Investigations in Support of Flood Strategy Development in BC

ISSUE B-5: STRUCTURAL FLOOD MANAGEMENT APPROACHES

Final Report

Prepared by:
Northwest Hydraulic Consultants Ltd. (NHC)

Neil Peters, P. Eng.
Senior Flood Management Engineer
npeters@nhcweb.com

Prepared for:
Fraser Basin Council

Steve Litke,
Director, Water Programs
slitke@fraserbasin.bc.ca

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FINAL REPORT

Prepared for:

Fraser Basin Council
Vancouver, British Columbia

Prepared by:

Northwest Hydraulic Consultants Ltd.
North Vancouver, British Columbia

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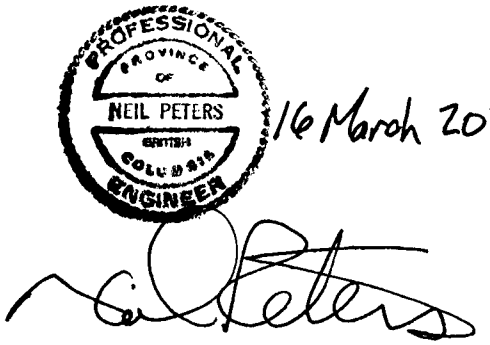

16 March 2021

Neil Peters, M.A.Sc., P.Eng.
Senior Flood Management Engineer

Report Reviewed by:

Monica Mannerström, M.Eng. P.Eng.
Principal

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The following NHC staff participated in the project, under the roles indicated in parenthesis:

- Kylie Knox (Jr. Hydrotechnical Engineer - Data analysis and Innovative Measures)
- Neil Peters (Senior Flood Management Specialist)
- Monica Mannerström (Project Manager and Senior Reviewer).

EXECUTIVE SUMMARY

The **Investigations in Support of Flood Strategy Development in British Columbia** project is a province-wide initiative aimed at developing a comprehensive understanding of current challenges and opportunities relating to flood management across BC. This report summarizes the Fraser Basin Council project "Investigations in Support of Flood Strategy Development in BC" as related to the B-5 issue: "Structural Flood Management Approaches". The purpose of this report is to investigate and recommend ways to better support diking authorities to improve the maintenance, management and future planning/upgrading of structural flood protection works, and to explore opportunities for other structural approaches to flood management.

The Fraser Basin Council identified four investigations to address this issue:

- **B-5.1** Investigate opportunities to incentivize or require diking authorities to maintain flood protection infrastructure and plan for future conditions such as changing flood hazards.
- **B-5.2** Investigate opportunities to improve the knowledge and capacity of local diking authorities regarding dike maintenance.
- **B-5.3** Investigate opportunities to improve coordination amongst diking authorities under non-emergency conditions.
- **B-5.4.** Investigate impediments to and opportunities for implementing innovative structural flood risk reduction measures, including the role of incentives and regulation.

Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) staff and the provincial dike database provided much of the information regarding dikes and diking authorities in BC. Many of the various potential incentives, requirements, and opportunities evaluated in this study were suggested by both FBC and MFLNRORD at the outset of the project. Diking authority feedback on these suggestions was provided through on-line engagement surveys.

Background

BC relies heavily on dikes as the primary structural flood protection approach. The 216 regulated dikes in BC, with a total length of about 1,100 km, are owned and maintained by 106 diking authorities. The dikes protect approximately 160,000 hectares of land, a few hundred thousand buildings (homes, businesses, industry, schools, hospitals etc.), transportation facilities and other critical infrastructure. These diking authorities and their dikes are regulated by the Provincial Inspector of Dikes (IOD) under the *Dike Maintenance Act* (DMA).

Slightly more than half of the diking authorities in BC are municipalities. The remaining are comprised of regional districts (10%), improvement districts (11%), *Drainage Ditch and Dike Act* districts (4%), government agencies (3%), First Nations (3%) and other (16%). While several First Nations own and maintain dikes and other flood protection structures, only a few of these dikes come under provincial jurisdiction through the DMA.

BC's diking authorities face significant challenges in maintaining and future planning/upgrading of their diking systems. Concerns, deficiencies and challenges previously identified include failure to submit required inspection reports, lack of up-to-date dike operation and maintenance manuals, inadequate legal access (statutory rights of way), insufficient vegetation management and other routine maintenance, and lack of funds for future planning and dike upgrading.

The key to developing effective incentives and requirements is to understand the wide variation in capacity, resources/tax base, technical expertise, and administrative authority of diking authorities. Depending on the type, size and capability, each diking authority may respond differently to a given incentive, disincentive, or requirement. This study looked at the pros and cons of each option and identified those incentives, requirements and opportunities that would be the most broadly effective. Preliminary cost estimates for implementation of several of these recommendations are provided.[1]

Recommendations

The responsibility for implementation of many of the study recommendations lies with the MFLNRORD Dike Safety Program, which has the leadership and regulatory role with respect to structural flood protection. Other provincial ministries and agencies, such as Emergency Management BC (EMBC) also have a key role, particularly in the administration of current funding programs.

Recommended Incentives and Requirements

- **Publicize dike inspection reporting compliance information and utilize enforcement powers of the *Dike Maintenance Act* (DMA).** This would provide an incentive for diking authorities to complete inspections, provide detailed inspection reports and should help to improve dike maintenance.
- **Make designing dikes for climate change a condition of DMA approvals for major upgrades.** To support this, the IOD will need to provide a guideline document and specific design standards.
- **Link provincial funding for structural works to land use planning and regulation.** This incentive should help to integrate structural works with non-structural measures but would be dependent on the province developing new standards for flood hazard land use regulation and supporting Integrated Flood Management Plans (IFMPs).

Recommendations to Improve Knowledge and Capacity

- **Increase the number of dike safety audits**. Complete dike safety audits of all diking authorities having "High" and/or "Major Consequence Dikes" (71 dikes) at least every 5 years and the remainder once every 10 years (approximately double the current effort). Audits can help to build the knowledge of both Deputy Inspectors of Dikes (DIODs) and diking authority

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

representatives, to share information, to build stronger relationships and to jointly develop specific dike safety action plans.

- **Develop an on-line introductory dike maintenance training course.** This would provide new diking authority maintenance staff with immediate access to basic training.
- **Provide increased dike inspection and maintenance training opportunities.** Options include increased dike safety workshop frequency, duration, mandatory attendance, and a certification requirement.

Recommendations to Improve Coordination and Collaboration

- **The Province should provide funds to match the federal Disaster Mitigation and Adaptation Fund (DMAF) program.** Where regional projects meet federal eligibility requirements, the province should lead, coordinate, and cost-share "bundled" applications.
- **The Province should implement an Integrated Flood Management Plan program (IFMP).** The new program should encourage and support coordination and collaboration on structural mitigation as well as non-structural measures for communities that share both dikes and floodplains.

Recommendations to Encourage Innovative Structural Measures

- **Funding programs should consider land acquisition as an eligible cost for setback dike projects.** The many benefits of setback diking include more reliable flood protection, enhanced riparian and fish habitat, and valuable community recreation (greenway) space. The greatest impediment to broader application of this approach is the cost of land adjacent to the river channel.
- **The MFLNRORD Dike Safety Program should develop design guidelines and standards for various innovative approaches**. These approaches include compartmentalization/preferential flooding, super dikes, floodwalls, habitat friendly alternatives to riprap erosion protection, and alternative approaches to standard sea dikes.
- **MFLNRORD should sponsor field scale pilot projects of smart dikes and bio-grouting.** In partnership with academia and local diking authorities, pilot projects would demonstrate the potential benefits and feasibility of these new techniques.

Discussion

The B-5 investigations and recommendations are focused on encouraging diking authorities to carry out their responsibilities within the current legislative, program, and funding (i.e. governance) framework. Although implementing the B-5 recommendations, as summarized above, will help to address dike operation and maintenance issues, and encourage wider adoption of innovative approaches, there is a much larger and critical dike safety issue to tackle.

The major structural flood protection issue in BC is that most of the dikes in the province do not fully meet provincial standards and many dikes are likely to breach during floods well below the design event even without consideration of climate change effects. Investigation of the necessary governance arrangements and outlining of programs and resources to upgrade the dikes to meet provincial standards within a defined time frame is required.

There is a need to align dike upgrade project funding with the actual costs to meet provincial dike standards as set by MFLNRORD. Further evaluation of the capacity of smaller diking authorities is also required. Some of these entities do not have the financial, administrative, and technical capacity, or jurisdictional authority to effectively manage the dikes that they are currently responsible for. Alternative governance models should be considered.

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ABOUT THIS INITIATIVE

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

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

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

Investigations were undertaken across 11 interrelated issues under 4 themes:

Project Investigations

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

Theme B – Flood Hazard and Risk Management		
B-1	**Impacts of Climate Change**	Investigate the state of climate change information and new and existing tools that can support authorities in integrating climate change impacts in flood management.
B-2	**Flood Hazard Information**	Examine the state of flood mapping and dike deficiency information and recommend ways to fill current gaps in flood mapping and manage and maintain information about flood hazards and dike deficiencies.
B-3	**Flood Risk Assessment**	Explore approaches to completing flood risk assessments at various scales, methods for prioritizing risk reduction actions, and standards- versus risk-based approach to flood management.
B-4	**Flood Planning**	Examine the ability of local authorities to undertake integrated flood management planning and opportunities to improve capacity.
B-5	**Structural Flood Management Approaches**	Assess the potential for improvements to dike management, improve the capacity of diking authorities, and implement innovative structural flood risk reduction measures.
B-6	**Non-Structural Flood Management Approaches**	Investigate current and alternative approaches to managing development in floodplains and opportunities for implementing non-structural flood risk reduction actions.

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

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

1 INTRODUCTION

1.1 Project Description

In British Columbia, most riverine and coastal flood protection infrastructure is regulated under the provincial *Dike Maintenance Act* (DMA). These works consist primarily of dikes that are owned and maintained by local diking authorities, with the provincial and federal governments providing a degree of technical and funding support. Because some of the most densely developed floodplain lands in BC are protected by dikes, the role of diking authorities is critical. Detailed inspections, thorough maintenance, and work to complete upgrade projects in the face of changing flood hazards is essential for public safety and for reducing flood risks.

The overall objective of this project is to investigate and recommend ways to better support diking authorities to improve the maintenance, management and future planning/upgrading of structural flood protection works, and to explore opportunities for other structural approaches to flood management.

The Fraser Basin Council has identified four investigations to address this issue:

- **B-5.1** Investigate opportunities to incentivize or require diking authorities to maintain flood protection infrastructure and plan for future conditions such as changing flood hazards.
- **B-5.2** Investigate opportunities to improve the knowledge and capacity of local diking authorities regarding dike maintenance.
- **B-5.3** Investigate opportunities to improve coordination amongst diking authorities under non-emergency conditions.
- **B-5.4.** Investigate impediments to and opportunities for implementing innovative structural flood risk reduction measures, including the role of incentives and regulation.

The scope of these investigations includes the diking authorities that maintain dikes and appurtenant structures considered by the Inspector of Dikes (IOD) to be regulated under the DMA. The report also considers various other opportunities to expand structural approaches beyond conventional diking. Issues related to “orphan” dikes and structures are not addressed in this project and are being investigated by the Fraser Basin Council in a separate study (KWL 2020a). Also, the scope of this project does not include dam/reservoir storage and diversions for flood risk reduction, nor does it consider storm drainage works within urbanized areas.

Except for investigating opportunities to incentivize diking authorities and communities to plan upgrades for future conditions and to implement innovative approaches, the concerns addressed by this report are primarily related to diking authorities and their capacity to adequately operate and maintain the existing dikes. However, most of the dikes in the province do not fully meet provincial standards, and many dikes are likely to breach during floods well below the design event, even without consideration of climate change effects (NHC 2015) and (NHC 2020 Investigation B-2.3). Investigation of the necessary governance arrangements and outlining of the new programs and resources to upgrade the dikes to meet provincial standards within a defined time frame is beyond the scope of this report.

To restate, the current B-5 investigations are focused on supporting diking authorities to carry out their responsibilities within the current legislative, program, and funding (i.e. governance) framework. Although this report includes some discussion of the limitations of the current framework, it is assumed that promising arrangements and programs for maintaining and upgrading the dikes, and integrating structural protection with other mitigative measures, will be covered by others as part of Theme A "Governance". Implementing the recommendations developed in this B-5 report will likely improve the existing governance and funding framework but will not address the larger issue that most dikes fall short of meeting current provincial standards.

To support the B-5 investigations, the FBC initiated a series of on-line engagement surveys targeted at different groups, including local governments (municipalities and regional districts) and Indigenous communities. A separate "Survey on Dike Management in BC" was sent out to all diking authority contacts and to the MFLNRORD staff involved in the provincial Dike Safety Program. The results, briefly discussed in **APPENDIX E**, helped to inform the identification of options and recommendations in this report.

1.2 Report Outline

An understanding of the structural flood mitigation approaches used in BC and how these structural works are managed is needed prior to identifying opportunities for improvement. Section 2 provides this background on dikes and diking authorities and lists the deficiencies and concerns in current dike management. To provide broader context, a brief discussion of dike management in other jurisdictions is also included.

Investigations B-5.1, B-5.2, and B-5.3 are described in Sections 3, 4, and 5, respectively. The pros and cons of various options are described. Sections 3 and 4 also provide estimated resources and costs to implement the most promising opportunities and options.

To identify opportunities for expanding structural approaches beyond conventional diking, Section 6 looks at where innovative approaches have already been applied in BC, such as set-back dikes, and where innovative approaches have been developed and applied in other jurisdictions (e.g. super-dikes in Japan, smart dikes in the Netherlands, storm surge barriers and various coastal protection options in several other countries). Brief descriptions of each approach, the benefits and challenges, and the potential for application in BC are presented in **APPENDIX B**.

Conclusions and key recommendations are summarized in Section 7. The on-line engagement survey questions and a brief discussion of the results are included in **APPENDIX E**.

2 BACKGROUND

2.1 Types of Structural Flood Mitigation Approaches in BC

For riverine flood mitigation, BC relies primarily on dikes as the primary structural approach. The reliance on dikes is directly related to the terrain (steep sided valley floodplains) and the hydrological characteristics (high runoff rates and flows) prevalent in the province. Other provinces such as Alberta and Manitoba have been successful in constructing flood storage dams and major river diversions/floodways for flood mitigation, given the greater availability of land and lower flows. For example, the 1:500 design flow for the Fraser River at Mission is approximately four times the 1:500 flow of the Bow River below Elbow River at Calgary (regulated by dams, in part for flood protection) and five times the 1:700 design flow for the Red River floodway at Winnipeg.

BC does have many dams and a few watershed diversions constructed for electrical power generation. Depending on operating procedures, these facilities may incidentally provide a measure of flood mitigation for downstream communities. However, storage dams and diversions proposed primarily for flood mitigation have generally not been cost-effective in this province - with a few exceptions such as the Okanagan Lake dam and floodway. As another example, the Columbia River Treaty dams provide some flood mitigation in BC, but very significant flood control benefits in the USA as well as power generation benefits.

In respect to coastal flood protection, there are only a few true “sea dikes” with significant wave exposure in BC, most of these being on the west side of the Fraser Delta and Boundary/Mud Bay. However, with sea level rise, several BC coastal communities will need to consider the need for new structural works to protect against coastal flooding, as well as considering other options such as floodproofing and managed retreat.

2.2 Dikes and Diking Authorities in BC

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

The nature of diking authorities has changed over time. In the late 1800’s and early 1900’s “dyking districts”, enabled by provincial legislation such as the *Drainage, Ditch and Dyke Act* (DDDA), were formed to raise taxes from the benefiting area, construct dikes and manage the infrastructure. The first improvement districts were created in the 1920’s – to provide basic local services (including diking and drainage) for areas outside municipalities. As municipal boundaries expanded, regional districts formed (1960’s) and diking programs were implemented, many of the earlier diking districts and improvement districts amalgamated or were taken over by regional districts or municipalities.

Today there are slightly more than one hundred diking authorities that own, operate, and maintain 216 regulated dikes, with a total length of about 1,100 km. These dikes protect approximately 160,000

hectares of land, a few hundred thousand buildings (homes, businesses, industry, schools, hospitals etc.), transportation facilities and other critical infrastructure (MFLNRO Dike Management web page). MFLNRORD's Dike Safety Program, led by the Inspector of Dikes (IOD) provides diking authority oversight, establishes flood protection standards, approves new dikes and changes to dikes, and provides technical support for major multi-jurisdictional flood issues (e.g. Fraser River design flood levels).

The key to developing effective incentives and requirements for diking authorities is to understand the wide variation in "capacity", including financial resources/tax base, technical expertise, and administrative authority. These diking authority characteristics are explored in detail as part of Investigation B-5.1 below.

Several First Nations own, operate, and maintain dikes and other flood protection structures. However, only a few of these dikes are located on treaty lands or on non-federal lands and come under provincial jurisdiction through the *Dike Maintenance Act* (DMA).

The capacity of diking authorities to both maintain existing works and to plan for and implement upgrades is closely related to available financial resources. Historically, a diking authority's primary responsibility was dike maintenance, and this is reflected in the content of the DMA and the types of diking authorities that were established. Until the early 1990's, provincial, or joint provincial/federal government programs set diking standards, provided design criteria, established project priorities and typically funded 100% of capital works upgrades. Diking authorities were expected to provide the land and/or rights of way and agree to maintain the works.

Today, diking authorities are not only expected to maintain and manage their dikes, but also to take the lead in planning for and raising the capital funds for structural mitigation upgrades.[2] Current senior government funding sources to assist with structural mitigation projects are comprised of two main programs, one provincial and one federal.[3] These are:

- The provincial Community Emergency Preparedness Fund (CEPF) – Structural Flood Mitigation Stream, administered by the Union of BC Municipalities (UBCM). Starting in 2017, this program provides grants of up to $750,000 to eligible applicants for projects to be completed within two years (UBCM 2020). In February 2020, the province announced that 18 communities received a share of more than $12 million to support structural mitigation

[2] These increased expectations arise primarily from the way the funding programs have been set up by the provincial and federal governments. However, the province has enacted additional legislation, that enables, but does not require municipalities and regional districts to establish dike management bylaws i.e. *Community Charter* S.69(c), *Local Government Act* S.312(2),and 314(2). The *Environmental Management Act* S. 5(f)(i) also provides the provincial government with broad, but as yet unused powers to prepare plans and measures with respect to "…flood control, flood hazard management and development of land that is subject to flooding".

[3] While CEPF and DMAF are focused on structural flood protection, local governments may be able to access other sources of funding such as the Federal "Rural and Northern Communities Fund". More information is available on the BC Government Disaster Mitigation Funding web page: https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/emergency-management-bc/bc-disaster-mitigation/flood-mitigation-funding-programs .

projects. Only local government diking authorities are eligible to apply (local governments comprise 63% of BC's diking authorities).

- The federal Disaster Mitigation and Adaptation Fund (DMAF). This program typically funds a 40% share for large structural mitigation projects, with a minimum project cost of $20 million (Infrastructure Canada 2020). A broad range of organizations can be eligible recipients, however, the requirement to provide a 60% local share for such large projects is a major barrier for many diking authorities. In 2019, five DMAF projects were approved for BC with a total federal contribution of $178 million.

Some dikes are more significant than others. MFLNRORD recently completed the "BC Dike Consequence Classification Study" (NHC, 2019) to better understand the consequences of dike failure for the population and assets at risk in the protected areas behind the dikes. The study classified 35 dikes as high consequence, 36 dikes as major consequence, 90 dikes as moderate consequence, 43 dikes as minor consequence, and 8 dikes as insignificant consequence. The 35 dikes classified as high consequence protect 75% of the total area protected by all dikes analyzed, 95% of the total protected population, and 94% of the total protected building value.

The classifications were based on the population, buildings, critical infrastructure, agriculture, environment, and cultural sites within the protected floodplain areas. Examples of dikes within the various classifications include:

High: Chilliwack East Dike Rosedale to Young Rd Dike No. 19, and Pemberton Miller-Lillooet Dike No. 232

Major: Pitt Meadows North Alouette Right Bank Dike No. 328, and Crescent Beach Sea Dike No. 294

Moderate: Barnston Island Dike No. 5, and Grand Forks Kettle River Dike No. 73

Minor: Chilliwack River Wilson Road Dike No. 155, and Zeballos Privateer Estates Dike No. 318

Insignificant: Kootenay R. Duck Lake Unit 2 Dike No. 39, and Ocean Point Near Newman Ck Dike No. 67

2.3 Dike Management in Other Jurisdictions

Many of the current issues in BC with respect to dike safety are broadly related to "governance" i.e. the organizational framework with respect to dike ownership and funding. Therefore, it is useful to look briefly at how other jurisdictions share structural flood protection responsibilities. **Table 2** provides a summary of this framework for a few other jurisdictions including the provinces of Alberta, Manitoba, and Nova Scotia, as well as the USA and the Netherlands.

With respect to ownership and funding responsibilities for the maintenance of structural works, the type and "level" of government organization varies between jurisdictions. In Manitoba and Nova Scotia, the major dikes and other flood protection infrastructure are owned and operated by the provincial governments. In Manitoba for example, major flood protection infrastructure includes the Assiniboine River dikes (150 km of diking), the Portage Diversion, the Red River Floodway, and other works. Only a few Manitoba communities own and maintain their own dikes.

Internationally, one of most successful diking authority arrangements is the long-time operation of Regional Water Authorities ("Water Boards") in the Netherlands. These institutions are locally based but

have significant administrative, technical, and financial resources and are well integrated with both provincial and municipal authorities (Slomp 2012). They have their own administration, governing body, and financial structure. As such, the budget for water management (including dike maintenance) is not balanced against that of health care, education, defense spending etc. (Lokman 2017).

In respect to capital works funding, with BC as a notable exception, the national and state/provincial level governments in the other jurisdictions reviewed provide the capital funding for major upgrading projects (see **Table 1**).

Table 1. Examples of Dike Ownership and Funding in BC and Other Jurisdictions

Jurisdiction	Dike/Levee Description	Ownership	Operation and Maintenance Funding	Capital Works Funding	Comments/References /Links
BC	Approx. 1,100 km of dikes (incl. 100 km of sea dikes)	106 Local "Diking Authorities"	Primarily local tax base.	Local diking authority cost share with senior governments (federal DMAF and provincial CEPF)	The capacity of diking authorities to cost share is highly variable. Historically, capital works for major projects were 100% funded by senior governments with local governments responsible for land acquisition and maintenance (e.g. Fraser River Flood Control Program). While CEPF provides $750,000 grants, this amount is insufficient for significant dike upgrading, and diking authorities usually contribute whatever funds they have.
Alberta	Southwest High River Dike (setback from river)	Town of High River	Not known	$21M grant provided by Gov. of Alberta (100%)	Compared to BC, there are relatively few existing dikes in Alberta. However, there are a number of "flood berms" and "barriers". High River project info: https://majorprojects.alberta.ca/details/Southwest-High-River-Dike/3534
Alberta	Proposed Springbank Off-stream Reservoir	Province of Alberta and City of Calgary	Not known (expected to be provincial)	Proposed $432M project to be funded by federal and provincial governments (Federal DMAF committed $168.5M)	This project is a major component of the Bow River Basin Flood Mitigation Strategy https://www.alberta.ca/about-springbank-off-stream-reservoir.aspx
Manitoba	Assiniboine River Dikes (150 km long)	Province of Manitoba	Provincial Funds	Provincial Federal Cost Share	Major flood protection infrastructure is owned and operated by the provincial government e.g. Red River Floodway, Portage Diversion etc. http://www.manitoba.ca/mit/wms/floodcontrol/index.html

Jurisdiction	Dike/Levee Description	Ownership	Operation and Maintenance Funding	Capital Works Funding	Comments/References /Links
Nova Scotia	Bay of Fundy Dikes (240 km long)	Province of Nova Scotia	Provincial Funds plus local taxation of benefitting areas.	Provincial Federal Cost Share	Recent project announced to spend $114M to upgrade 64 km of dikes. https://www.thechronicleherald.ca/news/local/province-ottawa-spending-114m-to-reinforce-bay-of-fundy-dykes-against-rising-seas-302999/ New "Flood Risk Infrastructure Investment Program" also being implemented to cost share small projects with communities. https://novascotia.ca/dma/funding/infrastructure/flood-risk-infrastructure-investment-program.asp
USA	15,000 miles of levees in US Army Corps of Engineers (USACE) Levee Safety Program	USACE owns approx. 15%, "local sponsors" own 85%	Local Sponsors responsible for operation and maintenance	Federal Government (USACE and FEMA)	Local sponsors include state governments, municipalities, counties, and levee districts. Levee safety varies: many safety issues with USA levees to be addressed by National Levee Safety Program. Integrated with national flood insurance program managed by FEMA. https://www.usace.army.mil/National-Levee-Safety/
Netherlands	3500 km of primary flood defences	25 Regional Water Authorities ("Water Boards")	Regional Water Authorities	National Government	The specialized responsibilities of Regional Water Authorities are integrated with those of the respective provincial and municipal governments. (Slomp 2012)

2.4 Deficiencies and Concerns

Investigation B-2.3 (NHC 2020) looked at the current state of knowledge with respect to dike deficiencies. From the B-2: Flood Hazard Information Report and other sources, the following concerns have been identified with respect to the capacity and functioning of diking authorities:

- A significant number of diking authorities (20% to 40% in recent years) have not submitted the required annual inspection reports to the Inspector of Dikes (IOD), and many of the reports submitted (20% to over 50% in recent years) have not been satisfactory.
- Diking authority personnel may not have the necessary equipment, time, training, or technical skills to manage a diking system.
- Diking authority personnel appear to have a high rate of turnover and there may be insufficient time for these individuals to build local knowledge of the flood hazards and diking system management.
- Diking authorities may not have a clear understanding of the level of protection provided by the dikes that they manage (except where assessments have been completed).
- Dike operation and maintenance manuals may not have been prepared or may be out of date.
- Many diking authorities do not have complete legal access (i.e. land ownership or rights of way) to allow inspections, maintenance and upgrading of the dikes. The diking authority also has no authority to remove buildings, fencing and other structures that have been built on the dike where the dike is located on private land.
- Opportunities to collaborate on technical studies and funding applications with adjacent diking authorities may have been missed through inadequate coordination, or other barriers.
- Opportunities to implement innovative structural approaches may have been missed.
- If vegetation on dikes is allowed to grow unmanaged, the trees and larger shrubs become classified as fish habitat by regulatory agencies. Removal and/or appropriate vegetation management becomes increasingly difficult, despite impacts on dike safety.
- The responsibility for sediment management to maintain dike design flood levels in aggrading river channels has historically not been part of dike operation and maintenance, and it is currently unclear who is responsible for this critical activity. However, diking authorities typically do not have adequate resources to address this issue.
- Most diking authorities have insufficient financial resources and/or face eligibility barriers to access the current senior government funding programs for dike upgrading (e.g. to meet current standards and to address updated design criteria for climate change).

The following sections investigate some of the underlying causes of the above deficiencies and provide recommendations on how these might be improved and addressed.

3 INVESTIGATION B-5.1: POTENTIAL INCENTIVES AND REQUIREMENTS

3.1 Objectives and Approach

The objectives of this investigation are to develop and recommend potential incentives and/or requirements for diking authorities to:

1) maintain existing flood protection infrastructure; and
2) plan and implement upgrades, or new structural measures to mitigate changing flood conditions.

The key to developing effective incentives and requirements is to understand the wide variation in capacity, resources/tax base, technical expertise, and administrative authority of diking authorities. Depending on size and capability, each diking authority may respond differently to a given incentive, disincentive, or requirement. This understanding is especially important when trying to support a diking authority with limited capacity and authority (such as an improvement district) that may be responsible for a "high consequence" dike.

The investigation consisted of the following tasks:

- Analyze the primary characteristics of BC's diking authorities. Information sources included MFLNRORD's "Flood Protection Works Database – Dikes Listed By Owner/Authority" (downloaded March 2020), the BC Ministry of Municipal Affairs and Housing "Local Government Statistics" and CivicInfo BC.
- Relate the type/capacity/capability of each diking authority with the flood risk associated with the dike(s) that they maintain using information from "Dike Consequence Classification Study", NHC 2019 and dike deficiency information from Investigation B-2.3.
- Develop incentives and requirements that have potential to improve both maintenance and future planning. Focus on the diking authorities that are responsible for significant dikes (e.g. major and high consequence).
- Provide Class D (±50%) resource and cost estimates for the opportunities identified.

3.2 Characteristics of Diking Authorities

A breakdown of the type of diking authority by percent is provided in Figure 1. Only slightly more than half (53%) of the 106 diking authorities in BC are municipalities. The remaining 47% are comprised of regional districts (10%), improvement districts (11%), *Drainage Ditch and Dike Act* districts (4%), government agencies (3%), First Nations (3%) and other (16%). "Other" includes entities such as residence associations, utility and forestry corporations, outdoor schools, wildlife management organizations, and strata corporations (MFLNRORD 2020).

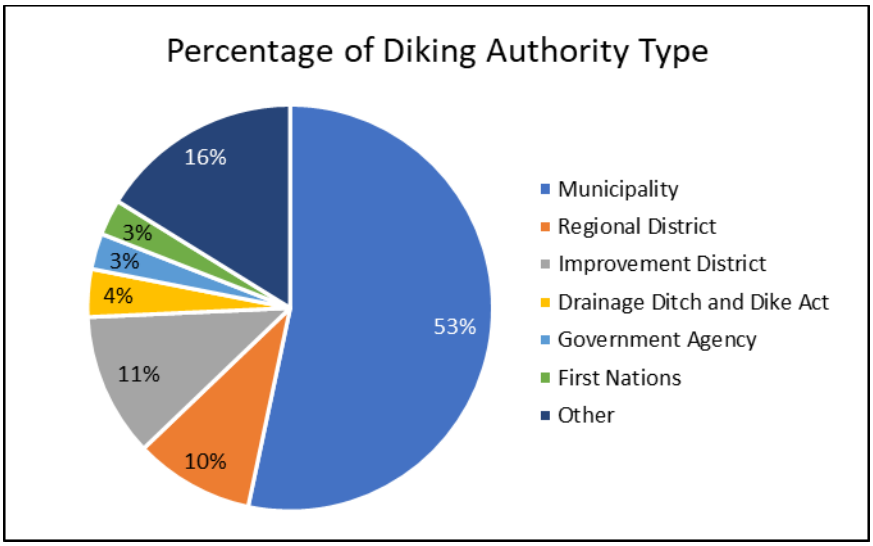

Figure 1. Percentage of Diking Authority Type

The capacity of diking authorities is highly variable and depends on the type of organization as well as the size. Local governments are the most appropriate legal entities to assume responsibilities for new flood protection structures because they have the broadest authorities related to all flood management activities. These include land use planning and regulation, emergency response, access to senior government funding, and powers of expropriation. Land use planning authority is especially critical, both for avoiding increasing risk (development) in flood hazard areas as well as land use planning for new dike alignments, such as upgrades, extensions or set backs to accommodate changing conditions including higher flows, sediment aggradation, bank erosion, riparian habitat, ice and debris jams.

For the last 20 years, the BC Inspector of Dikes has required that if any new dikes are constructed, the diking authority must be a local government (municipality or regional district). The detailed rationale for this approach is described in the "Diking Authorities for New Dikes" policy (MFLNRORD 2010).

Figure 2 shows the percentage of all BC diking authorities that have various powers and authorities related to dike and flood management. While linking improved dike maintenance as part of a local government's integrated flood management plan may be a reasonable policy for the 65% of diking authorities that are local governments and have land use and emergency planning responsibilities, this type of policy would not be effective for the remaining 35% that have no broader planning role.

In Figure 2, taxation authority is broken down into two categories that relate to the capacity of the diking authority to raise funds for dike maintenance and cost sharing of projects with senior governments. Municipalities can allocate funds for dike management from general revenue collected from the entire municipal tax base, including those properties outside of the diked protected area. However, the funding capacity of regional districts, improvement districts and DDDA districts is much more limited as they can only raise funds from taxation of the local service area, which is comprised of those properties in the floodplain behind the dike. A related issue is that some of the entities whose assets rely on flood protection provided by the dikes (i.e. highways, transmission lines, pipelines, communication facilities etc.) pay no taxes to the diking authority.

For many diking authorities, the lack of legal access (i.e. land ownership or rights of way) to the entire diking system is a major impediment to dike maintenance and dike management. Where negotiated settlements cannot be arranged with private property owners, or rights of way acquired through a development approval process, expropriation is the only legal tool available for local authorities to acquire the necessary permanent access. Because of high costs and length of time for the expropriation process, diking authorities have generally been very reluctant to expropriate. Furthermore, as shown in Figure 2, approximately 25% of diking authorities do not even have the power to expropriate.

The design and operation of flood protection works for riverine and coastal flooding is complex. Strong technical and project management skills are required to operate, maintain, and plan future upgrades. While engineering consultants can complete the necessary design studies, recommend options, and oversee construction, in-house technical and project management capacity is very important over the long term to maintain institutional knowledge and to take professional responsibility for dike planning and management.

As a rough indicator of technical capacity, an estimate was made of how many diking authorities have a professional engineer on staff by referring to CivicInfo BC and Engineers and Geoscientists of BC directories. As shown in Figure 2, only slightly more than 30% of BC diking authorities have an in-house professional engineer.

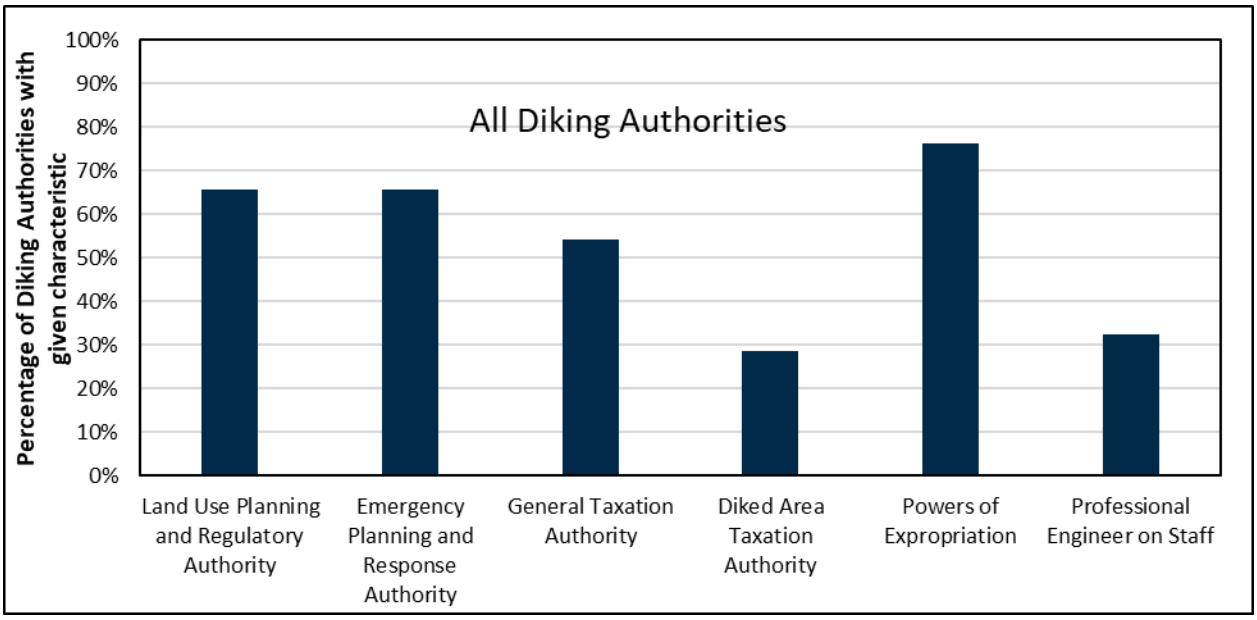

Figure 2. Percentage of All Diking Authorities with Various Authorities and Characteristics

3.3 Type of Diking Authority and Dike Consequence Classification

To be effective, any proposed incentives, requirements and supports should be helpful to the diking authorities that are responsible for the highest consequence dikes. Therefore, it is useful to look at the diking authorities who are responsible for "Major" and "High" consequence dikes as reported in the "BC

Dike Consequence Classification Study" (NHC 2019). This subset comprises 36% of the total number of diking authorities (Major – 18% of diking authorities; High– 18% of diking authorities, see Figure 3).

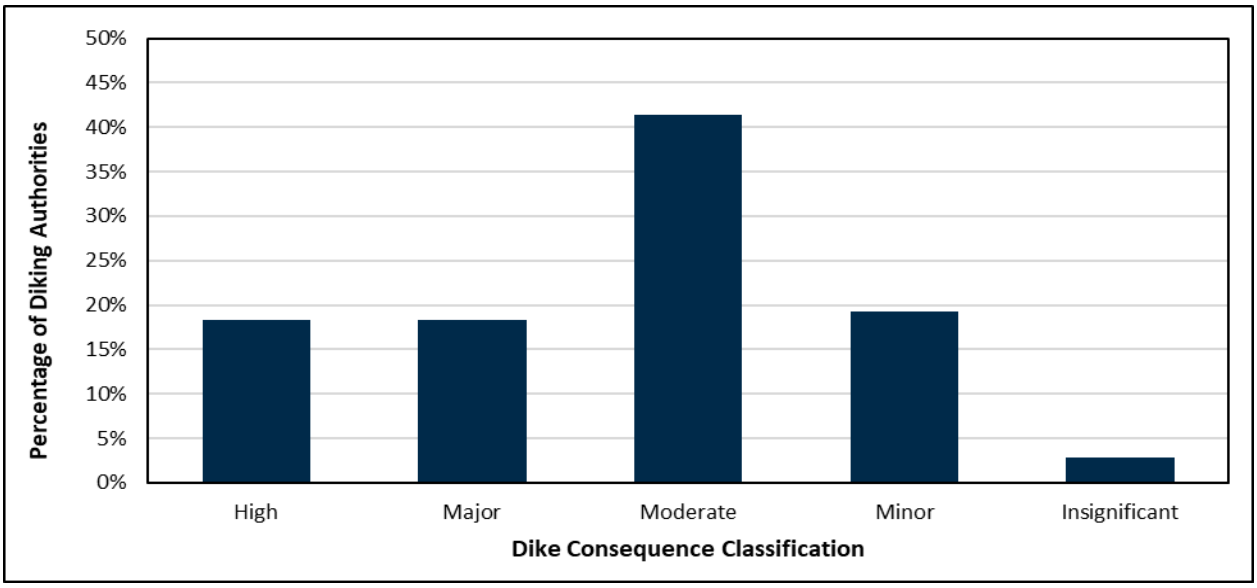

Figure 3. Percentage of Diking Authorities vs. Dike Classification

Note: where a diking authority owns more than one dike, the highest consequence dike was considered.

For the subset of diking authorities with the 36 Major and the 35 High consequence dikes, Figure 4 shows the percentage of these diking authorities with the characteristics presented in Figure 2. While the percentages of diking authorities with these characteristics have increased somewhat over that shown in Figure 2, there is still a substantial proportion (approximately 30%) that do not have the legal and technical attributes that are needed for integrated flood management.

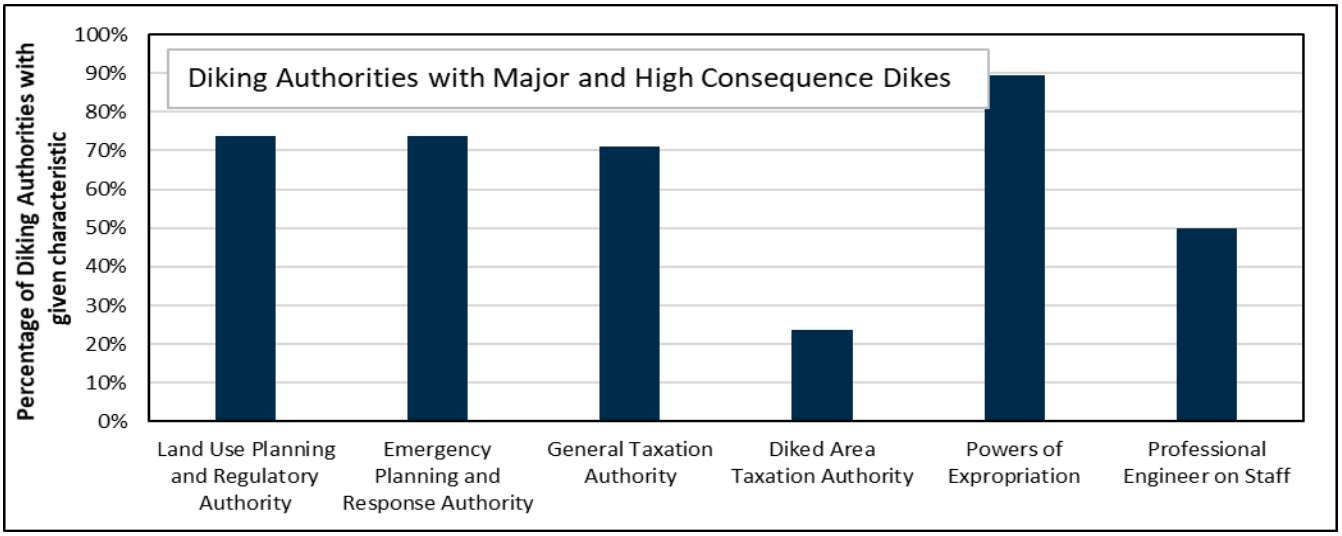

Figure 4. Percentage of Diking Authorities with Major and High Consequence Dikes with Various Characteristics

It is also useful to look at the types of diking authorities that are responsible for the most significant dikes (Figure 5). Incentives and requirements could be targeted at the 27 municipalities with Major and High consequence dikes, but there are also 6 improvement districts, 2 DDDA districts, one First Nation, and 2 "Other" diking districts with Major and High consequence dikes that need to be considered. A further complication is that more than 40% of all diking authorities (Figure 3) have Moderate consequence dikes and, therefore, incentives and requirements should be applicable to these entities as well.

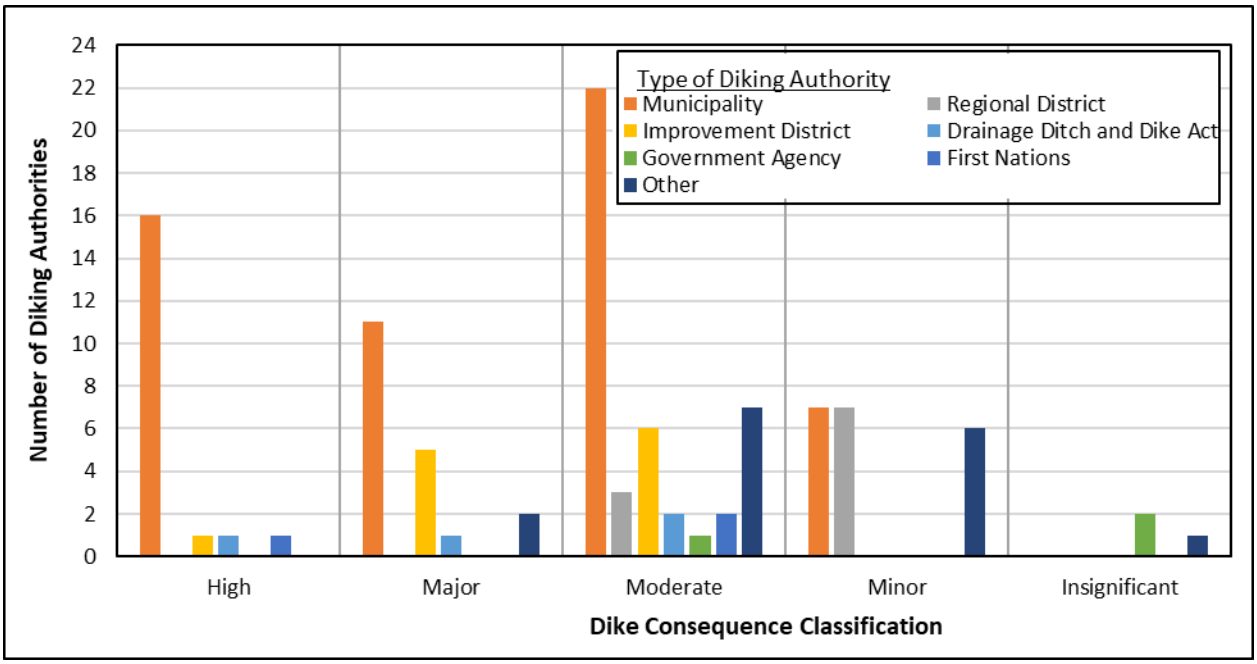

Figure 5. Number and Type of Diking Authorities for Each Dike Consequence Classification

Another diking authority characteristic that needs examination is financial capacity. A limited dike maintenance budget can impair the ability to do scheduled maintenance (e.g. including pump station and floodbox repairs/replacement). Limited financial capacity also impacts the ability of the diking authority to cost-share capital projects, or to access government funding (e.g. DMAF).

Dike upgrading to meet changing flood conditions and design requirements is costly – typical upgrades may be in the order of $2M to $5M per km of dike before incorporating seismic design, if required. As discussed, the current Infrastructure Canada "Disaster Mitigation Adaptation Fund" (DMAF) can provide up to a 40% contribution for projects costing over $20M. This means that a diking authority must come up with at least $12M for the smallest eligible project. These costs are prohibitive for many diking authorities.

General tax base data for municipalities are available from the BC Ministry of Municipal Affairs and Housing. Using "Total General Purposes Assessed Value" as an indicator of financial capacity, it is apparent that for the municipal diking authorities that are responsible for Major or High consequence dikes, the tax base varies by more than three orders of magnitude (i.e. the wealthiest municipal diking authority has more than 1,000 times the tax base of the poorest municipal diking authority). Figure 6

shows the Total General Purposes Assessed Value ("Tax Base") for each municipal diking authority, grouped by dike consequence classification and colour coded to show relative financial capacity.

There are several municipal diking authorities with a tax base of less than $1 billion (for example, City of Duncan, District of Houston, and District of Stewart) that are responsible for Major and/or High consequence dikes. In comparison, the Cities of Surrey, Richmond, and Burnaby, that are also responsible for Major and/or High consequence dikes, each have a tax base of over $50 billion.

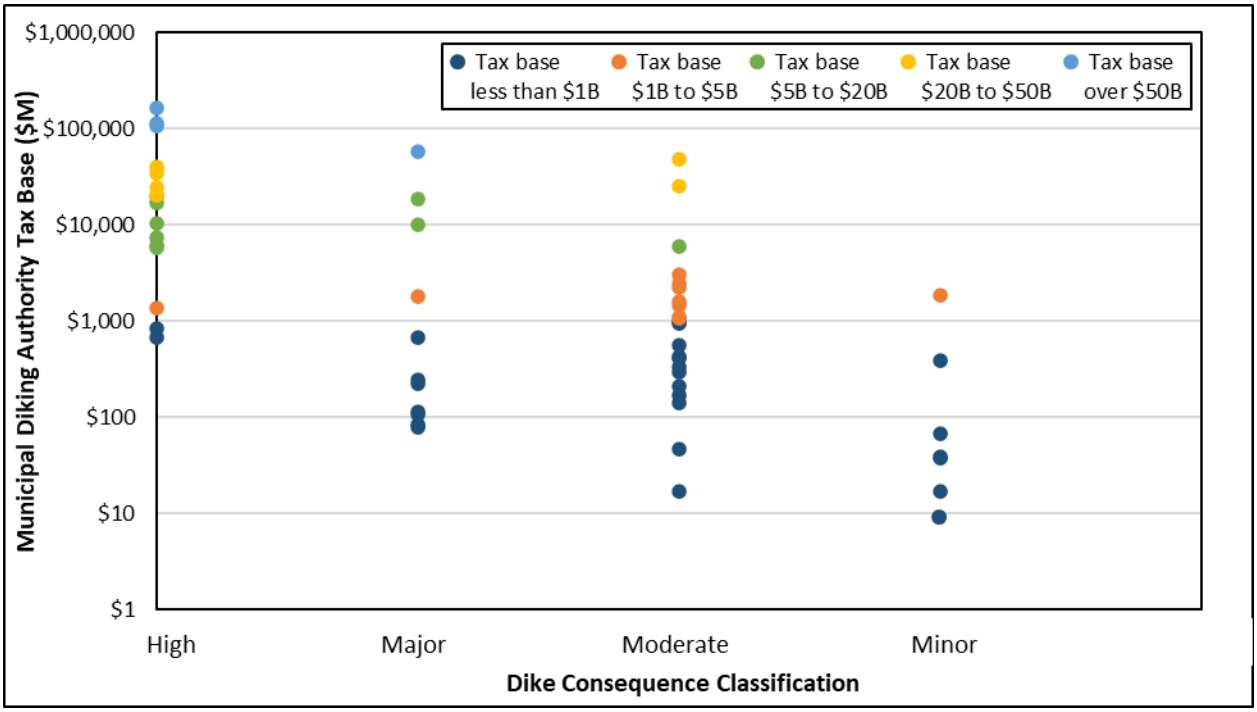

Figure 6. Comparison of "Tax Base" of Municipal Diking Authorities vs. Dike Consequence Classification

Note: In this chart, "Tax Base" is represented by the "Total General Purposes Assessed Values" for 2019 as compiled by BC Ministry of Municipal Affairs and Housing.

In summary, BC's diking authorities have a wide variation in "capacity", including financial resources/tax base, technical expertise, and administrative authority. Larger municipalities, with a substantial tax base, professional staff, and full local government powers, are the best positioned diking authorities to properly maintain flood protection infrastructure, to plan for future upgrades, and to access current senior government capital project funding programs. However, the smaller municipalities, regional districts, improvement districts and other diking authorities lack many of these advantages, yet still have similar flood risk management and financial responsibilities.

3.4 Potential Incentives and Requirements

Potential incentives and requirements to improve both dike maintenance and/or future planning are listed below. Most of these were identified by FBC and MFLNRORD in the May 2020 B-5 "Request for Proposals". The pros and cons of each option are described and evaluated in **Table 2.**

- Provide public and media access to diking authority inspection reporting compliance information.
- Link the availability of Disaster Financial Assistance (DFA) to satisfactory dike maintenance.
- Link provincial capital funding (i.e. approval and/or holdbacks) with satisfactory dike maintenance, inspection reporting, right of way acquisition, integrated flood planning, adoption of floodplain bylaws etc. (Incentives that would change eligibility rules for federal funding programs, such as the Disaster Mitigation Adaptation Fund, have not been considered.)
- Increased use of existing enforcement powers of the *Dike Maintenance Act* (DMA).
- Development and implementation of new regulations under Section 8 of the DMA.
- Make DMA approval of upgrades to dikes conditional upon adequate design for climate change.

As many of the issues facing BC's diking authorities are fundamentally related to the underlying BC governance framework and funding model, the incentives and requirements identified here may comprise only part of the needed solutions.

Table 2. Pros and Cons of Potential Incentives or Requirements to Improve Dike Maintenance and/or Future Dike Upgrades

No.	Incentive or Requirement	Intent	Pros	Cons
1	Provide public and media access to provincial dike inspection reporting compliance information. (this incentive was also identified in the B-2 Report NHC, 2020)	Incentive for diking authorities to complete and submit comprehensive dike inspection reports. (20% to 40% of diking authorities have not submitted the required annual inspection reports and 20% to 50% of the submitted reports have not been satisfactory.)	-Increased public awareness and motivation for diking authority. -Detailed inspections and reports should help to improve dike maintenance -Would likely be effective for the full range of types of diking authorities	-Increased provincial staff resources required to review reports, to compile and post compliance information, to explain requirements and maintain good working relationships with diking authorities. -Requires an engaged community; effectiveness may be limited unless information is well publicized. -Some diking authorities may view this as "public shaming". Increased diking authority staff time may be required to explain to public.
2	Link the availability of Disaster Financial Assistance (DFA) for dike protected areas to satisfactory dike maintenance as determined by the IOD. In the event of a dike breach, DFA could be withheld (from both the diking authority and property owners) if there	Incentive for diking authorities to complete adequate dike maintenance. Currently the availability of DFA is perceived by some as a disincentive for proactive maintenance. If DFA was withheld, the diking authority would likely have to directly	-Increased attention on dike maintenance. -Diking authorities may try harder to meet IOD maintenance standards.	-Increased provincial staff resources for IOD to specify standards and to assess "satisfactory maintenance" (e.g. audits of all diking authorities every 2 years) and to keep this information current. -Following failure, it may be difficult for the IOD to determine if a dike truly failed due to lack of maintenance or due to inadequate design. -For major events, diking authorities would typically not have the financial resources or insurance to cover the

No.	Incentive or Requirement	Intent	Pros	Cons
	was unsatisfactory maintenance. **Note:** This would likely require an amendment to the provincial "Compensation and Disaster Financial Assistance Regulation 1995"	compensate property owners with flood damage and/or face multiple lawsuits.		costs of potential flood damage – this would put them in a difficult position. -May only be "meaningful" for large municipalities – but most of these diking authorities already have good maintenance programs. -Could be perceived as a "threat" and may be politically unpopular with representatives of all levels of government – especially after a serious flood event when the community needs support for flood recovery.
3	Link provincial capital funding (i.e. approval and/or holdbacks) with satisfactory dike maintenance and inspection reporting. **Note:** Provincial/UBCM "Community Emergency Preparedness Fund" approved approx. 20 structural mitigation projects in 2019. Grant amounts are limited to $750k per local government or First Nation.	Incentive for local government and First Nation diking authorities to complete adequate dike maintenance.	-Local governments and First Nations who want to apply for funding would need to ensure that their inspection reporting and maintenance meets IOD requirements.	-Increased provincial staff resources for IOD to review inspection reports, compile, and post compliance information and to determine "satisfactory maintenance" (e.g. complete detailed audits every 2 years). -Additional resources for diking authorities may be required. - Would not be relevant to improvement districts and other diking authorities (i.e. 36% of all diking authorities). Only local governments and First Nations are eligible for CEPF structural mitigation funds.

No.	Incentive or Requirement	Intent	Pros	Cons
4	Link provincial capital funding (i.e. approval and/or holdbacks) with statutory right of way (SROW) acquisition for the works being funded.	Incentive for local government and First Nation diking authorities to acquire land ownership or rights of way for works being funded. (Many diking authorities do not have complete legal access to land to allow inspections, maintenance and upgrading of the dikes.)	-May encourage some local government and First Nation diking authorities to make a greater effort to acquire legal access.	-Land acquisition usually takes significant time. Without private land-owners' cooperation, diking authorities may miss funding application deadlines, or never recover holdbacks. -Where land costs comprise a significant proportion of the total project costs - putting full responsibility on the local diking authority to acquire the land may stop the project. - Would not be relevant to improvement districts and other diking authorities (i.e. 36% of all diking authorities). Only local governments and First Nations are eligible for CEPF structural mitigation funds. -While improvement districts have expropriation powers, they do not have the same authority as a municipality to require a SROW as a condition of new development (e.g. subdivision).
5	Link provincial capital funding (i.e. approval and/or holdbacks) with integrated flood planning, including adoption of floodplain bylaws or other	Incentive for local government and First Nation diking authorities to adopt non-structural flood mitigation measures.	-May encourage local government and First Nation diking authorities to make a greater effort to adopt non-	-Provincial staff would be required to determine if the land use planning and/or other non-structural measures proposed by the applicant met provincial standards. Therefore, mandatory, or direct linkage of funding

No.	Incentive or Requirement	Intent	Pros	Cons
	floodplain land use regulations. **Note:** The 2020 CEPF guide (UBCM, 2020) mentions that higher review scores will be given to applications that: "Align with non-structural work, such as amendments to floodplain zoning bylaws and land use planning updates and aligns with the Provincial Flood Hazard Area Land Use Management Guidelines".		structural flood mitigation approaches. -This policy could be "built-in" to a new provincial Integrated Flood Management Plan (IFMP) Program.	to specific types of land use regulations or IFMPs plans would likely be effective only if a provincial agency develops a new IFMP program. -May require coordination with neighbouring diking authorities. - Would not be relevant to improvement districts and other diking authorities (i.e. 36% of all diking authorities). Only local governments and First Nations are eligible for CEPF structural mitigation funds. -Even if made eligible for funding, improvement districts and other diking authorities do not have the administrative authority to adopt land use regulations or develop IFMPs.
6A	Increased use of existing enforcement powers of the *Dike Maintenance Act* (DMA) to order submission of reports. If the diking authority fails to comply with the order, the IOD could retain a consultant to complete the work and	Requirement for diking authorities to provide inspection reports, O&M manuals, and other reports.	-Could be effective in achieving a high level of compliance with dike inspection and other reporting requirements. -Where deficiencies exist, these actions should improve the level of dike maintenance for most diking authorities. -Applicable to all types of diking authorities	-Increased provincial staff resources for IOD to develop a comprehensive enforcement program (i.e. the program must be applied throughout the province and be consistent with administrative fairness principles). -Smaller diking authorities with limited resources (e.g. improvement districts, DDDA districts) may be unable to comply with the orders and may

No.	Incentive or Requirement	Intent	Pros	Cons
	charge the cost back to the diking authority. **Note:** Under the DMA, the IOD has broad authority to order diking authorities to provide reports, and to complete construction such as required maintenance, and improvements to dikes. However, IOD orders are appealable to the Minister.			"collapse" or "dissolve" if volunteer boards of directors resign. -may be politically unpopular, particularly for smaller diking authorities. -Historically, the IOD has used a collaborative approach and not used the legal powers of the DMA except where dike safety was critically threatened. - appeals would take up staff time
6B	Use of enforcement powers of the *Dike Maintenance Act* (DMA) to order completion of required maintenance. If the diking authority fails to comply with the order, the IOD could retain others to complete the work and charge the cost back to the diking authority.	Requirement for diking authorities to complete maintenance as specified by the IOD.	-Could be effective in completing required maintenance. -Applicable to all types of diking authorities	-All the "Cons" as per 6A above, except that these factors would be magnified by the larger costs and complexity of the province "taking on" maintenance projects. - Cost recovery from diking authorities would be challenging. -Legal issues would likely arise – this would also take staff away from their primary duties.
6C	Increased use of existing enforcement powers of the *Dike Maintenance Act* (DMA) to order dike upgrading to provincial standards.	Requirement for diking authorities to complete design work and upgrade dikes to provincial standards.	-No "pros" – generally not considered to be a workable option. However, there may be specific instances where a weak section of a diking system has been identified and an order	-The cost of upgrading dikes to current provincial standards is typically much greater than diking authorities can afford. (There is no point in ordering an action that is impossible.)

No.	Incentive or Requirement	Intent	Pros	Cons
			from the IOD would facilitate immediate action.	-In BC, upgrading of dikes has historically been a political and societal funding decision of the provincial government based on discussions and collaboration with all levels of government.
7	The IOD to adopt a formal policy that "designing for climate change" is required to obtain DMA approval of upgrades to dikes or new dikes. **Note:** Through the current DMA approval process and through EGBC Professional Practice Guidelines, design for climate change is already being required for many projects.	To ensure climate change is considered in dike upgrades and new dikes. **Note:** Incorporating climate change in design is already a strong consideration in mitigation funding program evaluations (Andrew Giles pers. com.).	-Would clarify climate change requirements for dike design, including upgrading in phases to match flood level projections. -Would provide consistency for larger river systems where there are several diking authorities (i.e. lower Fraser River). -Applicable to all types of diking authorities	-May prohibit some upgrading projects where the diking authority has insufficient funds to meet full climate change design requirements. -For river systems affecting multiple diking authorities (i.e. lower Fraser River) the IOD would need to adopt a dike design flood profile that considers climate change. -Climate change effects on peak flows and flood levels are very uncertain. The IOD would need to provide direction on how to address this uncertainty. Implementation of the Issue B-1 report recommendations would be helpful in this regard (Associated Engineering, 2020).
8	Development and implementation of a new regulation under Section 8 of the DMA.	Improve quality of dike inspection, maintenance and the design and construction of dike upgrades and new dikes.	-Diking authorities would have a clearer understanding of their legal obligations and responsibilities.	-Increased provincial staff resources to develop a new regulation (would likely take at least two years, including consultation).

No.	Incentive or Requirement	Intent	Pros	Cons
	Would replace many of the current dike safety "guidelines" and clarify requirements for both dike maintenance and for DMA approvals for dike upgrading and construction of new dikes.		-Could address some similar issues as the "Dam Safety Regulation" (i.e. consequence classification, O&M manuals, reporting requirements, maintenance, and emergency planning etc.) -Could streamline some categories of DMA approvals for minor changes to dikes by placing more reliance on qualified professionals. -Applicable to all types of diking authorities.	-Increased provincial staff to administer the new regulation (but would make activities of existing staff more effective). -Unless current capital project funding limitations for dike upgrades are addressed, the benefits of the new regulation would be limited to improving dike maintenance.

Of the ten items evaluated in **Table 2**, the following incentives and requirements would appear to have sufficient merit for further consideration:

Item 1: Provide public and media access to provincial dike inspection reporting compliance information. The only negative aspects are the costs associated with increased provincial and diking authority staff time allocations, and the extra efforts required by all parties to maintain good working relationships.

Item 5: The Issue B-4 Report (KWL 2020b) includes investigation and discussion of Integrated Flood Management Planning. If a provincial IFMP program were developed, there would be significant benefits in linking provincial capital funding (i.e. approval and/or holdbacks) with integrated flood planning, including adoption of floodplain bylaws or other floodplain land use regulations – at least for local government diking authorities.

Item 6A: Increased use of existing enforcement powers of the Dike Maintenance Act (DMA) to order submission of reports. If the diking authority fails to comply with the order, the IOD could retain a consultant to complete the work and charge the cost back to the diking authority.

Again, increased provincial staff resources are required to make this work, but the benefits could be significant. The IOD and DIODs would need to make significant efforts to clarify requirements and to encourage diking authorities, prior to issuance of any formal orders.

Some smaller non-local government diking authorities with minimal capacity may collapse if pushed too hard. The ownership and maintenance responsibilities for the dike may then revert to the province or the local government. Provincial recovery of the costs from diking authorities may be challenging.

Item 7: The IOD to adopt a formal policy that "designing for climate change" is required to obtain DMA approval of upgrades to dikes or new dikes. This would need to be supported by IOD provision of specific design standards (e.g. updated profile for Lower Fraser River and design parameters for other flood hazards in BC). Diking authorities are already experiencing major challenges in raising sufficient capital funding for dike upgrading projects to current standards without full consideration of climate change. Therefore, this policy could stop some projects where funding is only available for partial upgrades.

Item 8: Development and implementation of a new regulation under Section 8 of the DMA. A new dike safety regulation could be the primary tool for building a strong relationship between the province and the diking authorities. The province would need to make a significant investment in developing and administering the regulation. As noted in Table 3, unless current capital project funding limitations for dike upgrades are addressed, the benefits of the new regulation would be limited to improving dike maintenance.

3.5 Resources and Costs

Table 3 presents high level resources and cost estimates for the provincial government for the incentives and requirements identified in Section 3.4 above. The resources to implement Item 5, linking provincial capital funding with Integrated Flood Management Planning, would be incorporated into IFMP program development. Some potential financial implications for diking authorities have been identified but costs will vary; provision of these estimates is not within the scope of the present project.

Table 3. Resources and Costs to Implement Potential Incentives and Requirements

Item Table 3	Directed to	Incentive and/or Requirement	Resources	Contract Costs ($K)	Personnel/FTE Costs ($K)	
					One Time	Per Year
1	MFLNRORD	Publicize dike inspection reporting compliance information (e.g. via web page, provincial dike database, the Flood Portal and/or other).	0.1 FTE ongoing to keep compliance information up to date and respond to enquiries.			$10
6A	MFLNRORD and Diking Authorities	Increased use of existing enforcement powers of the Dike Maintenance Act (DMA) to order submission of reports. If the diking authority fails to comply with the order, the IOD retains a consultant to complete the work and charges the cost back to the diking authority.	0.3 FTE to develop a policy for report submission enforcement 0.3 FTE ongoing to administer the program Diking Authority staff time (will vary – not estimated)		$45	 $30
7	MFLNRORD	The IOD to adopt a formal policy that "designing for climate change" is required to obtain DMA approval of upgrades to dikes or new dikes. (assumes updated Fraser River dike design profile has been completed)	Contract Funds (to develop a new guideline/standards document) 0.2 FTE to manage contract and develop policy 0.2 FTE ongoing to implement policy	$200	 $30	 $30
8	MFLNRORD	Develop and implement a new regulation under Section 8 of the DMA.	Contract Funds (incl. consultation and engagement) 4.0 FTE to manage contract(s) and develop regulation (over two years) 0.5 FTE ongoing to implement		$200 $600	 $50

Note: To estimate MFLNRORD personnel costs (FTE = full time equivalent), used $100K/year for engineering tech; $150K/year for Professional Engineer/Project Manager.

4 INVESTIGATION B-5.2: IMPROVING KNOWLEDGE AND CAPACITY

4.1 Objective

Section 2.3 identified concerns related to the knowledge and capacity of diking authorities regarding dike maintenance. These include deficiencies in dike inspections and reporting, and the need for additional training and skills to adequately manage diking systems. There also is a high rate of staff turnover that limits the time for individuals to build local knowledge of the flood hazards and the dikes.

The objective of this investigation is to identify opportunities to address these issues through improving the knowledge and capacity of diking authorities.

The following sections estimate diking authority personnel turnover rates, describe existing communications, information and training being delivered by the provincial Dike Safety Program, and identify and evaluate possible options to increase knowledge and capacity.

4.2 Diking Personnel Turnover Rates

The provincial Dike Safety Program maintains a diking authority contact list as part of the provincial dike database (MFLNRORD 2020). For most diking authorities, the "contact person" named in the database is the diking authority's staff person responsible for the dike inspection and maintenance program. As the contact list is updated annually, an estimate of the "turnover rate" can be estimated by comparing the current lists with lists from previous years.

The contact lists were obtained for 2009, 2011, 2013, 2015, and 2019. Only the contact names for owners/administrators of dikes regulated under the DMA (i.e. currently 106 diking authorities) were compared. For the three two-year periods from 2009 to 2011, 2011 to 2013 and 2013 to 2015 there were changes of 42%, 21%, and 14%, respectively. For the two four-year periods from 2011 to 2015 and 2015 to 2019 there were changes of 31% and 75%, respectively. While the magnitude of year to year changes vary, there has been a typical turnover rate of about one quarter to one third of diking authority personnel every two years.

These high turnover rates are a significant obstacle to comprehensive dike inspection, maintenance, and future planning. Attendance at provincial workshops and study of dike safety guidelines is helpful but is only a small part of the steep learning curve for new dike management personnel. Given the complexity of flood hazards and diking systems, a few years experience to build local knowledge is crucial to identifying critical issues and future needs. The knowledge gained from observing system performance and from responding to high water events is particularly valuable.

4.3 Communications, Information and Training

The provincial Dike Safety Program provides the following communications, information, training, and other activities in support of dike maintenance (Mitchell Hahn and Rudy Sung, pers com).

Annual Letter: The IOD sends out an annual letter to all diking authorities just prior to the spring freshet flood period to provide a general flood outlook (as prepared by BC River Forecast Centre) and to outline

dike inspection reporting requirements. The letter may also include other information regarding DMA approvals, updates to design guidelines etc.

Dike Safety Audits: Comprehensive audits are another tool that the Dike Safety Program uses to communicate with diking authorities. An audit involves a joint field inspection of key facilities and problem areas by a Deputy Inspectors of Dikes (DIOD) with the diking authority and a review of all aspects of dike management. The review includes inspection and maintenance records, operation and maintenance manuals, recent changes to the dikes (DMA Approvals), dike crest surveys, flood emergency plans, dike upgrade needs and planning and financial statements. The audit outcome is a jointly developed Dike Safety Action Plan for follow-up by the diking authority. MFLNRORD's "Dike Safety Audit Outline" is attached as **APPENDIX D**.

DIODs complete approximately one to two audits per year for each of the five provincial regions (i.e. five to 10 audits per year in BC). The five regions are West Coast, South Coast, Southern Interior/Thomson Okanagan, Kootenay, and North. Diking authorities that appear to have significant operation and maintenance issues or have not submitted annual inspection reports are typically selected for auditing. Starting this year, the IOD is directing DIODs to give priority to completing audits of diking authorities that have high consequence dikes, and who have failed to submit an annual dike inspection report two years in a row (M Hahn pers com).

Although audits take up significant staff time and currently only involve five to ten percent of diking authorities each year, they are a valuable and useful tool for both improving dike safety and for building relationships between the DIODs and diking authority personnel. In addition to two-way technical information sharing, the DIODs (and Dike Safety Program) gain first-hand knowledge of the issues and challenges that the individual diking authorities are trying to address.

For example, vegetation management is a key component of dike maintenance that is assessed as part of an audit. Given the regulatory challenges and costs that diking authorities frequently face in addressing the requirements and constraints imposed by agencies responsible for habitat protection, DIODs can be effective in helping diking authorities in negotiating multi-year vegetation management plans.

Dike Management and Flood Mitigation Funding Web Pages: The provincial "Dike Management" web pages provide extensive information on the history of diking, DMA Approvals, design and construction guidelines, information for operations, maintenance and inspection, various maps, as-constructed drawings, and reports. Provincial government staff contact names and contact information for the Victoria IOD office and regional offices are also provided.

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/dike-management

Although many of the guideline documents are more than 15 years old, much of the content is still relevant. These documents are the primary tool that define best management practices for dike design, management, operation, and maintenance. A project to update several of the guidelines and templates would improve the accessibility and utility of this information.

Information on flood mitigation funding and a menu of funding programs are maintained by Emergency Management BC. Updating the BC Disaster Mitigation webpage and related linked pages to better outline a comprehensive approach to flood risk reduction in line with the modernized *Emergency Program Act* would help guide diking authorities in preparing funding applications.

https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/emergency-management-bc/bc-disaster-mitigation/flood-mitigation-funding-programs

Dike Inspection Workshops: The IOD and Deputy Inspectors of Dikes (DIODs) have developed a one-day "Dike Inspection Workshop" for diking authority representatives, and try to deliver at least one workshop in each of the 5 provincial regions, every two years. For example, over the period from November 2017 to February 2019, five workshops were held, with one in each region. A total of 91 individuals representing 42 different diking authorities attended these workshops (R. Sung pers com).

The 9:00 am to 4:00 pm workshops cover dike inspection and maintenance basics and, if local conditions and travel times permit, they include a 2-hour field inspection of a nearby dike. While these workshops are generally well-received, especially by staff that are new to dike operation and maintenance, this training has the following limitations:

- In the short time available, the training can only provide a basic overview and introduction to a broad range of topics.
- The training is not mandatory (e.g. less than half of all diking authorities participated in the 2017/19 workshops).
- The field inspections to demonstrate maintenance issues are very useful, but many workshops have not included this field component due to insufficient time.
- The workshops are "free" and lunch is provided, but some diking authorities have advised that travel time and costs (especially if overnight stays are necessary) are disincentives to attend.
- While First Nations diking authorities that maintain DMA regulated dikes have participated in the workshops, there is little available information on other First Nations that have "non-DMA" flood protection works (Brent Baron, pers com.).

As a very positive contribution, some diking authorities have sent 2 or even 3 staff to attend the workshops, offered use of their organizations' meeting rooms, volunteered their local dikes and shared their maintenance experiences on the field trips, indicating a strong interest in improving dike management skills and knowledge.

4.4 Options to Increase Knowledge and Capacity

The following options to increase knowledge and (technical) capacity with respect to improving dike inspection and maintenance were briefly evaluated. Pros and Cons of each option are provided in **Table 4**.

1) Increase the general capacity of the provincial Dike Safety Program and level of technical support provided by Deputy Inspectors of Dikes (DIODs) to diking authorities. This would include activities such as regular follow-ups on inspection reporting, joint field inspections, providing flood profile or other available information, assistance in preparing/approving DMA Approval applications, meeting with other permitting groups (e.g. fisheries and habitat agencies), assistance in preparing terms of reference for needed studies, participating on sediment management committees etc. Consideration should be given to creating positions with their sole focus being dike safety, with specialized skills and training, and with a direct reporting relationship to the Head of the Dike Safety Program (i.e. Inspector of Dikes).

   The intent of this option is to establish closer working relationships between DIODs and diking authority representatives. This should lead to greater understanding of inspection and maintenance requirements, better maintenance, and dike safety. Building capacity in the Dike Safety Program would also facilitate connections with EMBC Regional Managers and Disaster Mitigation Unit staff to better support a comprehensive approach to flood risk reduction and structural mitigation funding programs. This general level of support is in addition to the specific support options discussed below.

2) Increase the number of audits (dike management reviews) jointly completed by DIODs and the diking authorities from about 5 to 10 per year to 15 per year, as a minimum target number. This frequency would complete an audit of diking authorities with Major and High Consequence dikes (37 diking authorities) every 5 years and one audit every 10 years for the 69 remaining diking authorities with lower consequence classification dikes.

   The intent is similar to the first option above, however, a formal process is followed. The current MFLNRORD Dike Safety Audit Outline is attached as **APPENDIX D**.

3) Update several of the Dike Safety Program guideline documents related to dike design, operation and maintenance including: "Guidelines for Management of Flood Protection Works in BC" 1999, "Flood Protection Works Inspection Guide" 2000, "Operation and Maintenance Manual Templates", "Environmental Guidelines for Vegetation Management on Flood Protection Works" 1999 and "Dike Design and Construction Guide" 2003).

   These documents are the primary tool that define best management practices and requirements. By updating and maintaining these documents, it will ensure that they remain current as best management practices evolve.

4) Provide an on-line introductory training course in dike inspection and maintenance.

   This online course would provide new dike maintenance staff with immediate access to basic training, at least until they can participate in a regional dike safety workshop.

5) Increase the number of regional "Dike Inspection Workshops" from one workshop in each of 5 provincial regions every two years to an annual workshop in each region. Ensure that First Nations that have "non-DMA" dikes on their reserve lands are invited to participate in the workshops.

Increasing the frequency of workshops in each region should help to increase accessibility to training and the number of diking authorities and their staff that participate.

6) Increase the duration of regional "Dike Inspection Workshops" that are facilitated by the Inspector and Deputy Inspectors of Dikes from one day to two days, with the second day being field inspections of local dikes and maintenance issues. The workshop content could also be expanded to provide more in-depth discussion of critical dike maintenance issues.

7) Make regional "Dike Inspection Workshop" attendance mandatory (i.e. at least one representative from each diking authority must attend a workshop every two years). Subject to legal advice, the DMA would appear to give the IOD authority to make this a requirement. The intent is to increase the number of diking authorities participating. Other options, such as an advanced workshop, may need to be set up for those that have attended before.

8) Establish a comprehensive dike inspection and maintenance certification program (i.e. multi-day course at a central location). Require that inspection reports be completed and signed off by certified personnel or by a suitably qualified Professional Engineer.

   Consideration could be given to include more in-depth technical training and/or broadening the scope of the training to include information that would be helpful in planning flood mitigation upgrades. Also, this is the only option that directly addresses the high staff turnover rate – the assumption being that the investment of time and money to train an employee will be a significant incentive to retaining that person in the dike maintenance role.

Table 4. Pros and Cons of Options to Increase Knowledge and Capacity

Option No.	Description	Pros	Cons
1	Increase the general capacity of the provincial Dike Safety Program and level of technical support provided by Deputy Inspectors of Dikes (DIODs) to diking authorities.	-increased communication on provincial expectations and requirements -relationship building between diking authorities and the DIODs	-significant staff time for MFLNRORD
2	Increase the number of audits from about 5 to 10 per year to 15 per year, as a minimum target number. (Audit diking authorities with Major and High Consequence dikes every 5 years and the remainder once every 10 years).	-jointly developed comprehensive Dike Safety Action Plans -two-way technical information sharing and relationship building between MFLNRORD and diking authorities	-significant staff time for both diking authority and MFLNRORD

Option No.	Description	Pros	Cons
	(this option was also identified in the B-2 Report NHC, 2020)	-builds provincial awareness of key challenges faced by diking authorities	
3	Update Dike Safety Program guideline documents and templates related to dike design, management, operation, and maintenance.	-would clarify best management practices, modernize format, and increase utility of the information	-significant cost and staff resources -scope and priority list of documents required -likely a 5-year project
4	Provide an on-line introductory training course in dike inspection and maintenance.	-would provide an additional resource for new diking authority staff until they can participate in more comprehensive training. -would supplement the updates of existing guideline documents	-cost -not a substitute for group "workshop" training
5	Increase the number of regional "Dike Inspection Workshops" from one workshop in each of 5 provincial regions every two years to an annual workshop in each region. Ensure that First Nations (that have "non-DMA" dikes on their reserve lands) are invited to participate in the workshops.	-more opportunities for new staff to attend workshops -would offer training opportunities to First Nations that operate and maintain "non-DMA" dikes.	-may not increase number of diking authorities represented, if costs and time are barriers.
6	Increase the duration of regional "Dike Inspection Workshops" from one day to two days, with the second day being field inspections of local dikes and maintenance issues.	-field component is key component of training	-two-day course costs and time may be a significant barrier to diking authority attendance

Option No.	Description	Pros	Cons
7	Make regional "Dike Inspection Workshop" attendance mandatory (i.e. at least one representative from each diking authority must attend a workshop every two years)	-the participation rate of diking authorities in the offered training would be expected to improve from about 50% to perhaps 90%.	-difficult to enforce if diking authorities refuse to participate
8	Develop a comprehensive dike inspection and maintenance training and certification program (i.e. multi-day course at a central location). Require that inspection reports be completed and signed off by certified personnel or by a suitably qualified Professional Engineer. The content of the program could include more in-depth technical training and/or broaden the scope to address dike upgrading issues. An on-line version could also be developed.	-trained and certified personnel would be expected to deliver a high standard of dike operation and maintenance. -could model a new program on the BC Water and Waste Association (BCWWA) Water Treatment and Wastewater Treatment Plant Operator Education Programs.	-cost to develop and deliver program -cost and time for diking authority representatives to attend. -30% of DAs have in-house Professional Engineers. While technically proficient, they may not have the specialized dike maintenance and operational knowledge that would be covered in a comprehensive training course.

4.5 Resources and Costs

Table 5 presents high level resources and cost estimates for the provincial government to implement the options identified in Section 4.4 above. Some potential financial implications for diking authorities have been identified but costs will vary; provision of these estimates is not within the scope of the present project.

Table 5. Resources and Costs for Options to Increase Knowledge and Capacity

Item Table 5	Directed to	Incentive and/or Requirement	Resources	Contract Costs ($K)	Personnel/FTE Costs ($K)	
					One Time	Per Year
1	MFLNRORD	Increase the general capacity of the provincial Dike Safety Program. Consider direct reporting of DIOD positions to IOD.	3 FTEs (South Coast, North and Interior Regions)			$450
2	MFLNRORD and Diking Authorities	Increase the number of audits from about 5 to 10 per year to 15 per year (e.g. audit diking authorities with Major and High Consequence dikes every 5 years and the remainder once every 10 years).	0.4 FTE ongoing (DIODs) Diking Authority staff time (will vary – not estimated)			$40
3	MFLNRORD	Update Dike Safety Program guideline documents and templates related to dike design, management, operation, and maintenance.	Contract Funds 0.8 FTE to manage contract(s) (consider implementing as a multi-year program – e.g. 2 to 5 years)	$1000	$120	
4	MFLNRORD Diking Authorities and First Nations with Dikes	Provide an on-line introductory training course in dike inspection and maintenance.	Contract Funds 0.1 FTE to manage contract(s) 0.1 FTE ongoing to track participation and keep course up to date	$100	$15	$10
5	MFLNRORD Diking Authorities and First Nations with dikes	Increase the number of regional "Dike Inspection Workshops" from one workshop in each of 5 provincial regions every two years to an annual workshop in each region. Ensure that First Nations that have "non-DMA" dikes on their reserve lands are invited to participate in the workshops.	0.2 FTE Diking Authority and First Nation staff time (will vary – not estimated)			$20

Item Table 5	Directed to	Incentive and/or Requirement	Resources	Contract Costs ($K)	Personnel/FTE Costs ($K)	
					One Time	Per Year
6	MFLNRORD Diking Authorities and First Nations with dikes	Increase the duration of regional "Dike Inspection Workshops" from one day to two days, with the second day being field inspections of local dikes and maintenance issues.	0.1 FTE			$10
7	Diking Authorities	Make regional "Dike Inspection Workshop" attendance mandatory	0.1 FTE to track participation and encourage compliance			$10
8	MFLNRORD Diking Authorities and First Nations with dikes	Develop a comprehensive dike inspection and maintenance training and certification program. (At least two multi-day courses/yr at central locations with suitable field sites.) Inspection reports to be completed and signed off by certified personnel or by a suitably qualified Professional Engineer.	Contract Funds to Develop 0.5 FTE to manage contract and setup 0.3 FTE to manage program Contract Funds to Deliver (participant fees to cover this) DAs: approx. $2500 (fees and expenses) to attend 4.5-day course	$250 N/A	$75	$30

Note: To estimate MFLNRORD personnel costs (FTE = full time equivalent), used $100K/year for engineering tech; $150K/year for Professional Engineer/Project Manager.

5 INVESTIGATION B-5.3: IMPROVING COORDINATION AND COLLABORATION

5.1 Objectives and Background

The objective of this investigation is to look at ways to encourage diking authorities to coordinate and collaborate under non-emergency conditions.

Coordination and collaboration can improve all aspects of Integrated Flood Management Planning (IFMP) including efficiencies in hazard mapping, technical studies to develop dike design criteria, emergency planning, channel maintenance, funding application success, resolution of transfer of risk/adverse effects issues – all of which support dike management and safety.

There are at least three types of situations that need to be considered:

1) where two diking authorities "share", i.e. own and maintain, segments of what functions as a single dike, or "dike ring"
2) where two or more diking authorities have separate dikes in proximity that protect against flooding from the same source
3) where a diking authority (that may not be a local government) maintains a dike that can affect the interests of other local governments or First Nations.

Examples of the first situation include Lulu Island (the Cities of Richmond and New Westminster), Tsawwassen (Tsawwassen First Nation and City of Delta), "Town Dike" (Skwah First Nation and City of Chilliwack), Glen Valley (Glen Valley Diking District, Township of Langley and City of Abbotsford) and Left Bank Vedder Canal (Cities of Abbotsford and Chilliwack). Coordination and collaboration on dike maintenance, upgrades and future planning is essential for all aspects of dike safety for shared dikes.

Examples of the second and third situations include the lower Cowichan River (Cowichan Valley Regional District, City of Duncan, Cowichan Tribes and District of North Cowichan); and the Lillooet River (Pemberton Valley Diking District, Village of Pemberton, Lil'wat First Nation, and Squamish Lillooet Regional District).

Most local governments and other diking authorities recognize the importance and advantages of working with adjacent diking authorities on flood management issues. Two locations where there has been close coordination and cooperation: the Lower Cowichan River near Duncan and the Lillooet River near Pemberton (the various authorities involved are listed above) are both examples of where flood mapping and mitigation planning have been completed on a regional basis. In these cases, the authorities shared both in the costs and in the benefits from the jointly completed work.

However, for many areas, coordination and collaboration between diking authorities is ad-hoc. There are cases where recent floodplain mapping has been prepared for one side of a river but not for the adjacent municipality on the other side, even though the hydraulic modelling completed was applicable for both sides. Lack of coordination can be even more detrimental where one section of a shared dike

has been upgraded to higher standards, but the other section owned by a different municipality remains at the original grade, thus leaving both municipalities vulnerable to a flood event smaller than the upgrade standard.

The primary contributing factor to lack of coordination relates to the current funding model and governance framework. Flood management project funding, whether for mapping, risk studies, or for upgrading of structural works, is based on a competitive application process. The priorities of neighbouring municipalities and their respective annual budgets may not align at the same time. Unless one jurisdiction voluntarily takes a leadership role and is able to convince the adjacent jurisdictions to participate, full collaboration and the benefits of coordination will not be realized.

These situations become even more challenging when the diking authority is an improvement district and is ineligible to apply for funding. The scope for flood management projects should ideally be based primarily on the geography and physical characteristics of the flood hazard and risk issues to be addressed, not on local government jurisdictional boundaries.

5.2 Opportunities to Improve Coordination and Collaboration

Potential opportunities that could be applied under the current governance and funding framework can be grouped into the following three approaches:

1) Dike Maintenance Act (DMA): For diking authorities that "share" a dike, the Inspector of Dikes (IOD) could develop guidelines, policies and/or requirements to encourage and/or require coordination.

2) Funding Programs: To realize efficiencies in projects to complete design and construction of structural mitigation projects, the funding programs (i.e. CEPF and DMAF) could make stronger links between project funding success and the coordination/collaboration of applicants with adjacent jurisdictions.

3) Integrated Flood Management Plans (IFMPs): Coordination and collaboration with adjacent jurisdictions could be required as a condition of IFMP funding or approval, if future provincial IFMP guidelines and/or a program are developed.

The pros and cons of a few potential opportunities to improve coordination and collaboration are presented in **Table 6.**

Table 6. Opportunities to Improve Coordination and Collaboration

Option No.	Description	Pros	Cons
1	**Dike Maintenance Act (DMA) Opportunities**		
1A	The IOD/DIODs could assist both diking authorities in developing detailed design criteria, facilitating joint DMA approvals, and supporting joint funding applications. (For dike upgrade projects where two diking authorities "share" i.e. own and maintain segments of what functions as a single dike.)	-would help to ensure that different parts of the same dike are upgraded to a consistent standard. -may increase chances of successful funding applications. -could make the design, DMA approval process and construction more efficient by addressing the dike as one unit, instead of in segments.	-Requires provincial staff time and funds to assist with design criteria studies and leading coordination. -Efforts would be wasted if adequate funding not available, or funding applications are unsuccessful.
1B	The IOD could make DMA approval for upgrades conditional upon both diking authorities coordinating design and construction of their individual dike segments.	-would help to ensure that different parts of the same dike are upgraded to a consistent standard. -may increase chances of successful funding applications.	-unless both diking authorities have sufficient resources to proceed at the same time, this condition could be an obstacle to the party that is ready to move forward. (With coordination on the design, accepting a phased approach would mitigate this issue.)
2	**Funding Program Opportunities**		
2A	CEPF[1] Give highest priority (i.e. even more rating points than at present) to projects where diking authorities are contributing to a comprehensive, co-operative, and regional approach to flood mitigation.	- more coordination and collaboration may be realized if this rating factor is highlighted.	-"stand-alone" diking authorities, where they are the only community impacted by a given flood hazard, may find it difficult to compete for funding with regionally coordinated groups. - giving more weight to collaborative projects may diminish importance of flood

Option No.	Description	Pros	Cons
			risk reduction for critical dike safety projects where affected parties have been unable to build a regional partnership.
2B	DMAF[2] Where regional projects could be eligible to apply, the province could help to coordinate, lead and cost-share bundled projects.	-federal share increases to 50% if province takes lead -would improve likelihood of funding success -greater share of DMAF funds would flow to BC	-provincial staff resources and funding contribution required[3]
3	Integrated Flood Management Plans (IFMPs) If future provincial IFMP guidelines and/or a program are developed, coordination and collaboration with adjacent jurisdictions could be required as a condition of IFMP funding or approval.	-would encourage coordination and collaboration on structural mitigation as well as non-structural measures.	-requires provincial resources to initiate an IFMP program (see Issue B-4 Flood Planning Report for more information on IFMPs)

Notes:

1. For CEPF, in addition to several other application rating factors, "Higher application review scores will be given to applications that: Contribute to a comprehensive, cooperative, and regional approach to flood mitigation, identify stakeholders and partnerships, as appropriate to the project, and outline their level of engagement and commitment to the project."

2. DMAF is oriented towards large scale projects that may be comprised of bundled investments from coordinated partners. The DMAF application guide states:
   "Additionally, there is merit in projects that advance the objectives of or are aligned with climate adaptation and mitigation plans, strategies, frameworks, policies, related asset management plans and land-use plans, etc., as this demonstrates strategic and coordinated action across levels of government. Strong proposals advance approved national and provincial/territorial/ Municipal adaptation and mitigation plans, strategies, and/or frameworks."

3. In 2019, as part of a project to help the communities recover from severe flooding in May 2018, the province contributed $29 million to a $50 million flood mitigation project for the City of Grand Forks and Regional District of Kootenay Boundary (Infrastructure Canada 2020).

5.3 Discussion of Opportunities to Improve Coordination and Collaboration

The analysis of pros and cons in Table 6 does not bring to light any inexpensive or straightforward solutions that would improve coordination and collaboration. However, with allocation of major provincial funding for two new programs (options 2B and 3 below) significant improvements in coordination and collaboration could be achieved. (Note: other opportunities for improving coordination and collaboration will be explored in project "A-1 Improving Coordination and Collaboration".)

Option 1B: Future action by MFLNRORD to use the *Dike Maintenance Act* (DMA) to require coordination between adjacent jurisdictions as conditions of DMA approval for dike upgrading is more likely to cause frustration and project termination than any increased level of collaboration. Local governments are used to working closely together on mutually beneficial projects. The barriers to collaboration (mostly financial) cannot be overcome by a new requirement from the IOD.

Option 1A: Similarly, increased efforts by the IOD and DIODs to support more collaboration may be effective in coordination of design and facilitating DMA approvals, but could be wasted if the funding application(s) are unsuccessful for various other reasons.

Option 2B: The province does not currently have a matching cost sharing program to the federal DMAF program. Except for one-off DMAF projects such as the $50 million City of Grand Forks and Regional District of Kootenay Boundary flood mitigation project (this area was severely flooded in May 2018), there is usually minimal provincial involvement. Where regional projects meet federal eligibility requirements, the province could help to coordinate, lead and cost-share "bundled" applications. This could potentially provide significant coordination and collaboration benefits on structural flood mitigation projects, plus the leverage of more federal funds. Provincial budget allocations would depend on the number and size of projects but would be constrained by federal funding limits and project approval decisions.

Option 3: A new provincial IFMP Program could encourage and support coordination and collaboration on structural mitigation as well as non-structural measures. The scope of a new provincial program and resources to implement are discussed in the Issue B-4 Flood Planning Report (KWL 2020b).

6 INVESTIGATION B-5.4: IMPLEMENTING INNOVATIVE STRUCTURAL MEASURES

6.1 Objectives

Sea level rise, increased river flows due to climate change, seismic vulnerability, and ongoing development in diked floodplain areas are all increasing flood risk in BC. At the same time, the space to widen and raise existing conventional earthen embankment dikes is constrained by many competing uses, high land values and critical habitat. Innovative approaches in spatial, hydraulic, and geotechnical design are needed in situations where conventional approaches may be infeasible or cost prohibitive.

Innovation can be defined as "An idea, practice, or object that is perceived as new by an individual or other unit of adoption." (Rogers 2003). Looking for innovative ideas is a fundamental part of the iterative "engineering design process". After the problem to be solved and project objectives have been defined, the next step is to research and brainstorm for possible solutions including what others have done in similar situations. If these ideas and practices are perceived to be new, at least in the location where they may be applied, they can be considered innovative. Therefore, the engineering design process, including comprehensive scanning for solutions, is (or at least should be) inherently innovative.

The objectives of this investigation are to explore challenges and opportunities for the implementation of innovative structural flood risk reduction measures and to consider the role of incentives and regulation in overcoming any identified impediments. It is hoped that the inclusion of brief reviews of the various measures in this report will help to stimulate creativity and flexibility in approach, and wider application where the benefits can be realized.

6.2 Innovative Approaches Reviewed

Based on discussions with the Fraser Basin Council and MFLNRORD and building on content presented on FBC's new "FloodWise" website, twelve innovative approaches were identified for review. For each of the structural approaches listed in **Table 7** below**, APPENDIX B** provides a description of the technology, benefits, challenges, and short discussion of potential application in BC. Conventional dikes and related structures, dredging/sediment removal for channel capacity maintenance, removal of channel obstructions and rock riprap erosion protection are the primary existing structural approaches in BC and were not considered to be "innovations" to be included in this investigation.

Table 7. List of Innovations Reviewed

No.	Innovation	Description
1	Set-back dikes	Dikes built inland from riverbanks or coastal shorelines. Benefits can include less susceptibility to erosion, more riparian habitat, recreational opportunities as well as enhanced channel capacity for both flood flows and sediment, plus reduced wave run-up for coastal dikes.
2	Compartmentalization	Partitioning of protected floodplains to give urban areas a higher level of protection.
3	Off-stream reservoir storage	Preferential flooding of low risk floodplain areas.
4	Super dikes	A super dike is a high embankment with a wide base and gentle slope, combining flood protection with urban land use. It is much larger than a conventional dike and is resilient to earthquakes, erosion, and breaching.
5	Floodwalls – both permanent and erectable	Flood walls are vertical barriers designed to contain floodwaters from rivers and waterways. They function similarly to a dike but require far less land.
6	Smart Dikes	Instrumentation of critical dike sections to provide real-time data coupled with dike failure software.
7	Bio-grouting (also known as bio-cementation)	Bio-grouting is an evolving technology for ground improvement that may be necessary for seismic stabilization, or to reduce seepage flows through and under dikes.
8	Habitat friendly alternatives to riprap erosion protection	Measures that mitigate the negative effects of riprap on the environment by incorporating natural elements of live vegetation or woody material to enhance or replace the use of rip rap (a type of “bio-engineering”).
9	Sea gates/barriers	Structures at the mouth of a river or inlet that can be closed against coastal storm surge or high tides to prevent flooding.
10	Living Breakwaters	Off-shore breakwater structures that disperse wave energy, reduce shoreline erosion, and are designed to provide aquatic habitat and other benefits.
11	Beach Nourishment	Introducing or enhancing the supply of natural sediments to the foreshore to increase beach width, reduce wave energy and feed the longshore transport system.
12	Natural Shorelines and Living Dikes	Restoring or replicating natural coastal shorelines to protect against erosion and enhance ecosystems.

6.3 Highlights and Discussion

In addition to physical design limitations and the site-specific cost-effectiveness of various innovative structural flood management approaches, the major impediments to applying these approaches include funding, land ownership, and the challenges of integrating flood protection with land use and development. Technical information and relevant design examples may also be lacking and it can be challenging for regulators to approve designs without prior testing in BC. Opportunities to overcome these barriers could include broadening the eligibility criteria of funding programs (e.g. include land acquisition as an eligible cost), updating design guidelines, providing greater flexibility in regulatory approvals, and giving greater support for projects that enhance fish and wildlife habitat and/or provide other community benefits. The sponsorship and publicizing of pilot projects to demonstrate promising technologies that are unproven in BC may also be of value.

The following paragraphs highlight how some of the barriers to implementing innovative approaches might be overcome.

Set-back dikes: The benefits and challenges of set-back dikes are well known in BC as there are many good examples (e.g. Vedder River, Mission Creek). The greatest impediment to broader application of this approach is the cost of land and how to protect or address historic development adjacent to the river channel. Given that set-back diking projects often provide extensive environmental and recreational benefits as well as a high standard of flood protection, senior government programs should consider funding land acquisition for set-back dike projects.

Compartmentalization: Providing a higher standard of protection to an urban core than for the adjacent rural areas may make sense for some communities from a risk analysis perspective, but there are very significant physical design and political challenges. However, the concept may have merit in specific situations and should be investigated as part of integrated flood management planning. Development of design guidelines, including a risk analysis methodology and example calculations would assist in the assessment of this approach.

Off-stream reservoir storage: Diversion of flood waters into temporary storage usually through intentional flooding of low risk floodplain areas is a common urban stormwater management approach that can be scaled up for larger river systems if sufficient low lying, undeveloped land is available. Except for smaller rivers and streams with relatively wide floodplains (e.g. Serpentine/Nicomekl floodplain in Surrey, BC) this approach would appear to have limited application in BC.

Super dikes: Designing seismically stable dikes to meet higher flood levels due to sea level rise and/or increased flows is a major challenge, particularly along the lower Fraser River. Integrating urban development with large, wide dikes is one way to address this issue, however this requires long term land use planning and a complex design and construction process. This approach would be most applicable for larger urban communities, such as the City of Richmond, who are considering designation of wide dike corridors and super dikes as a potential design options for parts of their diking system.

Because constructing a super dike system may take many years, some flexibility in regulatory approach (i.e. DMA approvals) may be required. For example, where a long-term approach to integrate

seismically stable super dikes into a perimeter dike system was being implemented, the upgrading of seismically vulnerable conventional dikes to meet current flood design levels over the short term could be considered.

Floodwalls: Permanent Floodwalls (excluding temporary emergency works) have many disadvantages in comparison to conventional earthen embankment dikes (see list in **Appendix B**). However, they may be useful in specific cases with severe space, or grade restrictions. For dike upgrades in densely developed urban areas, more frequent use of floodwalls should be anticipated. Floodwall design guidelines, including demountable designs, should be prepared. This would assist the Inspector of Dikes, diking authorities and their consultants in assessment and implementation of appropriate floodwall designs.

Smart dikes and bio-grouting: These innovative approaches apply new and evolving technology. To benefit from the research being completed in other jurisdictions, it is suggested that the potential benefits for BC could be demonstrated by the sponsorship and initiation of field scale pilot projects.

Habitat friendly alternatives to riprap erosion protection: While these approaches are unlikely to replace large riprap where flow velocities are high and critical assets (such as dikes) are being protected, there does appear to be scope for broader application in BC. The most significant barrier is the lack of widely used engineering design standards applicable for BC's stream characteristics, climate, and vegetation types. These standards and design examples would be of value to both proponents and regulatory agencies. Flood mitigation funding programs could provide funds for these design approaches that provide fish and wildlife habitat benefits, as opposed to proponents having to fund habitat impact compensation work.

Sea gates/barriers: The application of sea gates/barriers is highly site specific. Because these structures are very costly to build, operate and maintain it is anticipated that large barriers will be rarely used in BC. Many jurisdictions throughout the world have implemented a variety of designs and technologies. If sea barriers are being considered, proponents should research and make full use of this global design knowledge and experience.

Innovative approaches to address coastal erosion and flood protection - Living breakwaters, beach nourishment, natural shorelines and living dikes: These "soft" approaches could potentially have significant benefits in maintaining aquatic and shoreline ecosystems while forming part of the flood protection systems needed to address sea level rise. As with habitat friendly techniques applied to riverine environments, a significant barrier is the lack of engineering design guidelines and examples applicable to BC where there are existing sea dikes, or where sea dikes may be required in future. For sites such as Boundary Bay, the "Design Basis for the Living Dike Concept" study identified several information gaps with respect to salt marsh development, geomorphic processes, and wind and wave data (SNC Lavalin 2018). Pilot and/or demonstration projects and research, (such as the UBC Living Breakwaters Project) should help to advance the broader application of these concepts.

7 CONCLUSIONS AND RECOMMENDATIONS

This report investigated various incentives, requirements and supports to help diking authorities improve dike maintenance, plan for future dike upgrading and to expand structural approaches beyond conventional diking. Recommendations have been identified where the benefits clearly outweigh concerns and costs.

Although the number of diking authorities that responded to the engagement survey was limited, the respondents overwhelmingly identified lack of senior government funding as the primary challenge to improved dike maintenance and upgrading (**Appendix E**). While the incentives, requirements and opportunities recommended below can help, the broader funding and governance issues must also be addressed.

7.1 Recommended Incentives and Requirements to Improve Dike Maintenance and/or Future Dike Upgrades

The capacity of diking authorities is highly variable with respect to financial resources, administrative authority, and technical expertise. Therefore, incentives and requirements that apply to all types of diking authorities, including the 37% that are non-local government entities, are likely to be the most effective. It is recommended that the following incentives and requirements be implemented.

Recommendation B-5.1 No. 1: To improve dike maintenance through increased compliance with provincial requirements for dike inspection reporting, the province should publicize provincial dike inspection reporting compliance information. The Inspector of Dikes (IOD) should also make use of existing enforcement powers of the Dike Maintenance Act (DMA) to order submission of satisfactory reports. If diking authorities fail to comply with the orders, the IOD should retain consultants to complete the inspections and charge the costs back to the diking authorities.

To implement the above, MFLNRORD's Dike Safety Program will need to spend more time working with diking authorities, plus evaluating and tracking inspection reports. A new enforcement policy and procedure will need to be developed (0.3 FTE one-time allocation). Approximately 0.4 FTE will be required on an ongoing basis. For those diking authorities that become the subject of enforcement, dike inspection and reporting will need to be given a higher priority.

Recommendation B-5.1 No. 2: To improve diking authority planning for future dike upgrading the IOD should adopt a formal policy that "designing for climate change" is required to obtain DMA approval of major upgrades to dikes or new dikes. The IOD will need to provide a guideline document and specific design standards where possible (i.e. new Fraser River design profile and other flood hazards in BC). Where feasible and cost effective, a phased design approach to match projected future flood levels should be considered.

Contract funds (approx. $200K plus 0.3 FTE) would be required to develop a new policy and guideline/standards document plus 0.3 FTE staff time to implement the new policy. (Any additional costs to complete the current Fraser River dike design profile update project are not included.)

Recommendation B-5.1 No. 3: To integrate structural approaches such as dike upgrading and new dikes with other non-structural approaches, provincial funding (such as CEPF) for structural works projects should be linked to integrated flood planning, including adoption of floodplain bylaws or other land use regulations that meet provincial standards. This recommendation is conditional upon the province developing new standards for flood hazard land use regulation and/or a new Integrated Flood Management Planning (IFMP) Program.

7.2 Recommendations to Improve Knowledge and Capacity

The knowledge and capacity of both MFLNRORD Dike Safety Program staff and many of the diking authorities may be insufficient to safely manage the existing structural flood mitigation works in the province. Therefore, the following recommendations are directed both at MFLNRORD and diking authorities in general. First Nations that have structural flood protection works that are not provincially regulated under the DMA should also be invited and encouraged to participate in any enhanced dike inspection and maintenance training opportunities.

Recommendation B-5.2 No. 1: To help build the knowledge of both DIODs and diking authority representatives, to share information, to build stronger relationships and to jointly develop specific dike safety action plans, the MFLNRORD Dike Safety Program should increase the number of audits from about 5 to 10 per year to 15 per year, as a minimum target number (e.g. audit diking authorities with Major and High Consequence dikes every 5 years and the remainder once every 10 years).

The additional DIOD staff time, required on an ongoing basis, is estimated to be 0.4 FTE (approx. 8 additional audits per year).

Recommendation B-5.2 No. 2: To provide new diking authority maintenance staff with immediate access to basic training, at least until they can participate in a regional dike safety workshop, MFLNRORD should develop and provide an on-line introductory training course in dike inspection and maintenance.

The resources to develop the training would include $100K in contract funds and 0.1 FTE staff time. Administering the training, tracking participation, and keeping the content up to date would require 0.1 FTE on an ongoing basis.

Recommendation B-5.2 No. 3: MFLNRORD should provide increased dike inspection and maintenance training opportunities and expand the content of the training. Determining an optimal approach will need to be worked out by the ministry, however some suggestions are provided below.

As at present, dike workshops should be provided at least every two years in all regions, but annually in the south coast region (approx. 35 diking authorities) and each workshop duration increased from one to two days to include a field component. The workshop content should be modified to be as relevant as possible to address current and specific regional dike maintenance issues (after consultation with regional diking authorities). If diking authority financial capacity is a barrier to participation, consideration should be given to subsidizing travel expenses. A single DIOD position should be designated to lead and develop dike safety training for the province with sufficient time allocated for this

function (approx. 0.5 FTE). As is current practice, regional DIODs should help to coordinate workshop logistics (i.e. field dike inspections) and attend workshops at least once every two years.

Evaluation of the establishment of a comprehensive dike safety training and certification program should be considered. A formal training and certification program delivered by a contractor may be more cost-effective than enhancing the in-house workshops as suggested above.

7.3 Recommendations to Improve Coordination and Collaboration

Recommendation B-5.3 No. 1: The province should develop a matching cost sharing program to the federal DMAF program. Where regional projects meet federal eligibility requirements, the province should lead, coordinate, and cost-share "bundled" applications. This could potentially provide significant coordination and collaboration benefits on structural flood mitigation projects, plus the leverage of more federal funds. Provincial budget allocations would depend on the number and size of projects but would be constrained by federal funding limits and project approval decisions.

Recommendation B-5.3 No. 2: The province should develop and implement an Integrated Flood Management Program. The new program should encourage and support coordination and collaboration on structural mitigation as well as non-structural measures for communities that share both dikes and floodplains. Specific initiatives the Province could consider to improve IFMP processes, including legislation, funding and a provincial approval process are discussed in the Issue B-4 Flood Planning Report (KWL 2020b).

7.4 Recommendations to Encourage Implementation of Innovative Structural Measures

A broad scan for all possible options should always be part of the process for designing and constructing structural flood mitigation works. The following recommendations would encourage the wider application of innovative approaches where they are technically feasible and cost-effective.

Recommendation B-5.4 No. 1: Provincial government funding programs (e.g. CEPF) should consider land acquisition as an eligible cost for set-back dike projects. This could include "strategic retreat" or wetland conservation.

Recommendation B-5.4 No. 2: The MFLNRORD Dike Safety Program should develop design guidelines to assist in the assessment and design of compartmentalization/preferential flooding, super dikes, and floodwalls. For applications where a long-term approach to integrate flood protection with community development will result in a seismically stable flood protection system (e.g. super dikes), the guidelines should offer some flexibility in application of seismic standards in the short term.

Recommendation B-5.4 No. 3: MFLNRORD should consider projects to establish engineering guidelines and design standards for: 1) habitat friendly alternatives to riprap erosion protection in riverine environments and 2) alternative approaches to standard sea dikes, building on work done by various organizations including the Stewardship Centre for BC, West Coast Environmental Law, UBC and others.

Recommendation B-5.4 No. 4: MFLNRORD should sponsor, in partnership with academia and local diking authorities, field scale pilot projects to evaluate and demonstrate the potential benefits and feasibility of smart dikes and bio-grouting.

Given the general nature of the above recommendations it is not possible to develop specific resource and cost estimates. However, increasing the capacity of the MFLNRORD Dike Safety Program as recommended in Sections 7.1 and 7.2 above should provide some capability to develop design guidelines and standards for the innovative approaches identified and to initiate and support field scale pilot projects.

7.5 Discussion

As noted in the Introduction, the above B-5 investigations and recommendations are focused on encouraging diking authorities to carry out their responsibilities within the current legislative, program, and funding (i.e. governance) framework, i.e. as set out by the four specific investigations required by the study terms of reference. Although implementing the B-5 recommendations will help to address dike operation and maintenance issues, there is a much larger and critical issue to tackle.

The major structural flood protection issue in BC is that most of the dikes in the province do not fully meet provincial standards and many dikes are likely to breach during floods well below the design event even without consideration of climate change effects. To help authorities and the public understand the scope and significance of this issue, investigation B-2.3 (NHC 2020) recommended that BC should establish a standardized dike assessment rating system.

Investigation of the necessary governance arrangements and outlining of programs and resources to upgrade the dikes to meet provincial standards within a defined time frame is required. Any dike upgrading must also be integrated with non-structural approaches at the local government level (i.e. through IFMPs approved by the province).

Resolution of the following governance issues is suggested to be fundamental to effective and safe structural flood protection in BC and will also help to achieve an integrated approach:

1) The need to align dike upgrade project funding with the actual costs to meet provincial dike standards as set by MFLNRORD.

   The current competitive, ad hoc application process with a set funding cap per application (i.e. CEPF) spreads limited funding between many applicants, but frequently is insufficient to complete a full upgrade of a single dike. The federal DMAF program can provide significantly larger amounts of funding, but the applicants' shares are typically only affordable by the larger municipalities.

   A sustainable senior government funded program, modelled in part on the 26-year long Fraser River Flood Control Program, but with a broader, integrated flood management approach, may be one option. This type of program would set standards, define, and prioritize projects, and allocate annual funding to complete projects in collaboration with local governments, First Nations, and other partners. Structural projects would be integrated with non-structural

approaches within an IFMP framework (such as weighing the benefits of dike upgrading against the costs of land acquisition and moving vulnerable uses). In developing this type of program, many of the recommendations provided by the 1994 report "Review of the Fraser River Flood Control Program" by the Fraser Basin Management Program appear relevant today (FBMP 1994).

2) Because of historical reasons, many diking authorities, including both small local governments and non-local government entities such as improvement districts, simply do not have the financial, administrative, and technical capacity, or jurisdictional authority to effectively manage the dikes that they are currently responsible for. No amount of training, guideline information, enforcement, requirements, or cost shared funding programs will address these limitations.

   Where the consequences of dike failure provide sufficient justification, the responsibilities and flood protection assets (dikes) of diking authorities with limited financial, jurisdictional, and technical capacity should be transferred to a "capable" diking authority. In the case of non-local government entities, the assets could be transferred to their respective local government (if their capacity is sufficient) or in the case of small local governments that lack sufficient capacity, other governance models should be considered.

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APPENDIX A: All Investigations

Investigations in Support of Flood Strategy Development in BC

List of All Investigations

Theme A. Governance

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

Theme B. Flood Hazard and Risk Management

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

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

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

Theme C. Flood Forecasting, Emergency Response and Recovery

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

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

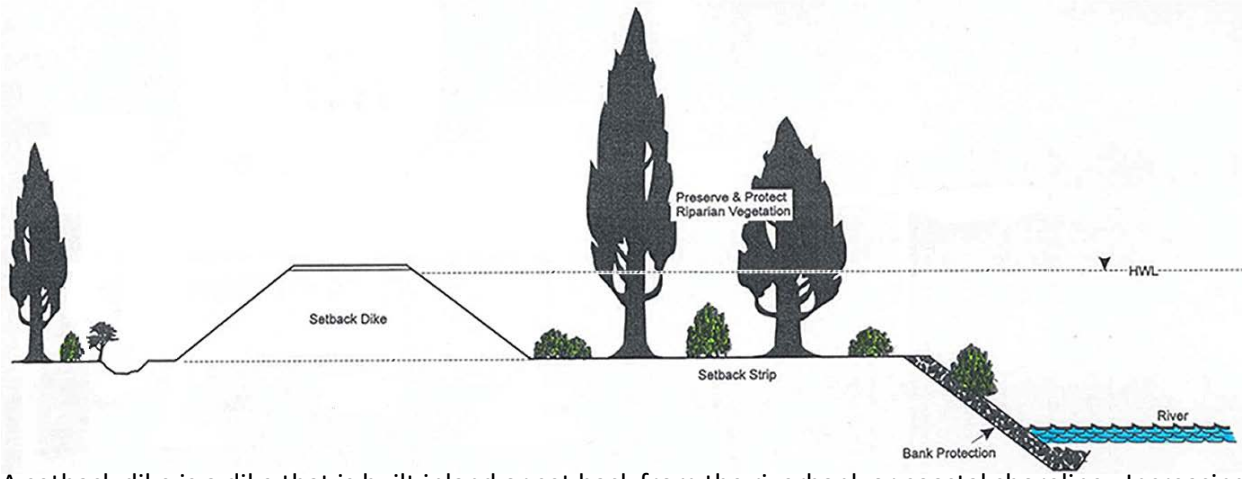
Theme D. Resources and Funding

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

APPENDIX B: Innovative Structural Flood Risk Reduction Measures

Innovative Structural Flood Risk Reduction Measures

Setback Dikes



A setback dike is a dike that is built inland or set back from the riverbank or coastal shoreline. Increasing the distance between the water body and the dike can reduce susceptibility to erosion. In the case of a dike set back from a river, there may also be more room for water flow and temporary storage during a flood.

Depending on size, the land in front of a dike can be used for public recreation, natural wetland and habitat, or potentially other uses, such as agriculture. If there is an existing dike on the bank or shoreline, it can remain to provide some protection for smaller flood events, or it can be lowered or removed entirely. Existing infrastructure and development in the exposed land could be floodproofed.

Benefits	Challenges
Widening the river channel or flood hazard area increases the ability to store water during a flood and could lower water levels elsewhere The dike height could potentially be somewhat lower as the larger flood conveyance area may reduce water levels The dike is less susceptible to bank erosion, water or wave action, reducing long-term maintenance costs The dike would better withstand earthquakes than a dike near the riverbank slope For aggrading rivers and streams, provides additional room for sediment storage giving more flexibility in timing for sediment removal (i.e. facilitates dredging from the channel within the “fish window” rather than on an emergency basis.) Provides more room for riparian habitat, other environmental functions, and “greenway” recreation Lands outside the dike could still be used in non-flood conditions	High cost: usually requires land purchase and rights of way acquisition Community impacts: challenging to construct in built-out communities and would require extensive consultations, negotiations with landowners, and regulatory approvals Any structures left outside the dike would need relocation, raising or other floodproofing (if allowed to remain) Lands outside the dike may be impacted by flooding and debris during flood events

Potential application in BC:

In many BC communities, land values and existing development make moving dikes inland particularly challenging, however large benefits can be realized over the long term. In the 1980's in Chilliwack, the Vedder River setback dikes replaced a 100 m wide riprapped channel with a 600 m wide floodway, providing flood mitigation, enhanced fish and wildlife habitat, parks and trails.

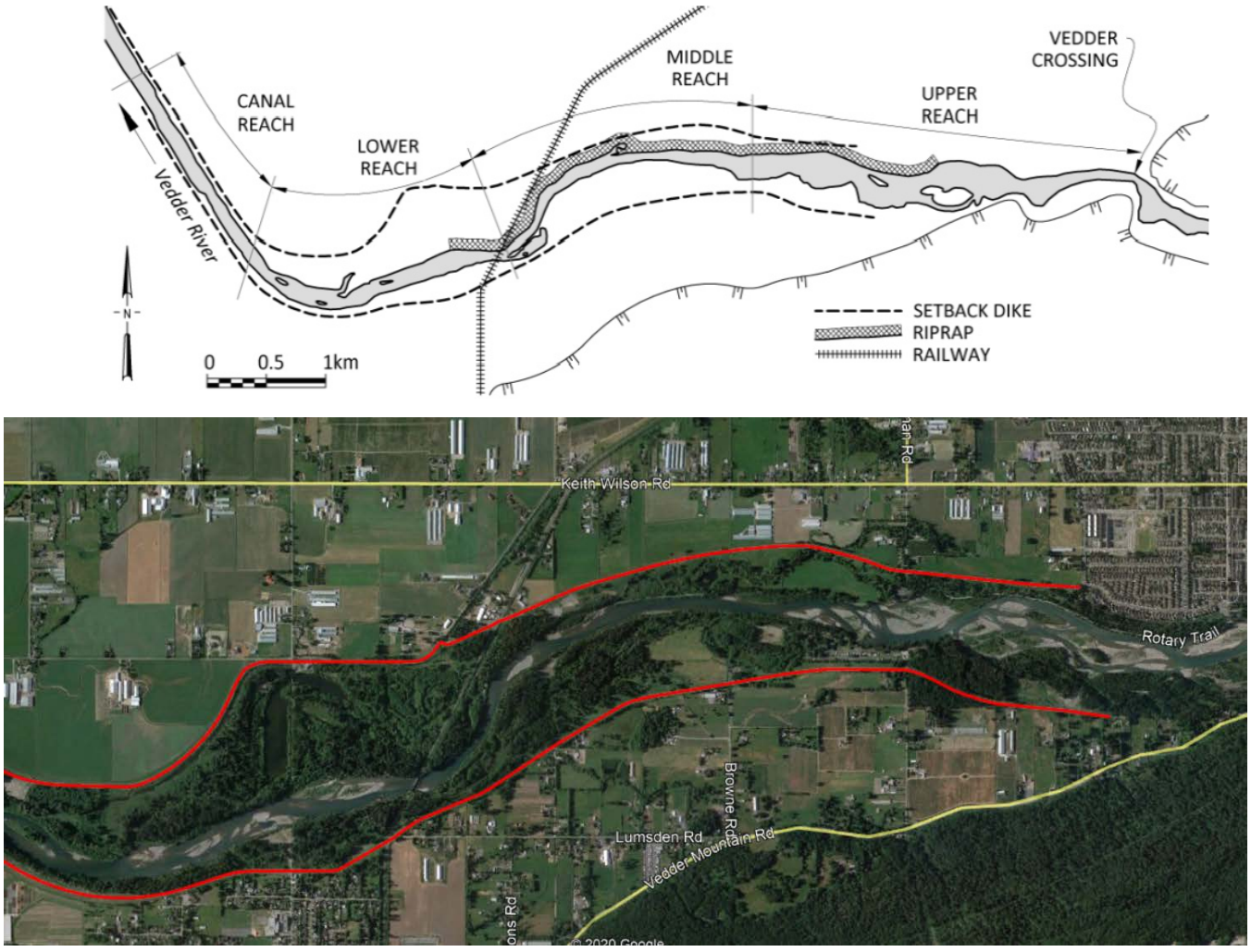
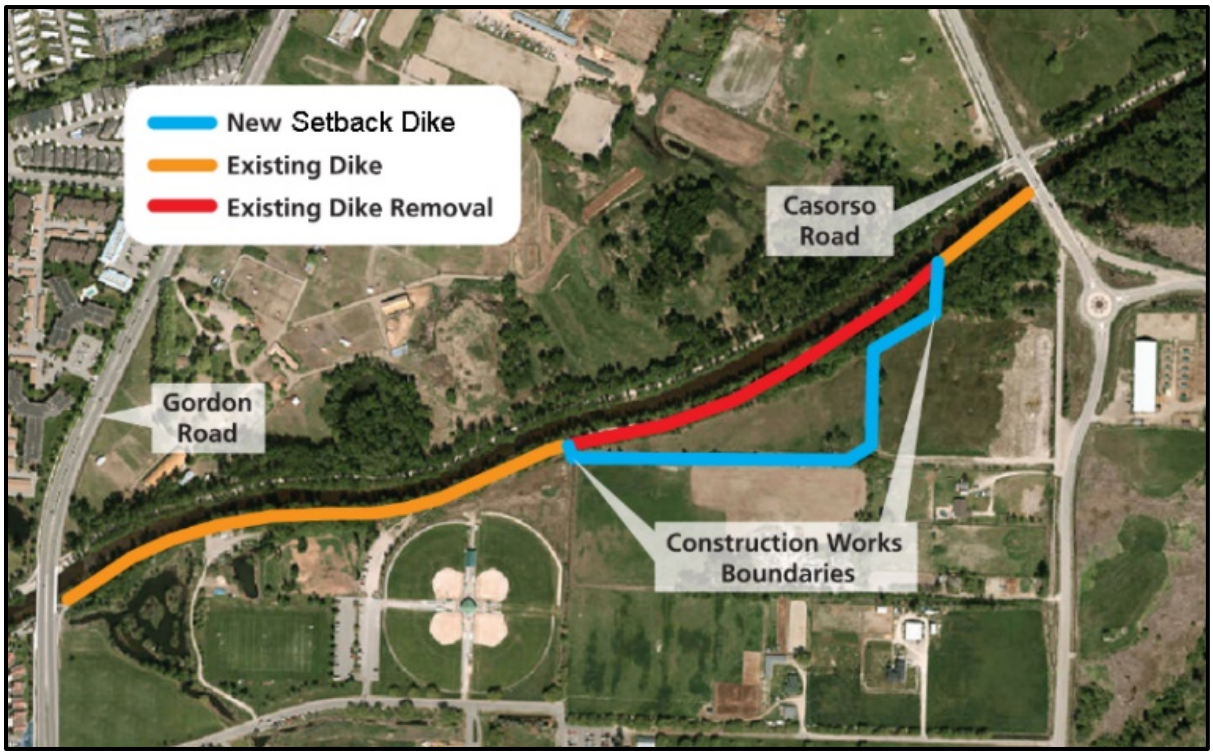


Diagram and Satellite Image of the Vedder River Set-back Dikes, Chilliwack BC Ref: McLean et al (2013)

Setback Dikes

In Kelowna, the Mission Creek Restoration Initiative involved the removal of existing dikes on one hectare of land and construction of 500 metres of new diking around it, widening the channel from 40 metres to 150 metres in that section of the creek. The setback dike allows a portion of the creek to do what it once did before human intervention — meander through oxbows and side channels during the spring freshet. The new dike, completed in 2016–2017, protected properties during freshet floods in 2017 and 2018.



New Setback Dike on Mission Creek, Kelowna, BC

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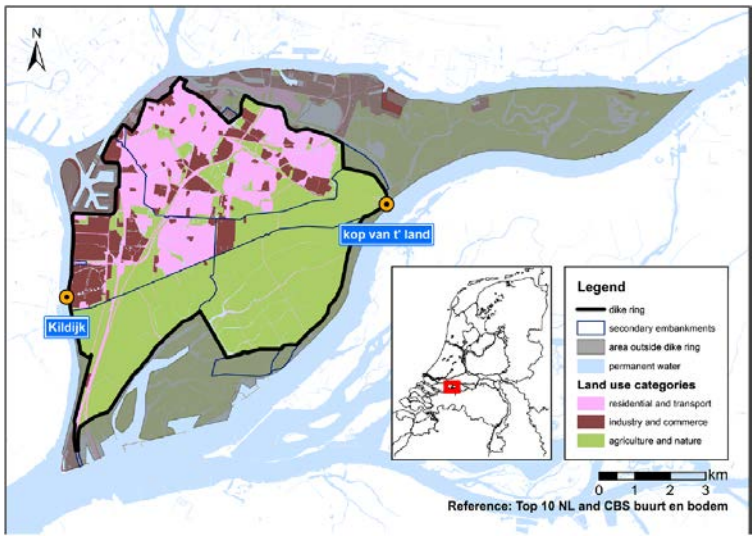
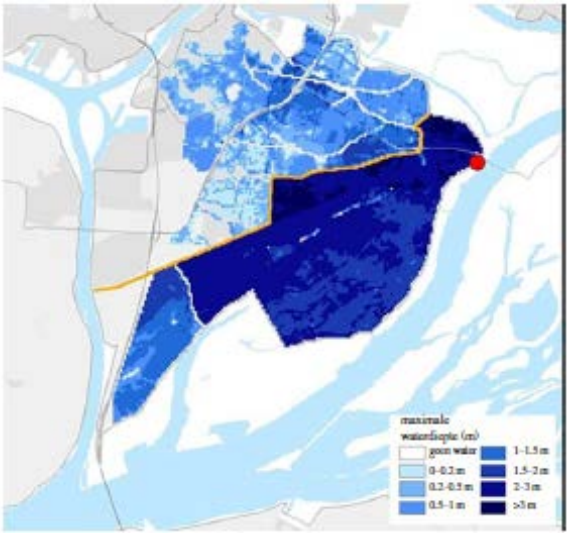
Innovative Structural Flood Risk Reduction Measures

Compartmentalization – Partitioning of Protected Floodplains to Reduce Flood Risk





Effect of a Compartmentalization Strategy on Flood Extent and Depths from a River Dominated Flood, Island of Dordrecht, Netherlands (Bruijn et al 2016 and Zenbergen et al 2020). North part of island is primarily urban – south part is rural.

As BC's diked floodplains become more developed, new risk-based dike standards are needed to better reflect the expected consequences of flooding due to a dike breach. For example, a higher standard of dike protection could be provided for densely developed urban areas than for relatively sparsely populated rural areas. For large diked areas having both urban and rural areas, one potential option to achieve this is to "compartmentalize" the floodplain.

The primary objective of compartmentalization is to diminish the area that can be flooded due to a single flood event resulting from the failure of a dike, thus reducing the consequences of the flood. For relatively large flood plain areas protected by a single "dike-ring" (or dike tied in to high ground) it may be cost effective to upgrade only the part of the perimeter dike that protects the urban area and to connect this to a new embankment that divides the urban from the rural area.

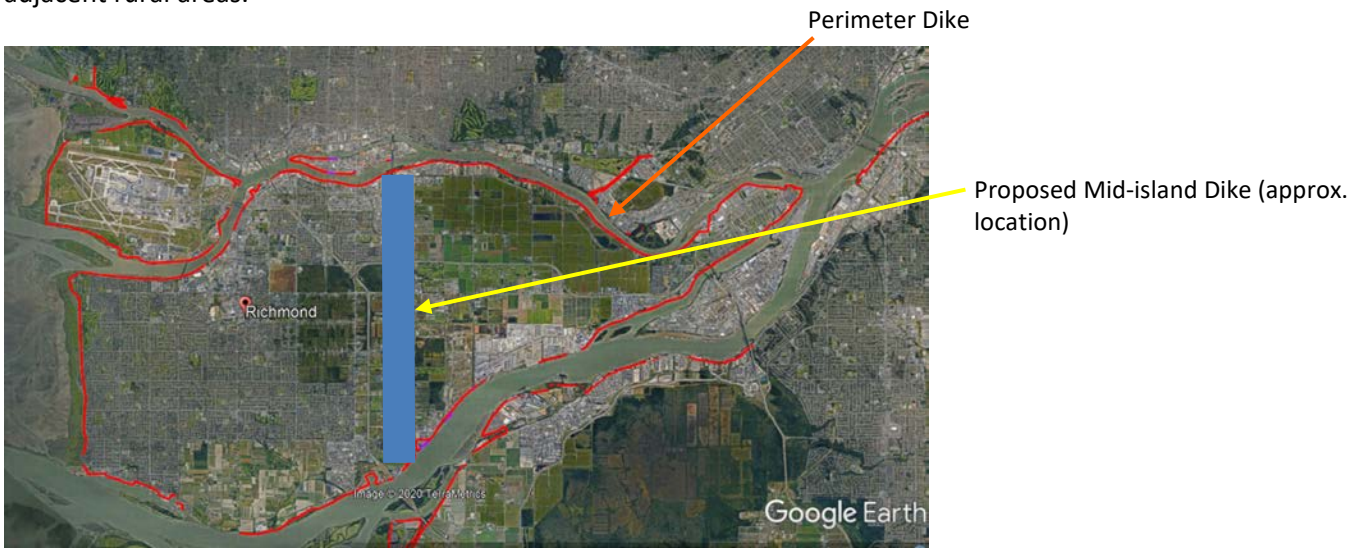
The potential advantages and disadvantages of compartmentalization for the Netherlands were investigated by Klijn et al (2010). Their paper concluded that compartmentalization is a proven concept that can reduce the consequences of disasters in terms of damage and number of people affected. However, from a narrow economic perspective, it may only be cost effective in a few cases such as where the perimeter dikes are very long and the floodplain is "easy" to split up (i.e. only a relatively short dividing embankment is required, or where the dividing embankment follows an existing major transportation route/embankment).

Compartmentalization is likely to be more attractive if the perimeter dike provides a lower degree of protection (higher probability of a dike breach). Economic calculations to compare compartmentalization with the reinforcement of perimeter dikes are very sensitive to flood probability estimates and damage assessment modeling.

Benefits	Challenges
Ability to provide different levels of flood protection for different levels of development on the floodplain (i.e. provides additional protection to highly developed areas and critical infrastructure where costs and impacts of flooding would be much greater) Reduction of the flooded surface area, damage and number of people affected from a single dike breach Easier evacuation of smaller numbers of people, over shorter distances, from the affected compartment Refuge for people on the additional embankments, as well as safe evacuation routes Compartmentalization may be an effective approach for diked floodplain areas affected by both river and tidal (sea) flooding, such as an island in a river delta. A mid-island barrier can: 1) reduce the threat of river flooding from an upstream breach in the perimeter dike to the downstream compartment, and 2) reduce the threat of storm surge flooding from a sea dike breach to the upstream compartment (see Richmond example below).	Challenging to construct in built-out communities or areas with high land values, as a dividing embankment requires new land, rights of way, consultations, and regulatory approvals. Closure sections may be required for crossings by major roads or railways If funding is limited, money could possibly be better spent on phased reinforcing of the perimeter dike There may be political challenges and community opposition to providing different standards of protection within a single local jurisdiction For areas where the floodplain has a downstream river gradient, a dividing embankment could increase the depth of flooding in the upstream compartment

Potential application in BC:

A few BC communities including Pemberton, Chilliwack and Richmond have given at least some consideration to construction of ring dikes or barriers that would give greater protection to developed urban areas than to adjacent rural areas.



Compartmentalization – Partitioning of Protected Floodplains to Reduce Flood Risk

The City of Richmond and Queensborough (part of the City of New Westminster) are located on Lulu Island in the Fraser River Delta. The island is protected by approximately 56 km of perimeter dike. Compartmentalization of Lulu Island with a mid-island dike was first proposed by Hayco (1989). A mid-island north/south barrier (located approximately between Highway 99 and No. 8 road) would isolate the highly developed area of West Richmond from the flood threat of an upstream dike breach during a large Fraser River flood. However, a 2009 scoping study for the City concluded that improvements to the perimeter dike could achieve equal or better levels of protection for West Richmond at lower cost (Delcan, 2009). The City of Richmond's "Flood Protection Management Strategy 2019" is to give highest priority to upgrading the perimeter dike, but the City also plans to re-evaluate the "Mid-Island Dike" concept once the perimeter dike has been raised.

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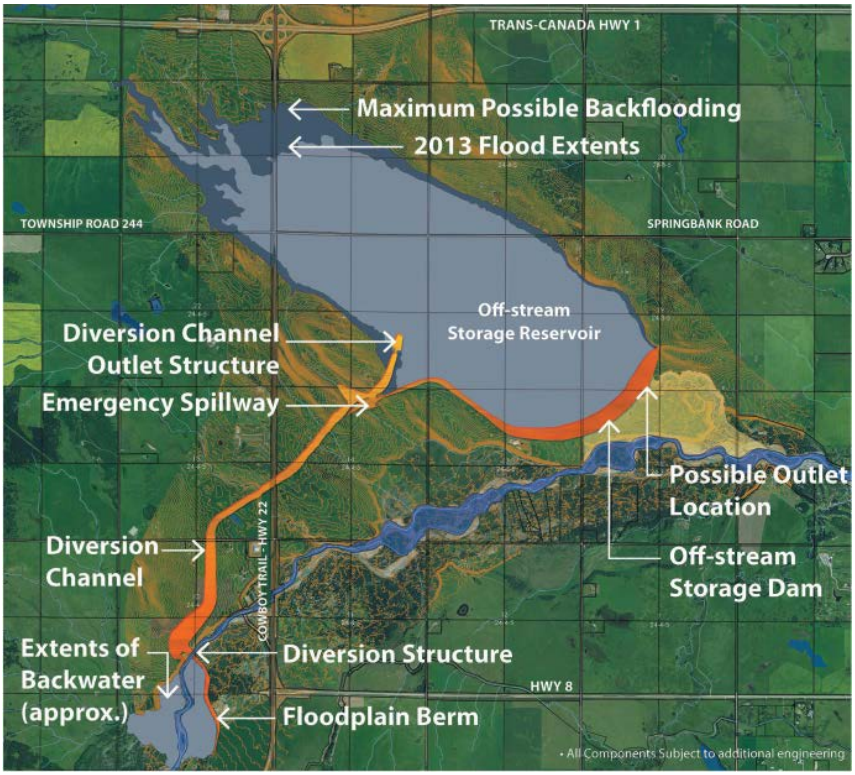

The Proposed Springbank Off-stream Storage Project, Elbow River, Alberta (Knox et. al., 2018)

The temporary diversion of flood flows to an off-stream reservoir and/or preferential flooding of low risk floodplain areas can be effective in reducing the magnitude of downstream flood flows. In the event of a flood, excess water can be redirected into a holding reservoir, or low-lying area of land where there is minimal potential for flood damages. These could be areas such as meadows, parks, wetlands, agricultural/farmland, recreational areas, etc. If agricultural land is involved, the project would need to address economic impacts to landowners and the need for compensation.

The Springbank Off-stream Reservoir Project (image above) is an example of a major diversion and temporary storage project. With a budget of $432 million, it forms one component of a larger flood management plan for the Bow and Elbow Rivers in Alberta. Up to 600 m^3/s of flood flow can be temporarily diverted, reducing impacts to downstream infrastructure and communities. Land acquisition is well under way and the intention of the Government of Alberta is to proceed with the project (Alberta Transportation, 2020).

In the USA, the Federal Emergency Management Agency (FEMA) is encouraging communities to incorporate flood diversion and temporary storage projects to mitigate the impacts of climate change (FEMA, 2017). FEMA's guidance focuses on projects implemented using "green infrastructure" methods as much as possible to address both drought mitigation and flood risk. The projects can also be used to retain water to allow infiltration to ground water supplies, allowing for a controlled stream base flow.

Off-stream Reservoir Storage and Preferential Flooding

Benefits	Challenges
Reduced flood impacts, including damage costs and risk of loss of life Active management of flood waters rather than relying only on dikes to contain high flows The diversion structure of an off-stream reservoir can actively manage flood debris (Knox et al, 2018) Potential for drought mitigation and environmental enhancement through wetland restoration, groundwater recharge etc.	Large areas of low-lying land required that can be temporarily flooded with minimal impact If land not purchased, property owners likely to resist having their land flooded (land could be leased back for farming, if frequency of flooding is very rare) High costs for diversion and other works

Potential application in BC:

Given BC's mountainous terrain, generally narrow valleys and large river flood flows, the potential for development of temporary diversion and off-stream storage projects is limited. However, there may be an opportunity for considering this approach for smaller rivers and streams with relatively wide floodplains.

Network of Spillways in the Serpentine and Nicomekl River Diking System, Surrey BC (City of Surrey, 2017)

One example is the City of Surrey's use of spillways in the Serpentine and Nicomekl River diking system. Specific cells, or areas of the floodplain bounded by dikes, road/railway embankments and high ground are preferentially flooded at very high flows through the construction of armoured spillways in low sections of the dike (see image above). These cells are primarily located on agricultural fields and typically only used in winter months when the fields are fallow. Once the flood event has ended and river level returns to normal, water held in the cells will drain back into the river through flood boxes or with the assistance of pumps.

Off-stream Reservoir Storage and Preferential Flooding

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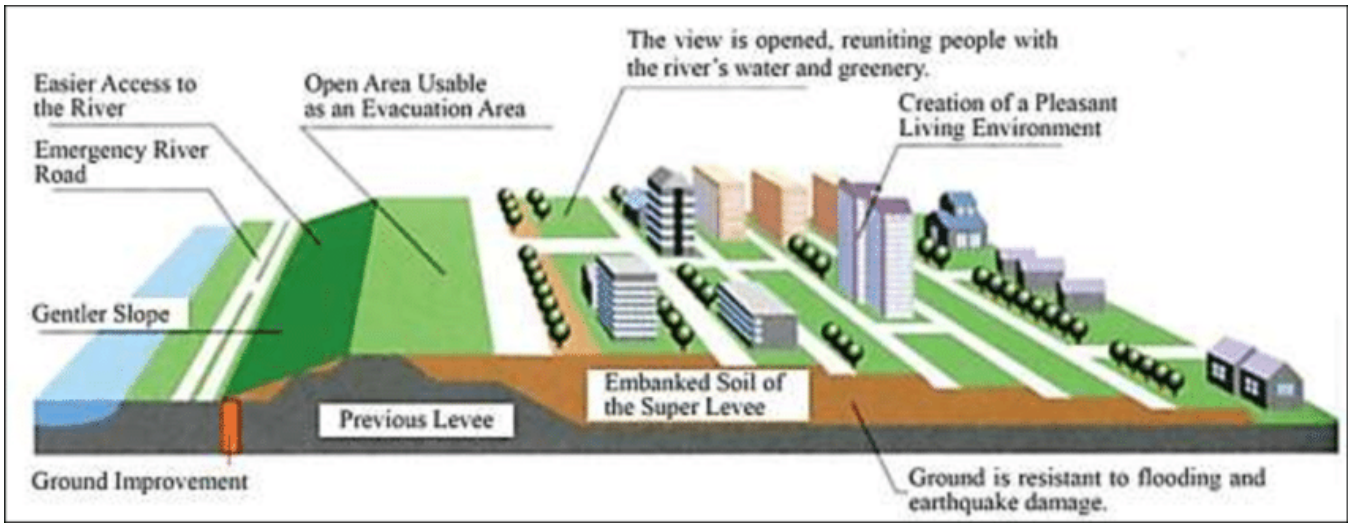
Innovative Structural Flood Risk Reduction Measures

Super Dikes

A super dike is a high embankment with a wide base and gentle slope. It is much larger than a conventional dike and is resilient to earthquakes, erosion and breaching. (Note: the text in this description is from the Fraser Basin Council (2020) FLOODWISE website).

Japan began building super dikes in the late 1980s along rivers in Tokyo and Osaka. These dikes are up to 30 times as wide as they are high. They may also be multifunctional, incorporating residential, commercial and public spaces. Since 2011, super dikes in Japan have been built to protect low-lying areas or densely populated, built-up areas in large cities where serious consequences are most likely to occur in a large-scale flood. The super dike concept is relatively new in other parts of the world.



Ref: Mabahwi et al (2019)

Benefits	Challenges
Super dikes are designed to be more resistant to breach, erosion, and earthquake Multifunctional design is possible Views of the water possible from atop the structure Gentle slopes can offer public amenities and access to water	Requires more land than regular dikes Similar to other dikes: • Can be overtopped if not sufficiently high • Over-reliance on super dikes can lead to more development and higher losses from a flood • On a river, they could constrain the channel Land acquisition and construction are a complex and expensive undertaking; requires long term land use planning Ownership and tenure issues for structures on (or inside) the dike

Ref: Super Levees along Arakawa River, Japan (see link below)

Potential application in BC:

In BC, the City of Richmond is integrating super dikes into its long-term flood plan for Lulu Island. The concept involves raising the land on the landward side to the same elevation as the dike crest. The District of Squamish is also looking at the prospect of super dikes in that community.

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Innovative Structural Flood Risk Reduction Measures

Flood Walls

Left: Demountable Flood Protection System on Danube River in Grein, Austria (Williams, F)
Right: Permanent glass flood wall with minimal visual intrusion in Waterford, UK (Flood Control International)

Flood walls are vertical barriers designed to contain floodwaters from rivers and waterways. They function similarly to a dike but require far less land. There are two types of flood walls: temporary/removable, and permanent. Temporary flood walls have a permanent foundation with the "wall" being removable. The above photo on the left is an example of a temporary flood wall from Grein, Austria. The foundations are permanent, but when a flood is not likely/imminent, the support columns and planks (stoplogs) can be removed for better local aesthetics, and pleasing views of the water feature.

Permanent flood walls are built to remain in place and act as constant, continuous flood protection. This is particularly important when the walls are protecting against unpredictable storm/flood events. The photo on the right depicts a glass flood protection barrier that provides visually pleasing flood protection while reducing installation/removal costs associated with temporary flood walls.

A major consideration for flood walls is the type of soil that the structure will be constructed upon, regardless of using a temporary or permanent design. The Federal Emergency Management Agency (FEMA, 2007) notes two important soil parameters to be considered: bearing capacity and permeability. If the soil has low bearing capacity, the flood wall may begin to sink and/or fail structurally due to differential settling. If the barrier sinks, the design height decreases, and the flood wall no longer protects against the anticipated design storm.

If the soil permeability is too great, water seepage under the flood wall becomes a major issue. Geotechnical design features, such as the use of deep cutoff walls, would be required to counteract seepage under flood walls on permeable soils, however this would greatly increase costs. Alternate flood protection measures would likely be preferable if soil permeability is too great.

Flood Walls

Benefits	Challenges
Minimal land requirement Useful where there are space or grade restrictions Can be "demountable" where there is adequate flood warning and time for installation. (this is an advantage for access and aesthetics, but requires space for storage of materials and a trained crew to install when needed).	Disadvantages over earth embankments: High seepage gradients at base – need for careful geotechnical design and construction control. Very inflexible as to future raising if flood profiles change. Difficult to flood fight (i.e. can't raise during an event). Walls are rigid structures and susceptible to cracking if there is differential settlement or ground movement. The waterproofing of lock block walls may fail if there is excessive movement. Riverbank erosion protection may be required - but the presence of the wall could make it difficult to maintain the erosion protection. The upstream and downstream tie-ins of a floodwall to high ground, or to earth embankments need careful design, to address seepage and differential settlement problems. Typically flood walls (if properly designed for all of the above) are much more expensive than other options. May be less seismically resilient or repairable.

Potential application in BC:

Given the above challenges, the BC Inspector of Dikes generally does not accept flood walls as part of a diking system unless there are no other alternatives. Where they have been approved, they are usually very short sections that deal with severe space, or grade restrictions (e.g. where a dike closure is required over a road or railway crossing). For example, the City of Surrey's South Westminster dike has several floodwall sections for road crossings, where the road grades could not be raised.

Costs:

Flood walls are typically more expensive than dikes (Sustainable Buildings Initiative, n.d.) and costs will be very dependent on site-specific conditions. With respect to "floodproofing" projects for individual homes, a homeowner on the Ottawa River spent approximately $100,000 on a demountable flood wall and related works to protect a 40 m shoreline (CBC 2020). Although costs are highly variable, the unit costs of permanent flood walls have been reported to be in the order of 2 to 3 times higher than earthen embankments (Aerts 2018) (FEMA 2007).

A UK Environment Agency (2015) publication provides a methodology for cost estimation of demountable and temporary defences in the UK. Estimation of operational costs become an important factor in assessing costs/benefits in comparison to other flood mitigation alternatives.

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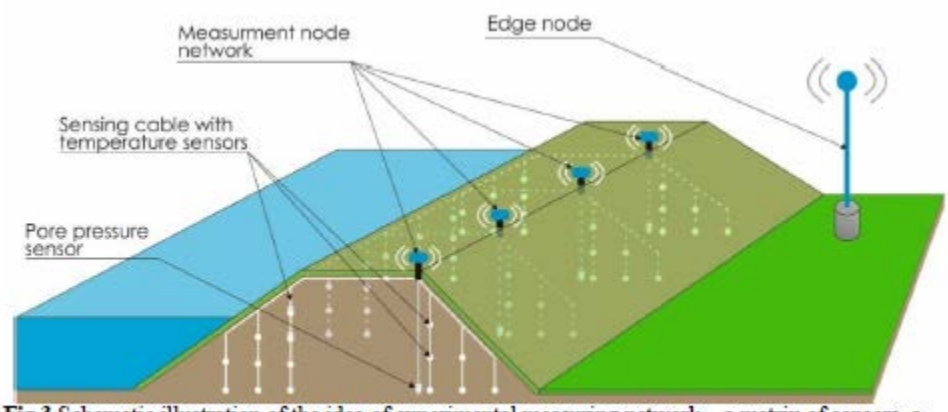
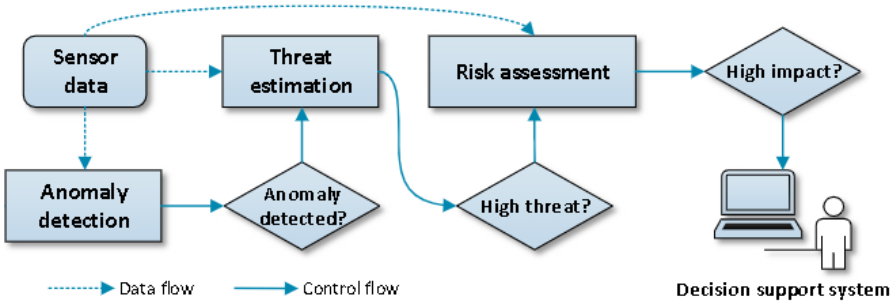


Fig.3.Schematic illustration of the idea of experimental measuring network – a matrix of sensors, a number of measuring nodes and an external base station from the edge node[7].



Source: Top: Sekuła et. al. (2018); Bottom: Balis et. al. (2017)

Smart Dikes are dikes that allow information on the structural integrity to be stored, monitored, and predicted. The "smartness" is not only in the application of sensor technology, but also in knowledge of the potential failure mechanisms of the dike and the coupling of these two elements.

In the Netherlands, studies have been conducted to determine the most effective use of this technology, since it is not feasible to convert all dikes. Hopman et. al. (2011) state that there are three categories of dikes that could benefit from the smart technology:

1. Dikes to be used as reference locations for frequently encountered types of dikes, this may cover up to 80% of all dikes (in the Netherlands) by instrumenting only a limited number of sections;
2. Problematic dikes or weak sections according to calculations; and
3. New levees and large scale upgrading of existing dikes.

The more important dike parameters to monitor include pore pressure, movement (strain, tilt, consolidation, deformation) and temperature. Pore pressure and deformation are important for determining slope stability. Monitoring of pore pressure and temperature are key to understanding seepage erosion by piping (Hopman et. al., 2011). While it is valuable and important to continue to monitor dikes through visual, human inspection, some important indicators of dike failure cannot be observed in this process.

Benefits	Challenges
Embedded sensors provide information on dike condition during high water events. Could greatly assist effective evacuation decisions, well in advance of potential dike breaching. Not all dikes need to be "smart". Dikes deemed most at risk/poorest quality and dikes determined to be of greatest importance can be upgraded with sensors as a first priority Provides information for designing of dike upgrades Increases confidence in dike reliability and structural integrity.	New technology still being tested. Minimal real-world applications to date.

Potential application in BC:

With respect to an example of dike instrumentation, the City of Chilliwack has used real-time monitoring technology to track the differential of Fraser River levels vs. groundwater levels within a section of the East dike (Frank Van Nynatten, City of Chilliwack, pers. com.).

Experience and technology developed in other jurisdictions (and from dam safety practice in BC) could be adapted to develop a Smart Dike pilot project for a BC dike. Potentially weak and/or critical sections of a "High Consequence Dike" could be considered first. On the lower Fraser River for example, a suitable pilot project could be located where the dikes are high and susceptible to high seepage flows (e.g. where the dikes cross former river channels or sloughs). Combined with flood level forecasts, dike breach modeling and other information, the monitoring and prediction of dike integrity at these critical locations would be of major assistance to emergency planners and responders.

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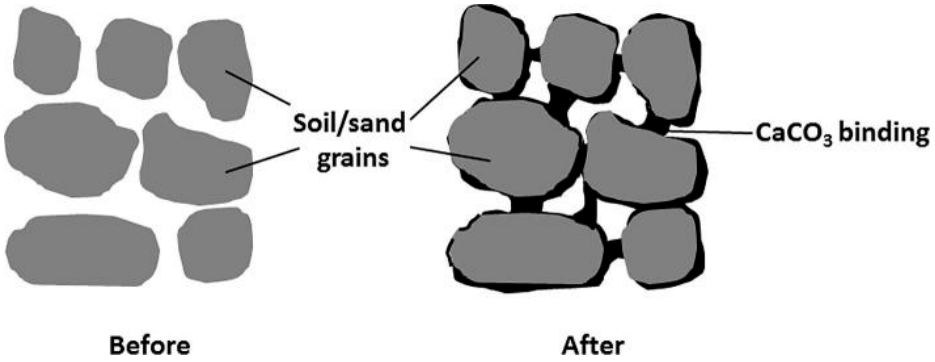

Schematic Representation of Soil/Sand Biogrouting with $CaCO_3$ (Krajewska 2017)

Bio-grouting (also known as bio-cementation or bio-mineralization) is the process of using bacteria to strengthen soil materials. These methods have been developed to provide alternatives to conventional grouting techniques. Successful development and implementation could have a wide application to many important geotechnical problems including liquefaction mitigation, enhancement of bearing capacity and reduction of associated settlements, slope stabilization, and reducing permeability to reduce seepage through, or beneath dikes and cut-off walls (Khodadadi et al 2018). By spraying bacterial cells and nutrient solutions into the surface sand of a dike, bio-grouting technology also has potential to be used for erosion control (Lu et al 2016).

Microorganisms can secrete calcium carbonate in environments rich in calcium ions, primarily by increasing the pH. There are various methods and technologies being developed using ureolytic bacteria, which increase pH by hydrolyzing urea, thus precipitating calcite, the crystalline form of calcium carbonate ($CaCO_3$) (Krajewska, 2017).

The process of precipitating calcium carbonate requires alkaline pH (pH > 7) as calcite dissolves in acidic environments, and significantly so at a pH of 4 or less (Blauw and Harkes, 2013). The precipitated calcite naturally binds to the soil medium and strengthens the internal cohesion of the soil by creating calcite bridges between particles. This reduces the void space within the soil, further strengthening the material. Additionally, reduced void space causes greater resistance to water flowing through and eroding the soil structure.

The potential for backward erosion of dikes (i.e. seepage induced “piping”) is reduced using bio-mineralization. With bio-mineralization, one study by Blauw and Harkes (2013) showed that the hydraulic head required to initiate internal erosion was increased by three times.

The process of bio-mineralization can be applied in situ with negligible impacts to the environment (Krajewska, 2017). This allows dikes that are already built and fully functioning to be enhanced and reinforced, rather than having to rebuild dikes using the new process. According to Blauw and Harkes (2013) it can be applied in areas that have limited access, due to the requirement of minimal equipment for application. However, bio-mineralization is new technology and has only been successfully applied on small-scale projects in the Netherlands and China (Katz, 2013; Lu et. al., 2016).

Bio-grouting/Bio-cementing

Benefits	Challenges
In situ application to current dikes Minimal environmental impacts during and post application Relative ease of application in areas with limited access Increased liquefaction resistance, increased strength and reduced soil permeability Potential to use vegetable waste for bio-mineralization (study by Omar et. al., 2018)	Can be costly depending on application (location, size, required strength, etc.) New technology still being tested. Minimal real-world applications to date. Byproducts of ammonium and chlorine ions, which pose ecological risks. These effects can be minimized by using lower concentrations of urea (an ingredient required by the ureolytic bacteria to precipitate calcite), and conducting a decontamination process after application. Generally, coastal BC has relatively acidic rock types and can have low pH groundwater. This could cause complications since calcite begins to dissolve in acidic environments. May be more effective where soils are derived from calcareous (limestone) rock. The bio-mineralization reaction is also temperature dependent. Blauw and Harkes (2013) found temperature requirements to be in the range of 5 – 70 °C, indicating that for BC, the optimum time of year for application would be summer.

Preliminary costs:

According to the study by Blauw and Harkes (2013), the main costs for biomineralization are "the production of bacteria, the treatment of ammonium chloride and costs for urea/ calcium chloride. The costs depend per application (e.g. location, size, required strength), but are in the range of high-grade technologies (500 - 1000 € /m^3)" ($685 - $1370/$m^3$ $CDN).

Although the use of bacteria to cause calcite precipitation is more developed, significantly lower costs (i.e. by an order of magnitude) may be possible with the use of the purified enzyme (urease) which can be extracted from plant sources (Krajewska 2017). For a rough comparison, "conventional" ground improvement costs for seismic stabilization can vary from about $20/ m^3 for vibro-replacement to $250/ m^3 for deep soil mixing (Delcan, 2012).

Potential application in BC:

The potential for application in BC is unknown at this time, however a pilot study test with a dike in the Fraser Delta could be useful to determine effectiveness and costs.

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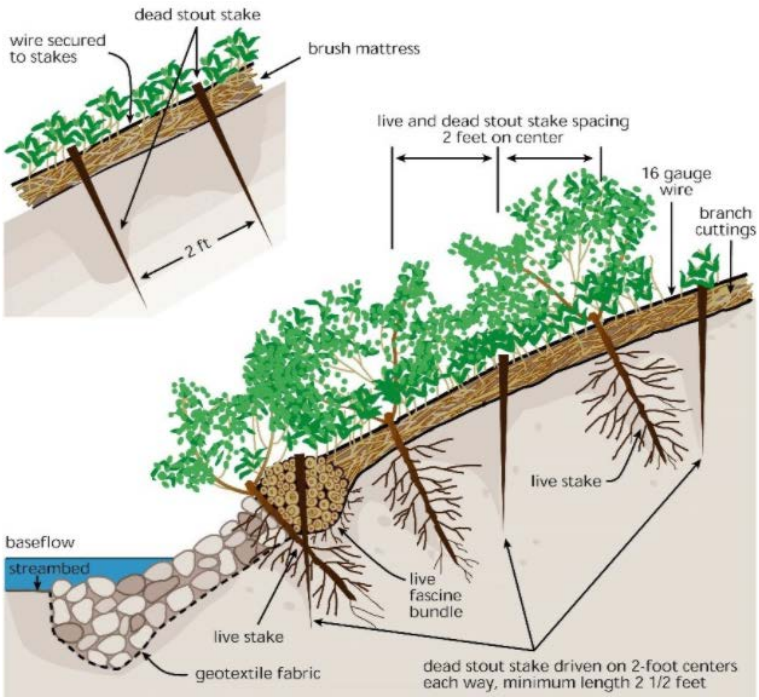


Brush Mattress Erosion Protection FISRWG (1998).

Eventually the coir fabric and the structural earth wall itself will be completely overgrown with hydro-seeded grass and other vegetation.

The completed project, a short distance down the road, is now fully vegetated and looks entirely natural.

Soil Wrap Structural Earth Wall FEMA (2009)

Rip rap is the installation of angular rock (and usually a filter layer) to protect native materials from the natural processes of river currents, waves, and ice action. It is the most commonly used method to slow or prevent riverbank erosion[1]; however, rip rap can have negative impacts to the natural physical and ecological processes of the surrounding environment that support wildlife and fish.

For example, where rip rap is used in a river, it tends to increase the local flow velocity, which causes erosion to occur in new places further downstream. Additionally, rip rap hinders the natural functions of the natural shoreline and riparian zone, which provide a buffer against erosion and serve other important ecological functions such as moderating water temperature, nutrient exchange, and retention of coarse organics in the stream channel (e.g. leaf litter, woody material, and fish carcasses). The hydraulically smoother surfaces of riverbanks treated with rip rap provides fewer opportunities for fish to find refuge during flood events and can lead to increased predation during lower flow periods.

There are several alternatives to rip rap that mitigate the negative effects outlined above by incorporating natural elements of live vegetation or woody material to enhance or replace the use of rip rap. Technical guidance related to the application of some of these techniques is provided by US Army Corps of Engineers (1997) and BC Ministry of Environment (1995). The design of habitat friendly alternatives to rip rap should consider several factors including:

[1] Approaches to address coastal shoreline erosion are discussed in a separate document, also in Appendix B.

- Riverbank zones: The location on the riverbank - for example, riverbank erosion is mostly focused on the lower toe, while upper bank erosion occurs because of undermining and then slumping.

- Scale: some of these techniques are better suited to smaller stream channels versus larger rivers.

- Matching the technique/approach to the natural system, including ensuring that vegetation that is used is native to that area. For instance, large woody debris structures are used on coastal streams because they are a natural feature in this environment due to the adjacent forest of large trees. Large woody debris structures would not necessarily be naturally present in a river flowing through grasslands.

- Exercising caution where protection of critical infrastructure or protection of human life is at stake. The techniques are typically employed at locations with lower consequence of failure.

- In contrast to rip rap design, which is supported by extensive research, field studies, and long usage, there is very little design guidance or engineering standards for these alternative approaches. Of the techniques reviewed, large woody debris structures are probably the best supported by engineering design guidance, yet there remains considerable uncertainty around their design and lifespan.

To illustrate the types of design options, a few examples are described briefly below.

Brush mattresses: A brush mattress consists of a thick (15 to 30cm) blanket of living cuttings and soil fill that is placed on a stream bank or lake shore to simultaneously re-vegetate and armor the bank. This method provides resistance to erosion because the dense layer of brush increases roughness, reduces velocities at the bank face and protects the bank from scour. As the live branches root and grow, they provide cover and reinforcement for the soil underneath. If these mats are used on stream banks, they trap sediments during high water and eventual plant growth will enhance aquatic habitat. This method is relatively cost effective but can be quite labour intensive depending on the area (Alberta Sustainable Resource Development, 2011).

Live Staking: Live cuttings are staked into the bank to stabilize the shoreline, allowing for the re-establishment of riparian vegetation. Pro: versatile technique, little environmental disturbance, low cost. Con: does not provide immediate protection (i.e. requires about two years to establish) (Rideau Valley Conservation Authority (RVCA), 2011). However, live cuttings will generally not provide protection for the lower riverbank zone where water depths prohibit growth.

Planting/Riprap Combination: Planting of riparian vegetation along shoreline with stone/rock placed on lower banks for stabilization. Pro: combines protection of the toe with a durable material and rehabilitation of the upper bank zone to enhance riparian function. Con: rock protection typically requires heavy machinery for re-grading purposes with moderate disturbance to the environment (RVCA, 2011).

Coir logs: Coconut/synthetic fibers bound together into a cylindrical structure and placed along the shoreline to absorb wave energy and allow vegetation to establish. Pro: bundles are flexible and capable of molding to the shoreline. Con: not suitable for high velocity or shear stress areas (RVCA, 2011).

Structural earth wall composed of soil wraps (see above photos): A section of the Snohomish River where it flows beside Riverview Road in Snohomish County was stabilized using stepped soil wraps of geo-grid fabric weighted with layers of gravel-borrow. Heavy coir fabric and topsoil covered the outside of the wall. The slope is then hydro-seeded and planted with live willow cuttings (FEMA, 2009).

Engineered Logjams: complexity from log jams is important for slowing down the river, and pools that establish behind provide valuable habitat and refuge for fish and other aquatic life. On the Mashel River, near the town of Eatonville, Washington, rip rap erosion protection was removed and replace with engineered logjams. FEMA (2009) note that typically, natural logjams are stabilized by very large pieces of wood. In this case the engineered logjams were stabilized using vertical log pile structures and gravity structures. The vertical log piles provided lateral stability, and gravity structures held the logjams in place through height and weight.

Rock groins with large log skeleton: The Big Quilcene River in Hiddendale, Washington, underwent bioengineering of a section of river in 1996. Large trenches were dug and filled with rocks, then large logs and root masses were added to provide structural support and stability. Branch cuttings and more rock were placed on the logs and then filled and covered with topsoil. Willows, dogwoods, conifers, and other trees were planted to create a mat of roots to help stabilize the riverbank (FEMA, 2009).

Rock spurs: installing rock spurs avoids applying rock in a continuous revetment along the shoreline, leaving some areas untreated, and improves hydraulic complexity in the channel. It is also possible to protect the bank between the spurs with large woody debris structures. For example, at a site on the Lillooet River downstream of Pemberton, subsequent monitoring noted very high fish usage in the channel between the spurs (D Ray, pers com).

Benefits	Challenges
Maintains and enhances natural habitat and ecosystem function. Filters nutrients and pollution from upland runoff and can help to improve water quality. Aesthetically pleasing Can strengthen the shoreline long term Can increase property value Avoids transferring erosion issues to adjacent riverbank or shoreline	May require additional land for a wider channel or greater shoreline setbacks May take time to establish full vegetative growth May reduce channel capacity and/or increase flood levels in constricted channel sections May not be an appropriate erosion protection solution where there are high flow velocities and/or intense wave attack/ice action, and where a very high standard of protection is required (i.e. usually not an acceptable alternative for large riprap that provides primary erosion protection for a dike or other critical infrastructure). Lack of established engineering design standards

Potential application in BC:

These techniques must have enough "hardness" to prevent scouring of the streambank toe and be correctly designed to prevent outflanking at either end of the treated section. A combination of hard points (groins or other structures) with appropriate treatment of the mid and upper bank using native plant species may be necessary. Work in the 1990s related to the BC Watershed Restoration Program developed many techniques applicable to BC, but in-stream structures were more typically designed to withstand a one in 50 flood event (Slaney and Martin, 1997) rather than to meet a dike design standard of one in 200.

Most of the referenced sources state that these alternatives to rip rap are cost effective. RVCA (2011) notes that "In general, shoreline work carried out using naturalized approaches and concepts can have an overall economic

benefit over more traditional erosion control methods (i.e. rip-rap, armour stone)." Both the RVCA paper and a document prepared by the US Department of Agriculture (2014) highlight some of the cost factors including site-specific attributes such as slope and access, project scope, availability/source of materials, equipment needs/availability, and labour costs.

References and Links:

Alberta Sustainable Resource Development. (2011). *Lake Shoreline Stabilization Techniques*. https://www.parklandcounty.com/en/live-and-play/resources/Documents/PRC/iceheave/Shoreline-Stabilization-Sample-Plans.pdf

BC Ministry of Environment (1995). *Bioengineering Techniques for Streambank Restoration* Watershed Restoration Proj. Rpt No. 2 by Martin Donat. https://www.for.gov.bc.ca/HFD/library/Documents/bib16124.pdf

Calgary, City of (2014). *Design Guidelines for Erosion and Flood Control: Streambanks and Riparian* https://www.calgary.ca/content/dam/www/uep/water/documents/water-documents/design-guidelines-for-streambank-stability-and-riparian-restoration.pdf

Calgary, City of (undated). *Bioengineering Demonstration and Education Project: Technical Project Details* https://www.calgary.ca/uep/water/watersheds-and-rivers/riverbank-health/bioengineering-demonstration-and-education-project-technical-project-details.html

FEMA (2009). *Engineering With Nature: Alternative Techniques to Riprap Bank Stabilization*. https://www.fema.gov/pdf/about/regions/regionx/Engineering_With_Nature_Web.pdf

FISRWG (1998). *Stream Corridor Restoration: Principles, Processes, and Practices. Federal Interagency Stream Restoration Working Group,* *http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043244*

Rideau Valley Conservation Authority (2011). *Solutions for Shoreline Erosion A Basic Guide to Bioengineering*. *https://www.rvca.ca/media/k2/attachments/SolutionsforShorelineErosion_PDF_EN1.pdf*

Ray, D pers. com. Derek Ray, P. Geo. Principal, Northwest Hydraulic Consultants Ltd.

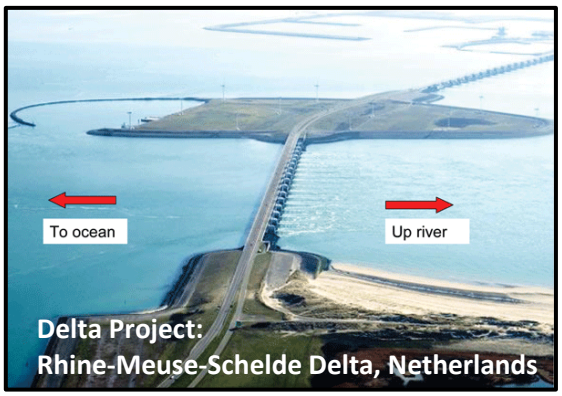
Slaney, P.A. and Martin, A.D. *The Watershed Restoration Program of BC: Accelerating Natural Recovery Processes, Water Quality Resources Journal of Canada, Vol 32, No 2 1997* http://digital.library.mcgill.ca/wqrj/pdfs/WQRJ_Vol_32_No_2_Art_07.pdf

US Army Corps of Engineers (1997). *Bioengineering for Streambank Erosion Control; Report 1, Guidelines.* Technical Report EL-97-8 https://www.engr.colostate.edu/~bbledsoe/CIVE413/Bioengineering_for_Streambank_Erosion_Control_report1.pdf

US Department of Agriculture (2014). *Scenario Cost: Practice 580 - Streambank and Shoreline Protection*. Natural Resource Conservation Service, Tennessee. *https://efotg.sc.egov.usda.gov/references/public/TN/CostSenarios_580_Streambank_and_Shoreline_Protection.pdf* and (2007) *Streambank Soil Bioengineering – Technical Supplement 14I* https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17818.wba

Innovative Structural Flood Risk Reduction Measures

Sea Gates and Barriers



Description:

A sea barrier (also known as a storm surge barrier) is a structure at the mouth of a river or inlet that can be closed against coastal storm surge or high tides to prevent flooding. Modern versions feature moveable sea gates, which stay open most of time to accommodate tidal action, ship navigation, marine life and estuary ecosystems. The gates close during storms and high-water events to prevent surges from moving up inlets, rivers and estuaries. (Note: most of the text in this description is from the Fraser Basin Council (2020) FLOODWISE website).

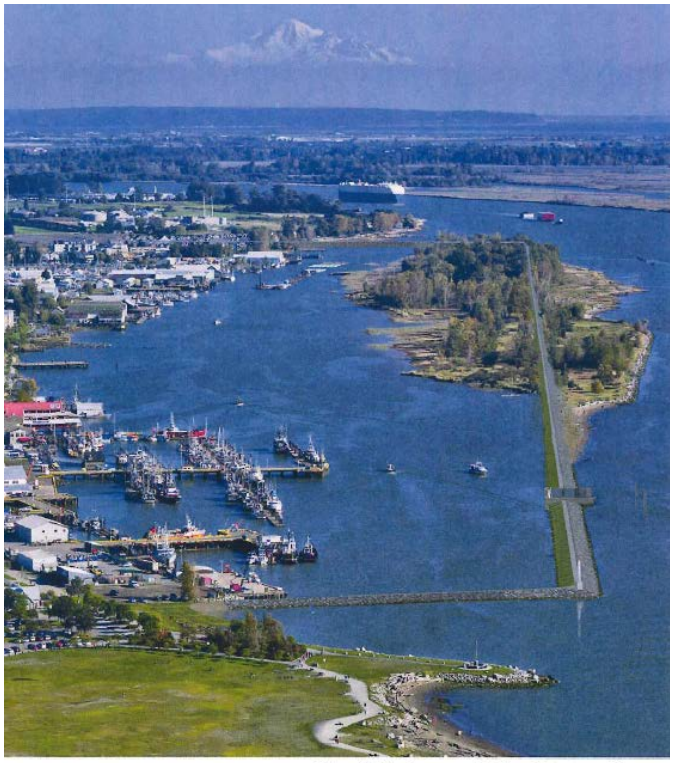
In the Netherlands, Delta Works is a series of 13 sea barriers and dams that defend against storms on the North Sea. Other well-known works include the Thames Barrier (London), Eider Barrage (Tonning, Germany), St. Petersburg Dam, MOSE project (Venice) and Marina Barrage (Singapore). In the United States, storm surge barriers to provide protection against Atlantic hurricanes include those in New Orleans, New Bedford, (Massachusetts) and Providence (Rhode Island).

Potential Benefits	Potential Challenges
Help reduce storm surge and high tide flooding	Costly to build, operate, and maintain
May allow lowering of onshore defenses	Lifespan may be shortened by climate change effects such as sea level rise and higher river flows
Can incorporate other benefits, such as: • wind and tidal energy generation • public attractions within or along the barrier	Specialized expertise is needed for construction
	Soft soils, particularly in areas subject to seismic instability, may make barriers less feasible or increase construction costs
	Closed gates can damage marine or estuary environment behind the barrier

Potential application in BC:

In the City of Surrey, the flows of the Nicomekl and Serpentine Rivers are controlled by “sea dams” that were constructed in the early 1900s and repaired/refurbished in 1973 by the Fraser River Flood Control Program. Regulated as Dikes under the *Dike Maintenance Act*, these flood control works span a cross-section of both rivers to minimize the flooding that could result during high tide and coastal storms. They also block most of the saline seawater from flowing in at high tide and thus support agricultural access to freshwater that would otherwise be unsuitable due to natural brackish conditions. Both dams are currently being re-designed and will be replaced as part of the City’s ongoing Coastal Flood Adaptation Strategy.

Location of Sea Dams on the Serpentine and Nicomekl Rivers, Surrey, BC



City of Richmond Dike Master Plan
Steveston Island Concept

Other municipalities in the Lower Mainland are considering the use of sea barriers for flood management.

For example, the City of Richmond is considering the future construction of a Steveston Island offshore dike with a sea gate, if further studies determine it to be cost effective (City of Richmond 2019).

The advantages of the offshore dike alignment with a sea gate vs. raising the existing shoreline dike include less disruption to existing buildings and infrastructure in Steveston, and that the offshore structure would be easier to adapt to future sea level increases.

References and Links:

Fraser Basin Council (2020) FLOODWISE in BC's Lower Mainland. Information Portal on Flood Risk Management https://floodwise.ca/

Richmond, City of (2019) *Flood Protection Strategy 2019* https://www.letstalkrichmond.ca/floodprotection2019 and Dike Master Plan – Phase 1 Report https://www.richmond.ca/__shared/assets/DikeMasterPlan_PWT_04171335480.pdf

Surrey, City of (2019) Coastal Flood Adaptation Strategy – Final Report*, November 1, 2019* *https://www.surrey.ca/sites/default/files/media/documents/CFASFinalReportNov2019.pdf*

Storm Surge Barrier, science Direct:
https://www.sciencedirect.com/topics/engineering/storm-surge-barrier
The Netherland's Impressive Storm Surge Barriers:
https://www.amusingplanet.com/2014/04/the-netherlands-impressive-storm-surge.html
Storm Surge Barrier Advantages and Disadvantages:
https://www.coastal-management.eu/measure/flood-and-storm-surge-barrier

Innovative Structural Flood Risk Reduction Measures

Living Breakwaters

City of Richmond Dike Master Plan
West Dike Breakwater Concept

A coastal breakwater is an engineered offshore structure, usually made of concrete or rock that is designed to disperse wave energy and reduce shoreline erosion. The waters on the shoreward side of the breakwater are calmer and the wave component of a storm-driven flood is reduced, thus reducing the design height for shoreline sea dikes.

Breakwaters are generally built parallel to the shoreline. They may be attached to the shore or unattached (as in barrier islands), and above water or fully submerged. They may be built as a single structure or a series of structures.

Living breakwaters, or artificial reefs, are structures designed to provide habitat for aquatic species and/or be colonized by coral or oysters. Living breakwaters can be designed to protect against the effects of storms and coastal erosion. A proposed project in lower New York Harbour consists of a 1.6 km long system of breakwaters with reef-like habitat enhancements. The works are specifically designed to attenuate damaging storm waves, reduce or reverse long-term coastal erosion, enhance ecosystems by creating structured marine habitat, and foster social resilience by encouraging the use and stewardship of the shoreline and nearshore waters (Baker et al 2018).

Potential Benefits	Potential Challenges
Can help dissipate wave energy Living breakwaters have co-benefits, such as marine refuge areas and underwater recreational opportunities Can be expanded as seas rise	Can disrupt natural shoreline function and change existing marine habitat Can affect sediment transport Can affect transportation and navigation Are expensive to build and maintain

Potential application in BC:

As part of flood mitigation planning for future sea level rise, the City of Richmond is considering the potential design and construction of off-shore barrier islands using dredged sand to provide both wave dissipation and habitat (see concept image above). The UBC Coastal Adaptation Lab has recently received support from Natural Resources Canada for the "Living Breakwaters Project", which (in part) will develop solutions to address the erosion of the Point Grey cliffs (UBC, 2020)

References

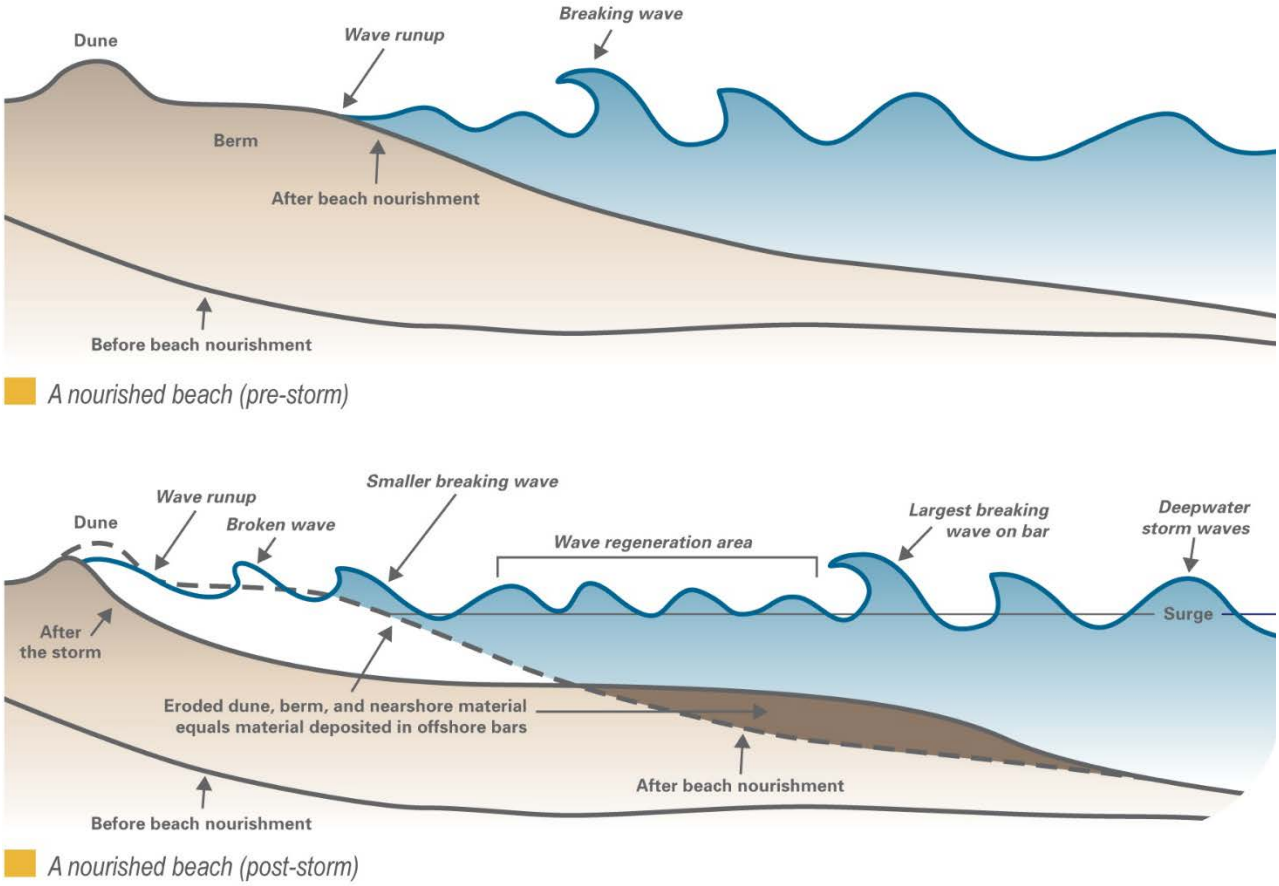
Baker S et al (2018) Design and Physical Model Studies of Innovative Living Breakwaters. https://www.researchgate.net/publication/329319974_Design_and_Physical_Model_Studies_of_Innovative_Living_Breakwaters

Fraser Basin Council (2020) FLOODWISE in BC's Lower Mainland. Information Portal on Flood Risk Management https://floodwise.ca/

Richmond, City of (2013) Dike Master Plan – Phase 1 Report https://www.richmond.ca/__shared/assets/DikeMasterPlan_PWT_04171335480.pdf

University of BC (2020) UBC Living Breakwaters https://blogs.ubc.ca/coastaladaptationlab/living-breakwaters-project/

Beach Nourishment



How Beach Nourishment Works in Storm Events (US Army Corps of Engineers)

Beach nourishment programs, which aim to replenish beach sand with sediment from offshore or an upland source, have become common in coastal communities worldwide. Beach nourishment involves using sediment to enhance dunes, the beachfront, and/or the shoreface. The sediment may be spread by machine and then moved by waves, tides and wind. (Note: most of the text in this description is from the Fraser Basin Council (2020) FLOODWISE website).

This approach is best suited for low-lying oceanfront areas with existing sources of sand and gravel. On the US eastern and southern seaboards, beach nourishment is used to replace sand lost to storms and protect against future erosion of the natural dunes and original shoreline. Nourishment projects require coastal modelling to be effective.

A comprehensive description of the advantages, disadvantages and financial information is presented by the Climate Technology Centre and Network on their website (see link below).

Application in BC:

Beach nourishment has been undertaken on some beaches across BC, including Parksville and Campbell River on Vancouver Island, and the Hot Sands Beach in Kelowna. Beach nourishment was proposed as a key component of one of the sea level rise adaptation options for Boundary Bay Village and Beach Grove in the City of Delta (CALP 2012)

Potential Benefits	Potential Challenges
Offers a protection against erosion and wave action Can expand the usable beach area for human use Increases the elevation and distance between the upland area and shoreline Typically has lower environmental impact than coastal armouring structures	Temporary solution that requires monitoring and repeated application Can disturb or damage habitats both at the site of nourishment and the source of the sediment Can alter the flow of sediment along the shoreline Not suitable for shorelines with high erosion rates

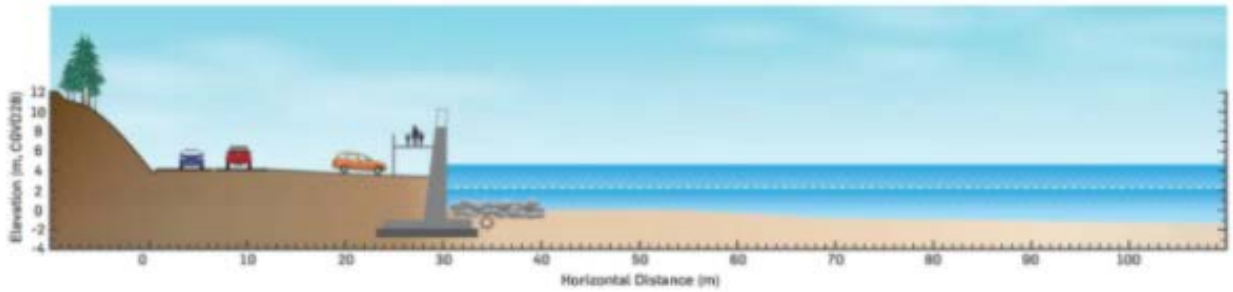
References

CALP (2012) Collaborative for Advanced Landscape Planning – UBC. Delta-RAC Sea Level Rise Adaptation Visioning Study Policy Report. https://www.fraserbasin.bc.ca/_Library/CCAQ_BCRAC/bcrac_delta_visioning-policy_4d.pdf

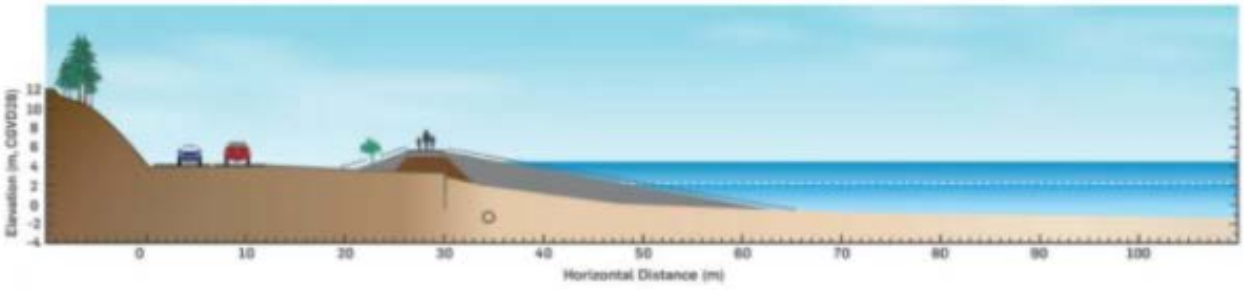
Climate Technology Centre and Network: Beach Nourishment
https://www.ctc-n.org/technologies/beach-nourishment

Fraser Basin Council (2020) FLOODWISE in BC's Lower Mainland. Information Portal on Flood Risk Management
https://floodwise.ca/

US Army Corps of Engineers: How Beach Nourishment Works in Storm Events
https://www.nad.usace.army.mil/Media/Images/igphoto/2001018727/ and
https://www.iwr.usace.army.mil/Missions/Coasts/Tales-of-the-Coast/Corps-and-the-Coast/Shore-Protection/Beach-Nourishment/



Hard Alternative with 1 metre sea level rise and storm surge (waves not shown)



Soft alternative with gravel/pebble/cobble beach and 1 metre sea level rise and storm surge (waves not shown)

Example of Green Shores gravel or pebble beach option to adapt to sea level rise (Stewardship Centre of BC)

Natural or living shorelines involve restoring or replicating natural coastal shorelines to protect against erosion and enhance ecosystems. These shorelines can also have flood protection benefits. A wide, shallow beach profile can help dissipate wave energy more effectively than a steep, narrow shoreline. Naturalized shorelines tend to have a gradual slope, vegetation on the seaward side, and woody debris, trees and other vegetation above the high tide line for stability. Information and guidelines to promote resilient natural shorelines have been developed by many jurisdictions (the US National Oceanic and Atmospheric Administration and Rideau Valley Conservation Authority in Ontario are two examples). (Note: much of the text in this description is from the Fraser Basin Council (2020) FLOODWISE website).

Potential Benefits	Potential Challenges
Can provide self-sustaining erosion protection	Requires maintenance (e.g., controlling invasive plants)
Can enhance natural ecosystems, providing intertidal habitat and linking aquatic and upland habitats	May disrupt sediment transport
Some designs can help dissipate wave energy and potentially lower the risk of flooding	

Potential application in BC:

The Stewardship Centre of BC has been promoting the Green Shores approach for about a decade to encourage the sustainable use of shoreline ecosystems through education, planning, and design while recognizing the ecological features and functions of shoreline systems. The approach seeks to work with the natural processes to dissipate wave energy and enhance the ecological functions of the shoreline. Green Shores projects have been implemented at many locations on the south coast including the Cities of Vancouver and Campbell River.

The concept of a "living dike" is being developed for Boundary Bay in the Cities of Delta and Surrey as a possible alternative to widening and raising a standard sea dike to protect against sea level rise (see plan and schematic dike profile below). The intent of the living dike is to provide a means to maintain or enhance existing salt marshes and habitat in Boundary Bay while still meeting relevant flood safety standards (SNC Lavalin 2018).

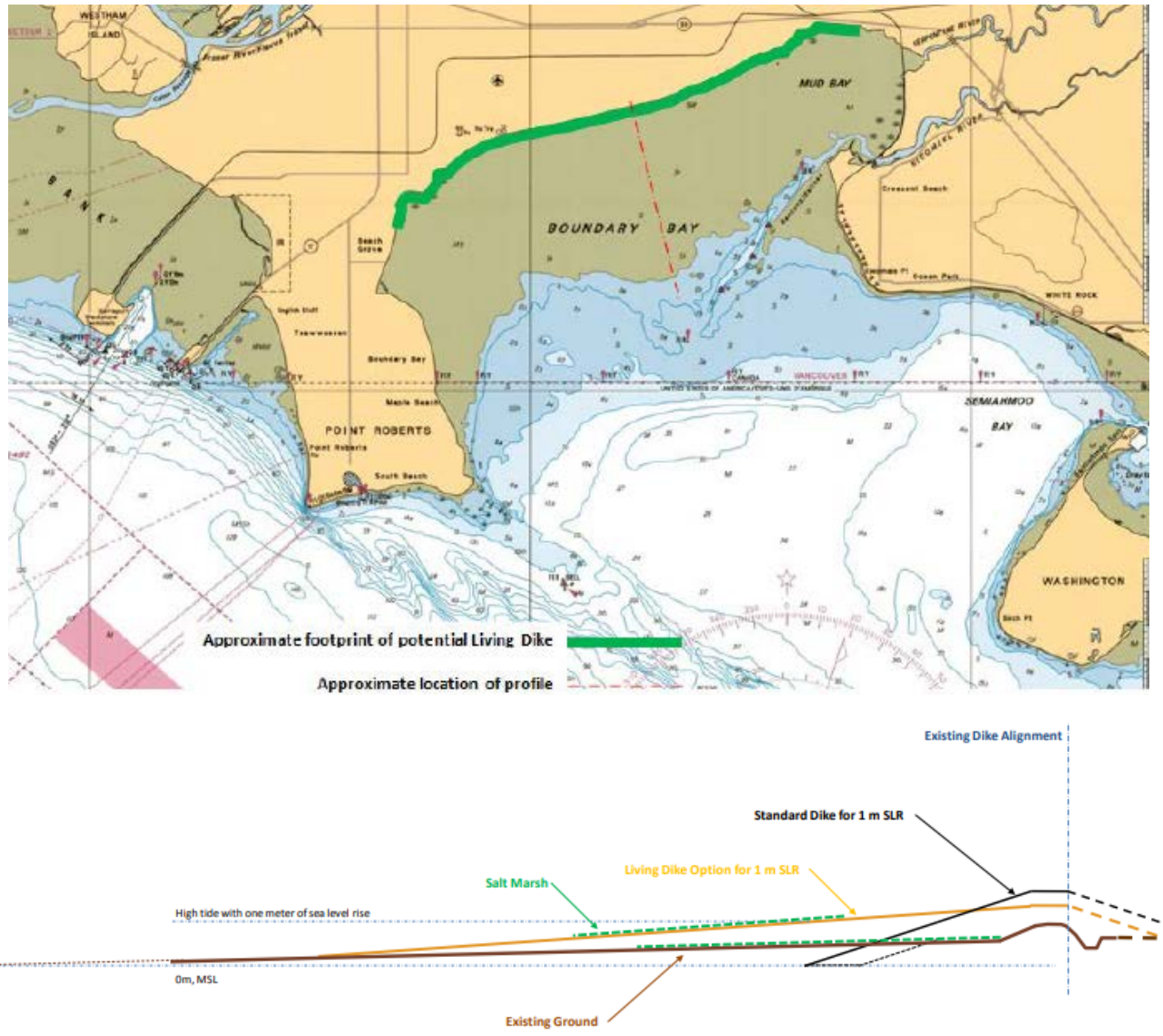


Figure 1: Schematic Illustration of a potential Living Dike Option and a Standard Coastal Sea Dike for 1 m of SLR

Location Plan and Living Dike Concept Profile (SNC Lavalin 2018)

References

Fraser Basin Council (2020) FLOODWISE in BC's Lower Mainland. Information Portal on Flood Risk Management https://floodwise.ca/

National Oceanic and Atmospheric Administration Natural and Structural Measures for Shoreline Stabilization https://coast.noaa.gov/data/digitalcoast/pdf/living-shoreline.pdf

Rideau Valley Conservation Authority Benefits of a Natural Shoreline. https://www.rvca.ca/stewardship-grants/shoreline-naturalization/benefits-of-a-natural-shoreline

SNC Lavalin (2018) Design Basis for the Living Dike Concept. Report for West Coast Environmental Law https://www.wcel.org/sites/default/files/publications/2019-livingdikeconceptbrief-final.pdf

Stewardship Centre for BC Green Shores Program. https://stewardshipcentrebc.ca/green-shores-home/

Stewardship Centre for BC (2014) Green Shores Coastal Development Rating System Demonstration and Training Project – Project Summary May 2014. http://stewardshipcentrebc.ca/PDF_docs/greenshores/GSCDRS2014ProjectSummary.pdf

APPENDIX C: Recommendations

B-5 Recommendations: Structural Flood Management Approaches

Investigation number: B-5.1

Investigate opportunities to incentivize or require diking authorities to maintain flood protection infrastructure and plan for future conditions such as changing flood hazards.

B-5.1 No. 1: Publicize dike inspection reporting compliance information

This would provide an incentive for diking authorities to complete inspections and provide detailed inspection reports. Increased compliance with provincial requirements for dike inspection reporting should help to improve dike maintenance.

The Inspector of Dikes (IOD) should also make use of existing enforcement powers of the *Dike Maintenance Act* (DMA) to order submission of satisfactory reports. If diking authorities fail to comply with the orders, the IOD should retain consultants to complete the inspections and charge the costs back to the diking authorities.

B-5.1 No. 2: Designing dikes for climate change should be a condition of DMA approvals

To improve diking authority planning for future dike upgrading the IOD should adopt a formal policy that "designing for climate change" is required to obtain DMA approval of major upgrades to dikes or new dikes.

The IOD will need to provide a guideline document and specific design standards where possible (i.e. new Fraser River design profile). Where feasible and cost effective, a phased design approach to allow for projected future flood levels (and uncertainties) should be considered.

B-5.1 No. 3: Link provincial funding for structural works to land use planning and regulation

To integrate structural approaches such as dike upgrading and new dikes with other non-structural approaches, provincial funding (such as CEPF) for structural works projects should be linked to integrated flood planning, including adoption of floodplain bylaws or other land use regulations that meet provincial standards. This recommendation is conditional upon the province developing new standards for flood hazard land use regulation and/or a new Integrated Flood Management Planning (IFMP) Program.

Investigation number: B-5.2

Investigate opportunities to improve the knowledge and capacity of local diking authorities regarding dike maintenance.

B-5.2 No. 1: Increase the number of dike safety audits

Complete dike safety audits of all diking authorities having "High" and/or "Major Consequence Dikes" (71 dikes) at least every 5 years and the remainder once every 10 years. This will approximately double the effort currently being made by DIODs from 5 to 10 audits per year provincially to 10 to 20 per year.

Audits are a very useful dike safety management tool for both Diking Authorities and DIOD/IOD. They can help to build the knowledge of both DIODs and diking authority representatives, to share information, to build stronger relationships and to jointly develop specific dike safety action plans.

B-5.2 No. 2: Develop an on-line introductory dike maintenance training course
To provide new diking authority maintenance staff with immediate access to basic training, at least until they can participate in a regional dike safety workshop, MFLNRORD should develop and provide an on-line introductory training course in dike inspection and maintenance.

B-5.2 No. 3: Provide increased dike inspection and maintenance training opportunities
MFLNRORD should provide increased dike inspection and maintenance training opportunities and expand the content of the training. Determining an optimal approach will need to be worked out by the ministry. Options include increased frequency, duration, mandatory attendance, and a certification requirement.

Investigation number: B-5.3

Investigate opportunities to improve coordination amongst diking authorities under non-emergency conditions.

B-5.3 No. 1: The province should provide funds to match the federal DMAF program.
The province should develop a matching cost sharing program to the federal DMAF program. Where regional projects meet federal eligibility requirements, the province should lead, coordinate, and cost-share "bundled" applications.

B-5.3 No. 2: The province should implement an Integrated Flood Management Program.
The new program should encourage and support coordination and collaboration on structural mitigation as well as non-structural measures for communities that share both dikes and floodplains.

Investigation number: B-5.4

Investigate impediments to and opportunities for implementing innovative structural flood risk reduction measures, including the role of incentives and regulation.

B-5.4 No. 1: Funding programs should consider land acquisition as an eligible cost for set-back dikes
The benefits and challenges of set-back dikes are well known in BC as there are many good examples (e.g. Vedder River, Mission Creek). The greatest impediment to broader application of this approach is the cost of land and how to protect or address historic development adjacent to the river channel.

B-5.4 Nos. 2 and 3: Develop design guidelines and standards for various innovative approaches
The MFLNRORD Dike Safety Program should develop design guidelines to assist in the assessment and design of compartmentalization/preferential flooding, super dikes, and floodwalls. For applications where a long-term approach to integrate flood protection with community development will result in a seismically stable flood protection system (e.g. super dikes), the guidelines should offer some flexibility in application of seismic standards in the short term.

MFLNRORD should also consider projects to establish engineering guidelines and design standards for: 1) habitat friendly alternatives to riprap erosion protection in riverine environments and 2) alternative approaches to standard sea dikes, building on work done by various organizations including the Stewardship Centre of BC, West Coast Environmental Law, UBC and others.

B-5.4 No. 4: Carry out field scale pilot projects to demonstrate smart dikes and bio-grouting
MFLNRORD should sponsor, in partnership with academia and local diking authorities, field scale pilot projects to demonstrate the potential benefits and feasibility of smart dikes and bio-grouting.

APPENDIX D: Dike Safety Audit Outline (MFLNRORD)

Dike Safety Audit Check List/Report Outline

Date of Audit: _____ File Number:_____

Diking Authority: _____
Dike Name(s): _____ GPS Nos. _____
Water Course: _____
Deputy Inspector of Dikes (DIOD) _____

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

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

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

3. **Documents and Records:**

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

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

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

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

5. Inspections:

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

a) Annual Inspections:

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

b) Special Inspections:

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

6. Maintenance/Repair Plan (Joint Inspection):

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

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

7. Changes to the Diking System - *Dike Maintenance Act* Approvals

Review Section 2(4) of the DMA with diking authority personnel. If any changes requiring DMA approval were made over the previous (at least) 5 years, confirm that DMA approvals were issued; note these in the audit report and prepare a list with brief descriptions of the work completed. If DMA approvals were not issued for significant changes, consider appropriate follow-up actions to identify dike safety issues and ensure adequate documentation of the changes (**NOTE – DMAs will not be issued for past works but we still need documentation of the unauthorized works**).

8. Flood Emergency Plan:

The dike safety audit should include a brief review of the Flood Emergency Plan and if necessary, identify action items to address deficiencies. A partial list of review questions is provided below.

Item	Yes	No
Does the diking authority have a flood response plan?		
Was the Plan recently reviewed with the local authority under the *Emergency Program Act*? (if different from the diking authority)		
Are the hazards and developed areas at risk identified?		
Are the weak spots in the diking system identified?		
Are stream gauges in place and "trigger" levels been developed?		
Is the flood Warning / Evacuation plan adequate and in place?		
Have flood/dike patrol personnel been identified and trained?		
Does the plan identify resources such as local contractors, equipment, pumps, rock riprap, sandbags and other materials?		
Is there a communications plan?		

If the plan was implemented recently and there were obvious issues or deficiencies, has this been reflected in an update plan and if not when do they plan to do so?

9. Recommended Dike Safety Action Plan (to be followed-up by Diking Authority):

Actions	Completion Date
1.	
2.	

10. Summary of Key Recommendations

Provide a brief overview (say 2-3 paragraphs) of the key issues and major actions required.

Audit Report to be signed off by the DIOD and sent to IOD.

APPENDIX E: Engagement Surveys on Structural Flood Management Approaches and Dike Management in BC

Appendix E

Engagement Surveys on Structural Flood Management Approaches and Dike Management in BC

1. Introduction

To support several of the Investigations in Support of Flood Strategy Development in BC – Theme B: Flood Hazard and Risk Management, the FBC conducted an on-line engagement survey that was directed primarily to planning and development staff of local governments (municipalities and regional districts) and Indigenous communities. The July, 2020 "Combined Survey" covered a range of topics including Flood Management Plans, Non-structural Flood Management Approaches, Public Education, Climate Change, as well as a few questions related to Structural Flood Management Approaches. The responses related to Structural Flood Management Approaches from the Combined Survey are summarized in Section 2 below.

A subsequent "Survey on Dike Management in BC" was sent out in August, 2020 to all diking authority contacts and to the MFLNRORD staff involved in the provincial Dike Safety Program. The results are presented and briefly discussed in Section 3 below. Responses from both surveys helped to identify the options and shape the recommendations in this report.

The preamble for both surveys provided a commitment to respondents that "responses will be treated as your opinions and not necessarily representative of those of your organization (unless you state so). Results will be aggregated and individual comments will remain anonymous." For most of the survey questions and results presented below, a few anonymous responses have been included to increase understanding of the reasons for supporting/not supporting the various policy options. These responses were selected to show a range of perspectives and/or to highlight particular themes and valuable insights, as expressed by the respondents in their own words.

2. The Combined Survey

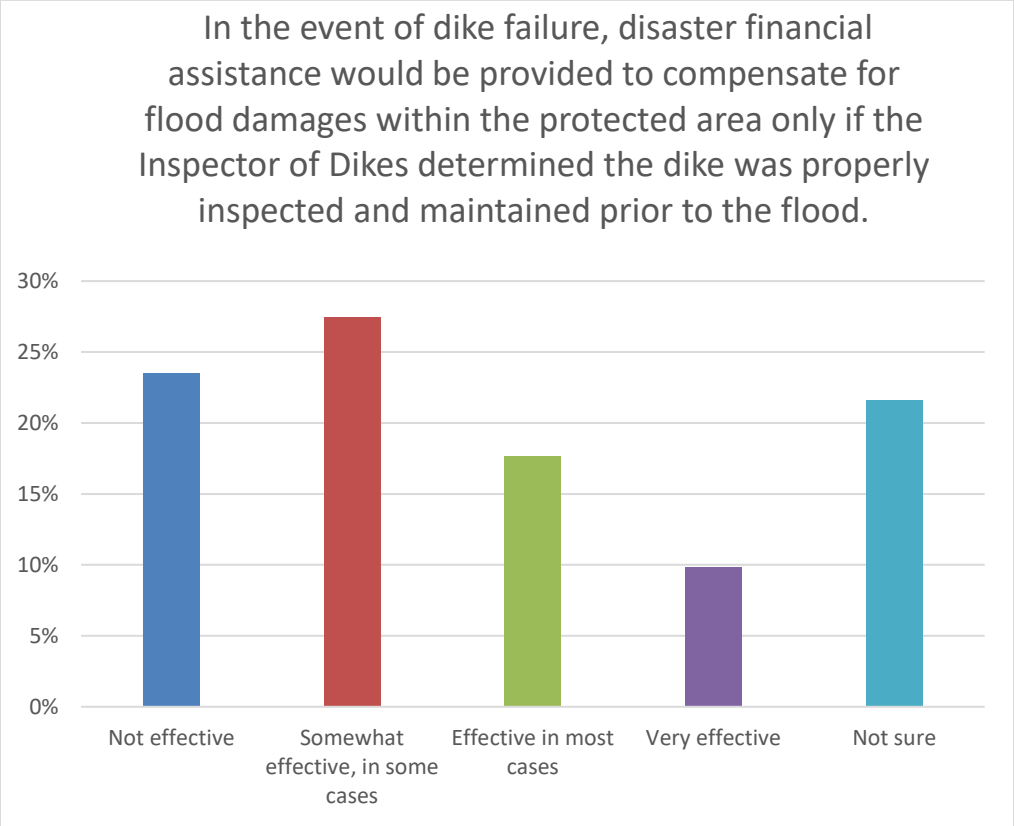
The survey was sent out in July 2020 by email to approximately 260 contacts representing First Nations, local and provincial governments, consulting firms, academia, and federal agencies. Responses were received from 67 persons that answered at least one question beyond the background questions page.

A significant proportion of the respondents (33%) were from Regional Districts and 30% were from municipalities. Responses were also provided by government ministry or agency staff (19%) and Academia/Non-profit organizations (5%) and various other entities, but there were no Indigenous community respondents.

The following sections briefly summarize the overall support/non-support for a given proposal or option and provide a few selected responses. The numbering of the questions below is consistent with the original survey; the charts are as presented in Appendix C of the B-6 report NHC (2020).

Section D: Structural Flood Management Approaches

Question D1: In your opinion, how effective would the following policy be in improving dike management and maintenance in BC? (51 responses)



Summary: Only 27% felt that this policy would be effective or very effective, with 23% indicating that this would not be an effective policy. This policy would not have broad support.

Selected Responses:

"Effective in most cases. It provides an incentive for proper dike maintenance before a failure occurs."

"Somewhat effective. Despite dikes being under engineered, politicians can't resist bailing people out after a disaster and my prediction is such a policy would be turfed out the window."

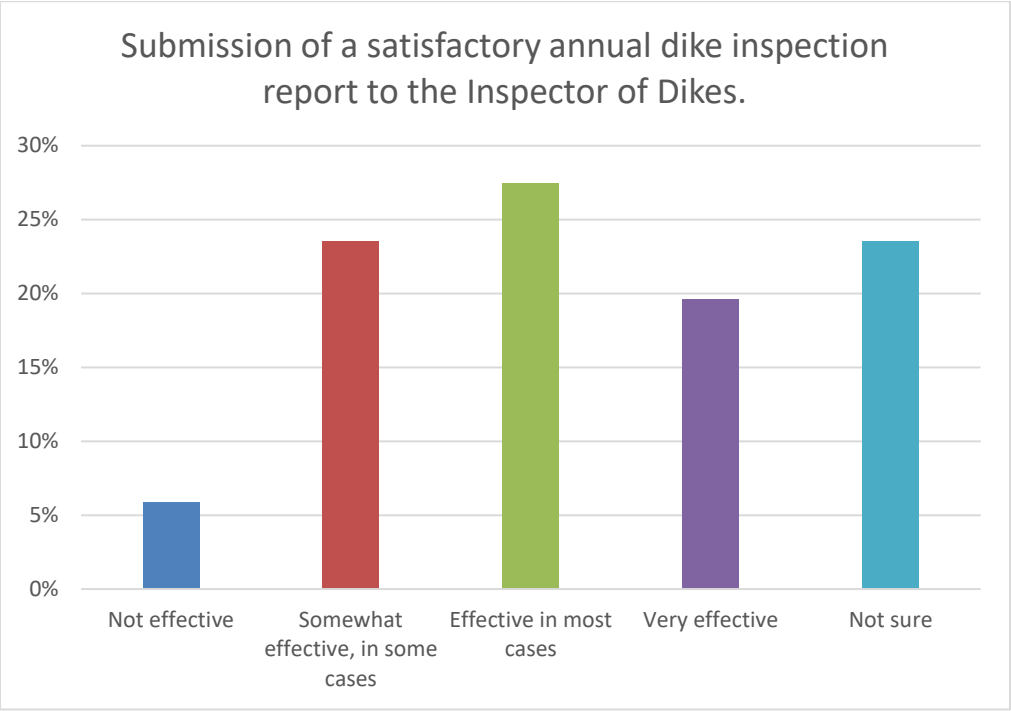
"Not effective. It's the diking authority's responsibility to ensure the dike is properly maintained and inspected. If flooding occurred, it is not the downstream property owners' responsibility. Disaster financial assistance should be available."

"Not effective; If there is no money to maintain a dyke, the threat of no compensation to residents does not have a role. Some of us already put RCs (restrictive covenants) on titles about not being able to sue the City should a dyke fail. Dykes can fail for many reasons beyond maintenance. Also the Province itself built non-standard dykes in the past (1970s) that many of us inherited - we would show that we inherited substandard structures."

Question D3

In your opinion, how effective would the following policies be in improving dike management and maintenance in BC?

If a dike construction project or major dike upgrade is eligible for provincial funding, funding approval and/or release of holdbacks would be made conditional upon:



51 responses

Summary: The survey indicates modest support (approx. 50% very effective, or effective in most cases) for this policy.

Selected Responses:

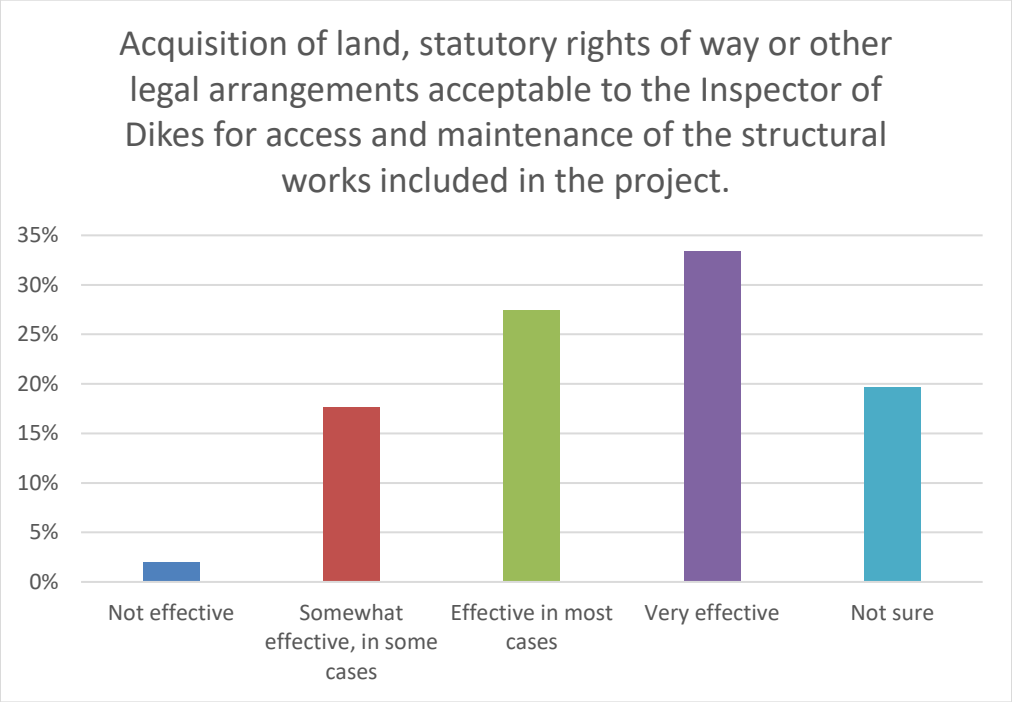
> "Submission of a single dike inspection report does not guarantee continuation of practice. Would prefer to see compliant with submission of annual dike inspection reports for past 5 years."

> "The province should take responsibility for dikes they allow to be built."

Question D3 continued

In your opinion, how effective would the following policies be in improving dike management and maintenance in BC?

If a dike construction project or major dike upgrade is eligible for provincial funding, funding approval and/or release of holdbacks would be made conditional upon:



51 responses

Summary: The survey indicates modest support (approx. 60% very effective, or effective in most cases) for this policy.

Selected Responses:

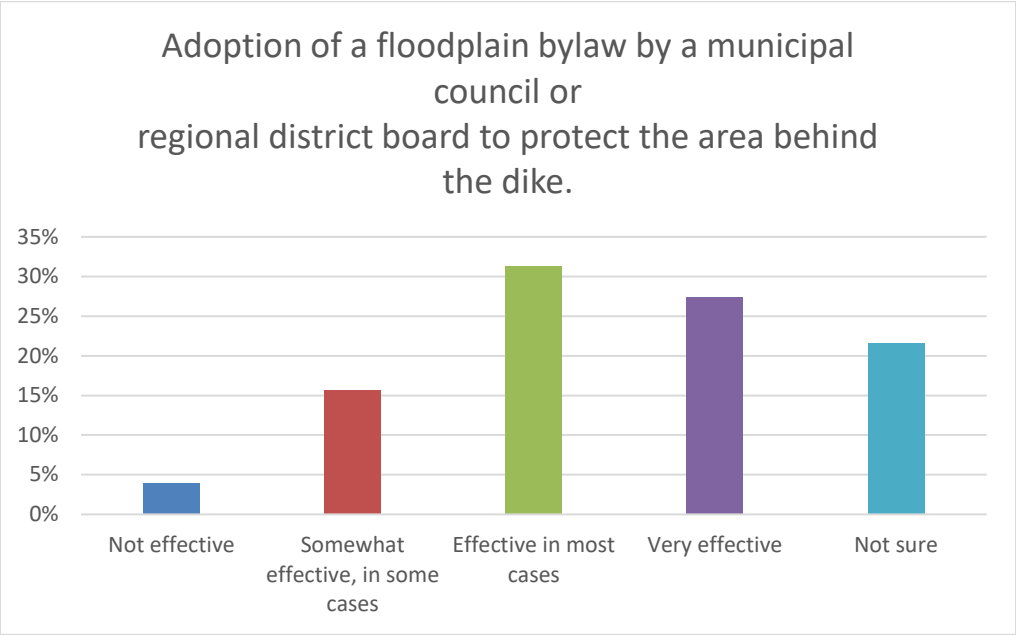
"The downloading of responsibility for natural hazard management in BC to local governments has been a disaster. Tools for local service areas that are financially responsible for dikes for paying for annual inspections and repairs are 100% dependent upon local government political support. This makes it certain that hazard management will never be successful Province-wide owing to differing abilities to pay. Also, in unincorporated areas, the Province approves all subdivisions and this makes it 100% clear that the Province itself should be responsible for any natural hazard protection measures that these approvals require."

"I think that funding should continue to be available to phase stepwise development of land acquisition / SRW, floodplain bylaw development and flood management plans through CEPF and similar tools. As said above, flood protection infrastructure also needs to be tightly integrated in an asset management plan - most communities I have talked with do not have any sense of their unfunded liabilities or long range funding needs to maintain and replace what they have."

Question D3 continued

In your opinion, how effective would the following policies be in improving dike management and maintenance in BC?

If a dike construction project or major dike upgrade is eligible for provincial funding, funding approval and/or release of holdbacks would be made conditional upon:



51 responses

Summary: The survey indicates modest support (approx. 60% very effective, or effective in most cases) for this policy.

Selected Responses:

"The question is - who would do all the work necessary to satisfy regulatory requirements. Limited staffing is a major issue for a small municipality."

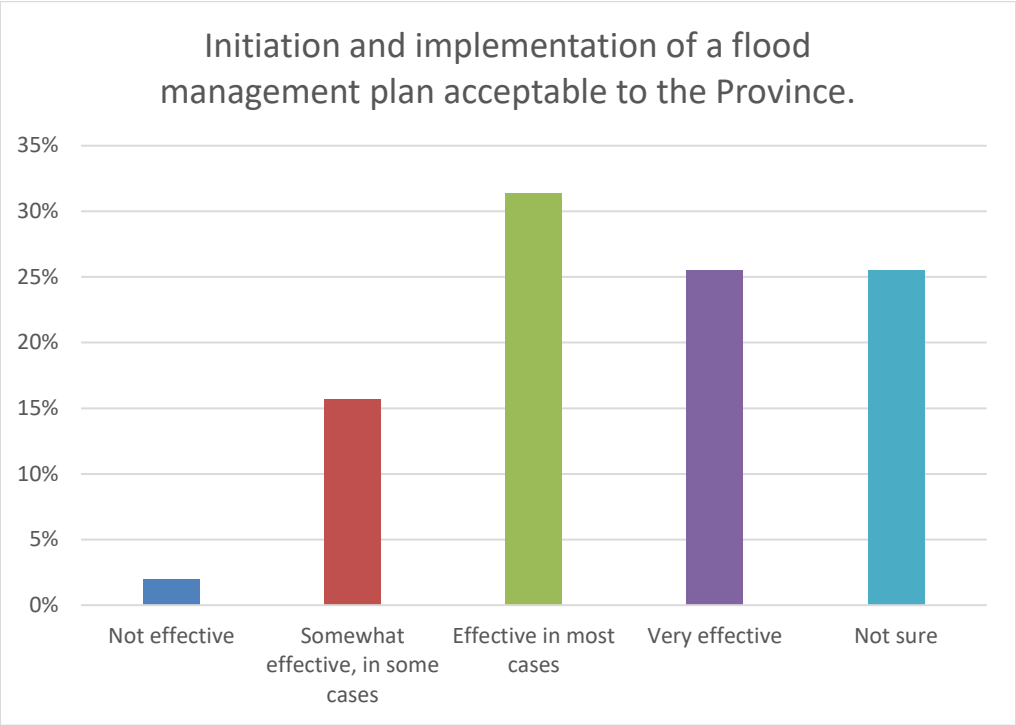
"They (these policies) would not be effective in RD's where MOT is the approving authority and ignore some referrals from staff, Fire smart covenant and flood plains. Unless the approving authority takes the suggestion from staff it is hard for a RD to be responsible for the emergency. The Province should update the flood construction levels and not put this on the local jurisdictions."

"These policies incentivize appropriate planning and preparation."

Question D3 continued

In your opinion, how effective would the following policies be in improving dike management and maintenance in BC?

If a dike construction project or major dike upgrade is eligible for provincial funding, funding approval and/or release of holdbacks would be made conditional upon:



51 responses

Summary: The survey indicates modest support (approx. 55% very effective, or effective in most cases) for this policy.

Selected Responses:

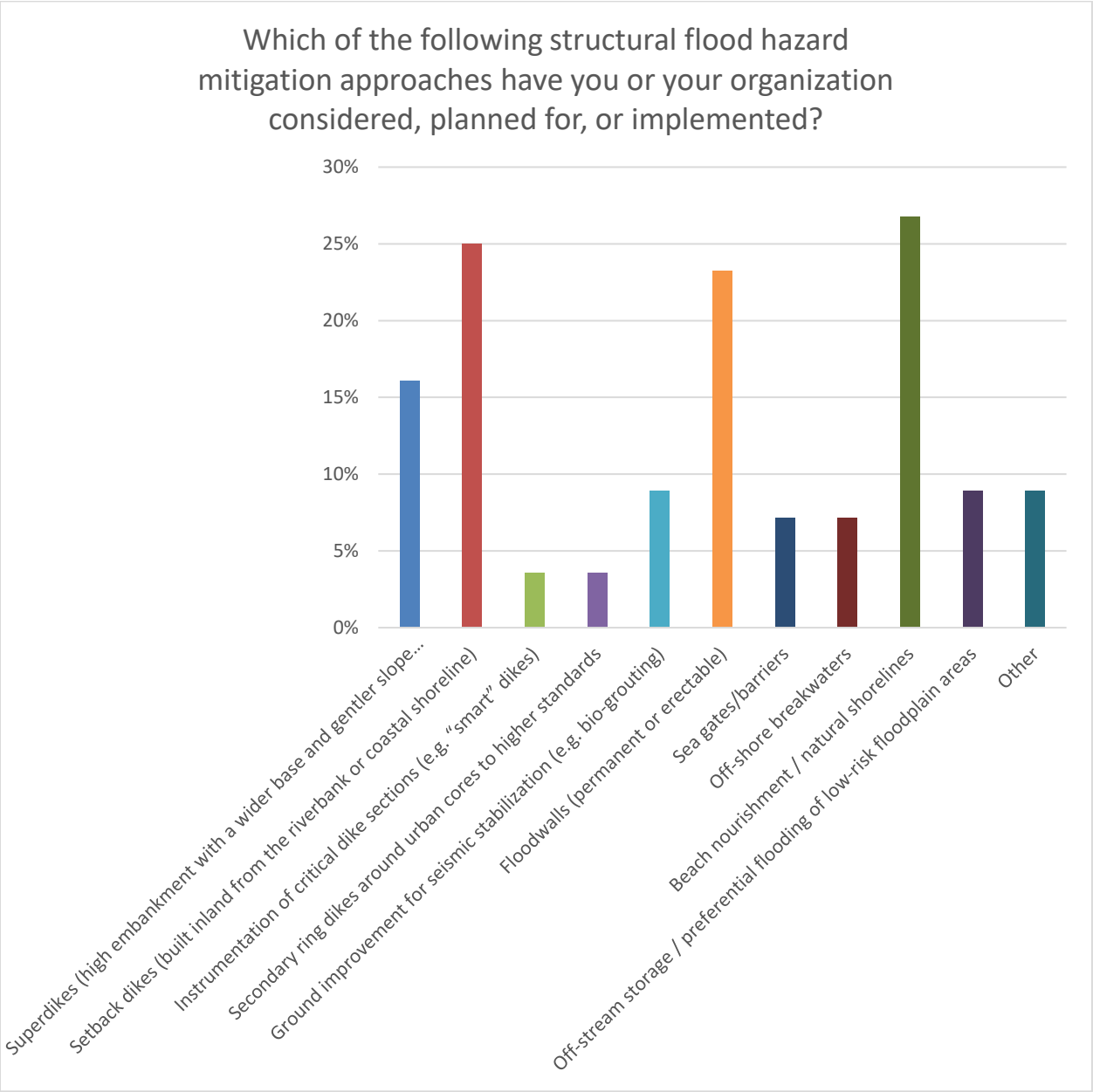
"In my opinion, all municipalities should be enacting the above policies/actions and it shows they are treating flood management seriously. I do think the provincial/federal government should incentivize good behaviour."

"Plans and bylaws that provide guidelines for cross-jurisdictional collaboration and regional cooperation will be most effective. Currently, municipalities are mostly concerned with solutions that work for their jurisdiction which may have adverse upstream or downstream consequences. Strategies and guidelines at a regional level would help tremendously to avoid the implementation of maladaptive solutions."

"The province should be responsible for dike/flood management."

"Seems like these questions are really trying to get at how effective can downloading to local government really be ..."

Question D5



56 responses

Summary: Approximately 25% of all respondents confirmed that they have considered, planned for, or implemented set back dikes, floodwalls and beach nourishment/natural shorelines; and 16% confirmed consideration or implementation of superdikes. This indicates a relatively high level of interest in these approaches. When asked to describe barriers to pursue these measures, several respondents cited lack of available public land and prohibitive costs as the primary challenges.

3. Survey on Dike Management in BC

The "Survey on Dike Management in BC", jointly prepared by NHC and FBC, was sent out by e-mail in August, 2020 to all diking authority contacts and to the MFLNRORD staff involved in the provincial Dike Safety Program (approximately 120 names). After a three week survey period, 15 comprehensive responses plus 3 partial responses were received.

Given the low response rate (approx. 15%), charts and statistics were not prepared. However, the comments and perspectives provided were useful to consider in formulating the report recommendations.

The survey was organized into 6 sections as follows:

1. Initial Questions
2. Potential Incentives (included questions D1 and D3 from Combined Survey)
3. Potential Requirements
4. Knowledge and Training
5. Coordination, Collaboration and Other Challenges
6. Innovative Approaches (included question D5 from Combined Survey)

A brief summary of the results and selected responses are provided below to provide a sense of the level of support for some of the options presented. A copy of the full survey text is provided at the end of this Appendix. The questions have been numbered to allow cross-referencing between the summary discussion and the full survey text.

1. Initial Questions

Of the 15 diking authorities that responded, 11 responses were from municipal diking authorities, 3 from improvement districts, and 1 from an "other" diking authority. Three Provincial Flood Safety Program staff (MFLNRORD) submitted survey responses. No responses were received from the 10 Regional District diking authorities, the 3 First Nation diking authorities, or the other types of diking authorities.

All of the diking authorities responding confirmed that their flood protection systems were designed for riverine flood hazards, plus 2 of these also had coastal dikes, 1 a debris flow dike and 1 a lake flooding dike.

2. Potential Incentives

The first five questions were similarly worded to question D3 in the Combined Survey:

How effective would the following policies be in improving dike management and maintenance?

If a dike construction project or major dike upgrade is eligible for provincial funding, funding approval and/or release of holdbacks would be made conditional upon:

2.1 Submission of a satisfactory annual dike inspection report to the Inspector of Dikes.
Summary: 10 out of the 15 diking authorities supported this policy (responded very effective, or effective in most cases).

Selected Responses:

"Continue informing municipalities of the quality of Annual Dike Inspection Reports they expect the receive. Host additional (maybe annual) Dike Inspection workshops in different regions of the province - the one I attended in Creston was very useful. Touring and inspecting other municipalities dikes is helpful to better understand common issues and what to look for, and to discuss repair options."

"No concerns - we are already submitting quality reports on an annual basis before the deadline."

"(for linked funding) Nice ideas but I think that funding needs to be easier to access not hindered by additional requirements. The Province should be responsible for annual inspections and provide funding, approvals and direction to appointed dike authorities for needed maintenance/repairs."

2.2 Acquisition of land, statutory rights of way or other legal arrangements acceptable to the Inspector of Dikes for access and maintenance of the structural works as required for the project.
Summary: 10 out of the 15 diking authorities supported this policy (responded very effective, or effective in most cases).

Selected Response:

"Our particular dike is situated entirely on private land or IR. We have no legal authority to access the dike if the owner says no unless there is an emergency."

2.3 Adoption of a floodplain bylaw (or regulations within a zoning bylaw) by a municipal council/regional district board for the protected area behind the dike.
Summary: 9 out of the 15 diking authorities supported this policy (responded very effective, or effective in most cases).

Selected Responses:

"Somewhat effective, in some cases. Floodplain bylaw restricting floodplain development would place large restrictions on land in our municipality."

"People need to be made aware of the flood hazards they may live in. Small municipalities are already overwhelmed and have no funds to do this properly. I think homeowners should be aware of the status of their dikes but the local governments also need resources to set this up properly. Funds and a more organized approach that comes from the regulator instead of each local government deciding their by-laws. We should be paying people to relocate and start removing dikes."

"There are some instances where the diking authority is an improvement district and they are tasked with maintaining flood works inside 1 or more other entities areas. Some locations could have an improvement district that covers both a Municipality and Regional Districts lands. The improvement district would be put at a disadvantage as they do not have any control over the zoning of the lands."

2.4 Initiation (formal decision and committed resources) or implementation of an integrated flood management plan acceptable to the Province.

Summary: 9 out of the 15 diking authorities supported this policy (responded very effective, or effective in most cases).

Selected Responses:

"We already have to submit an annual dike inspection report and have a floodplain bylaw and a flood plain development permit requirement in our OCP. What we don't have is funding to do dike maintenance and expand the diking system. As we are situated at the confluence of two rivers flooding it is a very real hazard each spring. Lack of funds = equals lack of dike maintenance or expansion. There is a need for funding for maintenance and expansion of the diking system (and) an expanded window of time to undertake dike work. The annual "fish window" each summer is extremely limiting. The actual flood is far more destructive to habitat than dike work."

"I think there is a need for easier access to funding for diking improvements versus additional conditions being placed to become eligible for funding. If a muni is designated diking authority by the Province the Province should have funding readily available to service needs of designated authority. Reduction of regulatory red-tape and ease of funding access."

2.5 How effective would the following policy be in <u>improving dike management and maintenance</u>?

In the event of a dike failure, disaster financial assistance would only be provided to compensate for flood damages within the protected area behind the dike if the dike was determined by the Province to have been properly inspected and maintained prior to the flood based on published requirements.

Summary: Only 5 out of the 15 diking authorities supported this policy (responded very effective, or effective in most cases). Several responded not effective and had significant concerns.

Selected Responses:

"Not effective This penalizes private property owners for actions outside of their control."

"Not effective Due to lack of funding. Districts can't keep up on the maintenance when all of the stakeholders aren't required to pay into the districts for their portion of the financial burden !!"

"Somewhat effective, in some cases. Akin to wielding a big hammer potentially at a time of dire community need."

"Effective in most cases. No concerns - diking authorities are required to provide proper dyke inspection and maintenance under the DMA."

2.6 How effective would the following be to <u>incentivize diking authorities to complete and submit comprehensive annual dike inspection reports</u>?

The Province would publish provincial dike inspection compliance information on its website, including the submission status and quality of the reports for each diking authority.

Summary: Only 7 out of the 15 diking authorities supported this policy (responded very effective, or effective in most cases).

Selected Responses:

"Not effective. Who cares if you publish on a website."

"Somewhat effective, in some cases. Smaller communities are often bound by available capacity and funding versus a penchant for non-compliance. Not sure public shaming is the answer here."

"Effective in most cases. This method is only effective and equitable if the Province inspects and releases inspections on orphaned dikes."

"Very effective. Public shaming may improve compliance."

3. Potential Requirements

Under the *Dike Maintenance Act*, the Inspector of Dikes has broad authority to order diking authorities to provide reports and to complete construction such as required maintenance and improvements to dikes.

3.1 What <u>requirements</u> do you think would be effective at strengthening dike management?

Selected Responses:

"Dike setback requirements (for new development) should be legislated rather than contained in guidelines."

"Broad authority should be coupled with timely approvals, necessary funding and construction resource management by Province."

"- Increased support to the municipality through the DMA and Inspector of Dikes when a municipality needs to require a private property owner to give approval to build up the dike on their private property.

- Increased support to the municipality through the DMA and Inspector of Dikes when private property is no longer in compliance with the DMA (Within the Dike Maintenance Act [RSBC] C.95 S3,6,6.1,6.2 and Drainage, Ditch, and Dike Act [RSBC] C.102 S.158,159 such offences could cause the damage or instability of works; as such in the event the offence warranted it, or did cause severe enough damage fines and or jail time could be levied against the offender), for example, actively going out to site and assisting City operations in getting compliance by the private property owner."

"The requirements are already written. Assistance and enforcement is lacking. In most cases upper management and the public do not have a good understanding of the importance of dikes. Most see them as recreation corridors with great views. Stronger consideration as an

asset. Perhaps regulations that require adequate funding be set aside both for maintenance and reserves to support improvements and or repairs."

"Gaining right of way over dikes. Have a dike be either up to engineering standards (rock sizing, continuous structure) or be removed as there are lots of crumbling dikes in the province."

3.2 What additional powers should the Inspector of Dikes have to ensure that dike maintenance and repair are being adequately carried out by diking authorities?

Selected Responses:

"The existing powers under the DMA are very strong - but underutilized due to lack of staff and ministry executive support."

"If dikes are not funded by the province, how do you expect small municipalities to fund them? We have a population of 1000 people, 530 households. How can we possibly fund extensive dike work and also maintain our water and sewer infrastructure and land and building maintenance? It's just not possible."

"Perhaps the scope of the DMA can expand to the foreshore - just after the freshet this year, we experienced another bank erosion caused by trees toppling, bringing root balls with them."

"Create an inventory of dikes in the province and have an outside body do the inspections."

3.3 What types of enforcement measures would be effective and appropriate to improve dike maintenance and upgrades across the province?

Selected Responses:

"Provide direction and time frames. Keeping in mind improvements cost money that many do not have or allocated."

"None!! Requires money to do the work!"

Please indicate how effective each of the following requirements would be in improving dike management.

3.4 Inspections to be undertaken by the Province, with dike operations and maintenance remaining with diking authorities.

Summary: 6 out of 15 supported this suggestion (responded very effective, or effective in most cases) but 3 were very concerned and felt this requirement would not be effective.

Selected Responses:

"Not effective. Would have major concerns if Province did inspection but Municipality did repair. There needs to be an understanding of the deficiency that is based on local surrounding conditions and a solution that will work for the Local Diking Authority to install and maintain."

"Not effective. Municipalities are the experts of their own dikes and areas and should remain responsible for all inspections."

"Somewhat effective, in some cases. Would be best to have the inspections completed together. Currently the dikes in the province vary widely from being actual engineered dikes or not - so it is difficult for the Inspector of Dikes to determine what needs to be done. Also, the Inspector of Dikes would be taking on a lot more liability. I think all the dikes should be classified as either dikes or not and all those that do not meet minimum engineering requirements should be abandoned until they are re-built."

3.5 Increased auditing of dikes determined to be high consequence dikes by the Province
Summary: There was general support for this proposal as 9 out of 15 supported this suggestion (responded very effective, or effective in most cases) and none expressed concerns.

3.6 If diking authorities do not complete adequate maintenance, the Inspector of Dikes could use enforcement powers of the Dike Maintenance Act to order completion of required maintenance. If the diking authority fails to comply with the order, the Inspector of Dikes could retain contractors to complete the work and charge the cost back to the diking authority.
Summary: 7 out of 15 supported this suggestion (responded very effective, or effective in most cases) but several felt this requirement would not be effective unless additional funding was provided.

Selected Responses:

"Very effective. It's a bit heavy handed to undertake the measures above and unnecessary for authorities that are already doing a reasonable job, but to have the power to undertake the above for authorities that are not doing the necessary work seems like a good idea. To have a dedicated team with experience would ensure consistency across the Province but there would need to be significant interaction with authorities to get relevant information (dike crest relative to flood profile, presence (or lack thereof of SRW's)."

"Somewhat effective, in some cases. The Province should be responsible for inspections, fund repairs, affect timely and necessary approvals, undertake management of the work with provincial funding if more effective for reducing risk associated with failures/degradation."

"They would be effective in some cases but could be unreasonable in others. Consider an (aggrading) creek excavated of its sediment 20 years ago and the material placed on the banks. Now that material is the dike holding back that creek who's sediment has the water much higher than the land around it. Would it be fair to that district or even possible for that district to afford to rectify the situation. Just an example."

3.7 Through legislation and/or regulation, the Inspector of Dikes would make "designing for climate change" a requirement to obtain DMA approval for new dikes or major upgrades to dikes (e.g. dike raising or widening).

Summary: This proposal was generally supported but the design criteria have to be clear and funding made available to align with the additional costs.

Selected Responses:

"Not effective. No point in designing a dike if you can't build or maintain it for lack of funds to do so."

"Very effective. If the design requirements and guidelines are clearly articulated by the province and can be provided to design engineers, there shouldn't be any issues getting the engineers to meet the requirements. It only becomes a problem if additional requirements are enforced by the DIOD if they were unknown prior to the design phase - leads to project delays etc."

"Effective in most cases. This is a good idea in principle, but I would hate to see an effective short term dike upgrade not approved because it does not meet climate change guidelines. There will be cases where there is not adequate land or other technical constraints that prevent meeting climate change guidelines and a dike upgrade that meets current climate (i.e. sea level) should not be stymied because it cannot meet future requirements due to funding or land issues."

"Somewhat effective, in some cases. Funding remains a challenge for municipalities for dyke upgrades. In addition, there needs to be clearer direction on addressing seismic risk. If adequate funding is provided by senior governments for dyke upgrades to address climate change and seismic risk, then we see no concerns."

"Somewhat effective, in some cases. Comes down to adequate funding from the province!!"

4. Knowledge and Training (12 diking authority responses received to these questions)

How effective would each of the following be in improving dike inspection and maintenance?

4.1 Provide an online introductory training course in dike inspection and maintenance.

Summary: 10 out of the 12 diking authorities supported this proposal (responded very effective, or effective in most cases).

4.2 Increase the <u>number</u> of regional Dike Inspection Workshops that are facilitated by the Inspector and Deputy Inspectors of Dikes. (Currently, the IOD's objective is to deliver one workshop in each of five provincial regions every two years).

Summary: 10 out of the 12 diking authorities supported this proposal (responded very effective, or effective in most cases).

4.3 Increase the <u>duration</u> of regional Dike Inspection Workshops that are facilitated by the Inspector and Deputy Inspectors of Dikes from one day to two days, with the second day being field inspections of local dikes and maintenance issues.

Summary: 7 out of the 12 diking authorities supported this proposal (responded very effective, or effective in most cases).

4.4 Make regional Dike Inspection Workshop attendance mandatory (i.e. at least one representative from each diking authority must attend a workshop every two years)
Summary: Only 5 out of the 12 diking authorities supported this proposal (responded very effective, or effective in most cases) and some had significant concerns (see comments to 4.5 below).

4.5 Establish a comprehensive dike inspection and maintenance certification program (i.e. multi-day course at a central location). Require that inspection reports be completed and signed off by certified personnel or by a suitably qualified Professional Engineer.
Summary: Only 5 out of the 12 diking authorities supported this proposal (responded very effective, or effective in most cases) and some had significant concerns.

Selected Responses:

> "Not effective Who's going to pay for it? Some of us have full time jobs and Business to operate!"

> "Somewhat effective, in some cases. Dike authority staff and funding capacity will always be a challenge. Mandatory workshops for free might work if travel expenses are covered and time away can be managed for attending individuals. A certification program should be proposed on an elective vs mandatory basis. If it can't be refer to previous commentary wherein Province should take back inspections, provide repairs funding and potentially manage repairs."

> "Effective in most cases. Training frequency/length is good. If there is turnover and a municipality does not have a certified person when the dike inspection report is due it could create unfair challenges."

> "Very effective. Would be very interested in having a dike inspection & maintenance certification course to receive more frequent and longer duration training. Building in house capacity is very important. Would want to structure certification so that it doesn't force local governments to hire outside consultants to complete the work."

5. Coordination, Collaboration and Other Challenges

See questions 5.1 and 5.2 from the full survey text at the end of this Appendix. With respect to coordination and collaboration, the 12 responding diking authorities expressed very few comments or concerns, other than acknowledging the importance of working with adjacent jurisdictions.

Selected Responses:

> "We have good relationships with our neighbouring municipalities and are not aware of any coordinating/collaborating issues at this time. However, for information purposes, perhaps it would be a good idea for the Dike Inspector to inform neighbouring municipalities that dike upgrades are being planned for, so that work may be planned and funding may be sought to

protect the municipalities as a whole, rather than exposing another area as a weak point. In addition, we suggest a process be developed to include First Nations. We have just developed a MOU with the FN and the Province on one dike - but would be good to see a process developed for other dikes."

"We recently collaborated with the RD on flood plain mapping, and will possibly work with them again on mitigation works."

5.3 What other challenges, if any, has your diking authority experienced? Please provide additional comments if desired.

Summary: Several diking authorities noted challenges with the length of time to get permits related to environmental/riparian regulations, and how these impact vegetation management and regular maintenance. 11 of the 12 responding diking authorities cited resource capacity as a challenge, primarily funding, but several also staff limitations. Other challenges included land acquisition for dike rights of way and addressing "invasive vegetation" issues.

Selected Response:

"All of these - funding is big issue. Have a recent Flood Mitigation Plan and Flood Plain Mapping that recommends approx. $12M in investments in our dikes, will take the municipality way too long to save up for these projects. By the time we have them implemented our Floodplain Mapping will likely need updating. Additionally, if we have a reliable funding stream for dike projects over multiple years we would plan to allocate the capacity in our engineering department appropriately."

6. Innovative Approaches

See questions 6.1 from the full survey text at the end of this Appendix and D5 in the combined survey above. 5 of the 12 diking authority respondents confirmed that they have considered, planned for, or implemented set back dikes, but that land acquisition was the barrier preventing implementation. Similarly, 4 out of 12 had considered superdikes, but land acquisition was again the key barrier. Limited consideration and comments were provided for the other approaches.

Selected Responses:

"Setback Dikes. This works really well for us for maintenance, inspection, and construction. Only issue we are running into is that then all of our park space is "unprotected" and we want to continue to make improvements/investments to our Parks to increase quality of life, but need to balance investment with flood risk."

"Superdikes but land is issue. Setback Dikes but land is issue. Ground improvement: Challenge: dyke needs to be deconstructed to meet 1:2475 seismic event, based on modelling results."

"Floodwalls. Regulatory approvals from Dike Inspector were challenging but delivered with significant consultant information clarification re design."

6.2 What tools, guidance or resources would help your organization pursue these or other innovative structure flood mitigation measures?

Selected Responses:

"More information on these approaches/technologies. Maybe videos, seminars or courses that provide an overview of these technologies from the O&M and construction perspective. Then we would be better prepared to discuss these alternatives in the preliminary design phase with our consulting engineers."

"Examples from other municipalities, funding incentives."

"funding, funding funding... both for improvements and land acquisition."

If you have any final comments, questions or suggestions for us, please share them here.

Selected Responses:

"Communication - no one has ever been here to discuss these topics."

"All of the stakeholders should be able to pay for their part of use or benefits that have been gained from the utilization of our diking system. From the power generation to the transmission lines, phone lines and the commerce that's being trucked through our district. The Ministry responsible for the dike should be more willing to help solve problems in the districts instead of their hands-off approach. So adding penalties to the system is a poor way to get things done!"

"Need to start moving people away from the rivers and creeks that continue to flood and encourage local governments to make better decisions about how the manage their floodplains."

"There are a few jurisdictions in BC where the diking authority is the improvement district and they are tasked with flood mitigation across First Nation lands, Regional Districts and Municipalities. In the current condition the improvement district is arms lengths from the other 3 entities. This works well as the improvement district can look at projects that benefit the whole, and are the best use of taxpayer funds. Should the improvement district amalgamate with either of the other 3 entities then it would not be long before policy to benefit that entity over the others could be evident. …improvement districts should be given the rights to stay in existence and qualify for Grant Funding."

SURVEY ON DIKE MANAGEMENT IN BC – FULL SURVEY QUESTIONS AND TEXT

(Note: The questions have been numbered for this appendix to allow cross referencing to the responses and discussion above)

Thank you in advance for participating in this survey!

The Fraser Basin Council (FBC) is a charitable, non-profit society that brings people together to advance sustainability in the Fraser River Basin and throughout British Columbia. FBC is managing an initiative titled *Investigations in Support of Flood Strategy Development in BC* through a service agreement with the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development. A project backgrounder is available here.

In BC, most riverine and coastal flood protection infrastructure is regulated under the provincial Dike Maintenance Act. These works consist primarily of dikes that are owned and maintained by local diking authorities, with the provincial and federal governments providing a degree of technical and funding support. Because the most densely developed floodplain lands in BC are protected by dikes, the role of diking authorities is critical. Detailed inspections, thorough maintenance, and work to complete upgrade projects in the face of changing flood hazards is essential for public safety and for reducing flood risks.

Part of this initiative examines opportunities to incentivize or require better dike management, improve the capacity of diking authorities, and implement innovative structural flood risk reduction measures. Your input will help shape the recommendations on this issue.

This survey is intended for those working in a diking authority or in the Provincial dike safety program. Please feel free to share or discuss this survey with any other individuals in your organization that are involved with dike inspection, operation, maintenance and/or planning, design, and construction of dike upgrades.

The survey will be open through September 3 and can be completed in about 20 minutes (more if you'd like to provide detailed comments). Please answer to the best of your knowledge and feel free to skip questions you can't answer or that aren't applicable. Your responses will be treated as your opinions and not necessarily representative of those of your organization (unless you state so). Results will be aggregated and individual comments will remain anonymous.

Note that FBC is also facilitating other surveys and engagement to learn from professionals and practitioners on these and other aspects of flood management.

Please contact Frances Woo at fwoo@fraserbasin.bc.ca if you have any questions about the survey or this project.

1. Initial Questions

1.1. What type of diking authority do you represent?

- ☐ Municipality
- ☐ Regional District
- ☐ Improvement District
- ☐ Drainage Ditch and Dike Act District
- ☐ Government Agency

- ☐First Nations
- ☐Provincial Government **(not a local diking authority)**
- ☐Other diking authority type:

1.2 What is your position or role?

1.3 In which region(s) of BC is your work primarily based?

Please choose **all** that apply:

- ☐Vancouver Island
- ☐Lower Mainland
- ☐Thompson
- ☐Kootenay
- ☐Cariboo
- ☐Skeena
- ☐Omineca
- ☐Okanagan
- ☐Peace
- ☐All of BC

1.4 What flood hazard(s) is your flood protection dike system designed for?

Please choose **all** that apply:

- ☐Riverine
- ☐Coastal
- ☐Debris flows
- ☐Lake flooding
- ☐Geomorphic hazards (channel migration, sedimentation, aggradation, avulsion)
- ☐Other:

1.5 What is the approximate length of the dike system that your authority manages?

2. Potential Incentives

BC's diking authorities vary in their ability to maintain their flood protection infrastructure and plan for future hazards. The following questions invite your input and opinions on a range of possible **incentives** that could help strengthen dike management in BC, including improving the operation and maintenance of diking systems and the planning and implementation of dike upgrades or new flood infrastructure. **Please note that the measures presented below are hypothetical scenarios. The Province is not officially considering or consulting on these measures at this time.**

How effective would the following policies be in improving dike management and maintenance?

If a dike construction project or major dike upgrade is eligible for provincial funding, funding approval and/or release of holdbacks would be made conditional upon:

2.1 Submission of a satisfactory annual dike inspection report to the Inspector of Dikes.

2.2 Acquisition of land, statutory rights of way or other legal arrangements acceptable to the Inspector of Dikes for access and maintenance of the structural works as required for the project.

2.3 Adoption of a floodplain bylaw (or regulations within a zoning bylaw) by a municipal council/regional district board for the protected area behind the dike.

2.4 Initiation (formal decision and committed resources) or implementation of an integrated flood management plan acceptable to the Province.

Please choose the appropriate response for each item above:

- ☐ Not effective
- ☐ Somewhat effective, in some cases
- ☐ Effective in most cases
- ☐ Very effective
- ☐ Not sure

Why do you think they would or wouldn't be effective? Would you have any concerns if any of these measures were adopted? Please comment, if desired.

2.5 How effective would the following policy be in <u>improving dike management and maintenance</u>?

In the event of a dike failure, disaster financial assistance would only be provided to compensate for flood damages within the protected area behind the dike if the dike was determined by the Province to have been properly inspected and maintained prior to the flood based on published requirements. Please choose **only one** of the following:

- ☐ Not effective
- ☐ Somewhat effective, in some cases
- ☐ Effective in most cases
- ☐ Very effective
- ☐ Not sure

Why do you think it would or wouldn't be effective? Would you have any concerns if this measure were adopted? Please comment, if desired.

2.6 How effective would the following be to incentivize diking authorities to complete and submit comprehensive annual dike inspection reports?

The Province would publish provincial dike inspection compliance information on its website, including the submission status and quality of the reports for each diking authority.
Please choose **only one** of the following:

- ☐Not effective
- ☐Somewhat effective, in some cases
- ☐Effective in most cases
- ☐Very effective
- ☐Not sure

Why do you think it would or wouldn't be effective? Would you have any concerns if this measure were adopted? Please comment, if desired.

2.7 What other incentives do you think would be effective at strengthening dike management?

3. Potential Requirements

The following questions invite your input and opinions on a range of possible **requirements** under the Dike Maintenance Act that could help strengthen dike management in BC, including improving the operation and maintenance of diking systems and the planning and implementation of dike upgrades or new structural flood management measures.
Please note that the measures presented below are hypothetical scenarios. The Province is not officially considering or consulting on these measures at this time.

Under the Dike Maintenance Act, the Inspector of Dikes has broad authority to order diking authorities to provide reports and to complete construction such as required maintenance and improvements to dikes.

3.1 What requirements do you think would be effective at strengthening dike management?

3.2 What additional powers should the Inspector of Dikes have to ensure that dike maintenance and repair are being adequately carried out by diking authorities?

3.3 What types of enforcement measures would be effective and appropriate to improve dike maintenance and upgrades across the province?

Section 8 of the Dike Maintenance Act gives the Province the power to make regulations with respect to dike maintenance, operation, and construction. A new dike safety regulation could clarify and formalize requirements for inspections, reporting, dike maintenance, emergency planning and design standards for upgrades and new construction.

Please indicate how effective each of the following requirements would be in improving dike management.

3.4 Inspections to be undertaken by the Province, with dike operations and maintenance remaining with diking authorities.

3.5 Increased auditing of dikes determined to be high consequence dikes by the Province

3.6 If diking authorities do not complete adequate maintenance, the Inspector of Dikes could use enforcement powers of the Dike Maintenance Act to order completion of required maintenance. If the diking authority fails to comply with the order, the Inspector of Dikes could retain contractors to complete the work and charge the cost back to the diking authority.

Please choose **only one** of the following:

- ☐Not effective
- ☐Somewhat effective, in some cases
- ☐Effective in most cases
- ☐Very effective
- ☐Not sure

Why do you think they would or wouldn't be effective? Would you have any concerns if any of these measures were adopted? Please comment, if desired.

3.7 To build resilient structures, the design of new dikes and upgrades should consider the potential effects of climate change on flood hazards. Through the current Dike Maintenance Act (DMA) approval process and through EGBC Professional Practice Guidelines, design for climate change is already being partially implemented as part of many diking projects. How effective would the following be in addressing climate change?

Through legislation and/or regulation, the Inspector of Dikes would make "designing for climate change" a requirement to obtain DMA approval for new dikes or major upgrades to dikes (e.g. dike raising or widening).

Please choose **only one** of the following:

- ☐Not effective
- ☐Somewhat effective, in some cases
- ☐Effective in most cases
- ☐Very effective
- ☐Not sure

Why do you think it would or wouldn't be effective? Would you have any concerns if this measure were adopted? Please comment, if desired.

4. Knowledge and Training

Existing deficiencies in dike inspections, reporting and maintenance may be related to a need for additional training and skills to adequately manage diking systems. In some diking authorities, there is a high rate of staff turnover that limits the time for individuals to build local knowledge of the flood hazards and the dikes.

Please note that the measures presented below are hypothetical scenarios. The Province is not officially considering or consulting on these measures at this time.

How effective would each of the following be in improving dike inspection and maintenance?

4.1 Provide an online introductory training course in dike inspection and maintenance.

4.2 Increase the number of regional Dike Inspection Workshops that are facilitated by the Inspector and Deputy Inspectors of Dikes. (Currently, the IOD's objective is to deliver one workshop in each of five provincial regions every two years).

4.3 Increase the duration of regional Dike Inspection Workshops that are facilitated by the Inspector and Deputy Inspectors of Dikes from one day to two days, with the second day being field inspections of local dikes and maintenance issues.

4.4 Make regional Dike Inspection Workshop attendance mandatory (i.e. at least one representative from each diking authority must attend a workshop every two years)

4.5 Establish a comprehensive dike inspection and maintenance certification program (i.e. multi-day course at a central location). Require that inspection reports be completed and signed off by certified personnel or by a suitably qualified Professional Engineer.

Please choose the appropriate response for each item:

- ☐ Not effective
- ☐ Somewhat effective, in some cases
- ☐ Effective in most cases
- ☐ Very effective
- ☐ Not sure

Why do you think they would or wouldn't be effective? Would you have any concerns if any of these measures were adopted? Please comment, if desired.

5. Coordination, Collaboration, and Other Challenges

5.1 Has your organization encountered any challenges or barriers with respect to coordinating or collaborating with nearby diking authorities or other jurisdictions? If so, please briefly describe the issue and provide suggestions on how senior government policies, funding arrangements, or enabling legislation could be changed to help resolve these issues.

5.2 What opportunities do you see for improved coordination and collaboration with neighbouring diking authorities or other jurisdictions? If you have experienced any successes, please share them here as well.

5.3 What other challenges, if any, has your diking authority experienced? Please provide additional comments if desired.

Please choose all that apply and provide a comment:

- ☐Regulatory requirements and/or processes (e.g. vegetation management and environmental regulations, review and approval cost and timeline)
- ☐Resource capacity (e.g. limited local funding, senior government assistance, staffing, need for consultants)
- Other:

6. Innovative Approaches

Many organizations are exploring innovative structural approaches to manage flood risk within their jurisdictions other than conventional dikes.

6.1 Which, if any, of the following approaches has your diking authority considered or implemented? For each selected, please describe any barriers encountered and what guidance or resources helped your organization pursue the measure.

Please choose all that apply and provide a comment:

- ☐Superdikes (high embankment with a wider base and gentler slope than conventional dikes, designed to be resilient to earthquakes, erosion and breaches)
- ☐Setback dikes (built inland from the riverbank or coastal shoreline)
- ☐Instrumentation of critical dike sections (e.g. “smart” dikes)
- ☐Secondary ring dikes around urban cores to higher standards
- ☐Ground improvement for seismic stabilization (e.g. bio-grouting)
- ☐Floodwalls (permanent or erectable)
- ☐Sea gates/barriers
- ☐Off-shore breakwaters
- ☐Beach nourishment / natural shorelines
- ☐Off-stream storage / preferential flooding of low-risk floodplain areas
- Other:

6.2 What tools, guidance or resources would help your organization pursue these or other innovative structure flood mitigation measures?

If you have any final comments, questions or suggestions for us, please share them here.

Thank you very much for completing this survey! We are very grateful for your input today.