation intensity leading to the need for enhanced stormwater management measures in urban areas and along major communication routes.

- Increased probability of forest fires due to more intense droughts and more pest-afflicted forests will lead to higher runoff and increase probability of debris floods and debris flows in affected watersheds.

The foregoing circumstances need to be factored into analyses of Flood Hazard that forecast likely conditions for more than a decade ahead.

G4 ANALYTICAL ISSUES

G.4.1 NON-STATIONARITY OF HYDRO-CLIMATIC TIME SERIES

Contemporary climate change is a continuing phenomenon, while humans continue to modify Earth's surface environment in ways that will induce further climate change. Even if climate change and land-surface changes were controlled, climate, as perturbed by greenhouse gas emissions, will continue to change for decades to centuries. It will require Earth's environment a long period to re-equilibrate to the changes that already have occurred. This implies a stormier and more variable climate in future. In addition, land-cover change is ongoing. Consequently, hydrometeorological and hydrological time series are and will continue to be non-stationary: mean values will certainly continue to shift, and variance will probably increase as well.

Practically, this means that traditional methods of predicting extreme flows and water levels based on past experience will statistically be invalid and increasingly unreliable. If one expects only a shift in the mean, forecasts based on past experience might be rescued if consideration is given to changing frequencies of events (practically, this would mean that the flood frequency curve is shifted in magnitude). But if variance also changes, then future distributions of events will be quite unlike those of the past. Hydro-climatological model-based forecasting of flood flows will become important from a precautionary point of view, but proper use of such analyses will require a much deeper understanding of model stability and verisimilitude than is currently available.

G.4.2 CHANGE IN STATISTICAL METHODS AND APPLICATIONS

Statistics in flood analysis and forecasting in the past has mainly been applied to summarize historical experience and to make simple forecasts based on the magnitude-frequency relation revealed by the historical data. As noted above, non-stationary conditions obviate this approach (unless we know the trajectory of change precisely). An alternative is to use regional hydro-climatological models to forecast future scenarios. In this instance, statistics remains important in a different way. Given uncertainty about future conditions, models must be run iteratively to produce ensemble forecasts of the range of probable outcomes (in our case, flood flows), using a range of input conditions. Probabilities associated with the input conditions will weigh the outputs so that, among the ensemble of results, most likely conditions can be identified and probabilities of occurrence can be assigned to all outcomes. It will be important to realize that these probabilities will reflect the state of our knowledge, not firm information about what the future will deliver.

The historical record should still be examined. Time trend analysis of flood magnitude is an important first step in any flood analysis, for it will reveal whether there is a significant historical trend (see, for example, Bauch and Hickin 2011). Block maxima analysis (using only annual maxima) may not suffice, and partial duration series may yield more reliable results. Hydro-climate trend analysis should be combined with flood frequency and magnitude analysis to gain a more complete picture of the hydrodynamic changes.

Analysts should consider also the effect of hydrological extremes that are produced by short-term climate excursions such as the El Niño/Southern Oscillation (for example, the stormy winters associated with La Niña phases), and the decade-length climate phases associated with the Pacific Decadal Oscillation (PDO). These hydrological extremes may induce periods of several years to decades when increased storminess or winter snowfall may create clusters of high-flow events that do not necessarily signal a trend. It remains important, then, to refer to historical experience to identify such excursions and ensure that the results of model simulations represent plausible projections. For relatively short-term extrapolation, recent flooding histories (approximately the most recent 30 years, corresponding with a climate normal period) may be used to guide analysis.

G5 CHANGES IN SEA LEVEL, STORM SURGE, AND COASTAL CONDITIONS

Because climate change affects both the mean temperature (hence volume) of seawater and the volume of water locked in perennial snow and ice on land, sea level is changing. The rate of sea level rise in the latter half of the 20th century was, on average, near 2 mm/year, but it appears to have accelerated to approximately 3.4 mm/year globally within approximately the past 20 years. It is important to understand, however, that the observed rate is not the same everywhere in the world ocean because of both circulation effects and gravitational effects of adjacent land masses. In addition, what is important for public safety is not absolute sea level change but change relative to the land surface, which factors in movements of Earth's crust. Much of the BC coast, for example, is experiencing a relative rise of sea level, but the west coast of Vancouver Island is actually experiencing relative fall of sea level because the land is rising faster due to tectonic effects than current sea level rise.

Recent studies (Mazzotti et al. 2008) project relative sea level rise on the BC coast to 2100. For the Fraser River delta, the rise is expected to be between 32 and 68 cm, with a contribution of 1 to 2 mm/a (10 to 20 cm for a century) from sediment consolidation (Mazzotti et al. 2009). (On loaded sites, short-term subsidence may be an order of magnitude higher.) At Victoria, the range of expected sea level rise is 17 to 34 cm, and at Prince Rupert it is 18 to 75 cm (from projection of GPS trends). These results are different than global averages. On the outer coast of Vancouver Island, however, sea level is expected to fall because of tectonic effects, but that effect might be offset by the occurrence of a major earthquake. There is evidence for past sudden coastal subsidence of up to 2 m (Hyndman and Rogers 2010). In view of changing rates of sea level rise, however, a recent conservative estimate for planning purposes is that sea level rise on the BC coast may be as much as 1 m by the end of the century (Ausenco Sandwell 2011). Ausenco Sandwell (2011) further discusses issues and guidelines to be incorporated into a program of upgrading sea defences to meet the circumstances of rising sea level.

Given the present awareness, sea level rise is sufficiently slow that it can be dealt with within normal engineering programs for the maintenance and improvement of coastal facilities, although eventually, major decisions concerning the repositioning of installations such as water intakes and outfalls, and dock and bridge decks, may have to be addressed.

Of more immediate concern is the future prospect for storm surges, tsunami waves, and coastal erosion. Storm surge elevations are influenced by mean sea level, by pressure differences in storms, and by wind-driven effects. The latter two factors will be affected by the changing incidence of severe storms on the coast. The prospect is for an increased incidence of severe winter storms particularly along the central and north coast of BC, but it is, at present, not quantified. It is notable that the El Niño/Southern Oscillation effects can produce an interannual variability of up to 20 cm sea level change on the BC coast, which appears not by itself to produce any outstanding effects.

Wave-induced erosion will depend upon mean water level and on the severity of storm-driven waves, as well as on the susceptibility of the coast. Most of the BC coast consists of bedrock, with low sensitivity to erosion. The map of sensitivity of the BC coastline (Province of BC 2007) shows only the Fraser River delta and the Naikoon area (Haida Gwaii) being highly susceptible. Some parts of the Gulf Islands in the Georgia Strait are also susceptible. A study of offshore wave height records recovered from ocean buoys (Gemmrich et al. 2011) showed, after appropriate adjustments for instrument changes, no significant trends in storm wave heights off the BC coast (35 years of record).

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APPENDIX H: FLOOD MANAGEMENT IN OTHER JURISDICTIONS

A number of European countries sustained severe flood damage during the past two decades. For example, between 1998 and 2002 there were 100 major floods in Europe resulting in damages amounting to CAN $25 billion and 700 lives lost. As a result, Europe's flood management approach and practices have advanced significantly. The key element has been the transition from a hazard-based to a Risk-based approach, including quantification of both hazards and Consequences. This experience provides some useful lessons for developing Risk-based flood management procedures in British Columbia (BC).

In 2002, the European Exchange Circle on Flood Mapping (EXCIMAP) was created to improve and standardize flood mapping. In 2007, it published guidelines on the use of flood maps, differences between hazard and Risk maps, and flood mapping process and dissemination.

A guideline for good practices for flood mapping was also published, and includes sections on the use of flood maps, the differences between hazard and Risk maps, the flood mapping process, and flood map dissemination. In the same year, a flood map atlas was compiled that contained examples of national practices from 19 European countries, the USA, and Japan, as well as sections on transborder flood mapping, flood maps for insurance, and emergency flood maps.

The European Flood Directive was issued in 2007, requiring all European Union countries to produce the following for all potential Flood Risk watersheds:

- Preliminary Flood Risk Assessments (FRAs) by the year 2011
- Flood Hazard and Flood Risk Maps by 2013
- Flood Risk management plans by 2015

The following provides a brief summary of recent European Union Flood Risk management initiatives agreed to after the damaging floods in 2002.

To standardize flood mapping, the EXCIMAP was created. This organization included both flood specialists and stakeholders. The principal objectives were to:

- review the current practices in flood mapping in Europe;
- identify the knowledge and good practices; and
- compile guidelines for good practices for flood mapping.

In contrast to previous efforts, return periods for Flood Hazard mapping were increased, depending on the length and continuity of hydrologic data, to 1,000 years. Flood Hazard Maps are being produced to show flood extents of a high, medium, and extreme probability event scenarios (<100-year, 100-year and 1,000-year return periods, respectively). For each scenario, the flood extent, water depths, and flow velocities are estimated and shown on a series of maps. (It must be realized that, in Europe, records of high water levels are much longer than in BC.)

Flood Intensity maps are being produced to show the flood depth for individual return period events using very high resolution (10 cm) topography, typically generated by LiDAR, with depth shown as 0.25 m or

0.5 m contours. Flood propagation maps are being produced to show flood depth and propagation time, information that is very useful for evacuation planning and emergency measures. Flood Hazard Maps are being reproduced with and without proposed or implemented Flood Risk reduction measures.

In Switzerland, for example, Flood Hazard Maps were translated into hazard zoning maps. A matrix was used to combine Flood Hazard into four classes (30-year, 100-year, 300-year and 1,000-year return periods) and by Flood Intensity (weak <0.5 m, medium 0.5 to 2 m, and strong >2 m water depths). This matrix provides guidance for new Construction, restricted Construction, and instances where landowners should be informed.

Flood Risk Maps are being produced to show the potential Consequences associated with the flood scenarios, expressed in terms of the number of inhabitants potentially affected, type of economic activity of the area, and installations that might cause accidental pollution, as well as other information that the country considers useful. They show the potential economic damage per unit area. The unit of choice varies from millions of €/ha for rural areas, to €/m^2 for cities with particularly high damage potential. These maps also show qualitatively the expected damage by overlaying Flood Hazard Maps with land use maps.

Flood emergency maps, created from Flood Hazard Maps, show emergency routes, lane directions, Dikes, evacuation zones, emergency residences, evacuation bus stops, and closed entrances and exits, and provide detailed advice for the public.

All of the above maps are disseminated through a variety of methods. Most commonly, the internet is used to show Flood Hazards and Risks, flood profiles, and photographs of rivers and creeks, together with legends and explanations. This method of communication provides essential information to planners but also educates the public on the nature of the Flood Hazards and associated Risks. Google Earth is employed to allow users to focus on an area of interest and quickly determine Flood Hazard and Risk.

Following are the key achievements from the recent European Flood Risk reduction initiatives:

- A uniformly high standard now exists for distribution and availability of comprehensive flood-related data.
- A focus is placed on accurate and up-to-date Flood Hazard and Risk maps for all of Europe.
- Flood Hazard and Risk maps must be used in all land use planning.
- Intolerable Flood Risk is to be avoided through sterilization of land as opposed to strict building requirements.
- Detailed and up-to-date flood information is provided to the general public.
- A broad holistic approach to floodplain management accounts for, or emphasizes, environmental and recreational values.
- Europe-wide and international cooperation and collaboration is promoted.

Additional information on the European Flood Risk management initiatives can be found on the European Commission's Environment site at: http://ec.europa.eu/environment/water/flood_risk/flood_atlas/index.htm.

The following Table H-1 summarizes Flood Risk tolerance criteria in different countries.

Table H - 1: Flood Risk Tolerance in Various Developed Nations

COUNTRY	JURISDICTION	FLOOD RISK TOLERANCE CRITERIA/PROTECTION STANDARDS	COMMENT
Germany	Bundesländer (provinces) Ministries of Environment, Nature Conservation and Traffic	• Q_{100} are designated as flood zones and either require permits for Construction (e.g., Baden-Württemberg) or are exempt from Construction (e.g., Bavaria).	There are no specific Risk tolerance criteria for the entire country or the individual Bundesländer
Netherlands	Entire country	• Southern Holland: 1:10,000 from ocean flooding; 1:2,500 to 1:1,250 from river flooding; 1:250 for small polders (ring Dikes) • Rest of country: 1:4,000 from ocean flooding; same as above for river flooding	
USA	National Flood Risk Management Program (NFRMP), operated by the Federal Emergency Management Agency (FEMA) U.S. Army Corps of Engineers (USACE) Association of State Floodplain Managers (ASFPM) National Association of Storm and Floodwater Management Agencies (NAFSMA)	• Mandatory flood insurance of "high risk" areas, defined as those areas having a 1% or greater chance of flooding in any given year (0.01 annual flood probability). Flood insurance is provided by the National Flood Insurance Program (NFIP), administered by FEMA in partnership with private insurance companies. The insurance covers replacement cost of building structure and contents, with some restrictions. • No adverse impact (NAI) floodplain management program. This program aims to ensure the action of any community or property owner, public or private, does not "adversely impact" the property and rights of others with respect to Flood Risk.	There are no specific Risk tolerance criteria for Risk to life, or quantitative thresholds set for Flood Risk tolerance beyond the flood probability tolerance threshold for mandatory flood insurance. The NAI program provides guidelines but does not enforce a specific set of standards, requirements or practices.
Hong Kong	Drainage Services Department	• Hazard-based flood protection standards, based on flood return periods • Flood warning system in areas subject to high-frequency flooding • Requirement for a "Drainage Impact Assessment" for Proposed Developments to ensure development does not increase Flood Risk to adjacent developments.	Areas subject to significant Flood Hazard (e.g., Sheung Wan low-lying area) are receiving significant Structural Mitigation Works (>$200M).
Australia	National Flood Risk Advisory Group (NFRAG), a working group of the Australian Emergency Management Committee (AEMC)	• Hazard-based design criteria: traditionally 1% Annual Exceedance Probability (AEP); more recently 0.2% AEP or probable maximum flood (PMF). Guidelines for completing FRAs have been compiled, but without reference to quantitative Risk tolerance thresholds.	
United Kingdom	Environment Agency	• Environmental Protection Flood Risk Legislation (2009): – Required assessment of Flood Risk in three areas: human health, economic activity, and the environment (including cultural heritage) – Required assessment components, in order of completion: Preliminary Flood Risk Assessment (FRA), Flood Hazard and Risk Maps, and Flood Risk Management Plans for areas judged as subject to "significant" Flood Risk.	Further consultation planned with regard to defining "significant Flood Risk"

APPENDIX I: FLOOD ASSURANCE STATEMENT

FLOOD ASSURANCE STATEMENT

Note: This statement is to be read and completed in conjunction with the current Engineers and Geoscientists BC *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* ("the guidelines") and is to be provided for flood assessments for the purposes of the *Land Title Act*, Community Charter, or the *Local Government Act*. Defined terms are capitalized; see the Defined Terms section of the guidelines for definitions.

To: The Approving Authority Date: ______________________

____

____

Jurisdiction and address

With reference to (CHECK ONE):

- ☐ *Land Title Act* (Section 86) – Subdivision Approval
- ☐ *Local Government Act* (Part 14, Division 7) – Development Permit
- ☐ Community Charter (Section 56) – Building Permit
- ☐ *Local Government Act* (Section 524) – Flood Plain Bylaw Variance
- ☐ *Local Government Act* (Section 524) – Flood Plain Bylaw Exemption

For the following property ("the Property"):

____

Legal description and civic address of the Property

The undersigned hereby gives assurance that he/she is a Qualified Professional and is a Professional Engineer or Professional Geoscientist who fulfils the education, training, and experience requirements as outlined in the guidelines.

I have signed, sealed, and dated, and thereby certified, the attached Flood Assessment Report on the Property in accordance with the guidelines. That report and this statement must be read in conjunction with each other. In preparing that Flood Assessment Report I have:

[CHECK TO THE LEFT OF APPLICABLE ITEMS]

___ 1. Consulted with representatives of the following government organizations:

____

___ 2. Collected and reviewed appropriate background information

___ 3. Reviewed the Proposed Development on the Property

___ 4. Investigated the presence of Covenants on the Property, and reported any relevant information

___ 5. Conducted field work on and, if required, beyond the Property

___ 6. Reported on the results of the field work on and, if required, beyond the Property

___ 7. Considered any changed conditions on and, if required, beyond the Property

8. For a Flood Hazard analysis I have:

___ 8.1 Reviewed and characterized, if appropriate, Flood Hazard that may affect the Property

___ 8.2 Estimated the Flood Hazard on the Property

___ 8.3 Considered (if appropriate) the effects of climate change and land use change

___ 8.4 Relied on a previous Flood Hazard Assessment (FHA) by others

___ 8.5 Identified any potential hazards that are not addressed by the Flood Assessment Report

9. For a Flood Risk analysis I have:

___ 9.1 Estimated the Flood Risk on the Property

___ 9.2 Identified existing and anticipated future Elements at Risk on and, if required, beyond the Property

___ 9.3 Estimated the Consequences to those Elements at Risk

10. In order to mitigate the estimated Flood Hazard for the Property, the following approach is taken:

___ 10.1 A standard-based approach

___ 10.2 A Risk-based approach

___ 10.3 The approach outlined in the guidelines, Appendix F: Flood Assessment Considerations for Development Approvals

___ 10.4 No mitigation is required because the completed flood assessment determined that the site is not subject to a Flood Hazard

11. Where the Approving Authority has adopted a specific level of Flood Hazard or Flood Risk tolerance, I have:

___ 11.1 Made a finding on the level of Flood Hazard or Flood Risk on the Property

___ 11.2 Compared the level of Flood Hazard or Flood Risk tolerance adopted by the Approving Authority with my findings

___ 11.3 Made recommendations to reduce the Flood Hazard or Flood Risk on the Property

12. Where the Approving Authority has not adopted a level of Flood Hazard or Flood Risk tolerance, I have:

___ 12.1 Described the method of Flood Hazard analysis or Flood Risk analysis used

___ 12.2 Referred to an appropriate and identified provincial or national guideline for level of Flood Hazard or Flood Risk

___ 12.3 Made a finding on the level of Flood Hazard of Flood Risk tolerance on the Property

___ 12.4 Compared the guidelines with the findings of my flood assessment

___ 12.5 Made recommendations to reduce the Flood Hazard or Flood Risk

___ 13. Considered the potential for transfer of Flood Risk and the potential impacts to adjacent properties

___ 14. Reported on the requirements for implementation of the mitigation recommendations, including the need for subsequent professional certifications and future inspections.

Based on my comparison between:

[CHECK ONE]

- ☐ The findings from the flood assessment and the adopted level of Flood Hazard or Flood Risk tolerance (item 11.2 above)
- ☐ The findings from the flood assessment and the appropriate and identified provincial or national guideline for level of Flood Hazard or Flood Risk tolerance (item 12.4 above)

I hereby give my assurance that, based on the conditions contained in the attached Flood Assessment Report:

[CHECK ONE]

- ☐ For <u>subdivision approval</u>, as required by the *Land Title Act* (Section 86), “that the land may be used safely for the use intended”:

  [CHECK ONE]

  - ☐ With one or more recommended registered Covenants.
  - ☐ Without any registered Covenant.
- ☐ For a <u>development permit</u>, as required by the *Local Government Act* (Part 14, Division 7), my Flood Assessment Report will “assist the local government in determining what conditions or requirements it will impose under subsection (2) of this section [Section 491 (4)]”.
- ☐ For a <u>building permit</u>, as required by the Community Charter (Section 56), “the land may be used safely for the use intended”:

  [CHECK ONE]

  - ☐ With one or more recommended registered Covenants.
  - ☐ Without any registered Covenant.
- ☐ For flood plain bylaw variance, as required by the *Flood Hazard Area Land Use Management Guidelines* and the *Amendment Section 3.5 and 3.6* associated with the *Local Government Act* (Section 524), “the development may occur safely”.
- ☐ For flood plain bylaw exemption, as required by the *Local Government Act* (Section 524), “the land may be used safely for the use intended”.

FLOOD ASSURANCE STATEMENT

I certify that I am a Qualified Professional as defined below.

____
Date

______________________________ ______________________________
Prepared by Reviewed by

______________________________ ______________________________
Name (print) Name (print)

______________________________ ______________________________
Signature Signature

____
Address

____

____
Telephone

____
Email

(Affix PROFESSIONAL SEAL here)

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

I am a member of the firm ______________________________
and I sign this letter on behalf of the firm. (Name of firm)

APPENDIX J: CASE STUDIES

The following hypothetical examples further illustrate the application of these *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (the guidelines).

The examples listed below illustrate an important differentiation between existing lots on which landowners have a basic right to build a house, and the creation of new lots where there is no right and it is subject to approval by the Approving Officer. The examples below are meant to span the entire spectrum of possible applications, from a single building permit on an existing lot to approval of a large-scale subdivision.

EXAMPLE 1: FLOODPLAIN BYLAW RELAXATION REQUEST

BACKGROUND

The Regional District building inspector receives a request for a relaxation of the building setback distance requirements in the Regional District's Floodplain Bylaw. The owner of a 5-ha parcel adjacent to a river proposes to build a new house 15 m from the natural boundary of the river instead of the 30 m distance required in the bylaw. The property is in a sparsely populated rural area. The applicant is informed that a report from a Qualified Professional (QP) must accompany the application before the Board will consider the application. The applicant has a site specified that is on the inside of a mild bend in the river and meets all the other requirements such as septic field location and setback from property lines. The river channel is 50 m wide. Floodplain mapping indicates that the ground level at the proposed building site is higher than the 200-year return period Flood Construction Level (FCL). The riverbank through this property is natural, and there are no armoured banks in the area. There is a 30-m high, unstable slope with evidence of recent landslide activity on the opposite side of the river on the outside of a bend approximately 300 m upstream from the proposed building site.

GUIDELINE APPLICATION

The QP consults **Figure 2: Flow chart for application of flood assessment guidelines** and conducts the following steps:

- The QP meets with the Client and informs the Client about the guidelines and their application to the requested bylaw relaxation.
- The QP obtains from the Approving Authority the applicable regulations, which appear to have been met. Standard Structural Mitigation Works do not exist and are not considered for mitigation purposes. The need for a formal Risk Assessment is discussed but the Regional District decides that it is not required because of the perceived low Risk.
- There is no current flood assessment for this reach of the river, which prompts the QP to generate one.
- The QP compares the floodplain maps and notes that the proposed site is above the specified FCL for the 200-year return period flood. The QP, however, also notes that the site is on the inside of a river bend consisting of sandy gravels with little apparent cohesion. The QP examines the

river's overall geomorphic stability and concludes that the river is not prone to sudden channel changes or avulsions and is well incised. A chronosequence of air photographs is compared to determine channel bank erosion rates. The QP finds that the bank in question could erode to the building within a 100-year time frame in absence of bank erosion measures. Furthermore, the QP investigates the instability noted in the Background section above on the opposite river bank upstream. Given that landslide assessments are outside his/her expertise, the QP recommends investigation by a landslide specialist.

- The landslide specialist visits the site and reports that landslide may be possible at this site at a return period of perhaps decades. Such landslides could be large enough to divert the river into the bank in question, thereby accelerating erosion processes on the river bank in question. This is noted in the Flood Assessment Report.
- The QP prepares a Flood Assessment Report as per regulatory considerations and his/her findings from the hazard assessment. The conclusion states that he/she cannot support a bylaw relaxation and that a different site should be identified on the 5-ha parcel that does not share the same degree of hazard. Alternatively, bank protection of the river reach in question could be contemplated, though in this particular case, the costs would likely be prohibitive. However, the QP points out that an alternate site has been identified upstream that does not share the same problems and that would be suitable for Construction.

EXAMPLE 2: SUBDIVISION APPROVAL

BACKGROUND

The Ministry of Transportation and Infrastructure (MTI) subdivision Approving Officer receives an application for approval to subdivide a 25-ha parcel of land into five 5-ha lots. The property is located in the Regional District of Columbia in an area without building bylaws or building inspectors. The property is located on a moderately sized Active Alluvial Fan as identified by Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD) Flood Hazard Maps. The subdivision Approving Officer advises the applicant that a Flood Assessment Report is required to determine if the land is safe for the intended use. There is no prior Flood Assessment Report.

The property is located on the lower half of a 2.5 km^2 Alluvial Fan at the mouth of a creek. The braided creek channel is 60 m wide on the fan and has an average gradient of 5%. There is a history of flooding on the fan; most recently during the high runoff years 1972 and 1974. During these floods, the creek flooded most of the fan surface and caused significant property damage by erosion. Up until the mid-1980s, the Flood Hazard was managed somewhat by regular bulldozing of the channel through the fan area. Since regular dredging was curtailed, gravel has accumulated in the channel, increasing the chance of a channel avulsion. In 1975, a berm was pushed up on the right bank following an avulsion, which again resulted in significant damage to property and the highway. The avulsion resulted in high-velocity flow through the property now being proposed for subdivision. The berm is classified by the MFLNRORD as an orphan flood control structure, meaning that the berm is not considered standard and is not under the jurisdiction of the local diking authority. The berm has deteriorated over the years and is located on private lands. It is vegetated and there are no access roads or trails to the structure. Prior to 2003, when the MFLNRORD was involved in the land use regulation in flood-prone areas, the Ministry refused subdivisions in this area. MFLNRORD staff has identified the hazard associated with this berm to the Regional District and the subdivision Approving Officer. There is no mechanism to establish a maintenance authority to enable the upgrade, inspection, and maintenance of this deteriorating structure.

GUIDELINE APPLICATION

The QP consults Figure 2: Flow chart for application of flood assessment guidelines and conducts the following steps:

- The QP informs the Client about the guidelines and their application to the requested subdivision as per Figure 2.
- The QP consultation with the Approving Officer exposes the findings listed in the Background section above. The Approving Officer agrees that a formal Risk Assessment may be appropriate in light of apparent hazard, if the outcome is still a statement that the site is or is not safe for the use intended.
- The QP consults Table D-1: Types of Flood Hazard Assessments for Rainfall- and Snowmelt-Generated Floods and Ice Jam Floods and determines that the site can be classified as a small subdivision, which prompts a Level 1 study.
- Following the guidelines in Section 3: Guidelines for Professional Practice for Flood Assessments; Appendix D: Flood Hazard Assessments; and Appendix G: Professional Practice in Light of Climate Change and Land Surface Condition Impacts on Flooding, the QP notes that large sections of the watershed are affected by beetles, with high tree mortality. Moreover, significant areas of the lower watershed have been clearcut. The QP concludes that such land surface changes may affect watershed hydrology. The QP also notes that the lower channel of the creek is characterized by an unstable braiding channel that also shows signs of channel bed aggradation.
- A review of future climate change and hydrological effects in the specified area suggests higher rainfall intensities, higher total annual precipitation, more precipitation falling as rain, and a thinning snowpack at lower elevations. The QP concludes that the frequency and magnitude of summer rainstorm floods and spring freshets are likely to increase.
- According to Table D-1, the QP determines the peak flow for a 500-year flood, to which 10% is added to account for climate change and land surface changes in the watershed. One-dimensional (1-D) modelling shows that the Proposed Development area would be inundated up to a 1.5 m water depth for this Flood Hazard Scenario, ignoring any fan aggradation during the event. The QP also concludes that a channel change into the area of the Proposed Development is likely for the lifetime of the Proposed Development.
- The QP applies the statutes in Appendix F3.1: Subdivisions on Unprotected Alluvial Fans and, in consultation with the Approving Authority and the Client, prepares a formal Risk Assessment following procedures outlined in Appendix E: Flood Risk Assessments.

- **Table E-1: Matrix to Determine the Level of Risk Assessment Needed Based on the Exposure of a Development and Vulnerable Populations to Flood Hazards** suggests a moderate Risk for the unmitigated scenario, which indicates a Class 2 Risk Assessment including calculations of Risks of loss of life. The formal Risk Assessment concludes that the life loss potential is tolerable when measured against international Risk tolerance standards. However, an unmitigated flood could lead to total losses for each proposed home.
- To reduce Flood Risk to levels that may be considered tolerable to the Regional District, the QP concludes that the buildings would need to be elevated at least 2 m above grade and the building platforms protected by riprap. Access and egress to the properties would equally have to be elevated, or lack of access and egress would need to be tolerated in a flood situation and may need to be completely reconstructed after a flood, including possible creek rechannelization.
- The QP submits the Flood Assessment Report in which the QP specifies that the development may be safe for the use intended, provided comprehensive mitigation is implemented to upgrade the existing non-standard Dike to a Standard Dike that could withhold a 500-year return period flood and the buildings are elevated 2 m above grade.
- Since, as stated in the Background section above, there is no mechanism in place to establish a maintenance authority for the Standard Dike, the MTI decides to reject the subdivision approval. The Flood Assessment Report also stipulates that if a maintenance authority is identified, the subdivision could be developable.

EXAMPLE 3: NEW SUBDIVISION ON A RIVER FLOODPLAIN

BACKGROUND

A large new subdivision of 300 new homes is proposed on a river floodplain that is protected by a Dike. Scientific studies conducted at a British Columbia (BC) university show that long-term sediment aggradation has reduced the Freeboard so that a 200-year flood may lead to Dike overtopping. The MTI Approving Officer requests a Flood Assessment Report from a QP.

GUIDELINE APPLICATION

The QP consults **Figure 2: Flow chart for application of flood assessment guidelines** and conducts the following steps:

- Previous flood assessments exist but do not include the channel bed aggradation and have not included changes in land surface or climate change.
- Applicable regulations are appropriate but allow for no contingencies with respect to changing Flood Hazard by channel bed aggradation, land surface change, and climate change. The QP concludes that a comprehensive Flood Hazard Assessment (FHA) is needed to revisit the existing Flood Hazard.
- The FHA includes a flood frequency analysis of up to a 1,000-year flood and accounts for climate change. Consultation with experts in the field of the effects of climate change on runoff for the watershed in question suggest that peak flows may increase by up to 15% by the end of the century. This estimate includes effects of widespread tree mortality due to beetle infestations in the watershed in question.

- In consultation with the Approving Officer and the Client, a formal Flood Risk analysis is agreed upon.
- The QP applies Table E-1: Matrix to Determine the Level of Risk Assessment Needed Based on the Exposure of a Development and Vulnerable Populations to Flood Hazards and finds that potential life loss in case of a Dike breach or Dike overtopping could result in up to 5 statistical deaths and an annualized building loss for the 200-year return period flood of $1,000 to $10,000. This results are in a High level of assessment, corresponding to a Class 3 study as per Table E-2: Types of Flood Risk Assessments.
- A more in-depth study on the potential mortality of subdivision residents concludes that for a flood scenario with no evacuations, the mortality could be as high as 25, while for an evacuated case, the statistical number of fatalities may vary between 1 and 5, depending on the chosen Flood Hazard Scenario. The data are plotted on an F-N curve, and the Risk is found to plot in the Unacceptable zone.
- Using depth-damage curves for the modelled assumed flood depths in case of Dike overtopping and Dike breach yields a total direct economic loss of $120 million.
- These results from the study are also entered into a Risk matrix similar to the one shown in Figure E-4: Example Risk matrix to determine the relative level of Flood Risk for Proposed Developments, and a "High" Flood Risk is determined.
- The QP prepares a Flood Assessment Report that concludes that the present Risk to the Proposed Development is such that, in consultation with the Approving Officer, the site cannot be classified as safe for the use intended.
- The QP specifies a comprehensive Flood Risk reduction strategy that proposes several alternatives. One is moving of the subdivision farther away from the river and setting back the Dikes to allow a higher river flow conveyance. The other alternative is to upgrade the existing Dikes to an elevation at which Flood Risk is reduced to at least Moderate, which in this case would require a Dike height increase of 0.8 m at a very high cost. The last alternative is to upgrade the Dike to the provincial standard for the river in question, which is the flood of record, and add the corresponding allowance for peak flow increases due to climate and land surface changes.
- In parallel, a cost-benefit analysis is conducted, and a multicriteria analysis addresses ecological, social, and intangible effects.
- Ultimately, an agreement is reached with the local diking authority, under consideration of existing development and perceived benefits of new development, that costs for Dike setback and ecological enhancement be shared between the District and the land developer. In addition, a 1 m FCL is prescribed.

APPENDIX K: LIST OF CONTRIBUTORS

2018 REVISION EDITORS & REVIEWERS

Adrian Chantler, Ph.D., P.Eng., Consulting Hydrotechnical Engineer

Mike V. Currie, M.Eng., P.Eng., FEC, Kerr Wood Leidal Associates Ltd.

David Sellars, P.Eng., Water Resources Engineering Consultant

Lindsay Steele, P.Geo., Engineers and Geoscientists BC

2012 AUTHORS & REVIEW TASK FORCE

AUTHORS

Michael Church, D.Sc., P.Geo., FGC, University of British Columbia

Mike V. Currie, M.Eng., P.Eng., FEC, Kerr Wood Leidal Associates Ltd.

Matthias Jakob, Ph.D., P.Geo., BGC Engineering

Peter Mitchell, P.Eng., Engineers and Geoscientists BC

David Sellars, P.Eng., Water Resources Engineering Consultant (Editor)

REVIEW TASK FORCE

Dwain Boyer, P.Eng., Ministry of Forests, Lands and Natural Resource Operations

Adrian Chantler, Ph.D., P.Eng., EBA, A Tetra Tech Company

Chris Coles, P.Eng., Golder Associates Ltd.

Lawrence Francois, M.Sc., P.Eng.

Monica Mannerström, P.Eng., Northwest Hydraulic Consultants Inc.

Neil Peters, P.Eng., Ministry of Forests, Lands and Natural Resource Operations

Rick Rodman, P.Eng., Rodman Hydrotechnical Ltd.

Jesal Shah, P.Eng., Ministry of Forests, Lands and Natural Resource Operations

NOTES:

200 • 4010 REGENT STREET, BURNABY, BRITISH COLUMBIA, CANADA V5C 6N2
MAIN 604.430.8035 TOLL FREE 1.888.430.8035 EMAIL info@egbc.ca WEBSITE egbc.ca