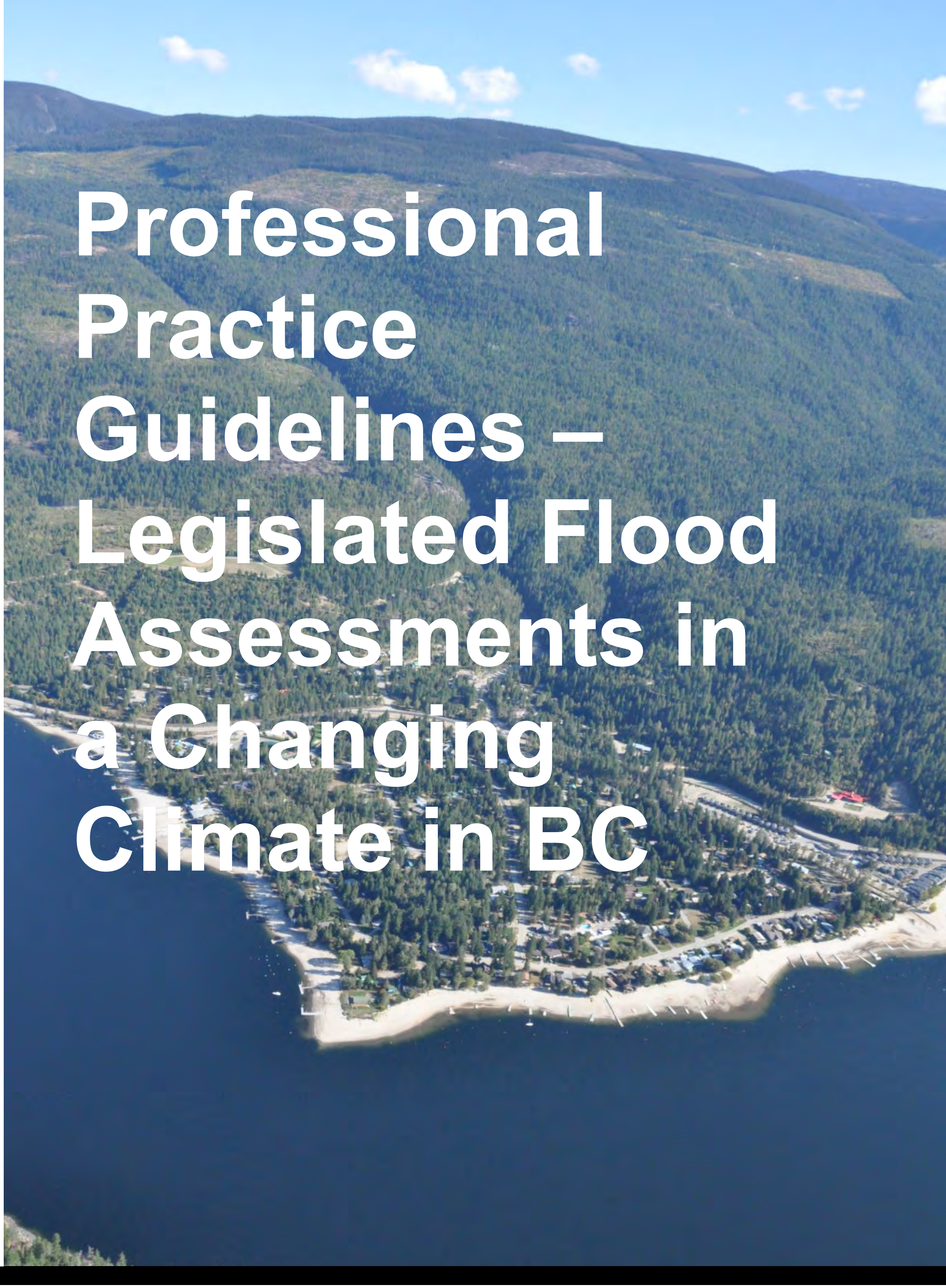
Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC



Professional Engineers and Geoscientists of BC

BRITISH COLUMBIA Ministry of Forests, Lands and Natural Resource Operations

Natural Resources Canada Ressources naturelles Canada

Canada

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Cover: “Hummingbird Creek”
Photo: Dr. Matthias Jakob, P.Geo.

PREFACE

These *Professional Practice Guidelines - Legislated Flood Assessments in BC* were commissioned by the British Columbia Ministry of Forests, Lands and Natural Resource Operations (MFLNRO). They have been written with the intent to guide professional practice for flood assessments, to identify the circumstances when *risk assessments* are appropriate and to emphasize the need to consider climate change and land use changes in such assessments.

The goals of the MFLNRO *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 their ongoing effort to achieve these goals, the Ministry has played a leadership role in working with the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) to develop these guidelines. The development of such guidelines is consistent with one of the primary objectives of APEGBC which is to establish, maintain and enforce good practice of professionals regulated by APEGBC. These guidelines complement the existing APEGBC *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC*.

The Ministry and APEGBC assembled a team of specialists from government and the engineering and geoscience community to prepare these guidelines. 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:

(i) outline the professional services that should generally be provided by APEGBC *members* conducting this type of work;

(ii) describe the standards of practice APEGBC *members* should follow in providing professional services in the field of *flood hazard* and *risk assessments*;

(iii) specify the tasks that should be performed by APEGBC *members* to meet an appropriate standard of care when preparing *flood hazard* and *risk assessment* reports, and which fulfills the *members'* professional obligations under the *Engineers and Geoscientists Act (*the *Act)*. These obligations include the *members'* primary duty to protect the safety, health and welfare of the public and the environment;

(iv) describe the roles and responsibilities of the various participants/stakeholders involved in such work. These guidelines will assist in delineating the roles and responsibilities of the various participants/stakeholders;

(v) identify various methodologies that can be used when dealing with tolerable and *acceptable risk*;

(vi) provide consistency in the reports and other documents prepared by APEGBC professionals when providing professional services in this field of practice; and

(vii) describe the appropriate knowledge, skill sets and experience that professionals should have who are working in this field.

1. INTRODUCTION

By the year 2035 the population of 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, 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 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.

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* (BC, 2004), but there remains a need to provide direction that incorporates *flood risk* management, climate change and land use.

Figure 1-1 exemplifies 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 thus be considered.

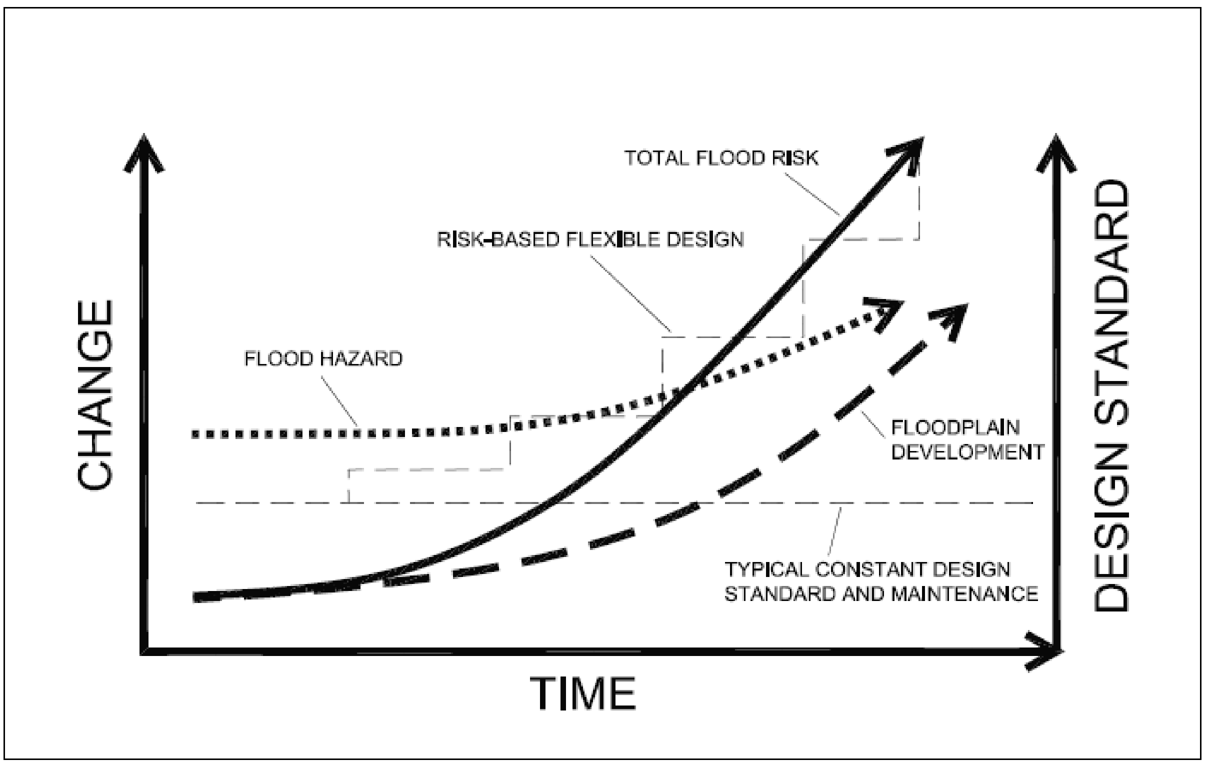

Figure 1-1: Changes in *flood hazard* and *risk* over time (Jakob and Church, 2012).

Further challenges are presented by global climate change that is also affecting BC. Increasingly, non-stationary data series invalidate traditional statistical analysis of flood frequency.

1.1 PURPOSE AND OUTLINE

These guidelines provide direction for professional practice for flood assessments. In summary the *Qualified Professional* (*QP*) should:

- undertake flood assessments consistently and transparently;
- provide for appropriate consultation with approving authorities;
- use a level of effort and approach appropriate for the nature of the *elements at risk*;
- standardize the flood assessments to make them directly comparable within BC;
- consider existing regulations and the level of protection provided by *structural mitigation works*;
- increasingly consider "*risk* management" and "adaptation" as opposed to solely "protection" and "defense";
- consider a broader range of issues and broader 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[1], local governments[2], as well as provincial and federal government ministries. Many of these parties require and rely on flood assessments prepared by a *QP*. The content of these guidelines may be of assistance to these parties.

By necessity there is some overlap between these guidelines and APEGBC's *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC*, and other guidelines produced by the provincial government (see Appendix D). 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 guidelines exist for these areas, they should also be considered.

1.2 ROLE OF APEGBC

These guidelines have been formally adopted by the Council of the APEGBC and form part of APEGBC's ongoing commitment to maintaining the quality of services that its *members* provide to their *clients* and the general public. *Professional engineers* and *professional geoscientists* are professionally accountable for their work under the *Act* (RSBC 1996, Chapter 116, as amended), which is enforced by APEGBC. A *member* must exercise professional judgment when providing professional services. As such, application of these guidelines will vary depending on the circumstances.

APEGBC supports the principle that a *member* 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 a *member's* agreement with his/her *client*.

By following these guidelines a *QP* should fulfill his/her professional obligations when carrying out these types of professional activities especially with regards to the APEGBC Code of

[1] Approving authorities include approving officers with various ministries including Ministry of Transportation and Infrastructure, building inspectors, and councils of local governments

[2] Local governments include municipalities, regional districts and the Islands Trust

Ethics Principle 1 (hold paramount the safety, health and welfare of the public, protection of the environment and promote health and safety in the workplace[3]). Professionals who diverge from guidance provided herein should document their decisions to do so. Failure of a *member* to meet the intent of the guidelines could be evidence of unprofessional conduct and lead to disciplinary proceedings by APEGBC.

1.3 Scope of the Document

These guidelines summarize the professional practice related to legislated flood assessments (see Appendix D for a summary and discussion of the legislative framework).

The introduction identifies the need and purpose of these guidelines, clarifies the role of APEGBC, introduces salient terms and points towards the applicability of these guidelines.

The second section guides the practitioner on how flood assessments can be organized and clarifies the responsibilities of the *client*, the *Approving Authority* and the professional conducting the study.

Section 3 is the backbone of these guidelines and provides guidance on anticipating climate change and land surface change, flood assessment procedures and a comparison of standard-based and *risk*-based approaches. Section 3 should be read in conjunction with Appendices E, F and G, which provide further guidance on specifics of flood assessments.

Similar to the *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC* (APEGBC, 2010) Section 4 informs on quality assurance and control and Section 5 explains the requirements for registration, education, training and experience. Section 6 provides references.

These guidelines are complemented by a set of appendices which provide a glossary of selected terms (Appendix A), a description of floods and flood-related hazards in BC (Appendix B), a summary of the current flood management approach in BC (Appendix C), a summary of current flood management legislation and guidelines in BC (Appendix D), a detailed description of *Flood Hazard* Assessments (FHAs) (Appendix E) followed by Appendix F which describes the details of a *Flood Risk Assessment* (FRA). Appendix G specifies considerations for flood assessments for development approvals. It is followed by Appendix H that describes professional practice in light of climate change and land surface condition impacts on flooding. Appendix I provides an overview of flood management in other jurisdictions. Appendix J is a *Flood Hazard* and *Risk* Assurance Statement, Appendix K provides case studies, and Appendix L lists the contributors to these guidelines.

These guidelines are directed to flood assessments for proposed development (institutional, commercial, industrial, and resource development; associated and non-associated infrastructure; emergency response; and in some situations existing *residential development*). These guidelines do not address other potential natural hazards such as landslides (APEGBC, 2010), soil erosion, subsidence or snow avalanches, except as related to flooding.

1.4 Applicability of the Guidelines

Notwithstanding the purpose and scope of these guidelines, a *professional engineer's* or *professional geoscientist's* decision not to follow one or more aspects of the guidelines does not necessarily mean a failure to meet required professional obligations. Such judgments and

[3] For the APEGBC Code of Ethics see http://www.apeg.bc.ca/library/actbylawscode.html. The Code of Ethics, along with accompanying Guidelines and Commentary, are published in the current (1994) edition of the APEGBC *Guidelines for Professional Excellence*.

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 specify the individual requirements for a flood assessment, or leave it to the consultant to determine the appropriate approach. Following these guidelines, however, does not ensure that the conclusions and recommendations contained within the flood assessment report will 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 two sets of guidelines may be used in conjunction with each other.

These guidelines reference current legislation, regulations and guidelines, but do not replace current legislation. They will be influenced by advances in knowledge and evolution of general professional practices in BC. 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

Appendix A explains many of the terms used in these guidelines. The following introduces some of the more common terms.

For the purpose of these guidelines a *QP* is a *professional engineer* or *professional geoscientist* or licensee with appropriate education, training and experience to conduct flood assessments as described in this guideline (see Section 3). Typically, such a *professional engineer* or licensee will be practising civil or geological engineering[4]; and such a *professional geoscientist* or licensee will be practising environmental geoscience[5].

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

A flood is a condition in which a watercourse or body of water[6] 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.

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[4] Geological engineering, and civil engineering are disciplines of engineering registration within APEGBC.
[5] Geology and environmental geoscience are disciplines of geoscience registration within APEGBC. Until 2000, APEGBC referred to the discipline of environmental geoscience as geotechnics.
[6] Watercourses includes creeks, streams and rivers; bodies of water includes ponds, lakes, reservoirs and oceans.

In BC high water levels of creeks, rivers, streams, ponds, lakes, reservoirs and oceans 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
- tsunamis.

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

- debris flows and debris floods/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, and
- 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 either predictable or 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 B.

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 measures 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 FHAs, FRAs and/or *flood risk* mitigation reports.

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

- subdivision of property;
- land use designation and zoning;
- *construction*, including *construction* of new buildings or structures; and
- structural alteration of, or addition to, existing buildings or structures.

1.6 ACKNOWLEDGEMENTS

These guidelines were prepared on behalf of APEGBC by a Committee of *QPs* and was reviewed by several diverse parties and stakeholders as members of an APEGBC Review Task Force. The authors and reviewers are listed in Appendix L. APEGBC and the authors thank the reviewers for their constructive suggestions. In addition APEGBC would like to acknowledge the contribution made by Lawrence Francois, M.Sc. (UK) who reviewed these guidelines during their development. Authorship and review of these guidelines does not necessarily indicate the individual and/or their employer endorses everything in these guidelines.

APEGBC thanks the Natural Resources Canada (NRCan), MFLNRO, and the Fraser Basin Council. NRCan and MFLNRO 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 MFLNRO.

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 a local government or the provincial government requesting the project proponent to retain a *QP* to carry out some form of flood assessment and prepare a report. The project proponent then forwards that report in support of a land development application. The report may be subject to review by the *Approving Authority*, occasionally with assistance being obtained 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 report submitted will ultimately be reviewed by an *Approving Authority*, and possibly another *QP*.

The *client* should be aware that the findings and recommendations of the *QP* could result in a development requiring modification, the *Approving Authority* requiring a restrictive *covenant* or the development being disallowed. In this regard, it is useful if the flood assessment is commenced early in the development planning process.

The role of the *QP* in relation to 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 been involved in land development or flood assessments, nor engaged a *QP*. In such situations the *QP* should consider reviewing with the *client* the typical responsibilities listed below, to assist in establishing an appropriate agreement for professional services and to inform the *client* of the expectation of appropriate and adequate compensation (APEGBC Code of Ethics Principle 5).

2.2 RESPONSIBILITIES

Sections 2.2.1 to 2.2.3 describe some of the typical responsibilities of a *client*, *QP* and *Approving Authority*. Section 2.2.4 describes some of the typical responsibilities of a *QP* when asked by an *Approving Authority* or *client* to review a flood assessment report prepared by another *QP*.

2.2.1 The *Client*

The *client* may be the landowner, a development consultant, the local government, the provincial government, a First Nation or the Federal Government. Prior to a flood assessment it is helpful, and will likely reduce the cost of professional services, if the *client* is knowledgeable about, and can provide the *QP* with the following:

- 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 Office and Survey Authority, and a copy of the current land registration including any relevant restrictive *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 *residential development*, including previous assessment reports conducted for the *client* or available to the *client*, and
- unrestricted access to and, if possible, 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 of Canada (ACEC) Document 31. Some specific points for consideration regarding the agreement are as follows:

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

The agreement should also include a clause that deals with potential disclosure issues due to the obligation of the *QP* under APEGBC Code of Ethics 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 *QP* will keep confidential all information, including documents, correspondence, reports and opinions, unless disclosure is authorized in writing by the *client*. However, in keeping with APEGBC's Code of Ethics, if the *QP* discovers or determines that there is a material *risk* to the environment or the safety, health and welfare of the public or worker safety, he/she shall notify the *client* as soon as practicable of this information and the need that it be disclosed to the appropriate 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 it is helpful if the *client*:

- reviews the assessment report, and understands the limitations and qualifications that apply;
- discusses the report with the *QP* and seeks clarification if desired;
- directs the *QP* to complete an assessment assurance statement, and provides the statement and the assessment report to the *Approving Authority*;

- allows the *QP* to confirm that his/her recommendations have been followed so that 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; and
- notifies the *QP* if land use, site development or other conditions change or vary from those described in the report.

The assessment report and any assurance statement are the property of the *QP* until outstanding invoices of the *QP* are fully paid by the *client*.

2.2.2 The *Qualified Professional*

The *QP* is responsible for carrying out the flood assessment and, if required/appropriate, outlining proposed measures to protect the proposed development.

Prior to carrying out an assessment the *QP* should:

- be knowledgeable about any the applicable approval processes for the proposed land 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 mitigative works potentially needed;
- appropriately educate the *client* regarding pertinent aspects of flood assessments;
- consult with the *Approving Authority* regarding applicable regulations, available information, application of the guidelines, role of *structural mitigation works*, applicability of *risk assessment* and requirements for development approval;
- determine whether the scope of work should include a hazard assessment, a *risk assessment*, a mitigation plan and/or engineering works;
- consider the need for and scale of investigations that 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;
- where possible and appropriate, review the draft report with the approval authority and the technical advisory staff;
- when a report recommends a significant variance from a guideline (e.g., variance of a bylaw Flood Construction Level (FCL) that covers a wide area), it is suggested that variance be discussed with the approval authority prior to final submission;
- obtain a copy of any guidelines or regulations that are pertinent to carrying out an assessment and/or preparing an assessment report; and
- if one exists, obtain the adopted level of *flood hazard* or *flood risk* tolerance, or other assessment approval criteria, for the proposed development in the approving jurisdiction.

The *QP* should comply with the requirements of APEGBC Bylaw 17 regarding professional liability insurance.

During the assessment the *QP* should follow the guidance provided in Section 3 and Appendices E, F, G and H. Furthermore, the *QP* should:

- 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 reasonably possible if the project scope and/or budget estimate requires modification;

- write the report clearly, concisely and completely to conform to applicable guidelines and regulations;
- ensure that the project work is subject to appropriate checking and review by qualified personnel;
- where appropriate, obtain an independent peer review;
- address any significant comments arising from the reviews; and
- where appropriate, submit a draft report for review by the *client* and other parties.

When the project work is complete, the *QP* may submit a signed, sealed and dated copy of the final report which should explicitly indicate reviews that were performed. If directed by the *client* and/or the *Approving Authority*, the report may be supplemented with a *flood hazard* and *risk* assurance statement as specified in Appendix J.

After the assessment the *QP* should:
- clarify questions the *client* and/or *Approving Authority* may have with regards to the assessment, report, and/or *flood hazard* and *risk* assurance statement, and
- carry out follow-up work if agreed with the *client*.

If aspects of the assessment are delegated, they should only be carried out under direct supervision of the *QP* who also assumes responsibility for all work delegated (refer to Section 4.2).

If the assessment report is followed by the *construction* of mitigative works, the *QP* should either oversee such works, or be satisfied that appropriate oversight is in place.

According to APEGBC Code of Ethics Principle 8, a *member* should clearly indicate to his/her *client* possible *consequences* if recommendations are disregarded.

To fulfill APEGBC 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) and Principle 9 (report to APEGBC or another appropriate agency any hazardous, illegal or unethical professional decisions or practices by a *QP* or others if a *client* fails or refuses to accept the conclusions and recommendations of the 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 APEGBC, the landowner (if different from the *client*) and/or appropriate authorities.

The above considerations are especially relevant if the *QP* identifies in the work done on behalf of the *client* a new *flood hazard* or provides the first detailed study of a known *flood hazard* that is within an area where developments are regulated by an authority having jurisdiction.

The above actions should be taken particularly if loss of life and/or other significant negative *consequences* are a possibility, or if workplace safety or the environment is potentially jeopardized.

2.2.3 The *Approving Authority*

For flood assessments, the *Approving Authority* is most often a local government as represented by the *Approving Officer*, Building Inspector or other representative. Within *regional districts*, the role of *Approving Officer* rests with the provincial government. For sale or lease of Crown lands MFLNRO Lands Officers act as the approval authority.

Where a flood assessment proposes physical mitigation measures (works in and around a stream or the *construction* of engineering works), other provincial and federal approval authorities may become involved. Such situations are generally outlined in Appendix C.

At the time of formal adoption of these guidelines by APEGBC (June 2012), the legislative environment in BC assigns to local and regional governments the authority to implement bylaws and other measures for natural hazard mitigation with due consideration of provincial guidelines. While some have adopted generic 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.

***Approving Authority* – Land Development Projects**

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

- to meet the requirements of a local government bylaw;
- to confirm appropriate implementation of conditions in an existing restrictive *covenant*; or
- to ensure that the land is suitable for the intended use in the absence of a bylaw, restrictive *covenant* or other applicable regulation.

It is recognized that few local governments presently have comprehensive bylaws to guide flood assessments. Over time it is expected that many local governments will adopt such bylaws considering these guidelines.

The *Approving Authority* may assist the *client* in defining the terms of reference for the study. Before the flood assessment is initiated, it is helpful if the *Approving Authority*:

- informs the *client* why a flood assessment is required;
- informs the *client*, if applicable, of the adopted level of flood safety (level of tolerable *flood risk*) in the approving jurisdiction;
- provides the *client* with any applicable guidelines and regulations for carrying out a flood assessment and/or preparing a flood assessment report;
- identifies known *flood hazard* information and reports relevant to the project (such as flood reports and maps) and describes how to access the documents;
- provides the *client* with information regarding existing *structural mitigation works* and input on the need for additional works;
- advises the *client* of any key policies or procedures that have the potential to 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;
- ensures the *client* is aware of the implications of the *Dike Maintenance Act* and *Water Act*; and
- provides an indication of any desired interaction with the *QP* during preparation of the report.

After the assessment is submitted the *Approving Authority* should:

- review the assessment report;
- if necessary, discuss the 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 measures. This will typically include registration of a restrictive *covenant* pursuant to Section 219 of the *Land Title Act*. Where the mitigation measures include engineering works, the *Approving Authority* will need to ensure that appropriate arrangements are made for design, *construction*, operation and maintenance (where appropriate in consultation with other jurisdictions).

***Approving Authority* – Engineering Works**

The *QP* may recommend upgraded or new *structural mitigation works* as part of a mitigation strategy. In this case, approvals will be required from various federal and provincial government agencies. For *structural mitigation works* to proceed, the proposed works must obtain or ensure:

- local government approval, 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 the *Inspector of Dikes* as the provincial regulator for flood protection works (*Dike Maintenance Act*);
- approval from the provincial MFLNRO (*Water Act*) if *construction* will involve works in or about a stream, or if a water licence is required;
- 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;
- there is compliance with the *Heritage Act*;
- First Nations are consulted if applicable; and
- approval from Transport Canada if the works could impact a navigable watercourse.

At the project outset, all of the above should be considered as potential approving authorities and input should be sought at the earliest possible opportunity. Any or all of the above may have regulations or requirements concerning scope, extent, timing, design, operation, maintenance, compensation, and/or reporting.

For any *structural mitigation works* that are constructed, there is generally a need to ensure that such works meet the criteria of a standard dyke as per Appendix A. In addition to meeting engineering standards, this includes the need for the works to be located on a right-of-way and under the jurisdiction of a local government maintenance authority. An operation and maintenance manual must be provided for this purpose.

Approval Authority - Reviews of Flood Assessment Reports

In some cases, the *Approving Authority* may use in-house experts or directly retain an independent *QP* to provide advisory services during a flood assessment, or to review a flood assessment report. Such a professional may provide advice regarding the type of flood assessment that would be appropriate, review any documents submitted by a *QP* retained by a project proponent, advise on improving the local flood management approach and developing new local guidelines and regulations.

An *Approving Authority* or *client* may also initiate an independent peer review of a report submitted by a *QP*. The need for an independent peer review on behalf of the *Approving Authority* is determined on a case-by-case basis, and may depend on:

- the credentials and experience of the author;
- the presence (or lack) of scientific consensus in understanding the relevant hazards;
- the capability of the *Approving Authority* to review and respond to the report;
- past precedent and/or the present state of local practice;
- the complexity of the report subject matter;
- the degree of judgment incorporated in the flood assessment;
- the concept and scale of any engineering works proposed for mitigation; and
- 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* considered.

In order for the independent reviewer to carry out an appropriate review, it is helpful if the requesting *Approving Authority*:

- is aware of the APEGBC Code of Ethics Principle 7; specifically, guideline (c), which states that a *member* should not, except in cases where review is usual and anticipated, evaluate the work of a fellow *member* without the knowledge of, and without communicating with, that *Member* where practicable;
- provides the reviewer with any applicable guidelines and regulations for carrying out an assessment and/or preparing an assessment report;
- explains the purpose of the reviewer's involvement;
- defines the role and scope of the review;
- provides relevant background information and reports;
- defines any intended interaction with the *QP* retained by a *client*;
- reviews any documents prepared by the reviewer;
- if necessary, discusses any review documents with the reviewer; and
- adopts an appropriate means of communicating the work of the reviewer to the *QP* responsible for the initial report.

An independent peer reviewer should also enter into an appropriate professional services agreement with the requesting approval authority or the *client* in view of the relevant provisions noted in Section 2.2.1.

The reviewing *QP* should consider whether there may be a conflict of interest and act accordingly (APEGBC Code of Ethics Principle 4), and conduct the review with fairness, courtesy and good faith towards colleagues and provide honest and fair comment (APEGBC Code of Ethics Principle 7).

Following guideline (c) of APEGBC Code of Ethics Principle 7, the reviewing *QP* should:

- if appropriate and authorized, inform the *QP* responsible for the initial report of the review, and the reasons for the review, and document in writing that the *QP* was so informed;
- ask the *QP* responsible for the initial report if the reviewing *QP* should know about unreported circumstances that may have limited or qualified the assessment and/or the report; and
- with the *client's* authorization, contact the *QP* who prepared the report and state if the results of the review identify safety or environmental concerns, in order to allow an opportunity for the *QP* to comment prior to further action.

The reviewing *QP* should submit a signed, sealed and dated review letter or corresponding report including:

- limitations and qualifications with regards to the review; and
- results and/or recommendations arising from the review.

The reviewer should clarify any questions the *Approving Authority* or *client* may have with regards to the review letter or report.

Occasionally, a *QP* is retained to provide a second fully independent 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, analysis and comparisons, as required, to accept full responsibility for his/her 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:

- obtaining building permits;
- subdivision developments;
- rezoning applications; and
- the sale or lease of Crown lands.

These guidelines not only provide guidance to the practitioner with regard to conducting such assessments but also inform approval authorities such that 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 chapter closely follows the flow chart below (Figure 3-1). It is structured chronologically into the phases of the study including Project Initiation, FHA, Regulatory Considerations, FRA, Recommendation of Structural Mitigation Works and Reporting. Generalities of the approach are presented in this chapter and specifics on the execution of the work are summarized in Appendices E, F and G.

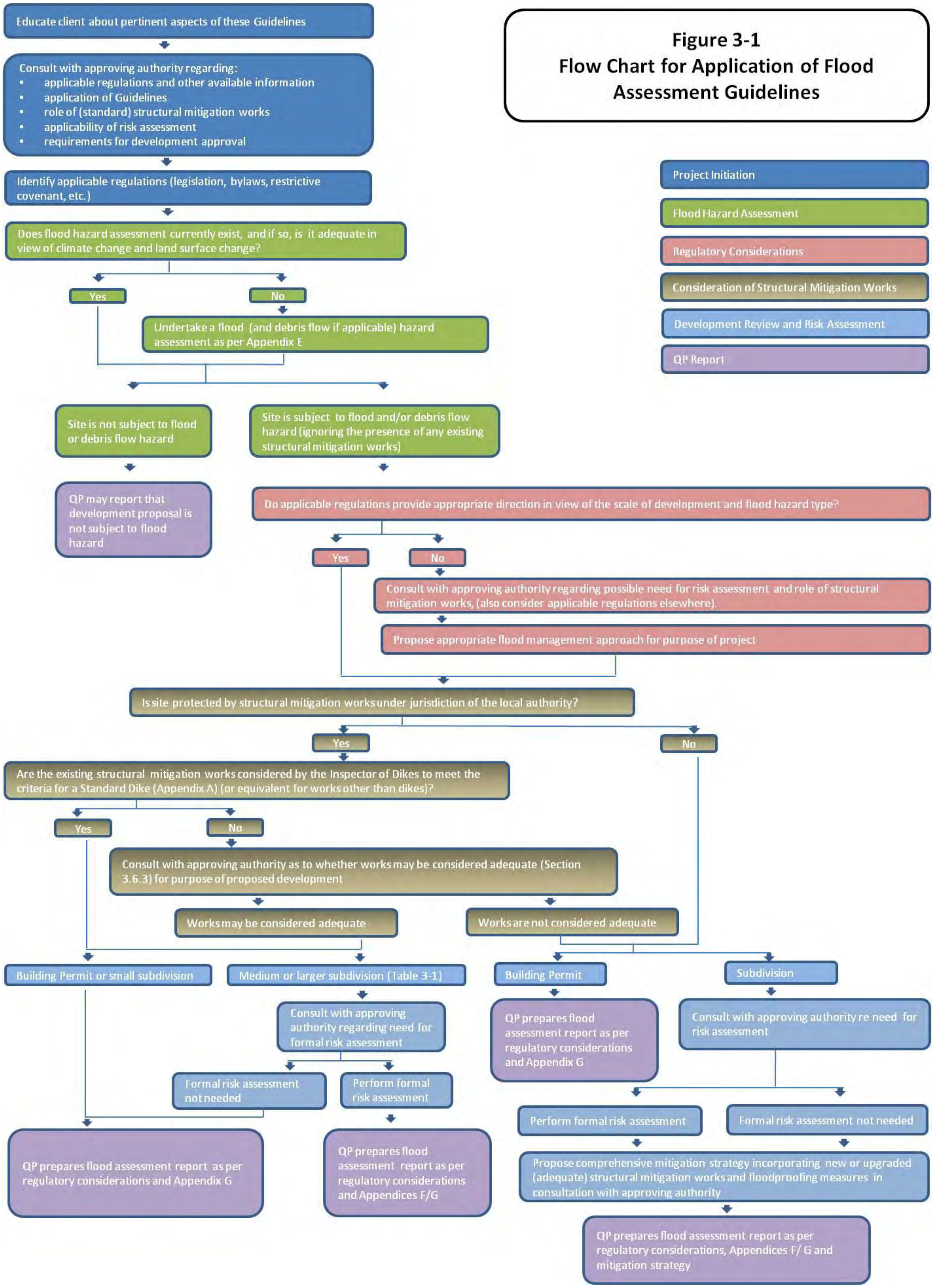

Figure 3-1 Flow Chart for Application of Flood Assessment Guidelines

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:

- define the study area;
- obtain background information;
- clarify the application of these guidelines;
- clarify the role of standard and non-standard *structural mitigation works*;
- clarify the role and applicability of a formal *risk assessment*; and
- clarify the requirements for a development approval.

3.4.1 Study Area

The study area should be determined by the study objective, the size of the parcel of land or the size of the specific site, the *elements at risk*, the number and types of structures to be protected and the nature of the flood processes involved. The study area should not be limited to the property or to the specific site, and where relevant, 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 development. Where deemed relevant, consideration must be given to the potential impact of *flood hazards* which cross jurisdictional boundaries. The *QP* should report on any hazards the proposed development may pose to other properties and infrastructure and, if requested, provide options for mitigating these effects. The *QP* should also assess hazards associated with flooding from all adjacent hydraulically-linked sources. These issues will also determine the size of the study area to be considered.

As a result, the study area can encompass a large variety of spatial scales ranging from a single lot to a major drainage basin, while the development to be protected may be very limited in spatial extent.

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 3-1 as possible sources of existing information.

Table 3-1: Background information for flood assessments

Previous Assessments	• *flood hazard maps* and reports, terrain maps • floodplain mapping and *alluvial fan* mapping • other resource inventory maps and reports previous flood assessment, geological and geotechnical reports that address the study area and, if available, neighbouring areas; • sedimentation records and reports • hydrogeology reports
Basemap Data	• large and small scale topographic and cadastral maps, LiDAR; • 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 waste water and/or sewage;

	• air photos of different years (historical to present) and scales; • bedrock and surficial geology; • in areas of logging: 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; • locations and number of Water Survey of Canada gauges and climate stations of the Meteorological Service of Canada used for hydrologic and hydro-climatic analysis; • streamflow and precipitation data gathered by municipalities, BC Hydro, Ministry of Forests, mining companies and others; • evidence and history of wildfires and insect infestations in the area.

Flood assessment reports from neighbouring areas can be useful to the *QP* and, in this regard, the local and provincial governments are encouraged to make such reports available to the *QP* since they are not always publicly accessible.

The *QP* should check whether there is a restrictive *covenant* pertaining to flooding registered against the land title. It may also be beneficial to check whether restrictive *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.

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 Light Detection and Ranging (LiDAR) images that can be used for topographical mapping and geomorphological or geological mapping. Regional flood frequency curves, Intensity-Duration-Frequency (IDF) graphs and other existing information on flood and rainfall frequencies should also be obtained.

Background information should be reviewed prior to undertaking subsequent phases, 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 reported.

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

Included with these guidelines are references that can be used in completing a check of the relevant background information to be compiled and interpreted. These 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 whether there is *risk* of injury or death, because larger developments imply higher potential *consequences* to severe floods.

On the lower end of the development spectrum, one may consider, for example, a request for relaxation of a bylaw floodplain setback for a house adjacent to a small creek fan or a river floodplain area. In these cases, the level of effort will be very site-specific and may be limited to a short (perhaps an hour to a day) field visit by the *QP* and a qualitative flood assessment. Details on what such an assessment may entail are provided in Appendices E and G.

In the middle of the spectrum of development scales, consider 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's fan. Peak flows would need to be determined for floods, and/or 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 even the potential effects of 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 requested, the *consequences* and thus *risk* to people and infrastructure on the fan.

At the high development spectrum scale, consider a study of *flood hazard* for a new township 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 their 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 (i.e., 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 *flood hazard* and/or *risk assessments* and that significant potential changes in land surface conditions be considered so far as they are foreseeable. Consideration of such factors will allow local government and provincial approving officials to incorporate climate change effects 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 H.

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%, the increase primarily occurring during winter months and in the mountains (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.,* 2010a) with potentially higher peak flows due to increased storm precipitation intensity;
- it is projected that a net sea level rise of as much as 1 m will occur along the BC coast (BC, 2007; Ausenco Sandwell, 2011a);
- 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; and
- increases in temperature, lightning strikes and summer droughts will increase the potential for forest fires (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 which need to be incorporated in flood assessments.

Additional details are provided in Appendix H, sections H-2 and H-3.

It is expected that the foregoing changes will result in an increase in the frequency of floods in small and medium drainage basins that will be dominated by rainfall runoff, and 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 that 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, of course, 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 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 at www.pacificclimate.org and should be consulted before making estimates for future flood flows.

Through PCIC, the MFLNRO, along with the Ministries of Transportation and Infrastructure, and Agriculture are working together 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, data quality and 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 program is available at: www.env.gov.bc.ca/epd/wamr/crmp.htm

The Pacific Institute for Climate Solutions (PICS) (www.pics.uvic.ca/index.php) is a useful technical resource focusing 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 this site.

The University of Washington Climate Impacts Group (http://cses.washington.edu/pubs/allpubs.shtml) is an interdisciplinary research group studying the impacts of natural climate variability and global climate change ("global warming") in the western U.S., with most work focused on the Pacific Northwest. Reports from this group are relevant to the heavily populated areas of southern BC.

Other useful sources of information and reports include:

- BC State of Environment reporting (www.env.gov.bc.ca/soe/indicators/#Climate Change);
- Environment Canada (www.ec.gc.ca/sc-cs/Default.asp?lang=En&n=56010B4-1);
- Ouranos (www.ouranos.ca), a consortium of scientists and organizations based in Quebec with a mandate to study climate change and social and economic adaptations; and

- Compendium of Forest Hydrology and Geomorphology in British Columbia, Pike *et al.* (2010) (www.for.gov.bc.ca/hfd/pubs/docs/lmh/lmh66/lmh66_frontmatter.pdf) provide an authoritative review of forest hydrology, including expected effects of climate change.

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, 2009; 2010). A basis for adjusting IDF curves is presented by Burn *et al.* (2011) in an analysis of rainfall totals for 1-12 hours for long-term recording stations in BC. See Appendix H 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 3.6.2 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 recognise 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 condition, 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 H for more discussion).

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,

- when IDF curves are to be applied, review current IDF curves and apply results of stormwater runoff modelling appropriate for expected land surface conditions; or
- 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 just proposed 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 variable of interest, such as short-period rainfall intensity, and these could become the basis for some estimates of possible future conditions.

If a statistically significant trend is detected:

- 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 results of stormwater runoff modelling appropriate for expected future land surface conditions, or;
- 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

A 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 measures should be designed. Appendix E provides supplemental information in this regard. A *freeboard* allowance is typically added to account for uncertainties in the analysis. Appendix E provides details as to the requirements and applications for different developments 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 or debris flow hazards. If it is not, the *QP* may summarize this finding in the flood assessment report to be submitted to the *client* and *Approving Authority*.

3.6.2 Regulatory Considerations

Flood assessments that pertain to development approval must comply with legislative requirements (federal and/or provincial). 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.

Flood assessments must also comply with existing restrictive *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* ought to consider the sufficiency and appropriateness of such requirements in view of 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 considered to be insufficient, the *QP* should consult with the *Approving Authority* regarding an appropriate approach for the proposed development. Such a consultation may require the *QP* to:

- confirm that the *Approving Authority* is conversant with these guidelines;
- encourage the *Approving Authority* to conduct studies that may lead to an appropriate bylaw or land use regulation;
- encourage the *Approving Authority* to consider establishing a tolerable limit for flood safety;
- inform the *Approving Authority* of some standards from elsewhere that may be applicable; and
- endeavour to obtain direction for the flood assessment to be performed.

Definitions of different development types as used in Figure 3-1 and elsewhere in the Guidelines are provided in Table 3-2.

Table 3-2: 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)
Medium Subdivision	Subdivision into ≥10-100 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. Appendix A defines a *standard dike*. The presence of a *standard dike* or other *structural mitigation works* 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 which will continue in perpetuity. 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, floodproofing measures and *risk assessment* principles are also important.

A *QP* should consult with the local authority and/or the *Inspector of Dikes* to determine whether existing flood control works meet current Ministry or local government standards. In some cases, an existing structure or works may not be constructed to high standards, but may still be considered appropriate following the *risk assessment*.

Figure 3-1 illustrates alternative procedures depending on whether the existing *structural mitigation works* are considered standard. Appendix G outlines a range of approaches that can be undertaken depending on the scale of development and whether standard works are present.

For building permit or small subdivision developments that are protected by a *standard dike*, Appendix G provides for a practical standards-based approach that may be used in a flood assessment report. In most cases, floodproofing measures will be defined without the need for a formal *risk assessment*.

For a medium or larger subdivision that are protected by a *standard dike* or other flood control works, Appendix G advises the *QP* to consult with the approval authority regarding the need for a formal *risk assessment*, and proceed accordingly.

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 works. Appendix G provides some recommendations for flood protection measures for building permits in the absence of major flood control works.

For a subdivision on a fan or floodplain that is not protected by a *standard dike* or equivalent *structural mitigation works*, Appendix G provides for the *QP* to consult with the approval authority regarding the need for a formal *risk assessment*, and proceed accordingly. Some limited provision is made for subdivision approval in such areas in the absence of standard works. However, in most situations, subdivision requires a comprehensive mitigation strategy incorporating standard *structural mitigation works* as part of the development.

3.6.4 Comprehensive Mitigation Strategy

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

- outline a comprehensive approach to mitigating flood-related hazards appropriate to the nature and scale of the proposed project;
- provide engineering designs and specifications for any structural works or non-structural strategies proposed as a primary level of protection;
- identify an appropriate maintenance authority (generally the local government) for any proposed structural works;
- define secondary protective measures within the proposed development area;
- document the need for land tenure in favour of the maintenance authority; and
- outline future operation and maintenance measures by the maintenance authority in order for the works to be effective over the long term.

3.7 STANDARD-BASED AND *RISK*-BASED APPROACHES

3.7.1 Standard-Based Approach

In some areas local government bylaws and *covenants* specify flood protection measures and in some areas flood assessment design thresholds have been established based on the Q_{200} design (Appendix G). There are no set criteria for the assessment of erosion hazard.

A typical application is the use of flood frequency analysis to determine the 200-year return period flood magnitude on a river. This is followed by numerical analysis of the cross-section of the river and, if found insufficient to carry the *design flood* plus *freeboard*, may lead to an upgrade or *construction* of *dikes* to meet the required standard. After such upgrade/*construction*, and implementation of appropriate FCL, safety (up to the design level) is assumed and considering some additional rules (Appendix G), the development is typically considered approvable as per the assessment of the *QP* and the regulatory agency's judgment.

In cases where development approval applications are proposed behind a *standard dike* in an area where floodplain bylaws exist that prescribe FCL and setback requirements, compliance with those bylaws will lead to development approval even in absence of a report by a *QP*.

The adoption of a standard-based approach incorporates an element of *risk*. For example, the 200-year return period *design flood* assumes that the residual *risk* of a higher magnitude flood, even if it would most likely overcome existing or proposed flood mitigation measures, is tolerable to the *client*, approving agency and society at large. It also includes implicit *risks* arising from the possibility that the magnitude or frequency of the *design flood* is uncertain and 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, economic and environmental losses are typically the most important *consequence* categories but loss of cultural values and mental stress associated with property loss can be included. The resulting *risk* estimates are then evaluated through comparison with existing local or provincial *risk* tolerance criteria, or, in absence of those, against applicable international criteria. Figure 3-2 summarizes how hazard and *consequences* are combined in a comprehensive *risk assessment*.

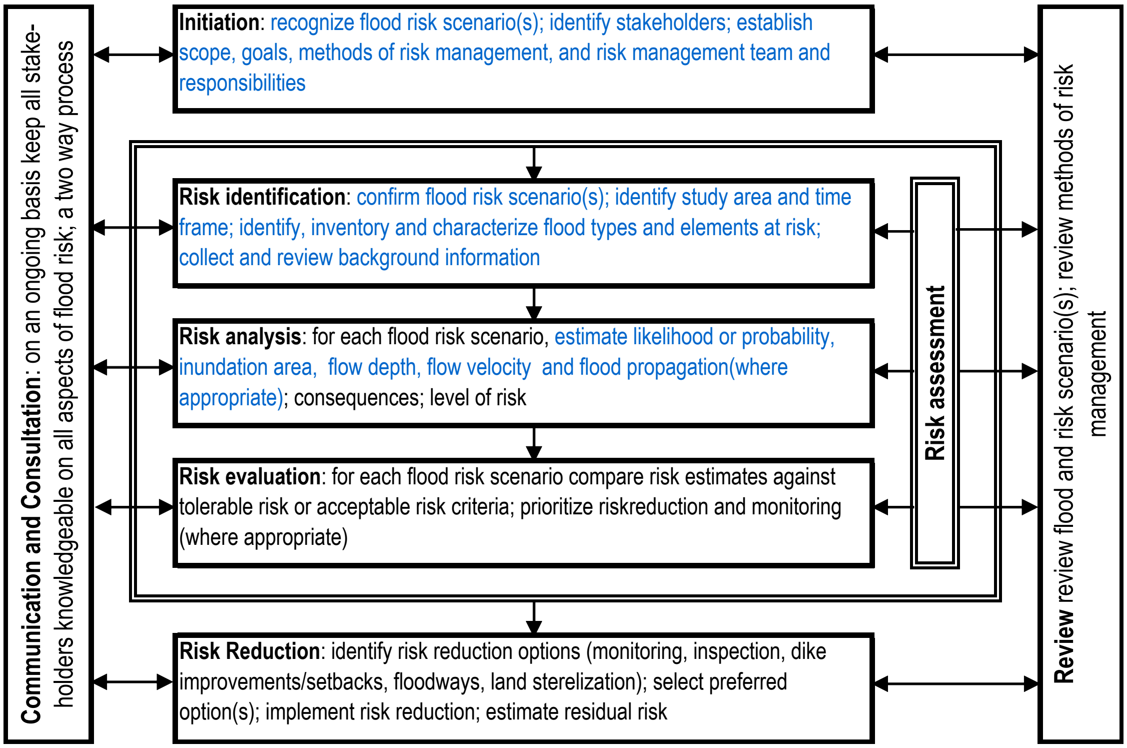

Figure 3-2: Generalized *risk*-based approach for *flood risk* management (modified from CAN/CSA-Q850-97). Elements of FHA are highlighted in blue.

3.7.3 *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 (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 either due to upward trends in the *flood hazard* 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 the Ministry of Transportation and Infrastructure subdivision *Approving Officers* and MFLNRO lands officers still regulate land use. At the present time economic *risk* to the individual and local governments is addressed through the flood damage compensation program with Emergency Management BC (EMBC). If the local government and/or individual builds to 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 evokes consideration of the area that should be included in the flood assessment and how it could affect 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, defined as "a zone that includes all existing and proposed development 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 F. 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". Through this statement, the *QP* declares that the *risks* consequent for a given *hazard scenario* are tolerable or acceptable[7]. Herein lies a significant paradox: 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 D). APEGBC recommends that "safety" be clearly defined by the *QP* in the flood assessment.

3.8 FLOOD ASSESSMENT REPORTS

This section contains a checklist of issues that may be included in a flood assessment report. A flood assessment report may be a hazard, or *risk assessment* or a flood mitigation report. The following bullets provide guidance as to the key elements of such reports.

The *QP* has a responsibility to convey the level of effort applied. This ensures that the approval authority understands the basis for choosing the analytical method selected. The level of documentation to be included in a report should be sufficient to assure repeatability of the work. In addition, the documentation provided as part of the report must be sufficient to facilitate report reviewers being able to understand how the *QP* arrived at his/her conclusions.

A *flood hazard* report could assume the following structure (further guidance is provided in Appendix E):

- 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;
- study area with a legal description of the 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;
- description of background information available, collected and reviewed, and its relevance including land use;
- recognition and characterization of flood processes (e.g., rainfall/snowmelt generated floods, ice related floods, debris floods, debris flows, glacial lake outburst floods,

[7] "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.

composite processes) within and, if required, beyond the development boundaries (see Appendix B for descriptions of flood types);

- description of methods of FHA and level of effort;
- reporting of results of the FHA with *flood hazard maps* showing, for example, area inundated, flow depths and flow velocities for different *hazard scenarios*;
- conclusions including, if applicable, a local level of partial *risk* tolerance;
- recommendations if requested and as required, to reduce the *flood hazards* and for further work;
- references including maps and airphotos, reports, manuals, guidelines and scientific papers;
- limitations and qualifications of the assessment and report, assumptions, error limits and uncertainties of the hazard assessment; and
- consideration of land use and climate change.

Typically, a *flood risk* report should include the following elements in addition to those listed above for *flood hazard* reports. However, this depends on the level of *risk assessment* specified (see Appendix F, Table F-6):

- a local, provincial or federal level[8] of *flood risk* tolerance for comparison with determined *risk* values;
- results of the FRP 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 of the assessment and report, assumptions, error limits and uncertainties of the *risk assessment*; and
- determination of the changes in *risk* in a changing climate.

A flood assessment report that includes provision for *structural mitigation works* may typically include the following:

- the objectives and basis for determination of the proposed concept for hazard mitigation (i.e., reference to *risk* tolerance criteria that were established as part of the project);
- references to any applicable local standards or provincial guidelines pertaining to hazard mitigation (e.g., MFLNRO *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 floodproofing measures);
- discussion of possible *risk*-transfer issues;
- design and specifications of proposed mitigative measures (in some cases this would be in a separate report) with consideration to applicable standards for such works;
- the *construction* of mitigative measures;
- *construction* and maintenance cost estimates;
- identification of a proposed maintenance authority for any proposed mitigative measures (generally local government);

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

- identification of operation and maintenance measures that will be required for the mitigative measures (a separate operation and maintenance manual will ultimately be required for this purpose); and
- attention to land tenure and other such operational issues.

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 (e.g., 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) loss estimation program HAZUS (FEMA, 2011) which has been adapted for Canadian use (see Appendix F, Section F-2.3.2).

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/or 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 *residential development*.

The report should be clearly written with 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. FHA reports are frequently included as part of a *covenant* on the Title, and should be written accordingly.

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

The limitations and qualifications provided with *flood hazard* and *risk* studies can be based on a range of 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 with the goal to avoid the illusion of exactness. Sensitivity analyses are recommended to acknowledge these limitations and assess the worst case scenario. This is particularly important for formal FRAs in which a series of *hazard scenarios* ought to be carried to a *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 demand a multi-disciplinary approach to meet their objectives. It cannot reasonably be expected that a *QP* has a broad enough background to address every specialty service required in order to complete a flood assessment. Specialties can include quaternary sciences applied to date 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.

The science of fluvial geomorphology is inseparably linked with *flood hazard* studies. An understanding of channel evolution, sediment transport mechanisms and river bank stability at various temporal and spatial scales needs to be linked to the channel hydraulics and is required to understand how *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* will need to 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 that for hazard assessments. The *QP* responsible for determining economic losses requires not only access to high quality data on housing and infrastructure but also must have a comprehension of the various losses that may be 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. If this is the case, additional qualified specialists should be retained, such as economists, or government institutions such as BCStats.

Similarly, cost-benefit analyses (CBA) or multi-criteria analyses (MCA) require at least some background in economics. For more sophisticated *flood risk* studies, CBA or MCA should be carried out by economists in collaboration with *professional geoscientists* or *professional engineers*.

Loss of life calculations also require specialized skill with a strong background in the various methods that have been proposed. These methods rely on very different input and are structured around different levels of sophistication, starting at very basic mortality statistics that hinge on water depth only and end at computing the loss of life potential for individuals living or working in the potentially flooded area. A summary of various loss of life estimation methods can be found in Jonkman (2005). As previous studies have shown, 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 Table F-2).

4.0 QUALITY ASSURANCE/QUALITY CONTROL

A *QP* should carry out quality assurance/quality control (QA/QC) for all phases of a FHA. Appendix J provides a quality assurance statement for the *QP*.

4.1 APEGBC Quality Management Bylaws

As a minimum, a QA/QC program must satisfy the requirements of APEGBC Quality Management Bylaws 14(b)(1), (2) and (3) with regards to:

- the work being performed under the direct supervision of a *QP*;
- retention of complete project documentation for a minimum of 10 years;
- documented checking of engineering and geoscience using a quality control process; and
- documented internal or external review of a flood assessment report.

These minimum requirements may be supplemented by an independent peer review where appropriate.

4.2 Direct Supervision

The *Act* (Section 1 (1)) states that direct supervision means taking responsibility for the control and conduct of the engineering or geoscience work of a subordinate. With regard to direct supervision, the *QP* having overall responsibility should consider:

- the complexity of the project and the nature of the *flood hazards* and/or *flood risks*;
- which aspects of the *flood hazard* and/or *risk assessment*, and how much of those aspects, should be delegated;
- training and experience of individuals to whom work is delegated; and
- amount of instruction, supervision and review required.

Field work is one of the most critical aspects of a *flood hazard* and/or *risk assessment*. Therefore, careful consideration must be given to delegating field work. Due to the complexities and subtleties of *flood hazard* and/or *risk assessments*, direct supervision of field work is difficult and care must be taken to ensure that delegated work meets the standard expected by the *QP*. Such direct supervision could typically take the form of specific instructions on what to observe, check, confirm, test, record and report back to the *QP*. The *QP* should exercise judgment when relying on delegated field observations by conducting a sufficient level of review to be satisfied with the quality and accuracy of those field observations.

4.3 Checking and Review

As referenced in Section 4.1 of the guidelines and consistent with the requirements of APEGBC Quality Management Bylaw 14(b)(2), as a minimum, a flood assessment must undergo a documented checking and review process before being finalized and delivered to the *client* and/or *Approving Authority*. This documented checking and review process would normally involve an internal review by another *QP* within the same firm. Where an appropriate internal reviewer is not available, an external reviewer may be engaged. Such an internal/external review should be documented in the report. The level of review should be discussed with the *client* but is based on the professional judgment of the *QP*. Considerations should include the complexity of the site, the nature of the *flood hazard*, type of development under consideration, *elements at risk*, availability, quality and reliability of background information and field data, the degree of judgment on which the assessment is based, and the *QP's* training and experience.

4.4 INDEPENDENT PEER REVIEW

An independent peer review is an additional level of review beyond the minimum requirements of Bylaw 14(b)(2) that may be undertaken for a variety of reasons (such as those listed above) by an independent *QP* not previously involved in the project. At the discretion of the *QP*, in consultation with the reviewer(s) involved in the regular checking/review process outlined above, such an additional level of review may be deemed appropriate. Alternatively, a local government or other *Approving Authority* may request an independent peer review to support project approval. An independent peer review may be undertaken by another *QP* within the same firm, or an external *QP*.

The independent peer review process should be more formal than the checking/review process carried out under Bylaw 14(b)(2). An independent reviewer should submit a signed, sealed and dated letter or report, to be either included with the report or put on file, that includes the following:

- limitations and qualifications with regard to the review; and
- results of the review.

When an independent peer review is carried out, the *QP* who signed the *flood hazard* and/or *risk assessment* report remains the Engineer of Record or Geoscientist of Record.

The independent peer review discussed above is not the same as an independent review or advisory service provided by a *QP* who is retained by an *Approving Authority*, or sometimes a *client* (see Section 2.2.4).

5.0 PROFESSIONAL REGISTRATION; EDUCATION, TRAINING AND EXPERIENCE

5.1 PROFESSIONAL REGISTRATION

As summarized in Appendix D, the following are the professional registration requirements for legislated flood assessments for proposed developments in BC:

- *Local Government Act* (Section 920(11)) indicates that, for a development permit, the local government may require a report from a *professional engineer* “with experience relevant to the applicable matter”.
- *Local Government Act* (Section 910(5)) indicates that, for floodplain bylaw exemption, a *professional engineer* or *professional geoscientist* “experienced in geotechnical engineering” is required.
- The provincial document associated with the *Local Government Act* (Section 910) (Ministry of Water, Land and Air Protection, c2004) indicates that a *QP* is a *professional engineer* or *professional geoscientist* with “geotechnical engineering experience and expertise in river engineering and hydrology, and in appropriate cases, … debris flow … processes.”

A *professional engineer* as described above is typically registered with APEGBC in the discipline of geological engineering or civil engineering and has developed expertise in hydrotechnical engineering which includes hydrology.

A *professional geoscientist* as described above is typically registered with APEGBC in the discipline of geology or environmental geoscience[9]. Although the *Land Title Act* and the *Local Government Act* refer to a *professional geoscientist* “experienced in geotechnical engineering,” by definition a geoscientist is not experienced in engineering. APEGBC 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 necessarily appropriately knowledgeable in geohazard assessments, river engineering, hydrology and/or debris flow processes. Similarly, not all *professional geoscientists* registered with APEGBC in the disciplines of geology or environmental geoscience are necessarily knowledgeable in geohazard assessments including debris flows and 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 *flood hazard* and/or *risk assessments* for proposed developments (APEGBC Code of Ethics Principle 2). Consideration should be given by APEGBC to creating a special designation for a Flood Assessment *QP*, possibly with sub-categories, that would formalize the recognition of appropriate individuals.

As noted previously, as the complexity of the *flood hazard* 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*, the following is an excerpt under Principle 2 of the *Code of Ethics Guidelines* (APEGBC 1994; amended in 1997):

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[9] Until 2000, APEGBC referred to the discipline of environmental geoscience as geotechnics.

> “The professions are distinct and registration in one does not give a *member* the right to practice in the other; however, the Association recognizes that there is some overlap of the practices of engineering and geoscience.
>
> Nothing in this principle authorizes a *professional engineer* to carry on an activity within the area of professional geoscience 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.”

On this basis, the *QP* who designs and oversees the *construction* of *structural mitigation works* to mitigate the impact of *flood hazards* and/or mitigate *flood hazard risks* requires registration with APEGBC as a *professional engineer*. The *QP* who investigates or interprets complex hydrogeological conditions and geomorphic processes in support of FHAs is typically registered with APEGBC as a *professional geoscientist* in the discipline of geology or environmental geoscience, or as a *professional engineer* in the discipline of 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 economics and biology. A *QP* must adhere to the APEGBC 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 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 E. 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 a team of professionals, who carry out FHAs for may include education and experience in:

- 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; and
- varve chronology

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:

- air photograph and satellite imagery interpretation;
- absolute dating methods (dendrochronology, radiometric dating, varve chronology);

- relative dating methods where applicable (lichenometry, soil development, etc.);
- 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; and
- design of debris flood and debris flow mitigation structures.

For formal FRAs, appropriate qualifications may include:
- database management;
- cost-benefit analyses;
- *risk analysis*;
- environmental surveying techniques; and
- aquatic resource inventory techniques.

Where *structural mitigation works* are contemplated, appropriate qualifications may include:
- 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;
- principals of seismic design; and
- principal of tsunami science.

The academic training for the above skill sets can be acquired through formal university or college courses, or through continuing professional development. There may be some overlap in courses and specific courses may not correlate to specific skill sets. A *QP* should also remain current, through continuing professional development, with the evolving topics of *flood hazard* and *risk assessments* and specialized services offered (refer to APEGBC 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; searching the web; and participating in field trips.

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APPENDIX A: GLOSSARY OF SELECTED TERMS

Acceptable Risk
A *risk* for 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.

Active and Inactive Alluvial Fan
An *active alluvial fan* can be defined as being subject to channel avulsions and where the main fan surface is still undergoing periods of aggradation and channel incision. 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 of 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, often fan-like in shape, 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 applied also to debris flow fans, those constructed from the deposits of debris flows, and many fans incorporate deposits of both types.

Approving Authority
Approving Officer, Building Inspector, or Planners and/or Councils of a local government.

Approving Officer
An official who is appointed under the *Land Title Act* (Section 77) and acts independently to (1) ensure that 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 British Columbia:

Approving Officers	**Appointed by**	**Jurisdiction**
Municipal Approving Officers	Municipal Councils	Subdivision approvals within municipal boundaries
Regional District and Islands Trust Approving Officers	*Regional District* Boards or the Islands Trust Council	Subdivision approvals within the boundaries of those local governments that have assumed the rural subdivision *Approving Authority**
BC Ministry of Transportation Approving Officers	Provincial Cabinet	Subdivision approvals outside municipal boundaries and within those *Regional Districts* and the Islands Trust boundaries that have not assumed the rural subdivision
Nisga'a Lands Approving Officers	Nisga'a Lisims Government	Subdivision approvals within Nisga'a Lands, including Nisga'a Village

*As of February 2006 no *Regional District*, nor the Islands Trust, has assumed responsibility for rural subdivision approvals, and therefore that authority is still held by the Ministry of Transportation.

Client
An individual or company who engages a *QP* to conduct a landslide assessment.

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 data base which currently includes approximately 210 *dike* structures that are considered to be regulated under the *Dike Maintenance Act*.

Elements at Risk
The population, buildings or engineering works, economic activities, public services, utilities, infrastructure and environmental features in the area potentially affected by floods or landslides.

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 includes 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, floodproofing of *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 Proofing
The alteration of land or buildings to reduce flood damage and includes the use of building setbacks from water bodies to maintain a floodway and to allow for potential erosion. *Flood proofing* may be achieved by either, or a combination 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.

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). As an 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 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 Inspectors of Dikes
Appointed provincial employees with the statutory authority to oversee maintenance of *dikes* by diking authorities, set diking standards and approve changes to existing *dikes* and new *dikes*.

Member
Professional Engineer or *Professional Geoscientist*. A *Member* of the Association of Professional Engineers and Geoscientists of British Columbia.

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.

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 26, Division 2).

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 Engineer

An engineer who is a registered or licensed *member* in good standing with APEGBC and typically is registered in the disciplines of geological engineering, mining engineering or civil engineering, which are designated disciplines of professional engineering.

Professional Geoscientist

A geoscientist who is a registered or licensed *member* in good standing with APEGBC and typically is registered in the disciplines of geology or environmental geoscience, which are designated disciplines of professional geoscience. Until 2000, APEGBC referred to the discipline of environmental geoscience as geotechnics.

Qualified Professional (QP)

A *professional engineer*, *professional geoscientist*, licensee, including limited licensees with the appropriate level of education, training and experience to conduct flood assessments for *residential development* as described in these guidelines and licensed to practice by APEGBC.

Regional District

A district incorporated under the *Local Government Ac*t, 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*.

Standard Dikes
Those *dikes* considered by the *Inspector of Dikes* to meet minimum provincial standards including:

- design and *construction* to contain the designated flood;
- design and *construction* completed under the supervision of a *QP* engineer;
- an effective *dike* management and maintenance program by a local diking authority (typically local government); and
- 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 *flood proofing* measures such as structural fill and erosion/scour protection works to raise and protect building foundations (see definition for *flood proofing*).

Tolerable Risk
A *risk* that society is willing to live with so as to secure certain benefits in the confidence that it 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*. It 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.

APPENDIX B: FLOODS AND FLOOD-RELATED HAZARDS IN BC

B1 INTRODUCTION

A flood is a condition in which a watercourse or body of water[10] 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 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;
- 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, 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.

B2 *FLOOD HAZARDS*

B2.1 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 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.

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

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 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 mobilising flows are much more rare.

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 by no means 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, with larger basins on the coast and in the eastern mountains 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.

B2.1.1 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.

B2.1.2 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).

B2.2 Other Flood Types

B2.2.1 *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. An important distinction in BC is between *alluvial fans* in the humid mountains and ones 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 that 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 that 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 FHAs are of very limited value. The active channel zone and all recently occupied channels should be regarded as hazardous. The most effective way to identify former channels likely to be reoccupied and to forecast the likelihood for an avulsion to occur is 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.

B2.2.2 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 (2010a) summarizes the application of dendrochronology for debris flow science and Chiverrell and Jakob, (2010a) describe radiocarbon dating of debris flow deposits on fans. Jakob (2010b) 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.

B2.2.3 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 B.2.2.2). 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 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.

B2.2.4 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: (i) 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; (ii) 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 which 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 B2.2.5 for reconnaissance assessment methods). Beaver dam failures are more widespread than realized (Butler and Malanson, 2005).

B2.2.5 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 temporarily blocked by a debris slide up to historic blockage of the Thompson River and prehistoric blockage of the Fraser River. The *flooding hazard* associated with landslide dams is twofold: (i) flooding in the upstream impoundment; (ii) 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 minesites 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 of damming 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 which would result 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, reported in Table B-1, 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 realized, 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).

Table B-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

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 $QP = aV_o^b$, in which QP is the peak discharge (m^3s^{-1}) and V_o (m^3) is the initial volume of the impoundment. *n* is the number of cases.

Assessments of lake outbreaks and subsequent debris flows and debris floods require the following steps to 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.

B2.2.6 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:

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

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

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

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.

B2.2.7 Ice Jams and Ice Runs

In rivers 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: (i) freeze-up; (ii) mid-winter; and (iii) 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, 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 it. 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, 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).

B2.2.8 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 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 at www.weather.gov/ptwc/.

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 of the west coast of Vancouver Island – (a so-called mega-earthquake), 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, 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.

B2.3 Erosion and Sedimentation

B2.3.1 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:

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

B2.3.2 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°, 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 Appendix B, Section 2.2.3). 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 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. Many tree species in BC, however, 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 metre 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 backwatered 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.

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APPENDIX C: CURRENT FLOOD MANAGEMENT APPROACH IN BC

C1 INTRODUCTION

Flood management refers to mitigation measures 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.

C1.1 Non-Structural Measures of Flood Management

Non-structural measures include avoiding development in flood-prone areas by means of land use planning and zoning, restrictive *covenants* on land titles, enforcement of flood *construction* levels and minimum building elevations, and floodproofing. 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 Lower Mainland Regional Planning Board, and its 1966 Official Regional Plan;
- the provincial Agricultural Land Commission created in 1973;
- the provincial Floodplain Development Control Program, which operated between 1975 and 2003, and subsequently has been delegated to local governments; and
- the Floodplain Mapping Program, funded by the provincial government from 1974 to 1998, and subsequently delegated to local governments.

C1.2 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. Examples of structural measures 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 flood 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 co-ordinated 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/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 Indian and Northern Affairs Canada. 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.

C2 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.

C2.1 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. The 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 floodproofing 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*.

C2.2 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.

C2.3 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 MFLNRO and MFLNRO 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 MFLNRO although the MFLNRO still provides guidance in the form of the *Flood Hazard Area Land Use Management Guidelines* (discussed in Appendix D).

C2.4 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/British Columbia Agreement Respecting Floodplain Mapping. 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 Canada/BC Agreement, both governments were restricted from further undertakings in designated floodplain areas. Canada and BC also agreed not to provide financial assistance for flood damage to any new undertaking in a designated floodplain unless it was floodproofed in accordance with provincial floodplain development policy. 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 Canada/BC agreement were not renewed and are no longer in effect.

The MFLNRO has recently worked with consultants to develop *Coastal Floodplain Mapping - Guidelines and Specifications* (KWL 2011) that provide a methodology to determine Flood Construction Levels considering storm surge, wave action and sea level rise. These guidelines are available at: www.env.gov.bc.ca/wsd/public_safety/flood/structural.html#coastal.

C2.5 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 MFLNRO 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 their own policies for zoning, development permits, subdivision approvals, bylaws, and building permits through the statutory authority described in Appendix D. 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 MFLNRO referrals and they still address *flood hazard* in their approval process.

C2.6 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 B 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 *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 floodmapping program but the basis for identification is restricted to landform interpretation, often only from air photography.

C3 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. 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 floodproofing. Erosion protection is sometimes necessary to safeguard floodproofing fill and/or building foundations during an inundation event, and should be considered an integral part of non-*structural mitigation works*.

Floodproofing requirements and development controls (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 portfolio.

The section below provides additional information for some non-structural mitigation measures.

C3.1 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 D.

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 re-development.

C3.2 *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.

C3.3 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*.

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.

C4 HISTORY OF STRUCTURAL MITIGATION

C4.1 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.

C4.2 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 co-ordinate 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 co-ordinated large-scale *construction* program for flood protection works in BC. The Fraser River Diking Board effectively ceased operations in 1950.

C4.3 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 focused 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.

C4.4 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 three 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 $300M (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* 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;
- 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.

C4.5 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 has recently worked with consultants to develop the *Seismic Design Guidelines for Dikes* (Golder Associates 2011) and the *Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use* (Ausenco Sandwell, 2011).

C4.6 Orphan Flood Protection Works (also see Section C1.2)

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*.

C4.7 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 Mitigative Works completed prior to the 2007 freshet.

In the fall of 2007, the province announced the Flood Hazard Protection Fund, which will provide $100M 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.

C4.8 *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 Aboriginal Affairs and Northern Development Canada (AANDC), 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).

AANDC can and does fund flood protection works as required on an emergency basis; for example, extensive Urgent Mitigative 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.

C5 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.

C5.1 *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 (see definition of *dike* in Appendix A).

Training berm *dikes* are typically used to confine shorter, 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 flood mitigation measures 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 both direct (against the slopes) and indirect (through undermining or outflanking).

C5.2 Floodwalls and Seawalls

In some special cases, forclosure sections, or where there is insufficient space to construct an earthen embankment between a potential *flood hazard* and 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 earth *dike*.

C5.3 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, 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, 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 further downstream.

C5.4 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, 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.

C5.5 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, a free-swinging gate hinged at 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 flood mitigation works. Care must be taken that drainage works do not create preferential seepage pathways through the structure that could lead to internal erosion.

C5.6 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 floodproofing measures, including elevation to the applicable FCL or MBE, erosion protection/foundation treatments, and the appropriate placement of key services and utilities.

C5.7 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.

C5.8 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 pre-requisite 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 MFLNRO) 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.

C5.9 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 upon 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 destabilise the channel if the banks remain erodible, and will in any case raise flood water levels.

C5.10 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* 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.

C5.11 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 measures 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.

C5.12 Limitations of Structural Mitigation

Structural mitigation measures 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 measures into public focus.

Structural mitigation measures 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 floodproofing 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*.

APPENDIX D: CURRENT FLOOD MANAGEMENT LEGISLATION AND GUIDELINES IN BC

This appendix introduces the main legislation and guidelines that govern *flood hazard* management in BC.

D1 OVERVIEW

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

- *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), and
- Community Charter (for building permits).

The *construction* and maintenance of many of the flood control 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 so 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[11] or within a watercourse may require approvals pursuant to the following environmental legislation:

- Riparian Areas Regulation under the *BC Fish Protection Act*,
- *BC Water Act*,
- *Federal Fisheries Act,*
- provincial or federal *Environmental Assessment Act*,
- federal *Navigable Waters 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*.

Integrated Land Management Branch of the MFLNRO Lands Officers may require flood assessments as a requirement for applications to lease and purchase Crown lands.

Flood management is guided at the local government level through *Official Community Plans*, 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 the local First Nations as well as Aboriginal Affairs and Northern Development Canada. Local governments

[11] 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.

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.

D2 *ENVIRONMENTAL MANAGEMENT ACT* (SECTIONS 5 AND 138)

Sections 5(f) and 138 (3) (e) of the *Environmental Management Act* provide the Minister of Forests, Lands and Natural Resource Operations 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 Ministry has published the *Flood Hazard Area Land Use Management Guidelines* (discussed in Section D8) that must be considered by local governments when adopting floodplain bylaws under Section 910 of the *Local Government Act*. These guidelines are periodically updated by MFLNRO.

D3 *LAND TITLE ACT* (SECTION 86) – SUBDIVISION APPROVALS

Section 86 of the *Land Title Act* (Section 86) 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; and/or
- one or more registered *covenants* under Section 219 of the *Land Title Act* in respect of any lots created by the subdivision.

A restrictive *covenant* is attached to the property title. The *covenant* will typically specify conditions the development must adhere to reduce *flood risk* and to indemnify the Crown and the *Approving Authority* against future flood damages.

D4 *LOCAL GOVERNMENT ACT* (SECTIONS 919.1 AND 920) – DEVELOPMENT PERMITS

The *Local Government Act* (Sections 919.1 and 920) 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.

D5 *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.

D6 Community Charter (Section 56) – 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 *QP* does not conclude the statement 'that the land may be used safely for the use intended', the building inspector may not issue the building permit.

Any conditions noted in the *QP* report necessary to render the land safe for the use intended are incorporated in a *covenant* registered under Section 219 of the *Land Title Act*. Usually, the *QP* report is registered in the *covenant* making the document publicly available.

D7 *Local Government Act* (Section 910) – Floodplain Bylaws, Variances and Exemptions

The *Local Government Act* (Section 910) 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 developed under regulation. However, the provincial document *Flood Hazard Area Land Use Management Guidelines* (discussed below) provides guidance for developing bylaws under Section 910 of the *Local Government Act*. Through Section 910 of the Act, local governments may, by bylaw, designate specific floodplain areas.

Section 910 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 use intended, 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 Section 903 of the *Local Government Act*, which governs zoning bylaws. However, it is preferable that a Section 910 bylaw be used.

D8 *FLOOD HAZARD AREA LAND USE MANAGEMENT GUIDELINES*

The Flood Hazard Area Land Use Management Guidelines (www.env.gov.bc.ca/wsd/public_safety/pdfs_word/guidelines.pdf) are published by the MFLNRO 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 910 of the *Local Government Act* and must be considered by local government in developing bylaws under that Section.

The *Flood Hazard Land Use Management Guidelines* (May 2004) 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 *Floodplain Mapping Guidelines and Specifications* (Fraser Basin Council, 2004) and *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC* (APEGBC, 2010) (see below).

As an important complement to the *Flood Hazard Area Land Use Management Guidelines*, 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 approval authority. Some approval 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.

D9 *GUIDELINES FOR LEGISLATED LANDSLIDE ASSESSMENTS FOR PROPOSED RESIDENTIAL DEVELOPMENTS IN BC*

In 2006, APEGBC produced 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, creep, and flow slides. Where *flood hazards* overlap with areas subject to one or more of the above hazards, the *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC* must be consulted in conjunction with these guidelines.

D10 *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*;
(e) construct a new *dike*.

Specialized mitigative structures 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 co-operate with the *Inspector of Dikes* are defined as offences under the *Dike Maintenance Act*.

Although *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*, application requirements include:

- conformance with the *Dike Design and Construction Guide: Best Management Practices for British Columbia*, July 2003, as amended from time to time and other published guidelines;
- design, *construction* and as-constructed drawings certified by a suitably *QP engineer*;
- works to be 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) shall not impact the safety of other *dikes*, or increase the *flood risk* to others; and
- 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.

D11 OTHER LEGISLATION RELATED TO STRUCTURAL MITIGATIVE MEASURES

The *Drainage, Ditch and Dike Act* and the *Local Government Act*, Part 23, 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 mitigative structures are constructed on or within a watercourse channel, authorization must be obtained under the provincial *Water 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*. Mitigative structures 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.

D12 KEY GUIDELINE DOCUMENTS

MFLNRO 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 mitigative measures. A *QP* should be thoroughly familiar with the following guidelines.

- *Guidelines for Management of Flood Protection Works in British Columbia* (1999);
- *Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment* (1999);
- *Flood Protection Works Inspection Guide* (2000);
- *Riprap Design and Construction Guide* (2000);
- *Dike Design and Construction Guide – Best Management Practices for British Columbia* (2003);
- *Guidance Document - Hydrologic and Hydraulic Report* (2008);
- *Guidance Document - Comprehensive Geotechnical Investigation and Design Report* (2011);
- *Seismic Design Guidelines for Dikes* (Golder, 2011);
- *Application Requirements - New Dikes and Upgrades to Existing Dikes* (2011);
- *Application Requirements - Pipe Crossing - Cut and Cover* (2009);
- *Application Requirements - Erosion Protection* (2008); and
- *Application Requirements - Exploratory Geotechnical Testing* (2009).

Other relevant guidelines include the *Flood Hazard Area Land Use Management Guidelines* (BC Ministry of Water, Land and Air Protection, now BC Ministry of Environment, 2004), the *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC* (APEGBC, 2010), the *Floodplain Mapping Guidelines and Specifications* (Fraser Basin Council, 2004), *Flood Hazard Maps* (MOE/Fraser Basin Council, 2004) and the *Coastal Floodplain Mapping - Guidelines and Specifications* (KWL, 2011). 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).

APPENDIX E: *FLOOD HAZARD* ASSESSMENTS

This appendix should be read in conjunction with Section 3 of the guidelines. It provides additional information on how to execute FHAs. FHAs provide the basis for FRAs in that they quantify the likelihood and intensity of a potentially damaging event. The *risk assessment* (Appendix F) combines the results of the hazard assessment with estimation of *consequences*.

E1 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 a 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* (Fraser Basin Council, 2004), 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* breached. For undiked rivers, 1-D 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 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* 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 and/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 *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.

E2 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 *flood hazard* 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, the 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 apt to be inundated with a return period of 10 or fewer years might be designated frequently active; while ones apt to be inundated with a return period of 10-30 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 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 C). 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.

E3 METHODS OF *FLOOD HAZARD* ANALYSIS

A typical FHA assessment 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, geology; and
- 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; and
- modelling of the *flood hazard* at the desired return period(s) to obtain:
  - water depth;
  - the velocity of surface water flow;
  - the chronology in which various parts of the study area might flood;
  - the event duration; and
  - 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 etc.)? If so, does the *QP* have the capacity to quantify those or does a specialist need to be consulted?
- Are there upstream structures existing 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, a change in the snowpack, its distribution and/or snow water equivalent and 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 and how have they changed over time and will 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 agency, or 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:

a. the flood sequence is stationary (i.e., floods in the future will have characteristics similar to those in the past); and
b. 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 in length 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 analysing 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 required requires estimation of the probably 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 analyse 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 analyse 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 mitigation structures.

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 FHA report.

E4 *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 E-1 and E-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 E-1 provides guidance on rainfall and snowmelt generated floods while Table E-2 focuses on unusual floods including debris flows that are, by definition, a landslide process. These two tables split hazard assessments into six classes, each one 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 preclude 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 E-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 rivers and floodplains, loss of life very unlikely	20-year 200-year 500-year (for *alluvial fans*)	*Building permit:* renovations, expansions, new single house, new duplex house
1	• all that was completed for Class 0, and • 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 socur and erosion rates where appropriate with maps showing erosion over time. If significant watershed changes (logging, beetle infestations, forest fires) have been detected, determine how this may affect watershed hydrology.	Possible loss of life even for single homes, scoping level studies for linear infrastructures, mines, urban developments		*Small Subdivision:* Subdivision into separate lots (3 to 10 single family)
2	• all that was completed for Class 1, and • 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, add factors to adjust for changes in runoff or model effects of climate change	Maps with 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 rivers and floodplains	20-year 200-year 500 to 1000-year (where appropriate)	*Medium Subdivision:* Subdivision into ≥ 10-100 single family lots, new subdivisions
3	• all that was completed for Class 1, and • 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 rivers and floodplains	200-year 1000-year 2500-year (where appropriate)	*Large Subdivision:* > 100 single family lots, new subdivisoins

4a	• all that was completed for Class 1, and • 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 rivers and floodplains	200-year 1000-year 2500-year (where appropriate)	*Very Large Subdivisions (new towns or townships):* >> 100 single family lots, new subdivisoins
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 rivers and floodplains	200-year 1000-year 2500-year (where appropriate)	

Note, the methods and deliverables are to supplement those listed in Section E-1.3

Table E-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 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, and • 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)
2	• all that was completed for Class 1, and • 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, consider how climate change could affect frequ/mag 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 > 10-100 single family lots, new subdivisions
3	• all that was completed for Class 1, and • 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 1000-year 2500-year where appropriate	*Large Subdivision:* > 100 single family lots, new subdivisions
4a	• all that was completed for Class 1, and • 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 1000-year 2500-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	as Class 4 assessment	200-year 1000-year 2500 year	

E5 FLOOD HAZARD MAPPING

The development, use, application and interpretation of *flood hazard maps* or floodplain mapping are professional activities which are crucial to the preparation of a quality FHA. The completion of these activities significantly and directly impacts the quality of flood assessment reporting.

Flood hazard 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:

- prevent the creation of new *risks* through planning or *construction*;
- reduce existing *risks*; and
- adapt to changing *risks*.

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

- *flood risk* management strategy (prevention and mitigation);
- land use planning and land management;
- emergency planning;
- raising public awareness; and
- flood insurance

E5.1 Floodplain and *Flood Hazard Maps* in BC

In BC, the floodplain mapping program (1987-1994) was created as a joint initiative between the federal and provincial governments with the ultimate goal to minimize flood damage in BC (*Floodplain Mapping Guidelines*, 2004). 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 floodproofing that can then be incorporated into building bylaws, subdivision approvals and local government planning and regulations.

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 *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 1987-1994 BC flood mapping system and if relevant addressed in the *QP’s* 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 authority having jurisdiction may require additional services in the development of *flood hazard maps* or a *QP* may recommend as such to their *client*. The following section provides guidance 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 are not referenced in the current provincial or local legislations. Before proceeding with the application of advanced *flood hazard* mapping as discussed below, the professional services to be provided should be agreed to by the *client* and the *QP*.

Flood hazard mapping has been conducted in a number of jurisdictions in BC (*Flood Hazard* Mapping Program, 2004). For example, the Fraser Valley *Regional District* has developed hazard maps including debris flow fans. The maps are part of an information map where different layers including hazards can be selected. These maps which are kept up-to-date are available at:
http://www.fvrd.bc.ca/Services/Mapping/Pages/RegionalInformationMapTermsofUse.aspx.

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, a database of 690 geohazard reports (status June 2011) accompanies such maps. However, the *QP* cannot solely rely on such maps because not all areas subject to flood, debris flow and debris floods have been mapped to date. As such 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 have been prepared by the Fraser Basin Council and the (former) Ministry of Water, Land and Air Protection 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* that can be accessed at
www.env.gov.bc.ca/wsd/public_safety/flood/fhm-2012/cabinet/flood_hazard_map_user_guide.pdf. 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 can be found 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.

E5.2. Proposed Flood Hazard Maps

Following the European example, *flood hazard maps* can follow at best three different probability scenarios: low (20 year), medium (100 and 200 years) and high (500, 1,000 and 2500 years) which are reflected in Tables E-1, E-2 and E-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 E-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	> 1000 km^2	10-1000 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** shown on hazard maps	• 20-year* • 100-year • 200-year • 1,000-year • 2,500-year***	• 20-year* • 100-year • 200-year • 500-year • 1,000-year	• 20-year* • 200-year • 500-year • 2,500-year***

* 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.
**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.
*** Peak flows, stages or debris volumes (debris flows) for return period 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 E-2) assessments.

Table E-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, 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: 2330 km^2), large landslide dams from the Quaternary volcano Mt. 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 herein to return periods considered in the *Canadian Dam Safety Guidelines* (2007). 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, E-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 E-4: Dam classification and suggested design return flood return periods (*Canadian Dam Safety Guidelines*, combined tables 2-1 and 6-1, 2007)

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 1000
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	Very high economic losses affecting important infrastructure or services (e.g.,	2/3 between 1,000 and

			fish or wildlife habitat Restoration or compensation in kind possible but impractical	highway, industrial facility, storage facilities for dangerous substances)	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

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 has no associated annual exceedence 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 on the last column in Table E-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 APEGBC (2010) *Guidelines for Legislated Landslide Assessments for Proposed Residential Developments in BC* provides additional guidance as to requirements to conduct 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 flood extent, the water depth, and where appropriate, the maximum flow velocities. This type of information is not provided in the floodplain maps that have previously been published by the MFLNRO.

E5.3 Proposed Basic Information

In order to be of use for planning processes and awareness campaigns an authority having jurisdiction or a *QP* may require the development of *flood hazard maps*, which include the following:

- 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;
- responsible authority or institute with address, website (and/or telephone number);
- for digital maps, include various data layers in GIS format;
- base date for the data and date of publication; and
- a disclaimer, including remarks on the quality of information can be added.

It is not expected that for small-scale developments (single, multi-family housing) a precise hazard map needs 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.

At the time of writing of these guidelines, a Geological Survey of Canada led initiative is aiming to introduce the HAZUS (HAZards United States) program to Canada. HAZUS is a geographic information system-based natural hazard loss estimation software package developed by the US Federal Emergency Management Agency. Once this is implemented, data should be provided in a format that can directly be implemented into HAZUS.

Freeboard is generally added to *flood hazard maps* and is defined by each ministry/jurisdiction. BC government *freeboard* criteria is discussed in Appendix C 3.3 and defined in Appendix A.

E5.4 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 ought to be included in a *flood hazard map*:

- Flood depth for a given recurrence interval expressed in centimetres or metres, 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 at 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 analysed 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 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 3-3) 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 (Table E-5). 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 and 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.

Table E-5: Examples of *flood hazard maps* for different countries

Country	**Ministry/Jurisdiction**	**Reference**
US	FEMA	*http://www.fema.gov/plan/prevent/fhm/rm_main.shtm*
Austria	Hochwasser Risikozonierung Austria HORA	*http://www.wassernet.at/*
Flanders, Belgium	Geoloket Overstromingskaarten	*http://geo-vlaanderen.agiv.be/geo-vlaanderen/overstromingskaarten/*
England & Wales	Environment Agency	*http://www.environment-agency.gov.uk*
Scotland	Scottish Environment Protection Agency	*http://www.multimap.com/clients/places.cgi?client=sepa*
France	Ministère de l'écologie, de l'aménagement et du développement durables	*(http://cartorisque.prim.net/index.html)*
Baden-Württemberg Germany	Hochwassergefahrenkarten in Baden-Württemberg, Ministerium für Umwelt, Naturschutz und Verkehr	*http://www.hochwasser.baden-wuerttemberg.de* *http://www.uvm.baden-wuerttemberg.de/servlet/is/1253/Leitfaden_HWGK_www.pdf*
Bavaria, Germany	Informationsdienst Überschwemmungsgefährdete Gebiete in Bayern	*http://www.iug.bayern.de*
Rheinland-Pfalz, Germany	Atlas der Überschwemmungsgebiete im Einzugsgebiet der Mosel	*http://www.gefahrenatlas-mosel.de*

Sachsen, Germany	Various maps under the subject “Wasser“ (water)	*www.umwelt.sachsen.de/de/wu/umwelt/lfug/lfug-internet/interaktive_karten_10950.html*
Ireland	National *Flood Hazard* Mapping	*http://www.floodmaps.ie/*
Italy	Tevere River Basin Authority	*(www.abtevere.it – click on “cartografia on line”)* or the other riverbasin Authority web sites
Netherlands	Dutch Ministry of Interior	*www.risicokaart.nl*
Norway	Norwegian Water Resources and Energy Directorate (NVE)	*http://webb2.nve.no*
Spain	Catalan Water Agency	*www.mediambient.gencat.net/aca/ca/planificacio/inundabilitat/delimitacio/pl_periode.jsp*
Canton Zug, Switzerland	Naturgefahren Kanton Zug	*http://www.zug.ch/forstamt/99_50.htm*

E6 REFERENCES

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APPENDIX F: *FLOOD RISK ASSESSMENT*

F1 INTRODUCTION

A FRA involves estimation of the likelihood that a flood will occur and cause some magnitude and type of damage or loss. The principal steps in the *risk assessment* are:

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 E. 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 2-2.
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 exceedence 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 one);
- 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 Equation 1 define the *flood hazard*, the last two terms define the flood *consequences*.

FRAs are an extension of 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 in 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.

These guidelines follow the steps in the Canadian Standards Association's *risk* management process from initiation to *risk* control (CAN/CSA, 1997), Figure 3-1.

F2 FLOOD CONSEQUENCES

Flood *consequences* can be expressed in different categories. Commonly used flood *consequences* are:

- 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, 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 entail:

- 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 replaced by flooding; and
- 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.

F2.1 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 that may not wish to share such information with third parties. *Flood risk* insurance does not exist in Canada for *residential developments* and applies only to businesses and industries.

Significant difficulty and uncertainty is 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.

F2.2 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)[12] 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; and
- *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[13] 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*.

F2.3 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 provide impetus or bylaws to store hazardous materials safely above a specified flood stage.

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[12] The ALARP principles are also known as ALARA, with the last letter standing for "achievable". Their use is interchangeable.

[13] 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.

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.

F2.4 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.

F2.5 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.

F3 FLOOD RISK ANALYSIS

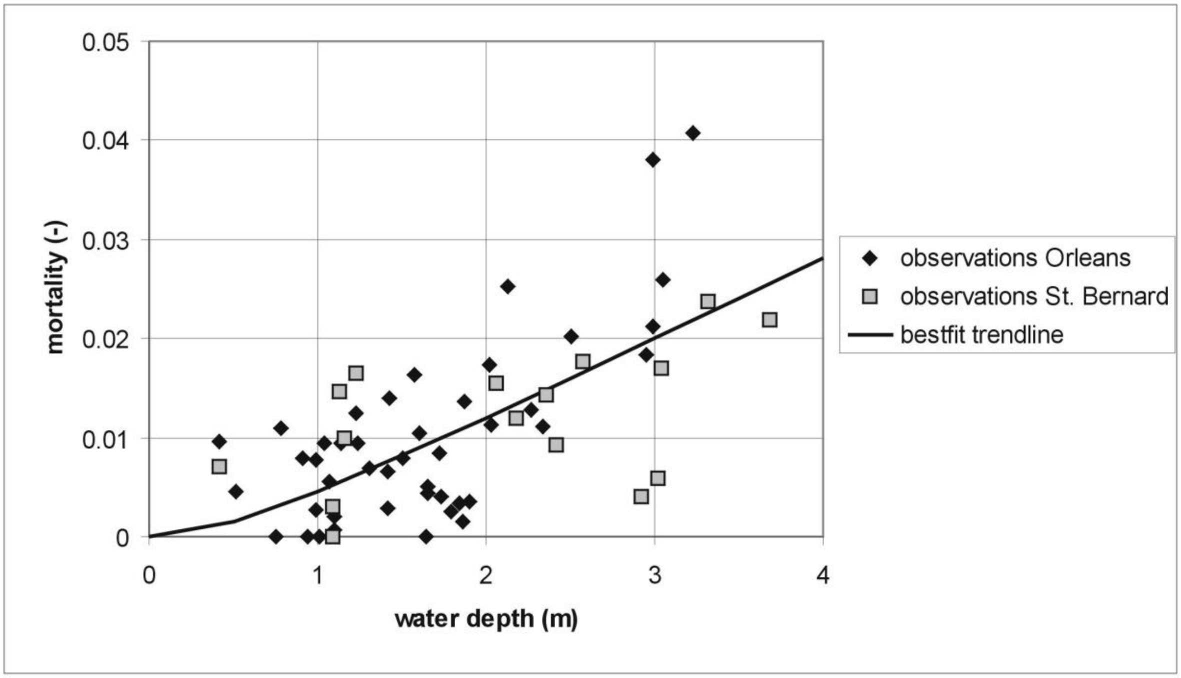
Once a decision has been made through stakeholder consultation that a formal *risk assessment* may be warranted, Table F-1 provides guidance as to the scope of a *risk analysis*. This can be done by examining the value of developments and vulnerable population exposed to *flood hazards*, based on the outcome of the FHA. In Table F-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 factor that drive most FRAs in the *risk* matrix shown in Table F-1. This table provides a screening tool to guide the level of *risk* study as per Table F-2.

Life losses can be estimated rapidly using Figure F-1 as well as rough scaling of expected losses in the development area affected by floods. It needs to be recognized that Figure F-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 forecasted 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).

Table F-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
1-2	M	M	M	H	H
0	VL	L	M	M	H

Figure F-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).



Economic losses can be determined as per methods outlined in as described in Section 2.2.1.

Table F-2 then suggests the appropriate level of study. For example, a Very High rating as determined by Table F-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 F-2 summarizes the methods, deliverables and contents for the different study levels.

Figure F-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 F-2: Types of *Flood Risk Assessments*

***Risk* Level**	**Class**	**Typical *Risk Assessment* Methods**	**Deliverables**	**Applications**	**Flood Return Periods (years)**
Very Low	0	• Includes a short site survey with qualitative assessment of potential *consequences*	• Memorandum or Letter • Sketch Maps	• Building permits	
Low	1	• provides qualitative descriptions or tabulation of potential economic losses associated with various *consequence* scenarios (see Figure F-6)	• Report • Maps	• Low loss potential 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[14]>tolerance threshold, FN[15]-graphs	• Moderate loss potential streams, rivers and floodplains	20 200 500*
High	3	• same as 2 for economic losses • inventory environmental hazards and likely environmental losses, cultural and historic values and intangibles (human suffering etc.), • assess *risk* via a semi-quantitative *risk* matrix (e.g., Figure F-5), • 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 rivers and floodplains	20 200 1000
Very High	4a	• same as 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 F-5) 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 rivers and floodplains	20 200 1000 2500
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 CBA	• Same as Class 3	

[14] PDI stands for probability of death of an individual
[15] FN graphs exemplify group *risk* with the number of potential death on the horizontal axis and the cumulative frequency of deaths plotted on the vertical axis.
* applies only to areas subject to debris floods and debris flows that may occur without warning

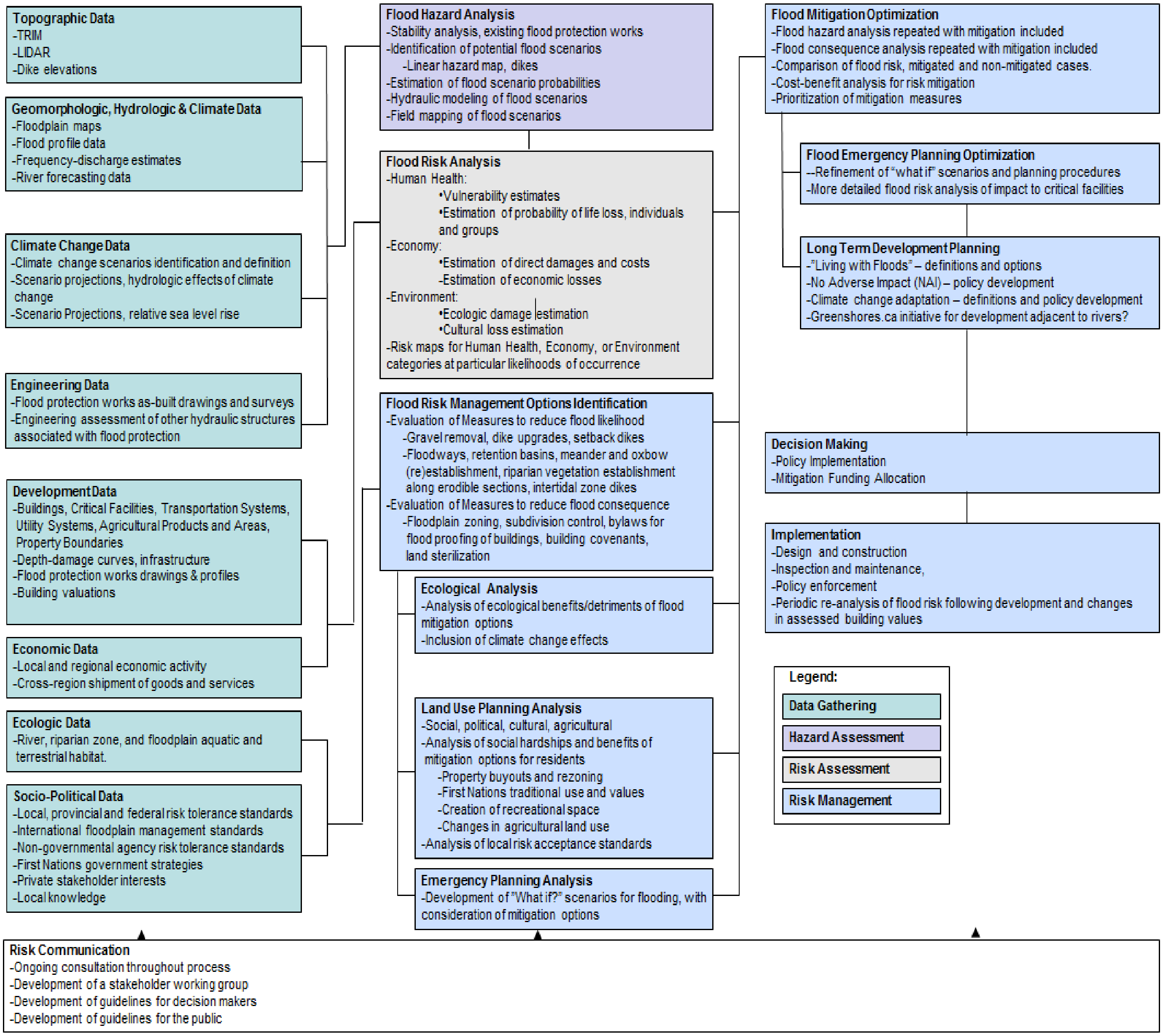


Figure F-2: *Flood hazard* and *risk analysis* embedded in the overall *flood risk* management approach. This chart applies mostly to Class 3 and 4 (High and Very High *Risk*) assessments (see Table E-5).

F4 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 *QP* when public safety issues, or the *client's* needs, require additional services which 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.

F4.1 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; and
- the location and type of facilities that may cause pollution in case of flooding as well as areas potentially affected by those pollutants.

As for the population these maps can be based on:

- the distribution of population per *municipality*, address, building, average number of people per building or block; and
- 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); and
- 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; and
- waste water 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; and
- rare wildlife habitat areas and ecological reserves.

F4.2 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.

F4.3 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 this 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.

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. More information, specific software and hardware requirements, and software download links can be found at http://drrplan.net/.

F5 *FLOOD RISK* TOLERANCE CRITERIA

F5.1 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*.

et al.,

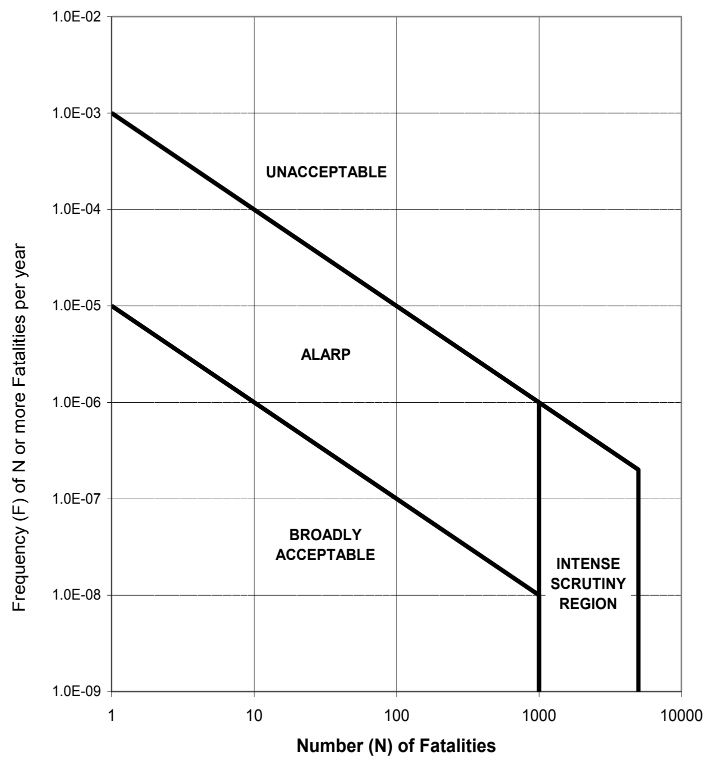


Figure F-4 allows a direct evaluation of life loss from floods. The principal error source in applying this graph to *flood risk* scenarios is the assumption of timely and orderly evacuations well before the flood inundates the developed areas. Furthermore, in some cases, particularly for sudden unpredicted 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).

F5.2 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, industries 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.

F5.3 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 agency 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 F-5 provides an example of a semi-quantitative framework, developed by BGC Engineering Ltd., 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 E-1, E-2, and E-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 agency 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.

Figure F-5: Example *risk* matrix to determine the relative level of *flood risk* for proposed developments

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 unnacceptable; medium-term risk reduction plan must be developed and implemented in a reasonable (< 5 yrs) 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	1	2	3	4	5	6
Scenario can be expected on average every other year	Very Likely	0.5 - 0.2	M	H	H	[illegible]	VH	[illegible]
Scenario typically occurs on average every 10 years	Likely	0.2 - 0.07	L	M	H	H	[illegible]	[illegible]
Scenario typically occurs on average every 50 years	Moderate	0.07 - 0.02	L	L	M	H	H	[illegible]
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 one 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 of business interruption; <$100,000	Major asset loss; several weeks business interruption; <$1,000,000	Severe asset loss; several months business interruption; <$10M	Total loss of asset; one year or more business interruption; >$10M
Social & 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	Irrepairable personal hardship
Ecological (flora & fauna)	Negligible impact	Slight impact; recoverable within days	Moderate impact, recoverable within weeks	Recoverable within months	Severe species loss	Irrepairable species loss

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APPENDIX G: FLOOD ASSESSMENT CONSIDERATIONS FOR DEVELOPMENT APPROVALS

G1 INTRODUCTION

G1.1 Overview of Appendix

A *QP* may be retained to prepare flood assessment reports pursuant to the statutes outlined in Appendix C (recognizing that these statutes will continue to evolve over time). With reference to the stages of land development, these can be 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 that may be appropriate for such land development projects, and is intended to be consistent with the provincial 2004 publication *Flood Hazard Area Land Use Management Guidelines*. Most of the numerical guidelines in this appendix are extracted from that document. It is important to recognize that legislative, local bylaw, and/or restrictive *covenants* may be applicable and take precedence over the measures outlined in this appendix, and should only be varied in consultation with the appropriate parties. Values other than those referenced in this appendix are appropriate for consideration where it has been determined (by analysing expected *flood intensities* and the corresponding *vulnerability* of the relevant structures) that their use will not result in significant damage to the relevant structure(s).

A FHA is a common component for flood assessments in each development category. In some cases, an existing FHA will suffice, but a *QP* needs to be satisfied that it is appropriate in view of climate change and land use change (see Section 3). 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 (floodplain, *alluvial fan*, fluvial terrace, bedrock, etc.). 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 further investigation by a specialist.

Flood assessment reports for proposed developments should consider the provision of flood protection in the form of *standard dikes* (Appendix A) 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.

This appendix is a key component of implementing the flow chart (Figure 3-1), and should be read in conjunction with that figure.

G1.2 Special Considerations Relating to *Dike* Standards

If development cannot practically be located outside an area subject to *flood hazard*, it is strongly preferred that it be located in areas protected by a *standard dike* (or an equivalent standard of protection for other types of *structural mitigation works*). The *standard dike* level of protection, as defined in Appendix A, 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 BC, the *Inspector of Dikes* has the function of determining 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, flood protection works that are not fully standard as per the definition (Appendix A) 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 pursuant to these Guidelines, the following minimum standard is to 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 and 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 does not unreasonably preclude the local diking authority from ensuring the overall integrity of the *dike*; and
- 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 other *structural mitigation works* other than *dikes*, to the extent that this would be applicable.

All flood assessment reports pertaining to 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 approval 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*.

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.

G2 BUILDING PERMIT

The conditions identified in this section are applicable for a building permit application that represents 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 report (in whole or in part) available to future landowners through registration of an appropriate restrictive *covenant*.

G2.1 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 by-law provisions and/or restrictive *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 not more than 25% of the floor space existing at the time of the original building *construction*, implementation of the measures outlined below is considered appropriate professional practice 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 shall not intrude into the setback zone further 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 shall 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; and
- where the building is subject to a *dike* setback, any expansion shall 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 shall 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 needs to establish such a threshold. The *QP* may then determine *flood risk* in accordance with Appendix F 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 mitigative 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).

G2.2 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 by-law provisions and/or restrictive *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.

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 are as follows:

- the building shall be set back an appropriate distance from the creek or river in view of the potential for long-term erosion;
- the building shall be elevated to an appropriate FCL;
- in addition to hydraulic considerations, the FCL shall 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 shall 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) shall be appropriately specified;
- areas used solely for vehicular parking may be located below the FCL;
- the design of the building foundation should consider hydraulic loading and scour);
- where the building is subject to a *dike* setback, any expansion shall 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*; and
- 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 an area subject to a lesser hazard, a preferable approach is to require the building to be located in such 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* of the less hazardous site is impractical, prohibitively expensive, and/or results in environmental degradation. Any erosion protection works shall 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.

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 floodproofing measures must be considered. In general, new buildings should only be considered for unprotected fans if:
- the local government has adopted an appropriate by-law 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 (for definition see Appendix A);
- 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 flood velocity greater than 1 m/s, and where safe access and egress is not possible); and/or
- 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.

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 floodproofing measures must be considered. In general, new buildings should be considered for unprotected floodplains only if:

- the local government has adopted an appropriate by-law 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); and/or
- 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.

Fan or Flood Hazard Area with Dike

Where a proposed building site is located on a fan or floodplain that is protected by a standard/adequate *dike*, the need for floodproofing 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 floodproofing measures and building restrictions. The building shall be set back an appropriate distance from any active internal drainage channels.

General

Where in the judgment of the *QP*, the proposed building would be subject to an unacceptable *flood risk*, the *QP* should not submit a report indicating that the land may be suitable for the intended use. The 2004 *Flood Hazard Area Land Use Management Guidelines* 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; and/or
- where safe access and egress is not possible.

G2.3 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 by-law 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); and/or
- 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. Variances of the standards is discouraged.

G2.4 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 by-law 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); and/or
- 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. Variances of the standards is discouraged.

Some specific considerations pertaining to industrial buildings are as follows:

- water-oriented industrial buildings may be located outside *standard dikes*;
- relaxation of the FCL may be considered, especially for heavy industrial buildings behind *standard dikes*; and
- for proposed major industrial developments, a *risk assessment* may be considered as a basis to develop site-specific mitigative measures.

Some specific considerations pertaining to commercial buildings are as follows:

- commercial buildings should generally not be located outside *standard dikes*; and
- the specification of floodproofing measures shall consider the potential for different building use in the future as per the applicable land zoning.

Some specific considerations pertaining to institutional buildings (schools, universities, hospitals, fire halls, police stations, emergency response headquarters, churches, community centres, etc.) are as follows:

- institutional buildings should not be located outside *standard dikes*;
- institutional buildings should be considered as potential places of local refuge during flood emergencies, so the FCL should not be relaxed; and
- 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 hazard mitigation may be site-specific.

G3 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 report (in whole or in part) available to future landowners through registration of an appropriate restrictive *covenant*.

Where there are local government by-law provisions and/or restrictive *covenants* 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.

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 E) 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 to 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 shall 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 shall be elevated to an appropriate FCL;
- in addition to hydraulic considerations, the FCL shall include the effects 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 shall 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) shall be appropriately specified;
- areas used solely for vehicular parking may be located below the FCL;
- the design of the building foundation should consider hydraulic loading and scour);
- where the development is subject to a *dike* setback, any expansion shall 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*; and
- 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 suitable development areas outside the hazard area, or an area subject to a lesser hazard, a preferable approach is to require buildings to be located in such 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:

- undertake a comprehensive FHA;
- consider a formal FRA in consultation with the local authority;
- implement effective land use regulations through the local authority;
- protect a subdivision in a floodplain with a *standard dike* having a design return period of at least 200 years;
- protect a subdivision on a fan with standard *structural mitigation works*;
- designate a local diking authority (typically local government) to be responsible for the works in perpetuity;
- 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;
- 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; and
- develop appropriate secondary floodproofing measures for the development area.

The *standard dike* level of protection is strongly preferred for proposed subdivisions, however as noted in section G-1.2, 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.

G3.1 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 by-law 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 G-3.3 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); and/or
- 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.

G3.2 Subdivisions on Floodplains not Protected by *Standard Dikes*

A new subdivision should only be considered for a floodplain not protected by a standard/adequate *dike* if:

- the local government has adopted an appropriate by-law 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 G-3.3 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); and/or
- 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. Bank protection works protecting more than three residential units should be subject to operation and maintenance by the local authority (with an appropriate land tenure).

G3.3 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 floodproofing measures must 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 shall 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 E), 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.

G4 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 restrictive *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 would best be implemented in order 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 in an unprotected fan or unprotected *flood hazard* areas unless an appropriate concept plan is developed to protect the development. Appropriate floodproofing measures should also be proposed to fully achieve the applicable standards for building setbacks, flood *construction* levels, and other measures.

G5 Crown Land Disposition

Sale or lease of individual existing lots shall be treated as a new building.

Sale or lease of raw land parcels shall be treated as a subdivision.

APPENDIX H: PROFESSIONAL PRACTICE IN LIGHT OF CLIMATE CHANGE AND LAND SURFACE CONDITION IMPACTS ON FLOODING

H1 INTRODUCTION

As noted in Section 3.6, 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 identifies various factors for consideration and 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.

H2 CLIMATE CHANGE SCIENCE – AN UPDATE

H.2.1 Overview

Successive reports of the Intergovernmental Panel on Climate Change 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 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 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/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 one metre 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.

H.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 (BC Government, 2007; Ausenco Sandwelll, 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, and 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 H-3.
- *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, whilst 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, such as have been 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.

H3 CONSEQUENCES OF CLIMATE AND LAND USE CHANGES

H.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, 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 waste-water 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 1-12 hours for long-term recording stations in BC.

H.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. So long as climate continues to change, however, glaciers will continue to change; the larger ones more slowly than small ones because of their longer adjustment times to reach equilibrium with the prevailing climate.

H.3.3 Changes in Land Use, Insect Infestations and Wildfires

Population in BC, in comparison with land area, is light. Whilst 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, chs. 6: *Hydrologic Processes and Watershed Response*, and 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 (1-5 year) rainfall return periods for various intensities (e.g., Cannon and Gartner, 2005).

H.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 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.

H4 ANALYTICAL ISSUES

H.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 currently available.

H.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 rather 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, amongst 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 realise 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 ENSO (for example, the stormy winters associated with La Niña phases) and the decade-length climate phases associated with the Pacific Decadal

Oscillation that may induce periods of several years to decades length when increased storminess or winter snowfall may create clusters of high flow events that do not, however, signal a secular 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.

H5 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 Fraser 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 17-34 cm and at Prince Rupert 18-75 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, dock and bridge decks may have to be addressed.

Of more immediate concern is the future prospect for storm surges and 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 ENSO 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 (BC, 2007) shows only Fraser delta and the Naikoon area (Haida Gwaii) being highly susceptible. Some parts of the Gulf Islands of 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 I: 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 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, 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 (EFD) was issued in 2007, requiring all European Union countries to produce the following for all potential *flood risk* watersheds:

- preliminary FRAs by the year 2011;
- *flood hazard* and *flood risk maps* by 2013; and
- *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 1000 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 realised 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* in four classes (30-year, 100-year, 300-year and 1000-year return periods) and *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 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, the type of economic activity of the area, the 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, 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 being 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*.

Key achievements from the recent European *flood risk* reduction initiatives include:

- 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; and
- Europe-wide and international cooperation and collaboration is promoted.

Additional information on the European *flood risk* management initiatives can be found at: http://ec.europa.eu/environment/water/flood_risk/flood_atlas/index.htm. The following table summarizes *flood risk* tolerance criteria in different countries.

Table I-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, 1:2500 to 1:1250 from river flooding, 1:250 for small polders (ring *dikes*) • Rest of country: 1:4000 from ocean flooding, same for river flooding as above.	

Country	**Jurisdiction**	***Flood Risk* Tolerance Criteria/Protection Standards**	**Comment**
US	National Flood Risk Management Program (NFRMP), operated by the Federal Emergency Management Agency (FEMA), U.S. Army Corps (USACE), Association of State Floodplain Managers (ASFPM) and the 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 the Federal Emergency Management Agency 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 flood 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 Exceedence 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		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 FRA, *Flood Hazard* and *Risk* Maps, and *Flood Risk* Management Plans for areas judged as subject to "significant" *flood risk*.	Consultation planned for Summer 2010 with regard to defining "significant *flood risk*".

APPENDIX J: *FLOOD HAZARD* AND *RISK* ASSURANCE STATEMENT

Note: This Statement is to be read and completed in conjunction with the "*APEGBC Professional Practice Guidelines - Legislated Flood Assessments in a Changing Climate*, March 2012 ("*APEGBC* Guidelines"*)* and is to be provided for *flood assessments* for the purposes of the *Land Title Act*, Community Charter or the *Local Government Act*. Italicized words are defined in the *APEGBC* Guidelines.

To: The *Approving Authority* Date: ________________________________

____

____

Jurisdiction and address

With reference to (check one):

- □ Land Title Act (Section 86) – Subdivision Approval
- □ Local Government Act (Sections 919.1 and 920) – Development Permit
- □ Community Charter (Section 56) – Building Permit
- □ Local Government Act (Section 910) – Flood Plain Bylaw Variance
- □ Local Government Act (Section 910) – Flood Plain Bylaw Exemption

For 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.*

I have signed, sealed and dated, and thereby certified, the attached flood assessment report on the Property in accordance with the APEGBC Guidelines. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items

___1. Collected and reviewed appropriate background information
___2. Reviewed the proposed *residential development* on the Property
___3. Conducted field work on and, if required, beyond the Property
___4. Reported on the results of the field work on and, if required, beyond the Property
___5. Considered any changed conditions on and, if required, beyond the Property
6. For a *flood hazard* analysis or *flood risk* analysis I have:
___6.1 reviewed and characterized, if appropriate, floods that may affect the Property
___6.2 estimated the *flood hazard* or *flood risk* on the property
___6.3 included (if appropriate) the effects of climate change and land use change
___6.4 identified existing and anticipated future *elements at risk* on and, if required, beyond the Property
___6.5 estimated the potential *consequences* to those *elements at risk*
7. Where the *Approving Authority* has adopted a specific level of *flood hazard* or *flood risk* tolerance or return period that is different from the standard 200-year return period design criteria[1], I have
___7.1 compared the level of *flood hazard* or *flood risk* tolerance adopted by the *Approving Authority* with the findings of my investigation
___7.2 made a finding on the level of *flood hazard* or *flood risk* tolerance on the Property based on the comparison
___7.3 made recommendations to reduce the *flood hazard* or *flood risk* on the Property

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[1] *Flood Hazard Area Land Use Management Guidelines* published by the BC Ministry of Forests, Lands , and Natural Resource Operations and the 2009 publication *Subdivision Preliminary Layout Review – Natural Hazard Risk* published by the Ministry of Transportation and Public Infrastructure. It should be noted that the 200-year return period is a standard used typically for rivers and purely fluvial processes. For small creeks subject to debris floods and debris flows return periods are commonly applied that exceed 200 years. For life-threatening events including debris flows, the Ministry of Transportation and Public Infrastructure stipulates in their 2009 publication *Subdivision Preliminary Layout Review – Natural Hazard Risk* that a 10,000-year return period needs to be considered.

8. Where the *Approving Authority* has **not** adopted a level of *flood risk* or *flood hazard* tolerance I have:

___8.1 described the method of *flood hazard* analysis or *flood risk analysis* used

___8.2 referred to an appropriate and identified provincial or national guideline for level of *flood hazard* or *flood risk*

___8.3 compared this guideline with the findings of my investigation

___8.4 made a finding on the level of *flood hazard* of *flood risk* tolerance on the Property based on the comparison

___8.5 made recommendations to reduce *flood risks*

___9. Reported on the requirements for future inspections of the Property and recommended who should conduct those inspections.

Based on my comparison between

Check one

☐ the findings from the investigation and the adopted level of *flood hazard* or *flood risk* tolerance (item 7.2 above)

☐ the appropriate and identified provincial or national guideline for level of *flood hazard* or *flood risk* tolerance (item 8.4 above)

I hereby give my assurance that, based on the conditions contained in the attached flood assessment report,

Check one

☐ for subdivision approval, 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 development permit, as required by the *Local Government Act* (Sections 919.1 and 920), my report will "assist the local government in determining what conditions or requirements under [Section 920] subsection (7.1) it will impose in the permit".

☐ for a building permit, 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* associated with the *Local Government Act* (Section 910), "the development may occur safely".

☐ for flood plain bylaw exemption, as required by the *Local Government Act* (Section 910), "the land may be used safely for the use intended".

______________________________ ______________________________
Name (print) Date

____
Signature

____
Address

____

______________________________ (Affix Professional seal here)
Telephone

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. (Print name of firm)

APPENDIX K: CASE STUDIES

The following hypothetical examples further illustrates the application of the Guidelines.

The examples listed below emphasize 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 is subject to approval by the *Approving Officer*. The examples below are meant to span the entire spectrum of single building permit on an existing lot to a large-scale subdivision.

Example 1: Floodplain Bylaw Relaxation Request

<u>Background:</u>
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-hectare 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 *QP* must accompany the application before the Board will consider the application. The applicant has a site specified which is on the inside of a mild bend in the river which meets all the other requirements for septic field location, setback from property lines, etc. 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 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.

<u>Guideline Application:</u>
The *QP* consults Figure 3-1 and conducts the following steps:

- The *QP* meets with the *client* informs him/her 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 under Background 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 *QP* 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 ought to be identified on the 5-acre 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, this would likely be cost 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 approval officer receives an application for approval to subdivide a 25-hectare parcel of land into 5 five-hectare 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 MFLNRO *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 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 proposed for subdivision. The berm is classified by MFLNRO 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 is no access roads or trails to the structure. Prior to 2003, when MFLNRO was involved in the land use regulation in flood prone areas, the Ministry refused subdivisions in this area. MFLNRO 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 3-1 and conducts the following steps:

- The *QP* informs the *client* about the Guidelines and their application to the requested subdivision as per Figure 3-1.
- 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 E-1 and determines that the site can be classified a small subdivision which prompts a Level 1 study.
- Following these guidelines in Section 3 and Appendices E and H, 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 will be 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 E-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. 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 of Appendix G 3-1 and, in consultation with the approving agency and the *client* prepares a formal *risk assessment* following procedures outlined in Appendix F.
- Table F-1 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 be 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 re-channelization.
- The *QP* submits the flood assessment report in which he specifies that the development may be safe for the use intended **if** comprehensive mitigation be implemented to upgrade the existing non-*standard dike* to a *standard dike* that could withhold a 500-year return period flood and buildings be 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 *QP* 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 which is protected by a *dike*. Scientific studies conducted at a 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 Officers* request a flood assessment report from a *QP*.

Application of Guidelines
The *QP* consults Figure 3-1 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* 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 FRA is agreed upon.
- The *QP* applies Table F-1 and finds that potential life loss in case of a *dike* breach or *dike* overtopping could result in up to five statistical deaths and an annualized building loss for the 200-year return period flood of $1,000 to $10,000. This results in a High level of assessment corresponding to a Class 3 study as per Table F-2.
- 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 one and five, depending on the chosen *flood hazard scenario*. The data are plotted on an F-N curves and the *risk* plots 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 in a *risk* matrix similar to the one shown in Figure F-5 and a high *flood risk* is determined.
- The *QP* prepares a flood 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 proposed several alternatives. One is moving of the subdivision further 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 being conducted, and a multicriteria analysis addresses ecological, social, and intangible effects.
- In the end, an agreement is reached between 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 L: CONTRIBUTORS

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