PROFESSIONAL ENGINEERING SERVICES FOR THE CRESTON VALLEY FLOOD RISK ASSESSMENT

RISK ASSESSMENT UPDATE

TOWN OF CRESTON

APRIL 2023

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FINAL VERSION

PROJECT #: 221-08591-00
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Reference to mention:

WSP. 2023. *Professional Engineering Services for the Creston Valley Flood Risk Assessment – Risk Assessment Update*. Report from WSP Canada Inc. to Town Of Creston. 49 p. and Appendices.

EXECUTIVE SUMMARY

The Town of Creston has retained WSP to update the 2014 flood risk assessment completed by BGC and develop a flood action plan based on prioritized flood mitigation options for about 92 km of the dikes within the Kootenay River floodplain from the US border to Kootenay Lake (including the Lower Kootenay Band [LKB] dike), and Goat River floodplain.

The project has been subdivided into two main stages:

- Stage 1: Data collection and review, and risk assessment update;
- Stage 2: Strategic plan development.

The main focus of this report is to summarize the analysis carried out to complete Stage 1. As part of this stage, WSP collected and reviewed background information to build a strong understanding of the project area, floodplain and wetland management, and the diking system.

Also, WSP reviewed the 2014 BGC hydrological and hydraulic analysis (Sections 3 and 4 of the current report) and concluded that the 2014 hydrological analysis, including estimated flood quantiles for the Kootenay River and Goat River, is generally still valid and can be used in the update. These flows are summarized in the following table.

RETURN PERIOD (yr)	KOOTENAY RIVER AT PORTHILL (m^3/s)	GOAT RIVER (m^3/s)
2	1,065	228
5	1,356	300
10	1,526	343
20	1,677	380
50	1,856	425
100	1,983	456
200	2,103	486

Reviewing the 1D HEC-RAS model for the Kootenay River developed by BGC in 2014 shows that the results, including simulated water levels along the river, should be sufficient for the current study. According to the results, the Kootenay River dike crest elevations are generally above the simulated 200-year water levels by at least 1.45 m.

A 2D hydrodynamic model of the Goat River was also developed by BGC in 2020. WSP reviewed the 2014 and 2020 Goat River hydraulic studies and concluded that the 2D model is more accurate since it was developed using more recent LiDAR and bathymetric data surveyed in 2018 and 2019, respectively. Also, 2D hydraulic models are generally more reliable for braided rivers like the Goat River. The results of this model show that the Goat River dike crest elevation is generally 0.4 m above the 200-year flood levels. However, several hundred metres of the dike, developed in 2006/2007, are expected to be overtopped during the 200-year flood by about 0.8 m.

WSP used the results of the previous hydraulic models to define the likelihood of overtopping failure of the Kootenay and Goat river dikes (Section 5.3). A likelihood rating ranging from Very Low to Very High was assigned for each dike based on the flood event magnitude required to overtop them. The dikes along the Kootenay River have a Very Low likelihood rating as a 200-year flood event would not overtop any dike section. In contrast, a 0.21 km section of the Goat River dike was assigned a Very High likelihood rating as it is expected to be overtopped by the 2-year flood. Also, 0.33 km of the Goat River dikes have an overtopping likelihood rating of Moderate as this section would potentially be overtopped by floods more severe than a 10- to 25-year event.

A site inspection was also conducted by WSP as part of an erosion assessment to determine the likelihood of dike failure due to excessive erosion. A likelihood rating of Very Low to Very High was assigned to each dike based on the dikes' current condition, erosion protection, and local fluvial geomorphology.

Using the likelihood of failure, combined with the dikes' consequence classification determined by NHC in 2019, a flood risk rating was assigned for each dike section along the Kootenay River and Goat River. A complete list of the dikes with the assigned likelihood of failure, the consequence of failure, and the flood risk rating is provided in Appendix B. The floor risk assessment results are summarized in the following table.

DIKING DISTRICT	FLOOD RISK RATING (km)					
	NEGLIGIBLE	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH
Creston Diking District	0.0	0.0	0.0	13.62 (4.31 km on LKB lands)	2.30 (0.49 km on LKB lands)	3.06 (1.41 km on LKB lands)
Reclamation Farm Diking District	0.0	0.0	0.0	22.43	4.81	0.76
Nick's Island Diking District	0.0	0.0	13.48	1.79	0.86	0.0
Duck Lake Diking District	0.0	0.0	0.0	10.88 (2.44 km on LKB lands)	0.15	0.27 (0.27 km on LKB lands)
Creston Valley Wildlife Management	3.49	0.31	0.0	10.1	0.0	0.0
Goat River Residents Associates	0.63	0.88	1.48	1.1	0.0	0.0
Total	**4.12**	**1.19**	**14.96**	**59.92**	**8.12**	**4.09**

The majority of the dikes with a Very High risk rating are located within the Creston Diking District (3.06 km, of which 1.41 km are on LKB lands) with smaller sections located within the Reclamation Farms Diking District (0.76 km) and the Duck Lake Diking District (0.27 km on LKB lands). Most dikes are classified as Moderate risk (59.92 km in total), while no dike is classified as Extreme. 1.68 km of the LKB dikes, including 1.41 km within the Creston Diking District and 0.27 km within the Duck Lake Diking District, are classified as Very High. Also, 6.75 km of the LKB dikes, including 4.31 km within the Creston Diking District and 2.44 km within the Duck Lake Diking District, are classified as Moderate.

The dikes were then ranked based on their risk ratings to prioritize structural repairs and upgrades within the study area (Section 5.7). The recommended risk reduction measures and associated cost estimates will be provided in a separate report (under preparation).

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

1.1 PROJECT OVERVIEW

The Creston Valley is home to the Kootenay River and its tributaries, including the Goat River, running from east to west. Being located at the confluence of two major streams and several creeks, the Creston Valley has been historically prone to flooding, as evidenced by the dike network protecting residential areas and agricultural lands along the Kootenay River and Goat River. Flooding of the Kootenay River floodplain was frequent until the dike system was built between the 1930s and 1950s, during which time close to 100 km of dikes were built on the banks of the Kootenay River and Goat River. The remnant floodplain area protected by these dikes now fosters rich agricultural lands as well as residential and commercial lots. Construction of the Libby Dam in the USA has significantly contributed to the reduction of peak discharges on the Kootenay River, further reducing the flood risk in the Creston Valley.

Nonetheless, flooding remains a hazard in the area, as concluded in the 2014 Creston Valley Floodplain Management Study (BGC, 2014a), and the existing dike system needs to be maintained and upgraded to remain resilient in a changing climate. The baseline study completed in 2014 as part of the Floodplain Management Study revealed that the dikes frequently need repairs due to channel erosion. Through hydraulic modelling, the study also revealed that significant portions of the floodplain sit at an elevation lower than the 2-year flood. Thus, a dike failure during a moderate to large flood event could potentially flood a significant area of the Creston Valley. A risk-based Floodplain Management Plan (FMP) was subsequently developed in 2014 for the Creston Valley to better quantify the flood risk and develop mitigation measures to decrease the incremental risk associated with a potential dike failure (BGC, 2014b). The FMP concluded that maintaining the dikes and implementing setback criteria appropriately are the preferred mitigation measures to be implemented locally, which constitute the foundation of the FMP – Phase 3 (BGC, 2014c).

The Town of Creston now recognizes that the FMP developed in 2014 needs to be updated to better address the impact of climate change and land use changes that have occurred since 2014. Given the extent of the required dike upgrades and repairs, prioritization is also essential to develop a realistic and workable resiliency action plan.

In this context, the Town of Creston has retained WSP to update the 2014 flood risk assessment and develop a flood action plan to identify and prioritize potential flood mitigation options. The results of this work will:

— Improve the understanding of the likelihood and consequences of dike failure;
— Provide the Town of Creston with information to be used for management, repairs, or monitoring of the diking system to reduce risk; and
— Provide the supporting information for funding applications.

This report details the flood risk assessment completed by WSP, whereas the flood action plan is outlined in a separate report. WSP's detailed scope of work for this study is listed in Section 1.2.

1.2 SCOPE OF WORK

The scope of work for this stage (Stage 1) of the project includes:

— Review the collected information and build an understanding of the project background;
— Study the floodplain infrastructure and management techniques and understand the potential changes in the diking system, floodplain management, wetland management, and land use since 2014;
— Review the 2014 hydrological and hydraulic analysis, confirm the validity of the methodology and results, and provide recommendations;
— Conduct a site inspection of the dike network and complete an erosion assessment;
— Conduct a flood risk assessment.

1.3 REPORT STRUCTURE

The following summarizes this report's structure by describing each chapter's content and goals.

Chapter 2: Study Area. Provides a description of the regional setting of the study area, which includes a description of the Kootenay River regulation, an inventory of the existing dikes, and an overview of wetland management.

Chapter 3: Hydrology. Provides information on the river's watershed and summarizes previous hydrological assessments completed for the Goat and Kootenay rivers.

Chapter 4: Hydraulic. Describes the previous hydraulic modelling assessments and summarizes the flood quantiles and flood levels for various return periods.

Chapter 5: Flood Risk Assessment. Describes the methodology and results of the flood risk assessment. This chapter also provides a prioritization of the dike's repairs and upgrades.

Chapter 6: Summary. Summarizes the main findings of this study.

Appendix A provides overview maps of the dikes, **Appendix B** shows the flood risk rating table is provided.

2 STUDY AREA

The study area covers the Kootenay River between the US border and Kootenay Lake and the Goat River for approximately 4 km upstream of Highway 21. Maps A-1, A-2, and A-3 (Appendix A), show the study area extent, including the diking district boundaries for the Kootenay River and Goat River. An extensive portion of the Kootenay River's banks and part of the Goat River's banks are diked, protecting the agricultural, residential, and commercial developments in the floodplains against the river floods. The main factors controlling the flood levels at the dikes along the Kootenay River are Kootenay Lake levels and the operation of Libby Dam. The following sections explain these factors.

2.1 GOAT RIVER

The Goat River, with a drainage area of approximately 1,274 km^2, originates in the Moyie Range and flows west toward the Kootenay River, as shown in Figure 2.1.

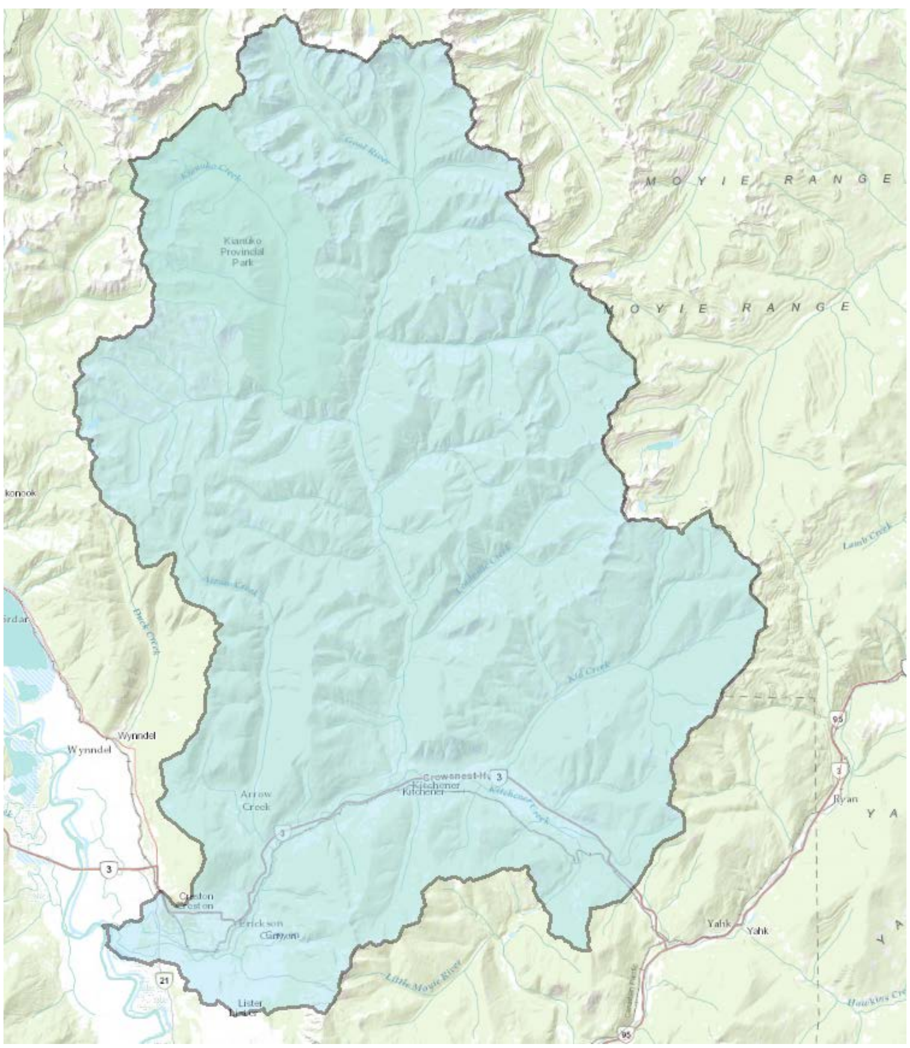

Figure 2.1 Goat River Watershed Delineation at the Junction of the Kootenay River

The Goat River dikes located within the study area are shown on Map A-3 in Appendix A. The risk ratings shown on this map are described in Section 5 of this report. Most of the dikes along the Goat River were built before 2006/2007 and approximately 1.25 km of new dikes were constructed in 2006 and 2007. A gravel berm about 0.35 km long with an unknown ability to withstand a flood fills a gap between dikes from km 0.65 to 1.

Unlike the dikes along the Kootenay River, most dikes along the Goat River are on private lands, and access depends on private agreements with each landowner.

2.2 KOOTENAY RIVER

The Kootenay River, with a drainage area of approximately 50,027 km^2, originates in Canada and flows south into Montana, as shown in Figure 2.2. About 45 km north of the border, the Kootenay River discharges into Kootenay Lake, which is a naturally formed lake whose levels are regulated by the Corra Linn Dam for low flow conditions and by the Grohman Narrows, located approximately 10 km upstream of the dam, in high flow conditions (BGC, 2014a).

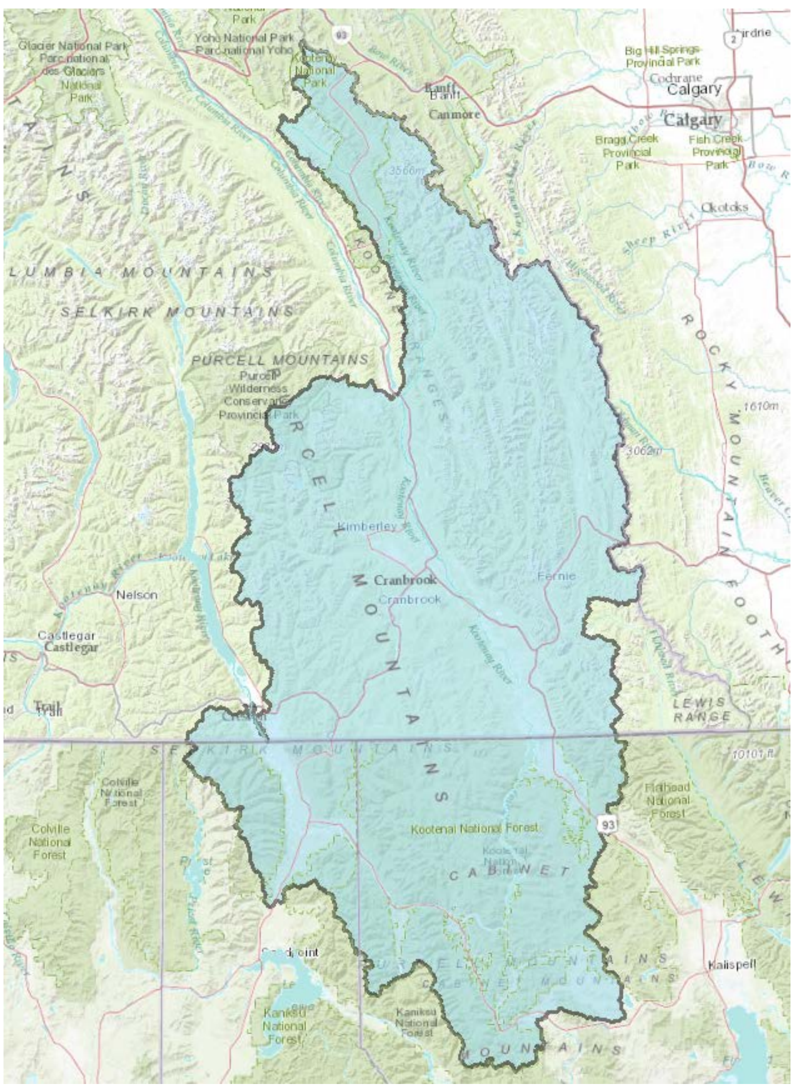

Figure 2.2 Kootenay River Watershed Delineation at the Town of Creston

The Columbia River Treaty (Treaty) was signed between the US and Canada in 1964 to develop and operate the dams and reservoirs on the Columbia and Kootenay rivers to optimize flood control and power generation in both countries. The Treaty resulted in the construction of the Duncan, Hugh L. Keenleyside, and Mica dams in BC and allowed the construction of the Libby Dam in the US.

2.2.1 DIKING SYSTEM

A significant portion of the Kootenay River within the study area is diked. Only the following segments of the river are not diked:

- Approximately 16.5 km of the right bank, from the US-Canada border to the confluence with the Goat River;
- Approximately 2.3 km of the left bank between the mouth of the Old Kootenay River Channel and Nick's Island Diking District, which is mostly within IR1C;
- The left bank downstream of Nick's Island Diking District and the last part of the right bank downstream of the fork at Six Mile Island. Also, the left bank of the side channel is unprotected is this area. All these areas lie within the Creston Valley Wildlife Management Area (CVWMA).

The footprint of the Kootenay River dikes was downloaded from the BC Water Resource Atlas website[1]. In total,14 dikes, which were surveyed in 2003, with lengths ranging from 0.72 km to 17.55 km, were identified in this database within the study area. The wetland management dikes are not included in this database.

Table 2.1 summarizes the total dike length for each diking authority. In total, the 88 km of dikes along the Kootenay River and the 4 km of dikes along the Goat River were considered in this project. About 8.9 km of the dikes are within the Lower Kootenay Band (LKB) Reserve, as shown in the following table. The wetland management dikes, shown by dashed green lines in Map A-1 and A-2 in Appendix A, were excluded from the current study given their negligible consequence level.

1 https://maps.gov.bc.ca/ess/hm/wrbc/

Table 2.1 Summary of Dikes Along the Kootenay River

DIKING AUTHORITY	DIKE NO.	DIKE NAME - LKB DIKES LENGTH (km)	TOTAL LENGTH (km)
Reclamation Farm Diking District	266, 267, 268	--	28
Creston Diking District	37, 120	IR1C – 2.71 IR2 – 1.87 IR3 – 1.62	19 (Including the LKB dikes)
Nick's Island Diking District	120, 141, 142, 143	--	16
Duck Lake Diking District	48, 120	IR5 – 2.68	11 (Including the LKB dikes)
Goat River Residents Associates	69	--	4*
Creston Valley Wildlife Management Area	38, 39, 40	--	14
Total		**8.9**	**92**

* Part of this dike was built in 2006-2007 (BGC, 2014a) and is therefore not available on the BC Water Resource Atlas website.

Figure 2.3 shows the share of each diking authority as a percentage of the whole diking system in the area. The Reclamation Farm Diking District owns 30% of the dikes, followed by Creston Diking District (21%), Nick's Island Diking District (18%), and Creston Valley Wildlife Management (15%).

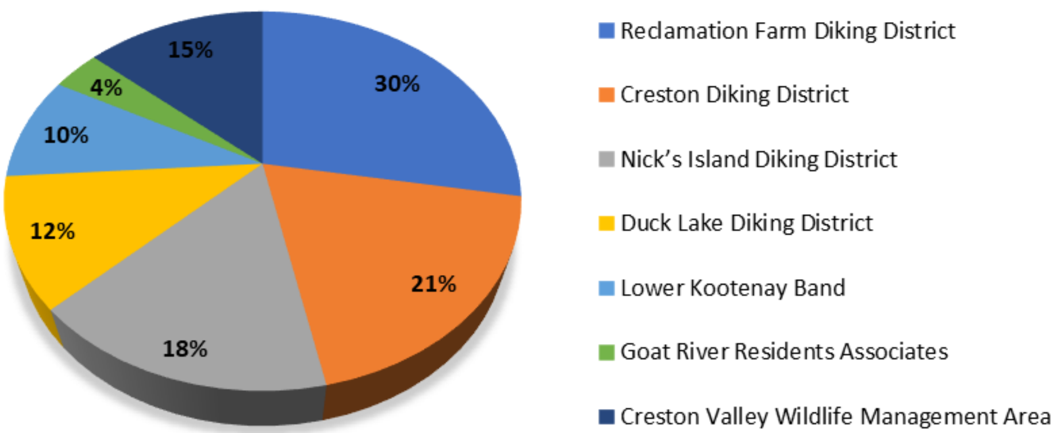

Figure 2.3 Diking Ownership Shares

The dikes along the Kootenay River are typically 5 to 6 m high, with a 4 m wide crest and 2H:1V side-slopes. These dikes were constructed between the 1930s and 1950s using fine-grained sands and silts dredged from the river or adjacent floodplain (BGC, 2014a).

The Duck Lake Unit (constructed to prevent water in Duck Lake from backflooding all the way upstream to Wynndel) and Duck Lake Unit 2 (constructed for wetland management), have not been constructed to a 200-year standard. The 4 km dike separating the Creston Diking District from the Duck Lake Diking District (constructed in the mid-1930s) was initially built to protect the Creston Diking District from Kootenay River flooding. After twenty years, this section of the dike was rendered as a secondary level of protection.

The LKB dikes (referred to as IR1B, IR1C, IR2, IR3, and IR5), which are located on First Nations land, protect 774 ha of land. No one holds the responsibility to maintain the dikes that were built on lands adjacent to the Kootenay River on IR1C, IR2, IR3, and IR5 lands, as they are located on Crown land. Nonetheless, the LKB attempts to maintain the dikes up to provincial standards.

The two dikes located on IR1B south of the Goat River (Long Dike [3.1 km] and Short Dike [1.3 km]) were built for wetland management, but they also provide flood protection from the Kootenay River and Goat River to some extent.

All the dikes except for the LKB dikes are regulated under the Provincial Dike Maintenance Act (DMA). The Act requires the diking districts to maintain their dikes to a high standard as advised by the Deputy Inspectors of Dikes Offices. On the other hand, dikes on LKB lands are owned and maintained by the LKB. The LKB attempts to maintain the dikes to a provincial standard (BGC, 2014a).

The diking authorities within the Creston Valley project area, including five diking authorities and the LKB on the Kootenay River and one diking authority on the Goat River, have managed their dikes independently for several decades. However, there is a growing realization that all the dikes must be managed as a whole to achieve optimum results.

2.2.2 WATERSHED REGULATION

The Kootenay River flow regime is significantly impacted by the Libby Dam operations, whereas Kootenay Lake levels are impacted by the Corra Linn Dam, Duncan Dam, Grohman Narrows, and Libby Dam operations (BGC, 2014a). These regulating features are described below.

Corra Linn Dam: This concrete hydroelectric dam was completed in 1932 to control upstream storage in Kootenay Lake and generate power. For the first six years of operation, the dam was not permitted to raise the level of Kootenay Lake. After the 1938 floods in Idaho farmlands, the International Joint Commission placed a limit on dam operations during the spring freshet to reduce the potential backwater effect of lake levels impacting farmers in Idaho.

Duncan Dam: This dam was completed in 1967 and “improves the amount and timing of power generation for downstream hydro projects, provides downstream flood control benefits, and provides fish flow regulation in the Duncan River below the dam” (BGC, 2014a). The dam regulates approximately 13% of runoff in the Kootenay Lake basin.

Grohman Narrows: This was a natural constriction of the West Arm of Kootenay Lake located about 10 km upstream of Corra Linn Dam until the West Kootenay Power and Light Company dredged the constriction as a condition of the International Joint Commission’s 1938 Order for Kootenay Lake. As a result, the potential flood levels on Kootenay Lake were lowered by about 1 m. The Narrows still control the water levels in Kootenay Lake during the spring freshet (BGC, 2014a).

2.2.2.1 LIBBY DAM

Construction of the dam started in 1972 and finished in 1973, and the reservoir was filled for the first time in 1974. Since then, Libby Dam operations have been evolving to reflect the downstream requirements from a flood control, fish habitat, and power generation point of view (BGC, 2014a). The Libby Dam operation history is summarized in Table 2.2.

Table 2.2 Libby Dam Operation History

SPECIFICATION	DESCRIPTION
Operator	US Army Corps of Engineers (USACE)
Purpose	– Provides storage for flood control on the lower Columbia River. – Provides local flood control on the Kootenay River. – Hydroelectric power generation.
1973 to 1992 Operation (Standard Flood Control)	– Almost exclusively for flood control and optimizing power generation in Canada and US.
1993 to 2002 Operation (Standard Flood Control)	– Flood control remains a top priority. – Operations for downstream fisheries have a higher priority than power operations. – Generally, less water release from Libby during the fall and winter, and more water release during the spring and summer. – Discharge ramping rate restrictions were adopted in the late 1990s.
2000 Libby Coordination Agreement (LCA)	– Agreement correspondents: Canada and US. – Reason: Canada's objection to the 1993 operation changes which resulted in power losses at downstream Canadian hydropower plants on the Kootenay River system. – Validation: 2000 to 2024 – Agreement: USACE can operate Libby Dam consistent with US fisheries objectives.
2003 to Present (VARQ Flood Control)	– Higher flood control curves for most water conditions. – Flood control remains a top priority. – Downstream fisheries continue to have higher priority than operations for power.
Annual Water Management Plan	– Authorities: Bonneville Power Administration (BPA), the Corps and Bureau of Reclamation, collectively referred to as the Action Agencies (AA). – Purpose: operation of the dam and reservoir projects in the Federal Columbia River Power System (FCRPS).

Source: BGC, 2014a and BGC, 2020a.

Until 1992, the USACE operated Libby Dam to optimize power generation and flood control in both Canada and the US. In 1993, the USACE started to lower the release in fall and winter and increase it during the spring and summer to address the US fisheries regulatory agency's concerns about some fish species. As a result, Canadian hydropower plants on the Kootenay River system suffered from power losses. Canada objected to this operating change which led to the Libby Coordination Agreement (LCA).

The VARQ Flood Control (VARQ FC) regime has been implemented since 2003 as a recommended measure to provide required flows for downstream endangered fish while providing a similar level of flood protection as Standard FC. "With VARQ FC, the release during refill varies according to the reservoir level, water supply forecast, and the estimated duration of flood control" (BGC, 2014a).

Each year the Action Agencies issue a water management plan to describe how they plan to implement specific operations identified in various governing documents, including the latest biological opinions (BiOp). The 2000 US Fish and Wildlife Service (USFWS) FCRPS BiOp was supplemented in 2006 with additional information for Libby Dam (collectively referred to as the 2000/2006 BiOp) (in the 2020 Water Management Plan [Bonneville Power Administration et al., 2019]). The 2006 BiOp provides recommendations for flow ramping rates (up and down), flow augmentation, minimum flows, and habitat improvements in the Kootenay River. This BiOp anticipated a reduction in the negative effects of rapid changes in Kootenay River flows and water levels. The aggressive flow ramping in the past was unfavorable to fish and has been identified as a primary reason for increased bank erosion rates observed in the Creston Valley (NHC, 1999).

Summer (May 1 to September 31)			
	Flow Release (kcfs)	**Max Hourly Change (cfs)**	**Max Daily Change (cfs)**
Ramp Up	4 – 6	2,500	1 unit
	6 – 9	2,500	1 unit
	9 – 16	2,500	2 units
	> 16	5,000	2 units
Ramp Down	4 – 6	500	500
	6 – 9	500	1,000
	9 – 16	1,000	2,500
	> 16	3,500	1 unit
Summer (October 1 to April 30)			
Ramp Up	4 – 6	2,000	1 unit
	6 – 9	2,000	1 unit
	9 – 16	3,500	2 units
	> 16	7,000	2 units
Ramp Down	4 – 6	500	1,000
	6 – 9	500	2,500
	9 – 16	1,000	1 unit
	> 16	3,500	1 unit

generating unit is ~ 5,000 cfs

Figure 2.4 Proposed Daily and Hourly Ramp Rates for Libby Dam by 2006 USFWS (BGC, 2014a)

According to the BC Hydro Columbia River Operations Summary (2022):

> "The Treaty Entities, BC Hydro, Bonneville Power Administration (BPA), and the US Army Corps of Engineers (USACE), periodically negotiate and sign supplemental operating agreements when there is mutual benefit to modify the water releases specified by the Columbia River Treaty. In September 2013, the Treaty Entities signed an agreement, reviewed annually, to address some of Canada's concerns about the timing of water releases from Libby Dam, known as the VarQ operating regime. This agreement was extended to be in effect until August 2021 and is supplemental to the Libby Coordination Agreement that was signed in 2000. Under the new agreement, the US has committed to continued coordination with Canada to consider alternative reservoir operations to reduce flood risk in both countries, similar to the extensive collaboration that occurred during 2012, 2017, and 2018 high water events."

Although the Libby Dam operation has not changed since 2003, negotiations between the US and Canada on the revisions and modernizations of the Columbia River Treaty, which expires in 2024, might affect the operation of Libby Dam and, consequently, the flows and water levels in Kootenay River and Lake.

2.2.3 WETLAND MANAGEMENT

The following dikes were built for wetland management purposes within the CVWMA (Map A-1 and A-2, Appendix A):

- Duck Lake Unit (1953) was built for land reclamation for agriculture while Duck Lake Uni2 dike was built in 1971 to create the Duck Lake Nesting Area (wetland management);
- The dike along the south end of Leach Lake (1971) to prevent water from Summit Creek from running through the original channels that existed before the creation of the wetland compartments;
- The dikes that partition Leach Lake into smaller wetland units (1973);
- The three cross-dikes on the northern portion of Six-Mile Island (1973 to 1975), and a more southerly cross-dike (1977);
- The north and south cross-dikes on the Corn Creek marshes (1974);
- The central dike on the Corn Creek marshes (1987).

In 1969, a number of wetland dikes, including the Long Dike and Short Dike, were constructed, along with pumping stations to pump water into five wetland compartments. In 2003, the Yaqan Nukiy Wetlands Friendship Society was formed in cooperation with the LKB to rehabilitate and maintain these lakes, and to service, repair, and maintain the pumps that will periodically re-flood the wetland compartments (BGC, 2014a).

According to an article by Higginson, LKB wetland restoration is five years into a plan which is providing wildlife habitat improvement and flood protection. LKB wetland restoration improves local wildlife habitat and provides natural flood protection by capturing a considerable amount of freshet, pluvial, or fluvial flows (Higginson, 2022).

Also, in 2020, a comprehensive environmental impact assessment of Columbia River System Operations was conducted (USACE et al., 2020). This study assessed different alternatives for future operations, maintenance, and configuration of the Columbia River System. Various mitigation measures were recommended to reduce the unavoidable adverse impacts of the selected alternative. Up to 100 acres of native forested and scrub-shrub wetland vegetation will be planted along the river. “This would offset effects to existing wetlands and riparian forests downstream of Libby, which would be caused by the Modified Draft at Libby measure, and result in lower water levels on the Kootenai River” (USACE et al., 2020).

These kinds of floodplain and wetland management alterations may change the hydraulics of the river at the project site. The effects of these alterations should be considered in any future hydraulic analysis.

3 HYDROLOGY

The most current hydrological assessment of the study area was completed by BGC in 2014 (BGC, 2014a). WSP reviewed the 2014 hydrological assessment to determine if it can be relied upon for the current flood risk assessment. This section describes the hydrological regime of the Kootenay River and Goat River and provides a summary and discussion of the previous hydrological study completed by BGC in 2014 (BGC, 2014a).

3.1 KOOTENAY RIVER

3.1.1 MEAN ANNUAL RUNOFF

Comparing the mean annual discharge for the four Kootenay River hydrometric stations of Fort Steele, BC (08NH065), Libby Dam, MT (12301933), Porthill, ID (12322000), and Goat River at Erickson (08NH004) shows that:

- About 57% of the runoff at Libby Dam originates upstream of Fort Steele, BC;
- Libby Dam regulates about 70% of the total Kootenay River runoff at Porthill, Idaho. The remaining 30% is generated from unregulated tributaries downstream of the dam;
- The Goat River accounts for about 5% of the Kootenay River mean annual flow.

3.1.2 LIBBY DAM FLOW REGULATION

The Kootenay River watershed's peak flows are dominated by snowmelt, which typically starts in April, with peak flows occurring in May and June. In natural conditions, flows generally decline gradually through the late summer and fall, with minimum flows occurring in March. In post-Libby Dam conditions, the average mean annual floods have declined to less than half of the natural conditions, whereas the mean discharge in the fall and winter are now three to four times higher than unregulated conditions. A similar trend is observed for average flow velocities at Porthill, Idaho (BGC, 2014a).

Further flow analysis shows that for about 77% of the streamflow record, discharge is below 605 m^3/s for both pre- and post-Libby Dam conditions (Figure 3.1). Kootenay River flows were below 200 m^3/s about 47% of the time during the pre-Libby period, compared to 22% after dam construction. However, flows used to exceed 1,100 m^3/s 12% of the time. Since the Libby Dam construction, this percentage has dropped to 2%, and the daily recorded flow hasn't exceeded 1,780 m^3/s. The results presented in Figure 3.1 indicate that the Libby Dam operations sharply reduced the occurrence of severe flood events but increased the occurrence of mid-range flow events.

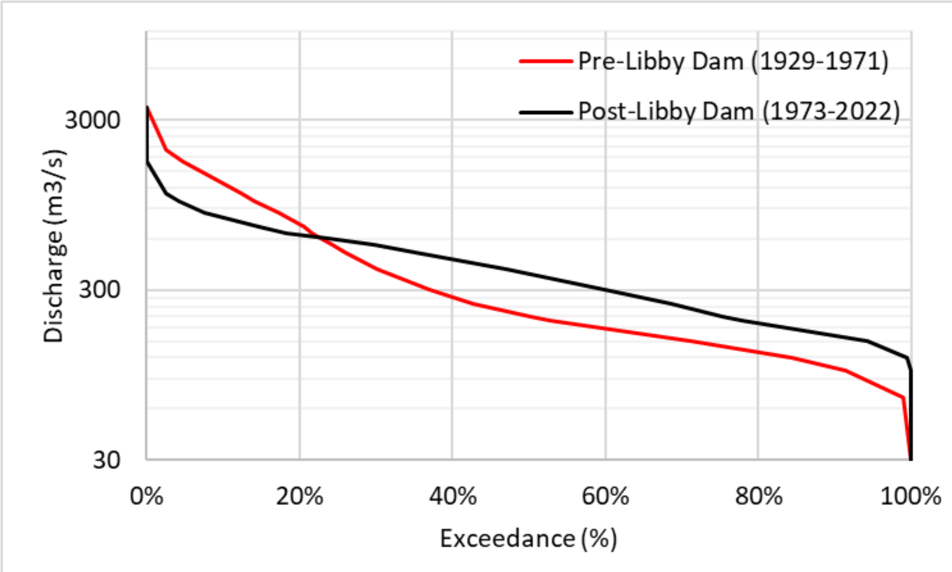

Figure 3.1 Discharge Exceedance Curve of Kootenay River at Porthill

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3.1.3 KOOTENAY LAKE LEVELS

As discussed in Section 2.1, Kootenay Lake levels are affected by different factors, among which Libby Dam has the most significant impact. Winter lake levels are similar for pre- (1938-1971) and post-Libby Dam (1973-2010) periods, but summer lake levels have decreased by 2 m since Libby Dam controls approximately 40% of runoff to Kootenay Lake (BGC, 2014a). As shown in Figure 3.2, the average annual peak water level at the Kootenay Lake has dropped by about 1.75 m for the post-Libby Dam period.

During the Libby Dam operation, the average annual lake levels have decreased by about 0.5 m and the average mean annual flood level has decreased by 2 m. For example, the highest flood level at Kuskonook since dam construction is 534.8 m (recorded on June 24, 1974), which is less than the mean annual flood level of 535 m for the 1936-1971 period (BGC, 2014a).

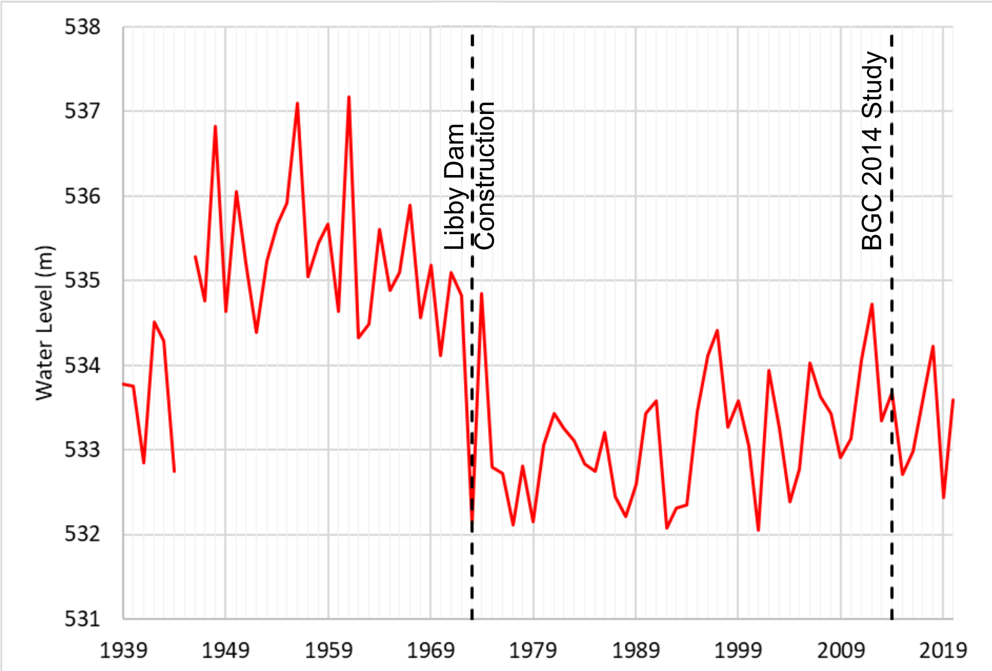


Figure 3.2 Annual Peak Water Levels at Kootenay Lake at Kuskonook Station

3.1.4 FLOOD FREQUENCY ANALYSIS – KOOTENAY RIVER AND KOOTENAY LAKE

Flood frequency analysis (FFA) is a widely used method for estimating river flow associated with flood events of different return periods. FFA should be applied on annual recorded peak flows where flow data is natural or naturalized and the record is long enough. However, in their 2014 analysis BGC faced two challenges in applying this method to the Kootenay River:

— Kootenay River stages are influenced by Kootenay Lake elevations due to the backwater condition;

— lack of homogenous flow data on the Kootenay River since the dam operation is evolving with time.

The USACE (2004, 2005) developed a reservoir routing and hydraulic model of the Kootenay River that extends from Libby Dam to the outlet of Kootenay Lake. Model simulations were done using the USACE's Streamflow Synthesis and Reservoir Regulations computer model (SSARR) and the Autoreg pre/post-processing program based on consistent flood regulation rules. The operating procedures at Libby Dam, Duncan Dam, and Corra Linn Dam, as well as the Kootenay Lake's outflow limitations caused by Grohman Narrows, were included in the model. The outputs from this model, including Libby Dam outflows and Kootenay Lake elevations, were then used in the USACE's HEC-RAS model as upstream and downstream boundary conditions. The intermediate flows from 1948 to 1999 were also included in the model. The model was developed based on the 2002 USGS (2004) surveyed cross-sections for a 52-year record (1948-1999). Also, the hypothetical hydrographs were generated for the 100-year, 200-year, and 500-year return periods (BGC, 2014a).

Flood stage frequency results are provided in Table 3.1 for various return periods at both Kootenay Lake at Kuskonook and Kootenay River at Porthill, Idaho. The last column of this table shows the estimated Kootenay River flow at Porthill. More details on the methodology of flow estimation are provided in Section 4.1.

Table 3.1 Stage-Frequency Results for Kootenay Lake and Kootenay River at Porthill, Idaho (BGC, 2014a after USACE 2004, 2005) and Estimated Flows- Post-Libby Dam

RETURN PERIOD	KOOTENAY LAKE AT KUSKONOOK (m)*	KOOTENAY RIVER AT PORTHILL, IDAHO (m)*	KOOTENAY RIVER AT PORTHILL (m^3/s)
2	533.4	534.9	1,065
5	533.9	535.4	1,356
10	534.2	535.7	1,526
20	534.5	535.9	1,677
50	534.8	536.1	1,856
100	535.0	536.2	1,983
200	535.2	536.8	2,103

* CGVD28 Datum.

There are some uncertainties and limitations in the USACE and BGC models. For example, the BGC HEC-RAS model assumes that Libby Dam is operated at powerhouse capacity. But, according to the BGC report, the sturgeon flow augmentation can exceed the powerhouse capacity when water supply conditions are conducive (BGC, 2014a). According to the Kootenay Lake exceedance curve for the May-July period presented in the BGC report, the lake levels are expected to increase up to about 0.8 m if Libby Dam operation exceeds the powerhouse capacity by 10,000 f^3/s.

However, the studies completed by the USACE and BGC are currently the most reliable analyses. Also, the dam VARQ FC operation is still effective for Libby Dam. Therefore, the models are still considered valid. Hence, the 2014 hydrological analysis of the Kootenay River is considered adequate for the current risk assessment.

3.2 GOAT RIVER

3.2.1 FLOOD FREQUENCY ANALYSIS – GOAT RIVER

The Goat River is one of the main tributaries to the lower Kootenay River. There is a dam on the Goat River but it is not expected to impact the peak flows given its limited storage volume. Therefore, a FFA could be conducted for the Goat River since it is not considered regulated and flood levels in the area of interest are not impacted by Kootenay River water levels. The Goat River hydrometric station has flow data records for the period of 1914-1995. Table 3.2 provides flood-frequency results for the Goat River based on instantaneous peak flows. The estimated 200-year flow of 486 m^3/s is similar to the 200-year flow of 474 m^3/s used in the 1984 provincial floodplain mapping study (BGC, 2014a).

Table 3.2 Flood Frequency Results for Goat River (BGC, 2014a)

RETURN PERIOD	FLOW (m^3/s)
2	228
5	300
10	343
20	380
50	425
100	456
200	486

More recently, BGC updated the Goat River FFA, which yielded similar results. The 200-year flow estimate in 2020 was 495 m^3/s (BGC, 2020b), which is about 2% higher than the 2014 estimates of 486 m^3/s. No additional data is available at the Goat River hydrometric station to update the results. The streamflow record at the Goat River hydrometric station could potentially be extended by correlating streamflow data from a nearby active hydrometric station. However, this is not expected to significantly change the flood quantiles calculated in 2014 and 2020 given the length and quality of flow data available at the Goat River station. The results presented in Table 3.2 are therefore considered adequate and up to date.

3.3 CLIMATE CHANGE

At the time of writing this report, a climate change analysis was being carried out (by others) to predict the effect of changing climate variables on future Kootenay Lake levels and Goat River flows. The Kootenay Lake levels have a direct impact on dike overtopping likelihood along the Kootenay River and understanding its future behavior under various climate models is essential for proper flood management planning. Similarly, the Goat River Dikes could potentially be overtopped during flood events and it is useful to understand how the frequency and magnitude of these events could evolve under a changing climate.

The main conclusions of the climate change assessment are listed below:

— Under Representative Concentration Pathways (RCP) 4.5 and 8.5, the snowpack at high elevation is expected to remain constant or increase slightly until about 2035 due to increasing winter snowfall at high elevation. Declines in snowpack follow after about 2035 as warmer winter temperatures become the dominant factor in snow dynamics. This is expected to slightly increase the trend in spring freshet levels for Kootenay Lake until about 2035, followed by reductions thereafter. The trend in annual peak flow for the Goat watershed is already in decline as warming temperatures are dominating the snow dynamics in this watershed due to its relatively low elevation.

— It was established in this project that Kootenay River Dikes could potentially be overtopped if a 200-yr flood event would occur on the Kootenay River while the Kootenay Lake is at elevation 537 m. However, the climate change assessment established that this is an improbable event as the Kootenay Lake is highly unlikely to reach an elevation of 537 m, even when considering future climate projections. This implies that the risk of overtopping of the Kootenay dikes is negligible, as long as the Libby Dam flood management remains unchanged.

— Goat River is expected to transition from a Nival regime to a Nival-Pluvial regime, which translates to more frequent high flow events produced by rainfall events. Peak annual flow values are however still expected to occur during the spring freshet and their magnitude is expected to decrease between 2045 and 2095. From a risk perspective, this implies that the Annual Exceedance Probability of having a flood event large enough to overtop the Goat River dikes is expected to decrease from 2035 to the end of the century.

It can be concluded from these findings that the climate change is not expected to amplify the frequency and severity of flood events on the Goat and Kootenay Rivers. From a risk management perspective, this implies that the likelihood of failure evaluation can conservatively be based on historical streamflow data.

4 HYDRAULIC

This section provides a review of the hydraulic studies that were previously completed within the study area. BGC developed 1D hydraulic models for the Kootenay River and the Goat River in 2014. A 2D hydrodynamic model of the Goat River was also developed by BGC in 2020. The following sections provide more details on these models and their results.

4.1 KOOTENAY RIVER

The HEC-RAS model developed for the Kootenay River covers the river from the US border to Kootenay Lake. The model was developed for the regulated conditions based on the 25 river cross-sections surveyed by the BC Ministry of Environment, Lands and Parks (MELP) in 1997. Kootenay Lake elevations measured at Kuskonook station (08NH067) and daily flow measured at Porthill, Idaho for the period of 1973 to 2007 were used as downstream and upstream boundary conditions, respectively. Also, the model included the measured flow at Goat River (1973-1994) as an intermediate inflow.

Model assumptions include:

- The flow over the floodplain is considered ineffective since the 1997 cross-sections do not extend beyond the top of the dike or bank;
- Flow conveyance in the Old Kootenay River channel is ignored since it is not included in the 1997 survey.

Model calibration involved running the hydraulic model in unsteady mode and varying the Manning's n values of the main channel and banks to minimize the difference between simulated and measured water levels at the Porthill, Idaho gauge (available from 1973 to 2007) and the Water Survey of Canada (WSC) Kootenay River at Nick's Island gauge (08NH129) (available until 1987). Calibration was achieved using Manning's n values in the range of 0.033 to 0.038.

The calibrated model was then used to model floods with return periods of 2, 5, 10, 20, 50, 100, and 200 years for regulated conditions (post Libby Dam). Kootenay Lake levels (Table 3.1) were used as the downstream boundary condition, while the upstream boundary condition flow was varied so that water levels at Porthill, Idaho, matched those provided in Table 3.1. In this model, the Goat River flows were assumed to be 75% of their peak flow for a given return period to account for the observed lag between the two watersheds' peak flows. BGC concluded that the 200-year flood level would generally be about 2 m below the dike crest along the river (BGC, 2014a).

BGC also ran the model for pre-Libby Dam conditions using daily Kootenay Lake water level and Porthill discharge data as downstream and upstream boundary conditions, respectively. Stage frequency analysis was then conducted on the annual maximum water levels to define pre-Libby Dam flood levels for different return periods, as shown in Table 4.1.

Table 4.1 Stage and Flood Frequency Results for Post- and Pre-Libby Dam Conditions (BGC, 2014a)

RETURN PERIOD (years)	KOOTENAY LAKE (m)		KOOTENAY RIVER AT PORTHILL (m^3/s)	
	PRE-LIBBY (1938-1971)	POST-LIBBY (BASED ON THE CORPS MODELING)	PRE-LIBBY (1929-1971)	POST-LIBBY (1973-2008)
2	535.0	533.4	2,224	1,065
5	535.9	533.9	2,690	1,356
10	536.3	534.2	2,933	1,526
20	536.7	534.5	3,132	1,677
50	537.1	534.8	3,356	1,856
100	537.4	535.0	3,505	1,983
200	537.6	535.2	3,641	2,103

WSP extracted the dikes' crest profile along the Kootenay River from the 2018 LiDAR data and compared it to the simulated water levels determined by BGC. The vertical datum for the LiDAR data is CGVD2013 while the datum for the BGC results is NGVD29, which according to BGC, is equivalent to CGVD28 (BGC, 2014a). The approximate shift from CGVD28 to CGVD2013 is +0.18 m in Cranbrook[2]. Therefore, the dike profile was adjusted to be comparable to the results from the BGC report.

Comparing the dike crest elevation with the simulated water surface (Figure 4.1) shows that the right bank (east) dike crest is above the simulated 200-year water levels by at least 1.7 m. The freeboard during a 200-year flood is at least 1.45 m along the left bank dike.

2 https://www2.gov.bc.ca/gov/content/data/geographic-data-services/geo-spatial-referencing/vertical-reference-system

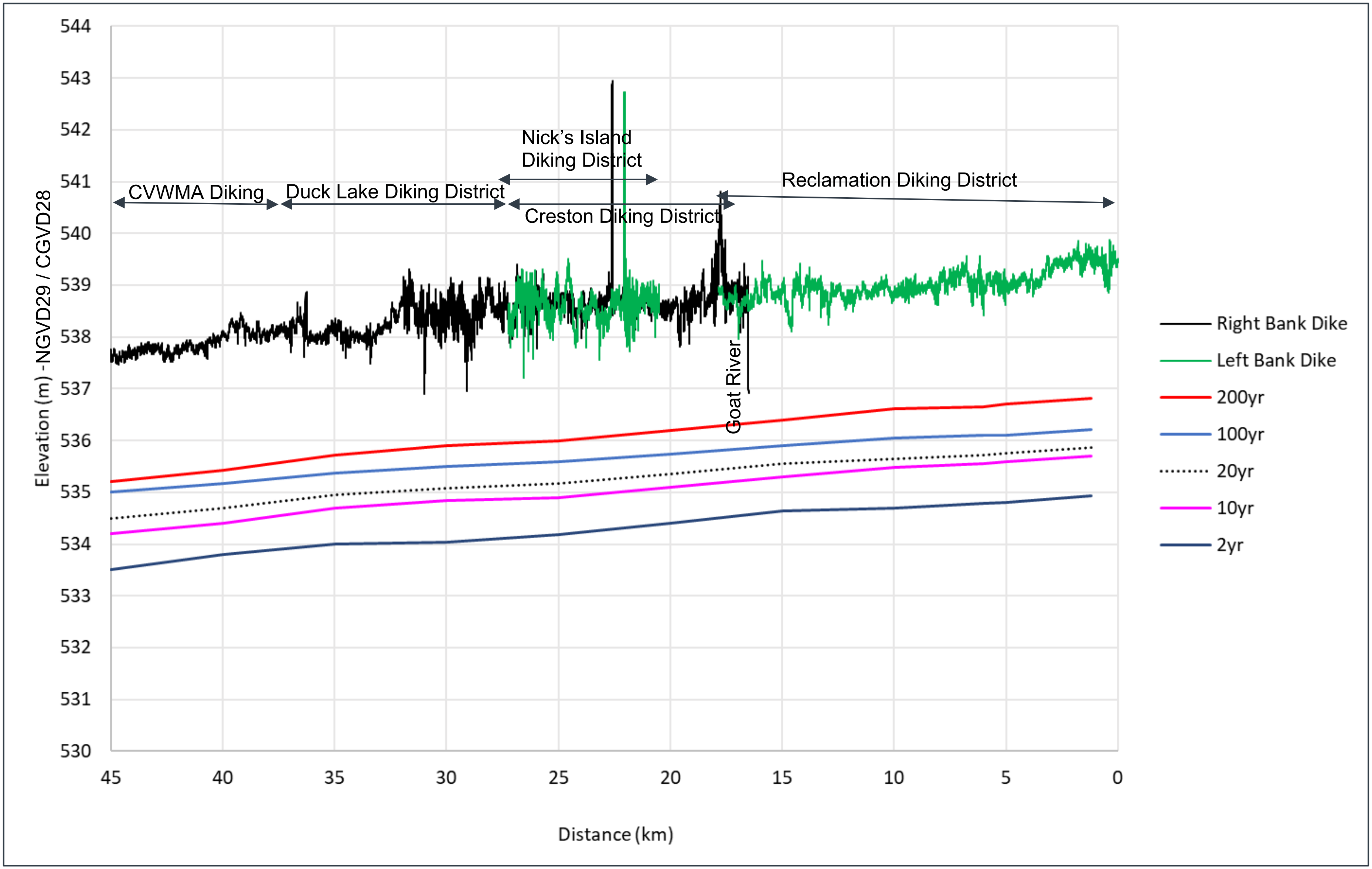


Figure 4.1 Kootenay River Simulated Water Levels Versus Bank/Dike Crest

4.2 GOAT RIVER

BGC developed a 1D hydraulic model in 2014 for the Goat River using the cross-sections surveyed in 1982 (unknown surveyor) along the main and south channels and the cross-sections surveyed by the Ministry of Water, Land and Air Protection in 1997. The model used the flows from Table 3.2 and the corresponding Kootenay River water levels for various flood return periods as upstream and downstream boundary conditions. This is a conservative assumption, given the observed lag between the two rivers' yearly peak flows. However, the downstream boundary condition does not impact the water levels within the study area, upstream of Highway 21.

Figure 4.2 shows the results of the model for 2-year and 200-year flood conditions upstream of Highway 21. The dike freeboard for a 200-year flood is generally 0.6 m, except for the area around km 6, where the dike was constructed in 2007.

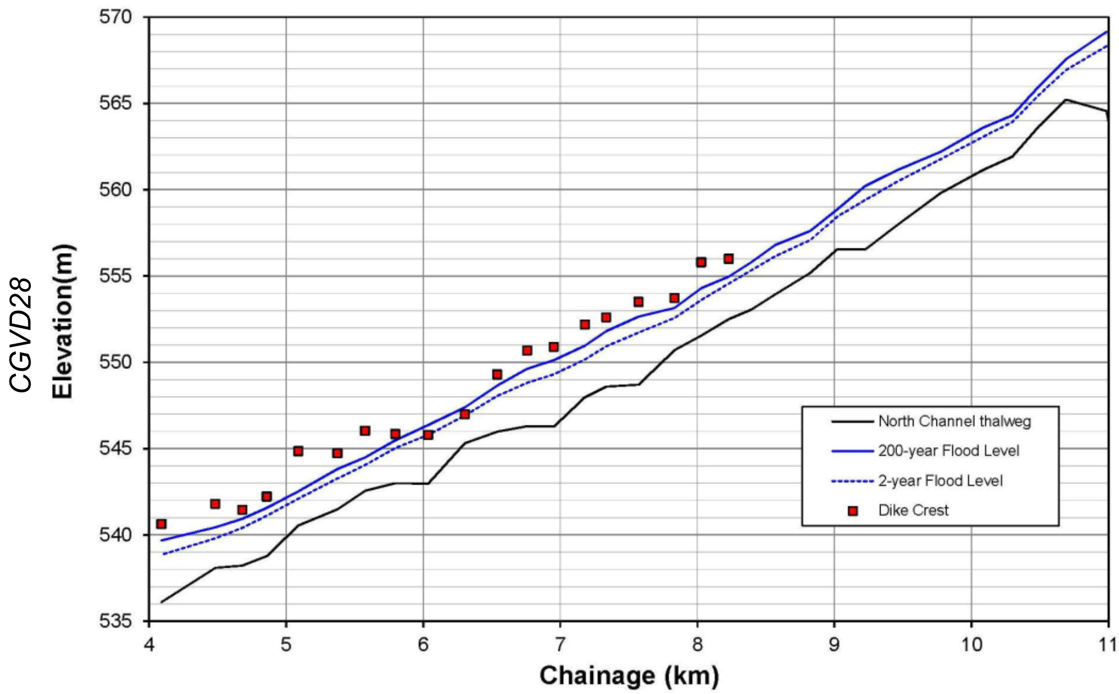


Figure 4.2 **Goat River Simulated Water Levels, 2-year and 200-year Floods (BGC, 2014a)**

The following concerns have been identified from the BGC report:

- 1D hydraulic modelling is generally not recommended for braided rivers like the Goat River;
- It is unclear if the model was calibrated;
- The 1D hydraulic model for the Goat River was developed based on the 1982 and 1997 bathymetric cross-sections. Klohn Crippen (2002) and AMEC (2005) compared the surveys and concluded that the 1997 thalweg is almost 1.5 m lower than the 1982 thalweg. It is unclear how BGC resolved this inconsistency;

— According to BGC (BGC, 2020b), the active channel keeps migrating due to aggrading and depositing large gravel bars. For example, comparing the 2018 LiDAR data and 2019 bathymetric surveys shows that there is a significant shift in the channel geometry, especially downstream of the Highway 21 north bridge, where the channel had migrated by over 50 m north in one location as a consequence of a 2-year to 5-year return period flood (Figure 4.3). Also, Figure 4.4 and Figure 4.5 show the general migration of the river over time. Therefore, the 1982 and 1997 cross-sections are likely outdated and inadequate for hydraulic analysis.

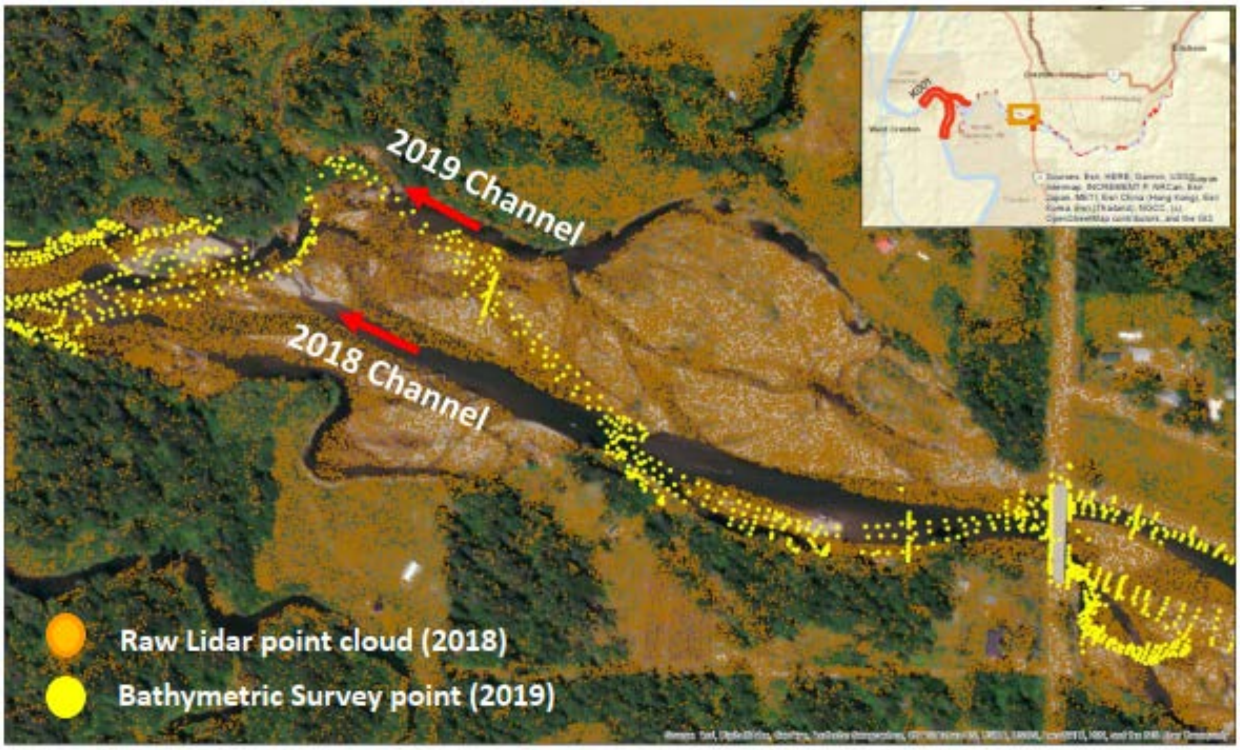


Figure 4.3 2018 LiDAR Data Versus 2019 Ground and Bathymetric Survey Data – Goat River (BGC, 2020b)

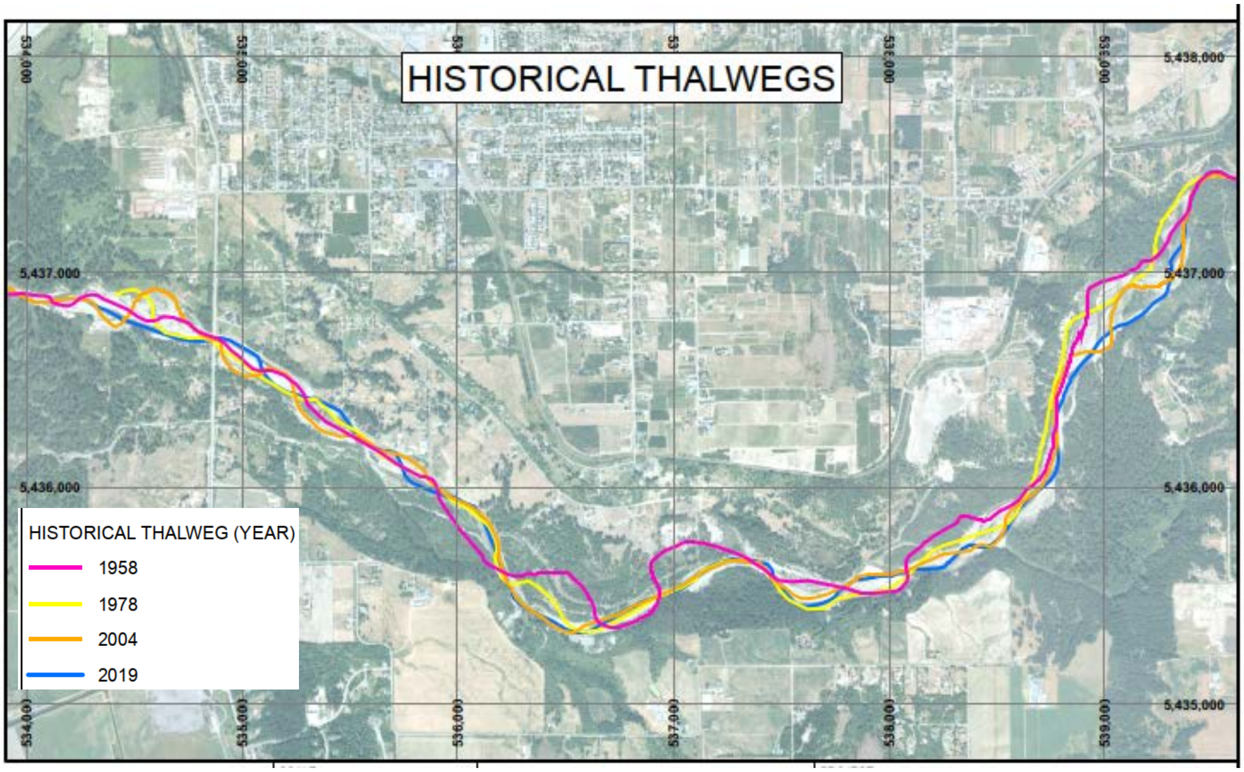


Figure 4.4 **Historical Goat River Thalweg (BGC, 2020b)**

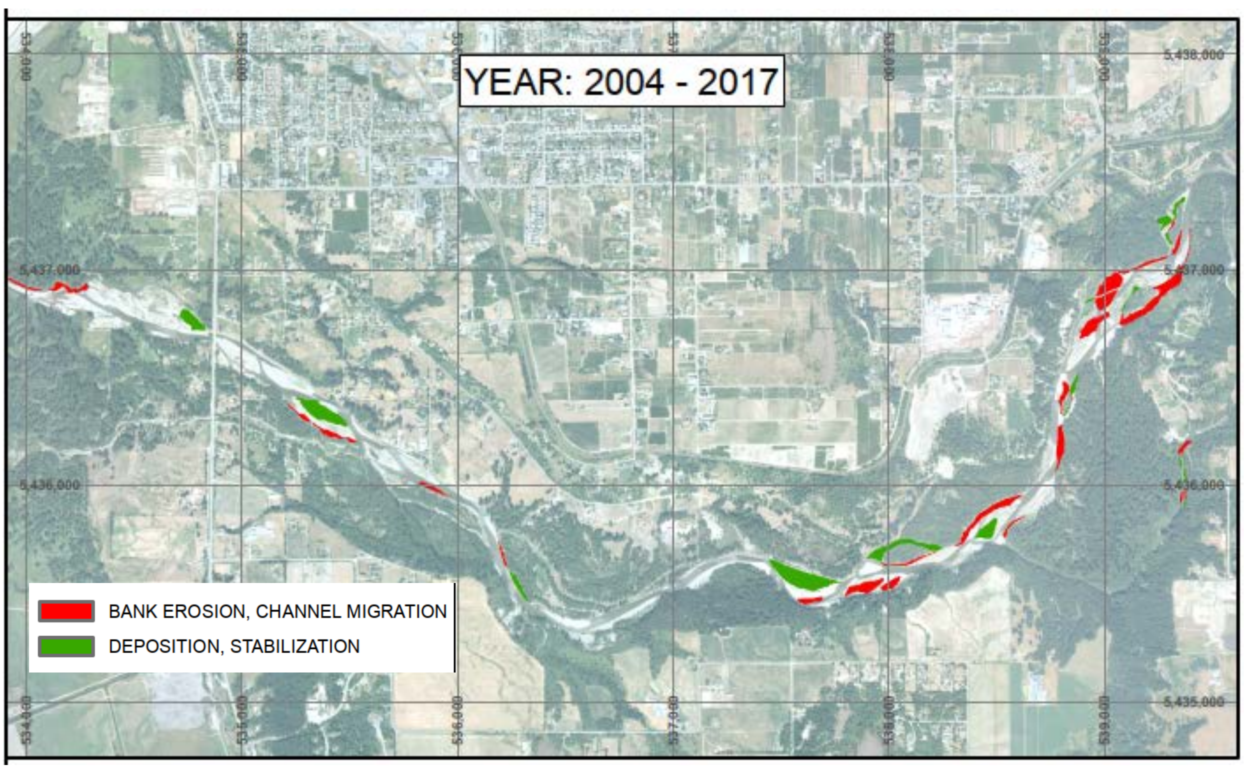


Figure 4.5 **Goat River Channel Erosion and Deposition Between Years 2004 and 2017 (BGC, 2020b)**

To address these issues, BGC developed a 2D hydraulic model for the Goat River in 2020. The model was built using the 2018 LiDAR data and the ground and bathymetric survey data collected for the channel bed, bridges, and dikes in 2019. The bridge along Highway 21 was surveyed as well. The stage of the 20-year flood of the Kootenay River was considered the initial downstream boundary condition. The stage was then gradually increased over 30% of the simulation time to include the design flow from the Goat River. According to BGC (BGC, 2014a), downstream boundary condition does not affect water levels upstream of Highway 21. Upstream flows were defined by conducting a FFA on the historical peak flows. The 200-year flood was estimated to be 495 m^3/s, which is slightly higher than the flow of 486 m^3/s from the 2014 report. The model is not calibrated.

The 2020 BGC flood inundation maps show the Flood Construction Level (FCL), which includes 0.6 m of freeboard. The results of this modelling show that:

- The dike crest is typically greater than 0.4 m above the 200-year flood level (without considering the 0.6 m freeboard). An exception is several hundred metres of the dike that was built in 2006/2007, including about 330 m of the dike around km 2.4, where the dike is expected to be overtopped by a 200-year flood by about 0.8 m. For more details, refer to Figure 4.6, below. The dike at km 0.51 to 0.55, 0.65 to 1.0, 2.7 to 2.8, and 3.1 to 3.45 is not classified as a dike in the BC Water Resource Atlas;
- Part of the inundation is due to flow around dikes (BGC, 2020b).

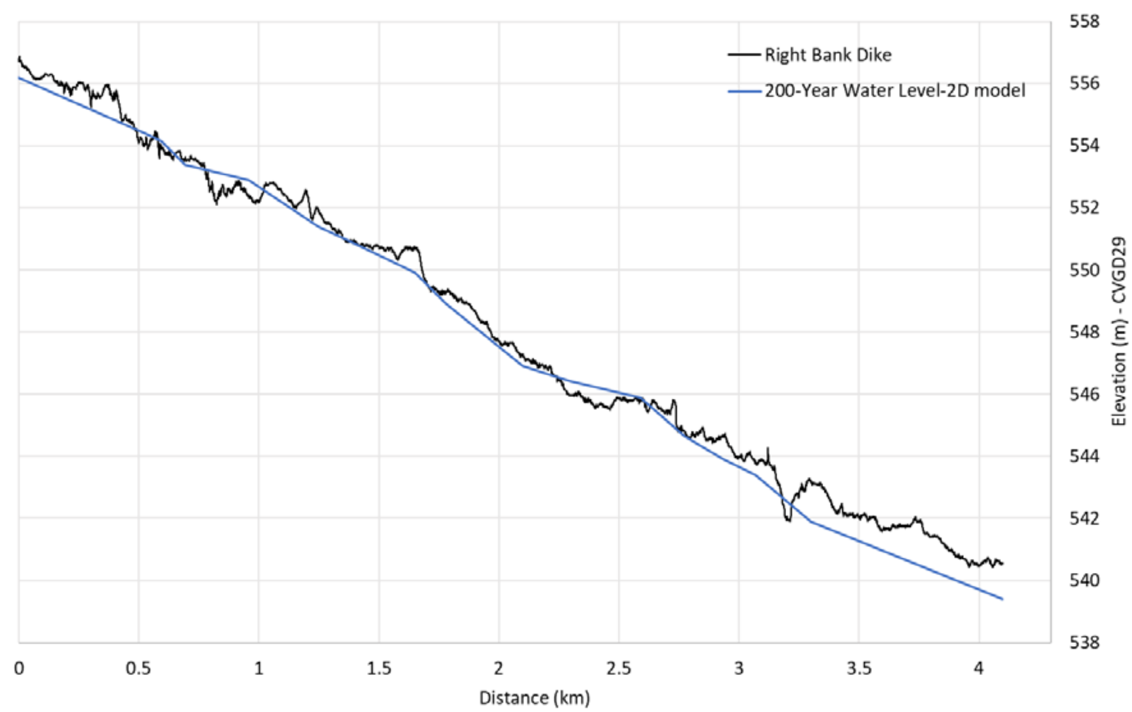


Figure 4.6 Simulated Water Levels for Goat River – 2D model

Comparing the simulated water levels from the 2020 2D model and the 2014 1D model shows that the simulated water levels are similar immediately upstream of Highway 21 but the difference increases in upstream areas. 2D water levels are about 1 m higher about 3 km upstream of Highway 21. The results of the 2D model are expected to be more reliable since the more recent topographic and LiDAR data were used in the model and 2D models are generally more appropriate for braided rivers such as the Goat River. The results of the 2D model are comparable to the 1984 flood inundation study results. Considering the analysis presented above, results from the 2D model presented in the 2020 BGC report were used for the current risk assessment.

5 FLOOD RISK ASSESSMENT

5.1 APPROACH

A Flood Risk Assessment (FRA) aims to evaluate the probability of a flood or dike breach occurring and the potential impact it may have in terms of the magnitude and type of damage or losses it may cause. It requires the completion of the following steps:

— Identify flood hazard scenarios;

— Evaluate the occurrence likelihood of the flood hazard scenario that would result in losses impacting the public and the environment negatively;

— Estimate the consequences of the flood hazard scenario. This typically includes economic losses, loss of life, environmental damages, cultural losses and other intangible effects;

— Define the flood risk rating based on the consequence and likelihood of a given flood hazard scenario;

— Prioritize risk mitigation measures.

Figure 5.1 presents a schematic arrangement of the main components of a flood risk assessment.

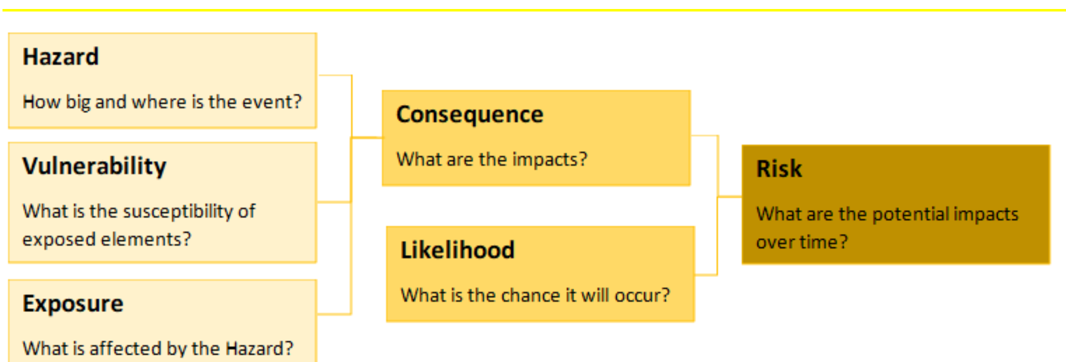


Figure 5.1 Conceptualization of a Flood Risk Assessment

For this study, the flood risk evaluation was completed using the risk matrix provided in Figure 5.2.

		Likelihood				
		Very Low	Low	Moderate	High	Very High
Consequences	Insignificant	Negligible	Negligible	Very Low	Low	Moderate
	Minor	Negligible	Very Low	Low	Moderate	High
	Moderate	Very Low	Low	Moderate	High	Very High
	Major	Low	Moderate	High	Very High	Extreme
	High	Moderate	High	Very High	Extreme	Extreme

Figure 5.2 Flood Risk Rating Matrix

Negligible and Very Low flood risk ratings are generally considered acceptable, and structural mitigation measures are not required for dike sections with these lower ratings. A dike section with a Low flood risk rating is tolerable but must be monitored to capture any increase in risk due to further dike deterioration. In contrast, dike sections determined to have a High to Extreme flood risk rating are unacceptable, and structural mitigation measures must be implemented in the short-term to reduce flood risk below an acceptable threshold. Finally, a Moderate risk rating is tolerable in the short-term but must be addressed in the mid-to long-term. The following sections detail the potential failure modes (hazard scenarios) considered for this study, the likelihood evaluation for these hazard scenarios, their consequence of failure, and the flood risk rating assigned for each dike section within the study site.

5.2 FAILURE MODES

The main mechanisms, or failure modes, leading to embankment dikes' deterioration and failure are the following:

- Erosion by overflowing/overtopping;
- Erosion of the upstream face of the dike due to wave and flow action;
- Internal erosion, such as piping, concentrated leak erosion, suffusion and contact erosion;
- Sliding (Slope failure).

These failure modes are illustrated in Figure 5.3. It is important to note that dike failures can result from a single mechanism or from a chain of events involving different failure modes as time evolves.

Two failure modes were investigated in this project: overtopping failure and erosion failure. Evaluation of internal erosion and sliding failure modes requires a strong knowledge of the dike construction method, compaction, and material grain size distribution. This information is not readily available for the dikes within the study area and, therefore, these failure modes could not be accurately studied. However, erosion failure is a good proxy for internal erosion failure since erosion of the upstream dike face reduces the dike thickness and increases the hydraulic gradient through the dike, thereby increasing internal erosion risk. Erosion risk is also a good proxy for sliding failure risk, as it steepens the upstream dike face and increases sliding risk by lowering the dike stability.

The likelihood of overtopping and erosion failures was determined for each dike section and the greater likelihood of the two failure modes was used in the flood risk assessment.

Even though surface runoff may cause inland flooding and concern landowners and residents, it is out of the focus of this study. Surface runoff analysis could be done separately to evaluate the effectiveness of the existing drainage system and the potential location and extent of local pondings. However, the ponding water is not expected to accumulate enough to overtop the dike and cause any dike failure issues.

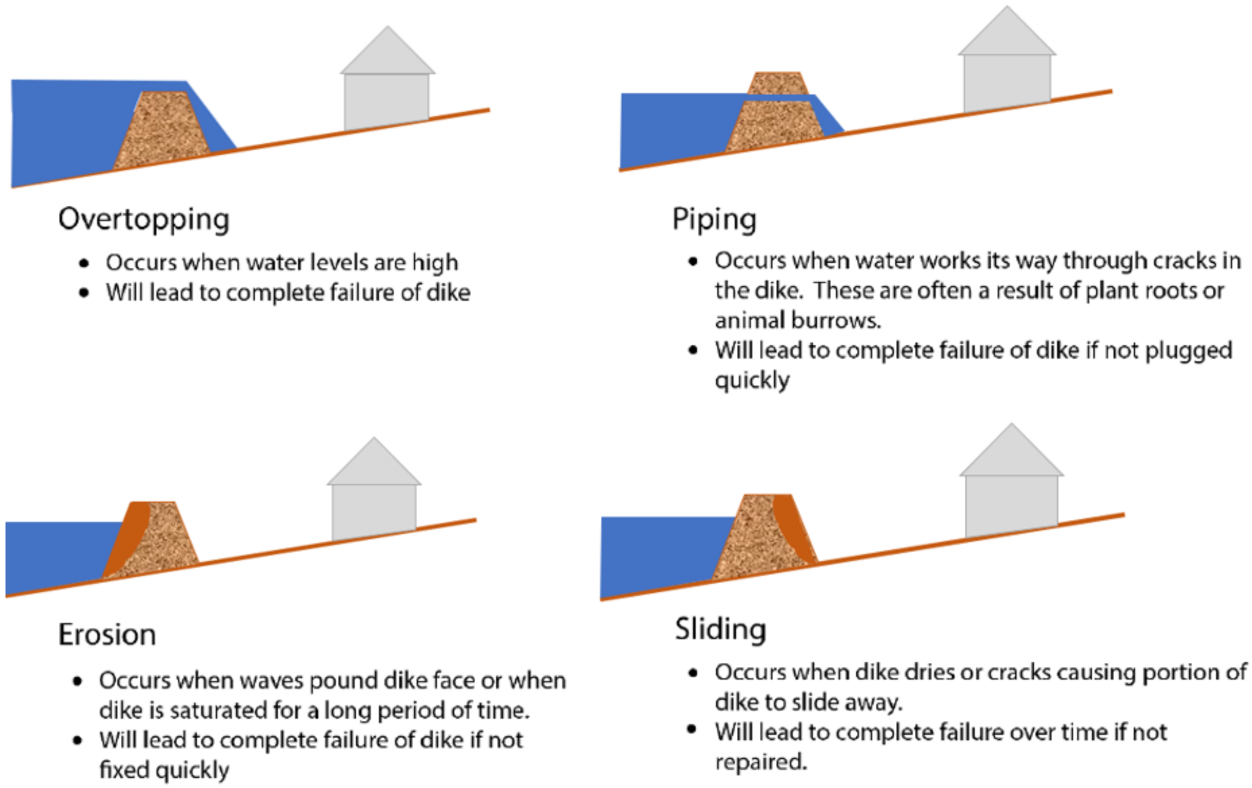


Figure 5.3 Examples of Failure Modes Adapted From KWL, 2020

5.3 LIKELIHOOD OF OVERTOPPING FAILURE

A list of all the dikes in the project area and their assigned overtopping likelihood rating is provided in Table B-1 (Appendix B). The likelihood of overtopping failure of the dikes is defined as shown in Table 5.1.

Table 5.1 Overtopping Failure Rating

RETURN PERIOD REQUIRED TO OVERTOP THE DIKE	LIKELIHOOD RATING
200 Years or Greater	Very Low
100 Years	Low
20 Years	Moderate
10 Years	High
2 Years	Very High

According to the BGC 1D model results, discussed in Section 4.1 and shown in Figure 4.1, the dikes along the Kootenay River are not expected to be overtopped for a 200-year flood event. Therefore, a Very Low likelihood rating was assigned to all the dikes along the Kootenay River.

For the dikes along the Goat River, 2D hydraulic modelling results are only available for the 2-year and 200-year flood events. The 2014 BGC results suggest that the middle part of the dike (between km 2.26 to 2.47 as per current study chainage), which was built in 2007, will be overtopped by the 2-year flood. Therefore, the assigned overtopping likelihood rating for this area would be Very High.

The 2020 2D modelling results suggest that the dikes between km 2.26 and 2.59 would be overtopped by the 200-year flood event. A comparison of the dike crest elevations and modelled 200-year flood levels indicate that this section of the dike would be overtopped for floods less severe than the 200-year flood, but the overtopping threshold cannot be determined accurately. Historical evidence indicates that these sections of dike were not overtopped during the 1997 and 2006 floods, which were 10- to 25-year events based on streamflow data from local hydrometric stations. Therefore, the probability of a dike overtopping for the remaining areas exceeds 25 years (BGC, 2014a). To be conservative, a Moderate overtopping likelihood rating was assigned to these dike sections.

No hydraulic model is available for the French (Big) Slough, Old Kootenay River Channel, and other drainage channels (Map A-1 and A-2 in Appendix A) in the area. Therefore, there is no reference study to determine the likelihood of overtopping for the dikes non-adjacent to the Kootenay River and Goat River (dike no. 38, 39, 141,143, 267, 268, and wetland management dikes as shown in Appendix A). As shown in Map A-1 and A-2, dike 39 separates Duck Lake from a wetland and dike 38 separates this wetland from the Duck Lake Diking District. Dike 143 is located along the Old Kootenay River Channel to the west of the Nick's Island Diking District and dike 141 is along the south boundary of this Diking District. Dike 267 is located along the Big Slough to the west of the Reclamation Farm Diking District and dike 268 is along the south boundary of this Diking District. The wetland management dikes (including Long Dike and Short Dike) are within the LKB lands or Creston Valley Wildlife Management Area. Further hydraulic analysis needs to be done in the future to make sure that there is enough freeboard for these dikes. For example:

- Dike no. 38 (Duck Lake Unit) and 39 (Duck Lake Unit 2) have not been constructed to a 200-year standard and could potentially be overtopped when Kootenay Lake water levels exceed a 5-year event. This would however require a breach of Kootenay River Dike (#40), a malfunction of the flap gates at pumping station CW1 or a pump failure. During the years with above-average inflows (5- to 10-year return period), the pumps would need to be operated to maintain Duck Lake water levels below the dike crest elevation (BGC, 2014a);
- The wetland management dikes, Long Dike and Short Dike, are expected to be overtopped during a 200-year flood. According to BGC (2014), the 200-year water level at the confluence of Goat River and Kootenay River is 536.4 m. Comparing this water level with the Short Dike and Long Dike crest elevations shows that these dikes would be overtopped, as shown in Figure 5.4.

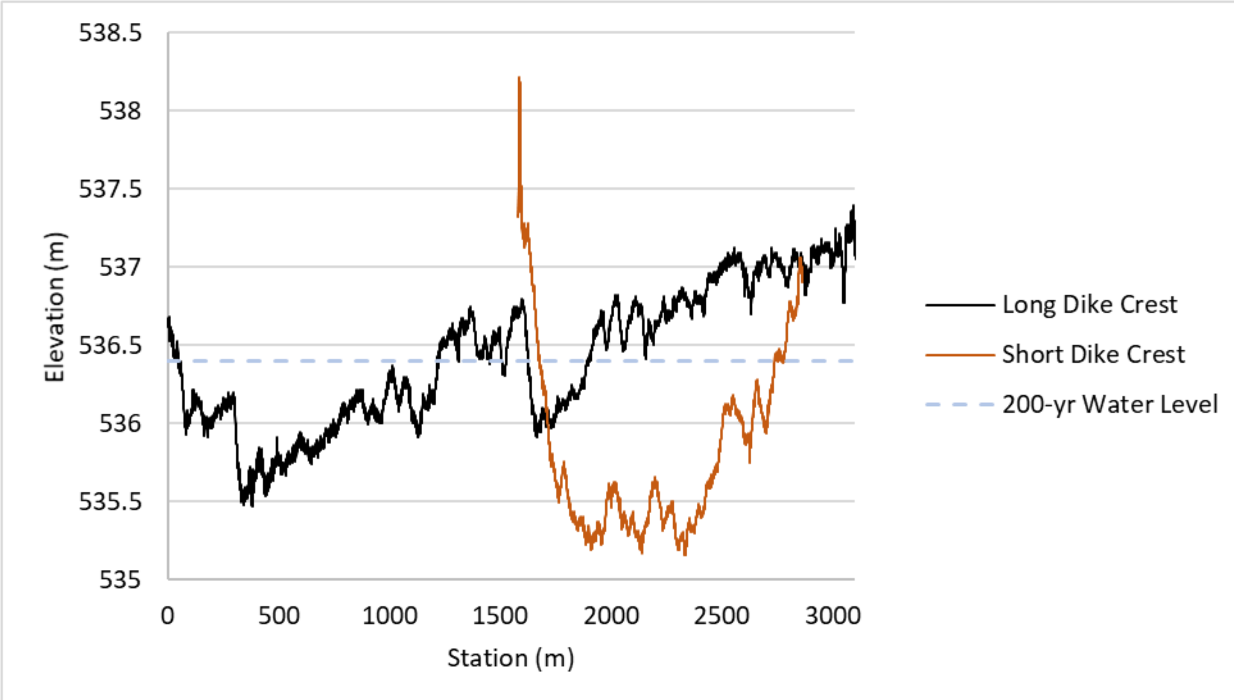


Figure 5.4 200-Year Water Level at Long Dike and Short Dike

5.4 LIKELIHOOD OF EROSION FAILURE

This section provides a summary of previous bank erosion assessments completed by BGC (2014a) and NHC (1999), as well as the updated erosion assessment conducted by WSP in September 2022.

5.4.1 PREVIOUS EROSION ASSESSMENTS

5.4.1.1 NORTHWEST HYDRAULIC CONSULTANTS (1999)

Desktop analysis for the Kootenay River showed that the banklines had not changed noticeably since 1961 downstream of the US-Canada border due to the low, lake-controlled river gradient and partially cohesive bank sediments. NHC assigned hazard ratings to 22 sites by conducting a site survey. They assigned a very high rating (attention and protection required in the next five years) to nine areas, a high rating (monitor and plan on protecting in the next five to ten years) to nine areas, and a moderate rating (monitor for further bank loss) for four areas.

NHC site inspections indicated that localized erosion, threatening the stability of the dikes, was continuing to occur in several locations. Localized erosion was classified into five categories: erosion at the outside of sharp bends, erosion at the inside of river bends, rotational arc slumps, long reach vertical slumps, and progressive slumps.

NHC investigations showed no significant change in deep scour holes and, therefore, in the overall stability of underwater slopes since 1968. However, shallow slumping was identified as the most significant contributor to bank erosion along the river.

According to NHC, a notch had been developed in the Kootenay River banks due to wave action, pore water pressure, and release of capillary tension, or freeze-thaw action that causes very shallow sloughing. As a result, slumping of soil, forming steep bare faces above the normal river level, and longitudinal fissures were occurring. It is considered probable that the notch developments are more probable during the post-Libby Dam period. A more limited range of water levels, winter flow fluctuations, and recurring wetting and drying appear to weaken the banks resulting in the toppling of soil (NHC, 1999).

5.4.1.2 BGC (2014)

BGC classified the erosion hazards as moderate (erosion has not yet reached the structure of the dike, but repairs would be required within 10 to 20 years) or high (repairs are estimated to be required within the next 5 to 10 years) as summarized in Table B-1 (Appendix B).

BGC noted that a significant factor in the observed erosion is a lack of riparian vegetation. Vegetation in many of the banks is limited to grasses and shrubs only. However, the riparian vegetation is well established on the right bank adjacent to IR1A, IR1, and portions of IR1B, which provide proper stabilization against bank erosion.

5.4.2 UPDATED EROSION ASSESSMENT

Given that bank and dike erosion is dynamic and could have evolved since the 2014 erosion assessment, an updated erosion assessment was completed as part of this study.

Multiple factors impact erosion mechanisms, such as slope angle, dike protection features, types of vegetation cover, evidence of active erosion, and river morphology. To account for the complexity of erosion processes, WSP developed a multi-criteria site-assessment protocol to assess the likelihood of erosion failure in a spatially explicit manner. The protocol requires the evaluation of several parameters that describe the river and bank/dike characteristics and assigns point values to the various aspects of dike conditions. Based on these inputs, a likelihood score is calculated. The protocol was implemented in the web application FULCRUM and was applied in the field at each site. The field survey took place in September 2022.

The following parameters were considered to establish the likelihood of erosion failure at each site:

- Vegetation cover type (directly on the dike face);
- Dike slope (upstream face);
- Erosion severity;
- Eroded length;
- Bank protection efficiency;
- River morphology.

A score of 0-10 was assigned for each parameter. The weighting for each attribute is listed in Table 5.2. Each parameter was evaluated on-site and was later confirmed in the office by reviewing site pictures and LiDAR data.

Table 5.2 Erosion Parameters Table

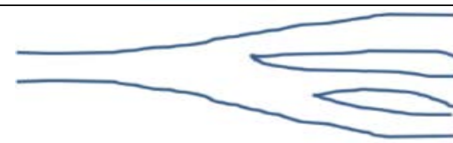
PARAMETER	CATEGORY	SCORE	DESCRIPTION
Cover type	Riprap	0	Visual assessment of the predominant vegetation cover. This parameter only considers the cover types directly on the dike face.
	Grass	6	
	No vegetation/bare soil	8	
	Shrubs and trees	10	
Erosion severity	None	0	No signs of erosion
	Minimal	2	Localized erosion
	Moderate	4	Gullying
	Significant	8	Gullying, vertical eroded faces, toe erosion
	Severe	10	Gullying, vertical eroded faces, advanced toe erosion, slope failure
Bank protection efficiency	Very good	0	Good toe protection, angular riprap and sufficient thickness
	Good	2	Adequate height and thickness, angular riprap, acceptable toe protection
	Acceptable	4	Adequate height and thickness but deficient toe protection
	Low	8	No toe protection, insufficient thickness and height, rounded riprap
	None/insufficient	10	Primary bank material exposed to river flow at several locations
Morphology	Straight or inner bend of a meander	0	
	Braiding	4	
	Wandering	6	
	Meandering	10	
Dike slope (H:V)	3:1	0	Dike slope angles were calculated based on LiDAR data
	2:1	2	
	1.5:1	4	
	1:1	8	
	Steeper than 1	10	
Eroded length	0	0	Visual assessment confirmed through satellite imagery analysis
	0-25 m	4	
	25-50 m	6	
	50-100 m	8	
	100-200 m	10	

Figure 5.5, Figure 5.6, and Figure 5.7 show examples of river banks/dikes with different vegetation types, erosion severity, and protection efficiency, respectively.

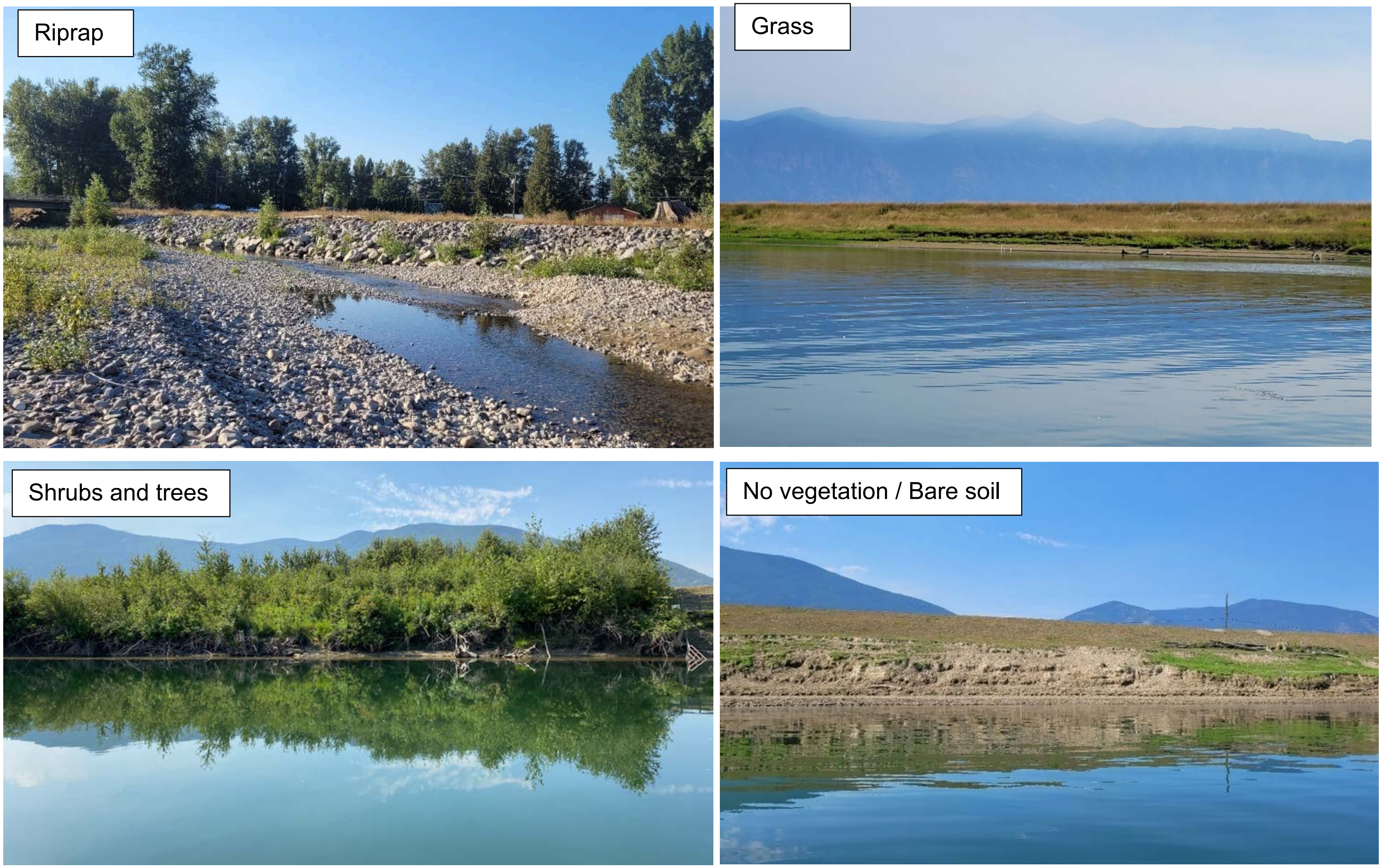


Figure 5.5 Examples of Vegetation Types

Figure 5.6 Examples of Erosion Severity

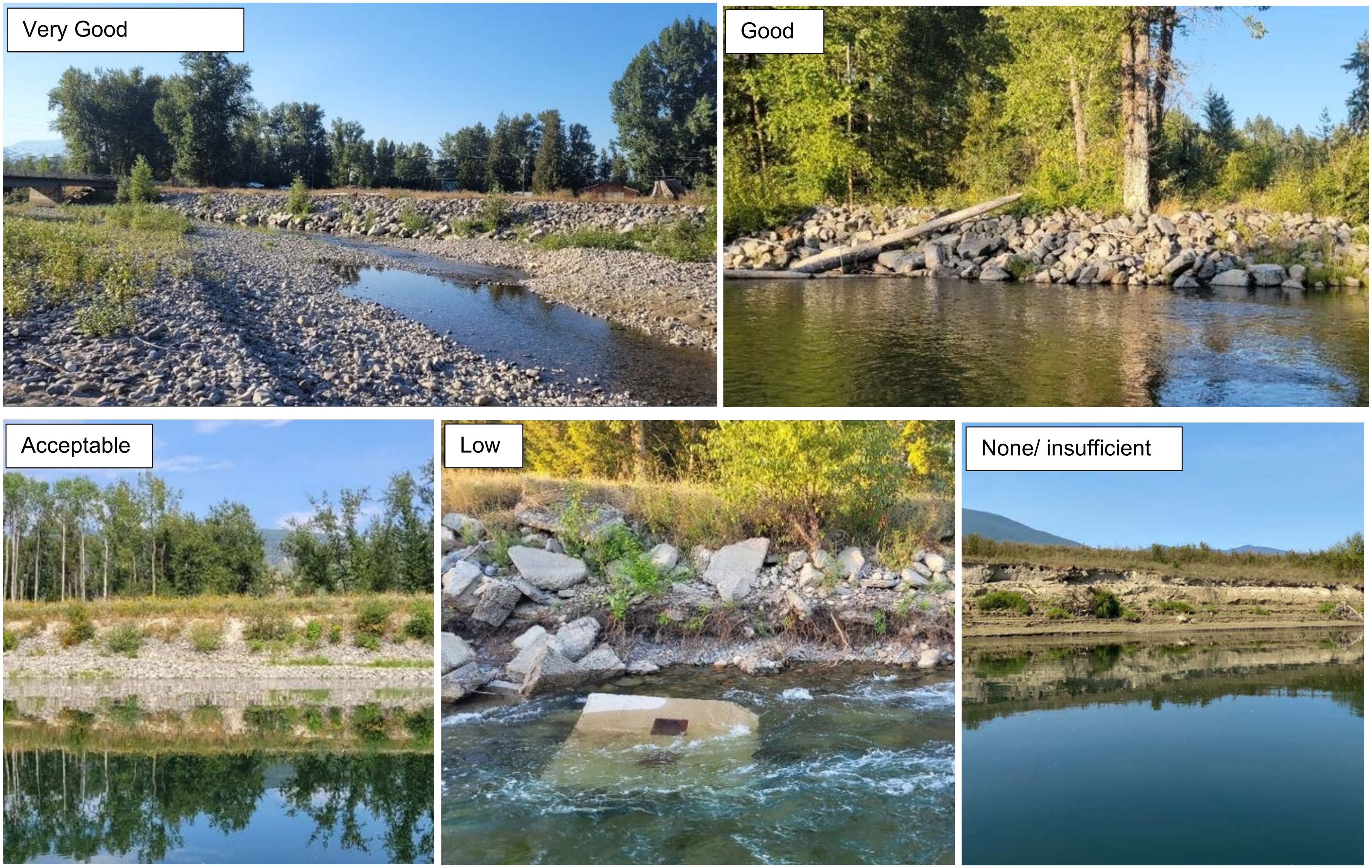


Figure 5.7 Examples of Bank Protection Efficiency

The site survey and LiDAR data review show that the dike configuration is generally similar to one of the two cross-sections shown in Figure 5.8. The toe of the dike is either adjacent to the river bank or located further from the river (set backed). The erosion severity criterion only applies to the erosion observed on the dike face. For cases where the bank is eroded but the dike is set back from the river and does not exhibit significant erosion, a score of 0 was assigned to the dike for the erosion severity criterion.

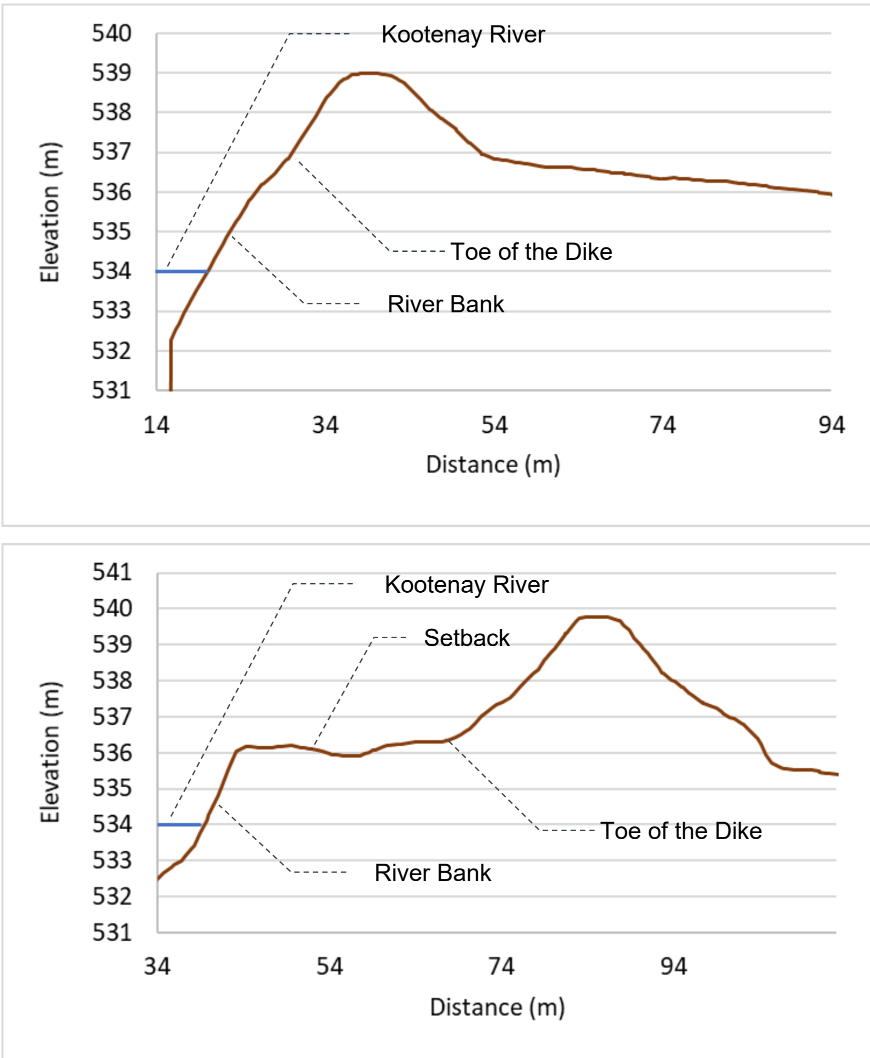


Figure 5.8 Typical Dike Cross-Sections

The likelihood rating was distributed based on the total weighting value, as shown in Table 5.3. The resulting erosion likelihood ratings are listed in Appendix B. WSP emphasizes that the likelihood rating defined in this study is based on our experience with bank erosion projects across Canada and different consultants may come up with different ratings. There are no guidelines yet that clearly define erosion risk rating. However, the likelihood rating defined in this study takes into account multiple parameters easily identified in the field and is appropriate for risk prioritization.

Table 5.3 Erosion Likelihood Rating System

EROSION LIKELIHOOD RATING	TOTAL WEIGHTING
Very Low	0-10
Low	11-20
Moderate	21-35
High	36-50
Very High	51-60

The main focus of the field investigation was on the dikes along the Kootenay River and Goat River. The remaining dikes could not be accessed by boat due to shallow flow conditions or navigation restriction. For these dikes (dike no. 38, 39, 141, 143, 267, and 268, as shown in Appendix A) the erosion likelihood was assigned based on desktop analysis as follows:

- Dike no. 38 (Duck Lake Unit) and 39 (Duck Lake Unit 2): Duck Lake Unit 2 is used and a road and mainly exposed to Duck Lake and might get eroded over time due to wave action. However, wave action would be limited, given the relatively small dimensions of the lake. Therefore, the erosion likelihood assigned to these dikes is Low;
- Dike no. 141: This dike is next to a small channel that collects surface runoff. From the aerial photos, it seems that there are some scattered trees on the dike toe. Therefore, the erosion likelihood assigned to this dike is Low;
- Dike no. 143: The buffer between the channel to the north of Nick's Island Diking District and the dike varies along the dike. The LiDAR data shows that there is a significant buffer between the river and the dike's toe. The erosion likelihood assigned to this dike is Low, except for a 0.28 km dike section north of Nick's Island, where active erosion could be observed from the dike's crest. An erosion likelihood of Moderate was assigned to this dike section;
- Dike no. 267: This dike generally has a good setback from the channel (French/Big Slough). From the aerial photos, it seems that there is a riparian buffer along the setback. Compared to the dikes along the Kootenay River, the erosion from the Big Slough flow is expected to be limited, given the relatively small watershed. Therefore, the erosion likelihood assigned to this dike is Low;
- Dike no. 268: This dike generally has a good setback from Boundary Creek. From the aerial photos, it seems that there are some scattered trees on the dike toe. Compared to the dikes along the Kootenay River, the erosion from the Boundary Creek flow is expected to be limited, given its relatively small watershed. Therefore, the erosion likelihood assigned to this dike is Low.

Table B-1 (Appendix B) provides the assigned likelihood rating for erosion failure of dikes defined by WSP.

5.5 CONSEQUENCE OF FAILURE

In order to define the consequences associated with a dike failure, it is essential to know the extent and severity of flood in the floodplain induced by a dike breach. Generally, comparing the simulated water levels along the river and LiDAR data shows that the majority of the diking districts are lower than the 1:2-year flood. However, the natural river embankments provide natural protection against low flows such as a 2-year flood even if the dike fails. Floodplain flooding is possible for more extreme floods, such as a 200-year event, as shown in Figure 5.9.

BGC in 2014 and NHC in 2019 carried out separate dike failure consequence assessments. The following sections provide a summary of their conclusions as well as the consequence assessment adopted by WSP.

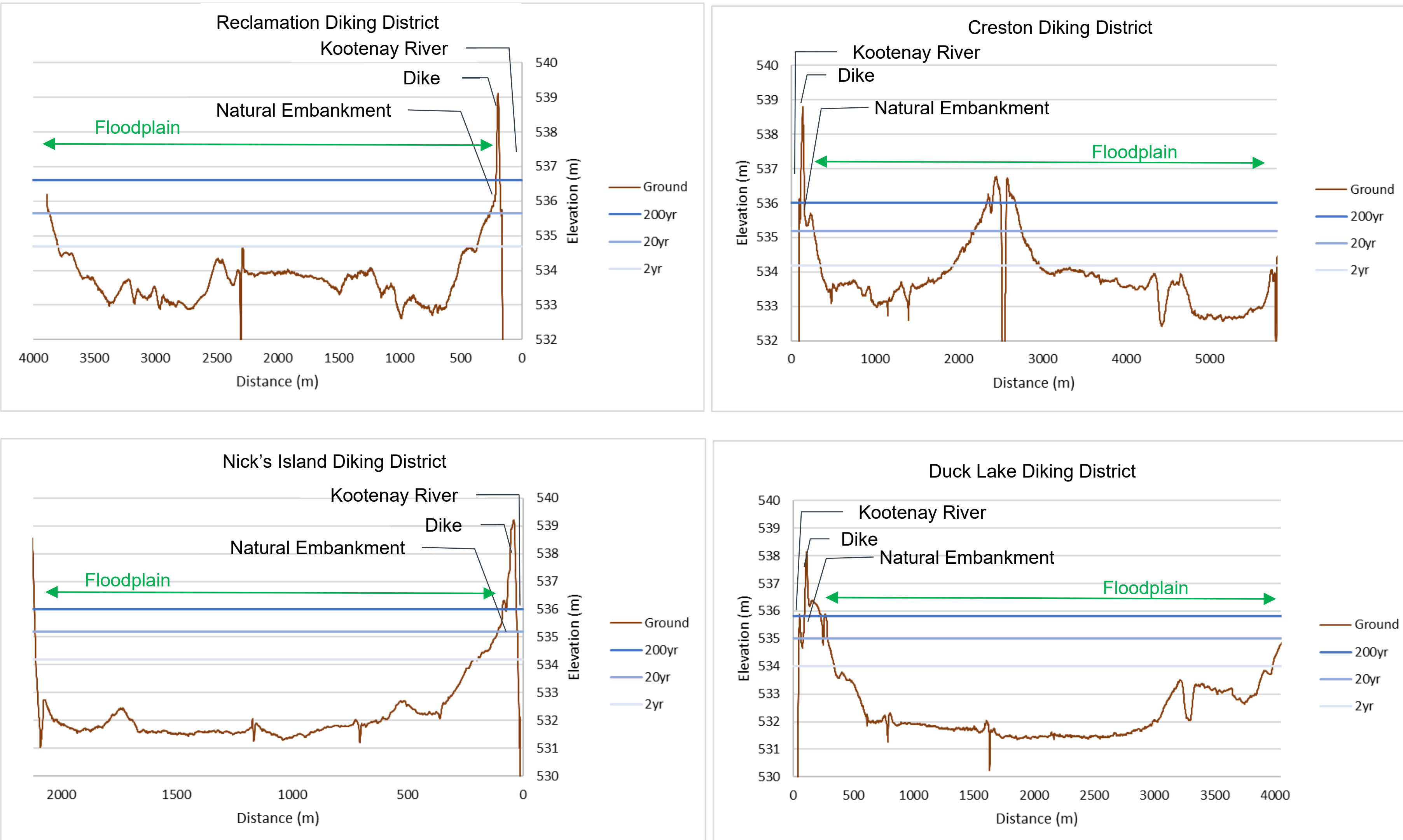


Figure 5.9 Cross-Sections Along Kootenay River Floodplain

5.5.1 BGC (2014)

The simplest way of estimating the flood inundation area is to extend the river's water level adjacent to the area of interest. The estimated water levels in this method would be overestimated since the carrying capacity of the floodplain is ignored. BGC developed a 2D model to simulate dike breach and flood inundation in two sample districts. Results show that Reclamation Farm and Creston Diking Districts would be fully inundated within 24 hours and 72 hours, respectively, following a dike breach. Therefore, most residents would have sufficient time to evacuate, thereby limiting the risk of having casualties (BGC, 2014a).

BGC evaluated the potential economic losses due to flood inundation of the various districts. The economic data were compiled from different sources, such as Rodman (2009), Dun & Bradstreet (2009), and field survey data, and represent the information available at the time of the study.

The main assets protected by the dikes along the Kootenay River and Goat River include building structures, buildings' contents, crops, and businesses (BGC, 2014a). Table 5.4 provides an estimated value for these assets based on the 2014 evaluations by BGC.

Table 5.4 Assets Value Located Within the Floodplain at the Project Site (BGC, 2014a)

	RECLAMATION	CRESTON VALLEY	NICK'S ISLAND	DUCK LAKE	GOAT RIVER
# Buildings	35	112	26	37	58
Building Value (million $)	5.54	11.97	1.98	1.72	4.47
Estimated Building Content (million $)	3.33	7.86	1.24	1.05	2.72
Estimated Crop value (million $)	4.5	2.1	0.8	1.00	-
Estimated Business Value (million $)	4.00	2.34	0.21	1.4	-
# Pumping Stations	3	2	2	2	-
Total Value (million $)	17.37	24.27	4.24	5.17	7.19

Flooding in the LKB lands affects minimal infrastructure since the land is mainly used for wetland management, agriculture, and a log sorting facility (BGC, 2014a). Flooding in other areas has more impact since financial losses, safety, environmental, social, and cultural aspects are also involved.

BGC evaluated the direct economic consequences of a dike breach along the Kootenay River based on the damage cost to building structures, building content, crops, and businesses at the time of the study, as shown in Table 5.5. Economic losses due to dike breach events were considered separately for each diking district. The indirect impact of the flood was estimated to be $2.7 million, assuming that the flood would disrupt 25% of businesses and the highway would be closed for about two weeks.

Also, the direct economic consequence of a breach of the dike along the Goat River was estimated based on the building and content damages. The results of consequence analysis by BGC are also provided in Table B-1 (Appendix B).

No losses were estimated for the identified utilities, including two Terasen Gas pipelines (Southern Crossing) and two BC Hydro transmission lines (500 kV and 230 kV).

Table 5.5 Estimated Direct Damage (BGC, 2014a)

	RECLAMATION	CRESTON VALLEY	NICK'S ISLAND	DUCK LAKE	GOAT RIVER
Value (million $)	17.37	24.27	4.27	5.17	7.19
Damage (million $) – 200-year flood	10.98	11.13	2.16	3.51	1.94

5.5.2 NORTHWEST HYDRAULIC CONSULTANTS (2019)

NHC assessed and classified most of the dikes in BC, including most of the dikes within the study area, using a Tier 1 analysis. Tier 1 analysis is an exposure-based technique that identifies what would be impacted by the flood but does not consider the magnitude of the impact except for the socio-economic vulnerability index used for the people consequence category.

The methodology for Tier 1 analysis is as follows:

- Collect receptor data from various sources;
- Determine protected floodplains for each dike (existing floodplain mapping – 200-year flood);
- Identify receptors in each protected floodplain using a spatial analysis exercise;
- Apply the consequence classification framework to the raw data, aggregate raw data into subordinate factors, consequence categories, and an overall score based on weighted aggregation and applicable tipping.

The main components of the classification framework are as follows:

- **Receptor**: The assets exposed to flooding;
- **Indicator**: How the impact on each receptor is measured;
- **Subordinate factors**: the sub-categories under each main consequence category;
- **Consequence categories**: aggregated group of receptors categorized to A: People; B: Economy – buildings; C: Economy – critical infrastructure and Agriculture; D: Environment; and E: Cultural Heritage.

Five consequence categories of Insignificant, Minor, Moderate, Major, and High were assigned for the dikes based on their respective scores. The overall score is a function of weighted consequence category scores unless either category A or B has a classification of 5, then the overall scores are classified as a 5.

Table B-1 (Appendix B) shows the overall assigned consequence classification as well as the classification of consequence categories for each dike.

NHC did not assign a consequence classification to dike number 120 and the Goat River dike sections built in 2006/2007.

5.5.3 CURRENT STUDY

WSP is adopting the same consequence classification as NHC (2019) since it was a comprehensive study in which classification was completed considering several factors based on various databases. It is also more recent than the BGC assessment and more accurately depicts the potential damage to assets located within the Kootenay and Goat river floodplains.

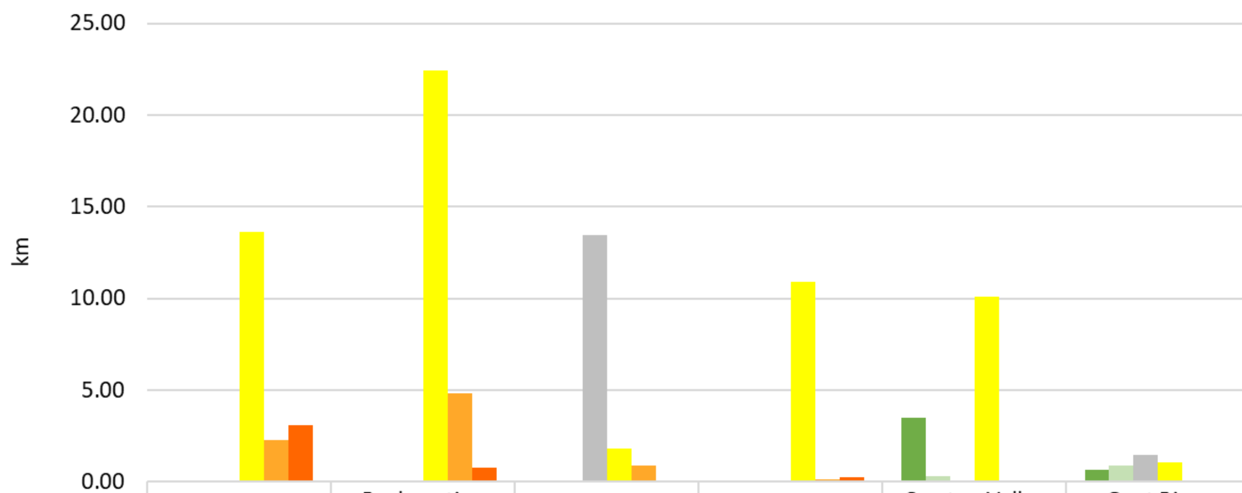
For the dike without a consequence classification (dike number 120), the same classification as the adjacent dikes was assigned, given that the flooded area would be the same. The assigned consequence classifications of the dikes are shown in Table B-1 (Appendix B).

5.6 FLOOD RISK RATING

By combining the consequence rating with the failure likelihood described in the previous sections, a risk rating was assigned to each dike along the Kootenay River and Goat River, using the risk rating matrix shown in Figure 5.2. The full risk rating breakdown is provided in Table B-1 (Appendix B) and illustrated in Maps A-1, A-2, and A-3 (Appendix A).

Figure 5.10 shows the total length of the dikes with different risk ratings by district. As shown in this figure:

- About 3.06 km of dikes within the Creston Diking District, 0.76 km of the dikes within the Reclamation Farms Diking District, and 0.27 km of the dikes within the Duck Lake Diking District have a risk rating of Very High (4.09 km in total);
- Reclamation Farm Diking District has the highest length of the dike with a risk rating of High (4.81 km), followed by Creston Diking District (2.30 km), Nick's Island Diking District (0.86 km), and Duck Lake Diking District (0.15 km);
- Most dikes are classified as Moderate (59.89 km in total);
- No dike is classified as Extreme as most consequence ratings are Moderate and Major (no dikes with a High consequence rating) and no dikes with a failure likelihood of Very High were identified among those with consequence ratings of Major;
- 1.41 km of the LKB dikes within the Creston Diking District (IR1C) and 0.27 km of the LKB dikes within the Duck Lake Diking District (IR5) are classified as Very High;
- 0.49 km of the LKB dikes within the Creston Diking District (IR1C and IR3) are classified as High;
- 4.31 km of the LKB dikes within the Creston Diking District (IR1C, IR2, IR3) and 2.44 km of the LKB dikes (IR5) within the Duck Lake Diking District are classified as Moderate;
- All the dikes with a flood risk rating of Very High have an erosion likelihood of High and a consequence rating of Major. These dikes are primarily identified to have Significant to Severe erosion, to be covered with shrubs and trees, and to be in a meandering area with no or insufficient bank protection.



	Creston Diking District	Reclamation Farm Diking District	Nick's Island Diking District	Duck Lake Diking District	Creston Valley Wildlife Management	Goat River Residents Associates
Negligible	0.00	0.00	0.00	0.00	3.49	0.63
Very Low	0.00	0.00	0.00	0.00	0.31	0.88
Low	0.00	0.00	13.48	0.00	0.00	1.48
Moderate	13.62(4.31)*	22.43	1.79	10.88(2.44)*	10.10	1.07
High	2.30 (0.49)*	4.81	0.86	0.15	0.00	0.00
Very High	3.06 (1.41)*	0.76	0.00	0.27(0.27)*	0.00	0.00

* The LKB dikes are shown in the parentheses.

Figure 5.10 Total Length of Vulnerable Dikes by Districts

5.7 PRIORITIZATION

The risk ratings defined in the previous section were used to sort the dikes in order of priority.

The dikes with the same risk rating (e.g., Very High) were sorted based on their overtopping likelihood or erosion likelihood score, whichever is greater. Table 5.6 ranks all the dikes within the study area in order of risk reduction priority. The following response time frame is recommended for the dikes within the study area:

- Priority score of 1 (Very High risk rating): Risk reduction measures should be implemented in a reasonable time frame (< 8-10 years);
- Priority score of 2 (High risk rating): Risk reduction measures should be implemented in a reasonable time frame (< 15 years);
- Priority score of 3 (Moderate risk rating): Sites to be monitored every year, implement opportunistic risk reduction measures if resources allow;
- Priority score of 4 (Low rating): Risk is tolerable, sites to be monitored following major hazard events (flood, seismic);
- Priority score of 5-6 (Very low to Negligible risk rating): Risk is broadly acceptable, no risk reduction is required.

All the dikes should be inspected and maintained as required. Risk reduction measures were developed and are provided for Very High and High risk dikes in a separate report (WSP, under preparation).

Table 5.6 Dike Priorities

DIKE NO.	DIKING AUTHORITY	VULNERABLE LOCATION (km)*	NATURE OF CONCERN	OVERTOPPING LIKELIHOOD	EROSION LIKELIHOOD	EROSION SCORE	CONSEQUENCE	HAZARD RATING	PRIORITY SCORE
120	Creston Diking District	17.45-17.95	Erosion	--	High	46	Major	Very High	1
37	Creston Diking District	27.1-27.25	Erosion	--	High	46	Major	Very High	1
120	Creston Diking District	16.55-17.03	Erosion	--	High	44	Major	Very High	1
120	Creston Diking District	20.02-20.75	Erosion	--	High	44	Major	Very High	1
266	Reclamation Farm Diking District	17.07-17.83	Erosion	--	High	42	Major	Very High	1
120	Duck Lake Diking District	30.93-31.2	Erosion	--	High	40	Major	Very High	1
37	Creston Diking District	20.75-21.95	Erosion	--	High	38	Major	Very High	1
142	Nick's Island Diking District	24.05-24.39	Erosion	--	High	40	Moderate	High	2
142	Nick's Island Diking District	20.6-20.9	Erosion	--	High	38	Moderate	High	2
120	Nick's Island Diking District	24.78-25	Erosion	--	High	36	Moderate	High	2
37	Creston Diking District	18.3-18.36	Erosion	--	Moderate	34	Major	High	2
37	Creston Diking District	18.5-18.68	Erosion	--	Moderate	34	Major	High	2
37	Creston Diking District	26.8-27.1	Erosion	--	Moderate	34	Major	High	2
37	Creston Diking District	27.25-27.4	Erosion	--	Moderate	34	Major	High	2
266	Reclamation Farm Diking District	16.02-16.68	Erosion	--	Moderate	32	Major	High	2
120	Creston Diking District	24.75-24.95	Erosion	--	Moderate	30	Major	High	2
37	Creston Diking District	27.4-27.65	Erosion	--	Moderate	28	Major	High	2
37	Creston Diking District	26.55-26.8	Erosion	--	Moderate	26	Major	High	2
120	Creston Diking District	24.44-24.51	Erosion	--	Moderate	26	Major	High	2
266	Reclamation Farm Diking District	13.83-14.1	Erosion	--	Moderate	26	Major	High	2
266	Reclamation Farm Diking District	9-9.85	Erosion	--	Moderate	26	Major	High	2
37	Creston Diking District	18.68-19.1	Erosion	--	Moderate	24	Major	High	2
120	Creston Diking District	17.03-17.45	Erosion	--	Moderate	24	Major	High	2
48	Duck Lake Diking District	28.05-28.2	Erosion	--	Moderate	24	Major	High	2
266	Reclamation Farm Diking District	4.36-6.5	Erosion	--	Moderate	24	Major	High	2
266	Reclamation Farm Diking District	12.45-12.95	Erosion	--	Moderate	22	Major	High	2
266	Reclamation Farm Diking District	16.68-17.07	Erosion	--	Moderate	22	Major	High	2
69	Goat River Residents Associates	3.2-3.4	Erosion	--	Moderate	30	Moderate	Moderate	3
120	Nick's Island Diking District	24.39-24.78	Erosion	--	Moderate	30	Moderate	Moderate	3
120	Nick's Island Diking District	25.35-26	Erosion	--	Moderate	28	Moderate	Moderate	3

DIKE NO.	DIKING AUTHORITY	VULNERABLE LOCATION (km)*	NATURE OF CONCERN	OVERTOPPING LIKELIHOOD	EROSION LIKELIHOOD	EROSION SCORE	CONSEQUENCE	HAZARD RATING	PRIORITY SCORE
69	Goat River Residents Associates	2.9-3.03	Erosion	--	Moderate	26	Moderate	Moderate	3
142	Nick's Island Diking District	27.05-27.52	Erosion	--	Moderate	22	Moderate	Moderate	3
69	Goat River Residents Associates	3.14-3.2	Overtopping	Moderate	Low	12	Moderate	Moderate	3
69	Goat River Residents Associates	0.49-0.65	Overtopping	Moderate	--	--	Moderate	Moderate	3
143	Nick's Island Diking District	0.28 km along the north channel	Erosion	--	Moderate	--	Moderate	Moderate	3
37	Creston Diking District	25.68-26.55	Erosion	--	Low	20	Major	Moderate	3
48	Duck Lake Diking District	36.2-38.95	Erosion	--	Low	20	Major	Moderate	3
37	Creston Diking District	17.95-18.25	Erosion	--	Low	20	Major	Moderate	3
37	Creston Diking District	18.25-18.30	Erosion	--	Low	20	Major	Moderate	3
37	Creston Diking District	18.36-18.50	Erosion	--	Low	20	Major	Moderate	3
120	Creston Diking District	24.95-25.68	Erosion	--	Low	20	Major	Moderate	3
120	Creston Diking District	19.1-20.02	Erosion	--	Low	20	Major	Moderate	3
266	Reclamation Farm Diking District	13.3-13.83	Erosion	--	Low	20	Major	Moderate	3
266	Reclamation Farm Diking District	7.7-9	Erosion	--	Low	20	Major	Moderate	3
266	Reclamation Farm Diking District	9.85-11.35	Erosion	--	Low	20	Major	Moderate	3
40	Creston Valley Wildlife Management	38.95-45.44	Erosion	--	Low	20	Major	Moderate	3
37	Creston Diking District	23.6-24.39	Erosion	--	Low	18	Major	Moderate	3
120	Creston Diking District	21.95-23.6	Erosion	--	Low	18	Major	Moderate	3
120	Creston Diking District	24.39-24.44	Erosion	--	Low	18	Major	Moderate	3
120	Creston Diking District	24.51-24.75	Erosion	--	Low	18	Major	Moderate	3
120	Duck Lake Diking District	31.2-31.85	Erosion	--	Low	18	Major	Moderate	3
48	Duck Lake Diking District	28.2-29.02	Erosion	--	Low	16	Major	Moderate	3
120	Duck Lake Diking District	29.02-30.93	Erosion	--	Low	16	Major	Moderate	3
48	Duck Lake Diking District	27.65-28.05	Erosion	--	Low	16	Major	Moderate	3
48	Duck Lake Diking District	31.85-35.9	Erosion	--	Low	16	Major	Moderate	3
48	Duck Lake Diking District	35.9-36.2	Erosion	--	Low	16	Major	Moderate	3
266	Reclamation Farm Diking District	0.21-4.4	Erosion	--	Low	16	Major	Moderate	3
266	Reclamation Farm Diking District	6.5-7.7	Erosion	--	Low	16	Major	Moderate	3
266	Reclamation Farm Diking District	11.35-12.45	Erosion	--	Low	16	Major	Moderate	3
266	Reclamation Farm Diking District	12.95-13.3	Erosion	--	Low	14	Major	Moderate	3

DIKE NO.	DIKING AUTHORITY	VULNERABLE LOCATION (km)*	NATURE OF CONCERN	OVERTOPPING LIKELIHOOD	EROSION LIKELIHOOD	EROSION SCORE	CONSEQUENCE	HAZARD RATING	PRIORITY SCORE
266	Reclamation Farm Diking District	14.1-16.02	Erosion	--	Low	14	Major	Moderate	3
37	Creston Diking District	Remaining	Erosion	--	Low	--	Major	Moderate	3
38	Creston Valley Wildlife Management	all	Erosion	--	Low	--	Major	Moderate	3
267	Reclamation Farm Diking District	all	Erosion	--	Low	--	Major	Low	3
268	Reclamation Farm Diking District	all	Erosion	--	Low	--	Major	Low	3
--	Goat River Residents Associates	2.26-2.47	Overtopping	Very High	Very Low	4	Insignificant	Moderate	3
142	Nick's Island Diking District	20.32-20.6	Erosion	--	Low	20	Moderate	Low	4
120	Nick's Island Diking District	25-25.35	Erosion	--	Low	16	Moderate	Low	4
120	Nick's Island Diking District	26-27.05	Erosion	--	Low	16	Moderate	Low	4
69	Goat River Residents Associates	3.05-3.14	Erosion	--	Low	16	Moderate	Low	4
142	Nick's Island Diking District	20.9-24.05	Erosion	--	Low	16	Moderate	Low	4
69	Goat River Residents Associates	3.4-3.97	Erosion	--	Low	14	Moderate	Low	4
69	Goat River Residents Associates	1.0-1.6	Erosion	--	Low	12	Moderate	Low	4
69	Goat River Residents Associates	2.59-2.81	Erosion	--	Low	12	Moderate	Low	4
141	Nick's Island Diking District	all	Erosion	--	Low	--	Moderate	Low	4
143	Nick's Island Diking District	remaining	Erosion	--	Low	--	Moderate	Low	4
69	Goat River Residents Associates	2.81-2.9	Erosion	--	Very Low	10	Moderate	Very Low	5
69	Goat River Residents Associates	1.6-1.68	Erosion	--	Very Low	8	Moderate	Very Low	5
69	Goat River Residents Associates	3.03-3.05	Erosion	--	Very Low	6	Moderate	Very Low	5
69	Goat River Residents Associates	3.97-4.1	Erosion	--	Very Low	6	Moderate	Very Low	5
69	Goat River Residents Associates	0.31-0.49	Erosion	--	Very Low	--	Moderate	Very Low	5
--	Goat River Residents Associates	0-0.31	Erosion	--	Very Low	--	Moderate	Very Low	5
--	Goat River Residents Associates	1.83-1.93	Erosion	--	Very Low	8	Insignificant	Negligible	6
--	Goat River Residents Associates	1.93-2.26	Erosion	Very Low	Very Low	8	Insignificant	Negligible	6
--	Goat River Residents Associates	2.47-2.59	Erosion	--	Very Low	6	Insignificant	Negligible	6
--	Goat River Residents Associates	1.68-1.83	Erosion	--	Very Low	18	Insignificant	Negligible	6
39	Creston Valley Wildlife Management	all	Erosion	--	Low	--	Insignificant	Negligible	6

* Map A-1 (Appendix A).

6 SUMMARY

The main findings of this study are summarized below.

HYDROLOGY

There are 88 km of dikes in the project area along the Kootenay River, 8.9 km of which are within the Lower Kootenay Band (LKB) Reserve, and 4 km along the Goat River. The Kootenay River is heavily regulated and its flows are significantly impacted by the Libby Dam operations. Therefore, the standard FFA technique is not applicable to define flood quantiles. Thus, in 2014 BGC used the estimated water levels by the USACE (2004, 2005) at Kootenay Lake and Kootenay River at Porthill, Idaho, to calculate the Kootenay River flow for different return periods. The USACE's models extend from Libby Dam to the outlet of Kootenay Lake and include the operating procedures at Libby Dam, Duncan Dam, and Corra Linn Dam, as well as the Kootenay Lake's outflow limitations caused by Grohman Narrows. The estimated flows by BGC are still valid because the operation of Libby Dam has not changed since 2014 and the USACE hasn't released a new version of their hydrological model for the Kootenay River.

The Goat River flows were estimated using the 2014 FFA by BGC. These results are still valid since no additional data is available at the Goat River hydrometric station and the length of record used in 2014 is sufficient.

HYDRAULIC

BGC developed one 1D HEC-RAS model for the Kootenay River and one for the Goat River to estimate the water levels along the rivers. For the Kootenay River, the results of the 1D model seem to be sufficient for the current study. For the Goat River, the 2D model developed by BGC is adequate and was used to assign overtopping likelihood to these dikes.

Comparing the Kootenay River's dike crest elevations with the simulated water surface shows that the right bank and left bank dike crests are generally above the simulated 200-year water levels by at least 1.7 m and 1.45 m, respectively.

For the Goat River, the dike crests are typically greater than 0.4 m above the 200-year flood level. There are some exception areas including about 330 m of the dike around km 2.4, where the dike is expected to be overtopped by a 200-year flood by about 0.8 m.

FLOOD RISK ASSESSMENT

The probability of a failure and the potential damages or losses it may cause were used to evaluate the FRA of the dikes. The two dike failure modes investigated in this project were overtopping failure and erosion failure.

Likelihood of Overtopping Failure

The likelihood of overtopping failure of the dikes is defined based on the return period required to overtop the dike. According to the results of the BGC 1D model, the dikes along the Kootenay River are not expected to be overtopped for a 200-year flood event. Therefore, a Very Low likelihood rating was assigned to all the dikes along the Kootenay River.

For the dikes along the Goat River, the dike between km 2.26 to 2.47 would be overtopped by the 2-year flood. Therefore, the assigned overtopping likelihood rating for this area is Very High. The 2020 2D modelling results suggest that the dike between km 2.26 and 2.59 would be overtopped by the 200-year flood event, but it might be overtopped for floods less severe than the 200-year flood as well. Historically this section of dike has not been overtopped by a 10- to 25-year event. Therefore, the overtopping likelihood rating of Moderate was assigned to the dikes in this area.

No overtopping failure assessment could be completed for dikes number 38, 39, 141, 143, 267, 268, and wetland management dikes, as no hydraulic assessments are available for these streams.

Likelihood of Erosion Failure

WSP developed a protocol to assess the likelihood of erosion failure for use during the erosion assessment field surveys, which is based on several aspects of a dike's condition. Using this protocol, a likelihood score was calculated for each section of the dike, and a likelihood rating of Very Low to Very High was assigned to the dike based on the total weighting value. The erosion likelihood was identified based on desktop analysis for dikes number 38, 39, 141, 143, 267, and 268.

Consequence of Failure

WSP is adopting the same consequence classification as NHC (2019), which was done using Tier 1 analysis (exposure-based technique). The consequence ratings of the dikes are mostly Moderate and Major (no dikes with a High consequence rating). More details are provided in Appendix B.

Flood Risk Rating and Prioritization

A detailed risk rating table is provided in Appendix B and illustrated in Appendix A.

About 4.09 km of the dikes (3.06 km of which are in the Creston Diking District) have a risk rating of Very High, and 8.12 km of the dikes (4.81 km of which are in the Reclamation Farm Diking District) have a High risk rating. In total, 59.98 km of the dikes are classified as Moderate, and no dike is classified as Extreme. These include the 1.68 km of the LKB dikes classified as Very High, and the 6.75 km of LKB dikes classified as Moderate.

All the dikes with a flood risk rating of Very High have an erosion likelihood of High and a consequence rating of Major. These dikes generally exhibit Significant to Severe erosion, are covered with shrubs and trees, and are in a meandering area with no or insufficient bank protection.

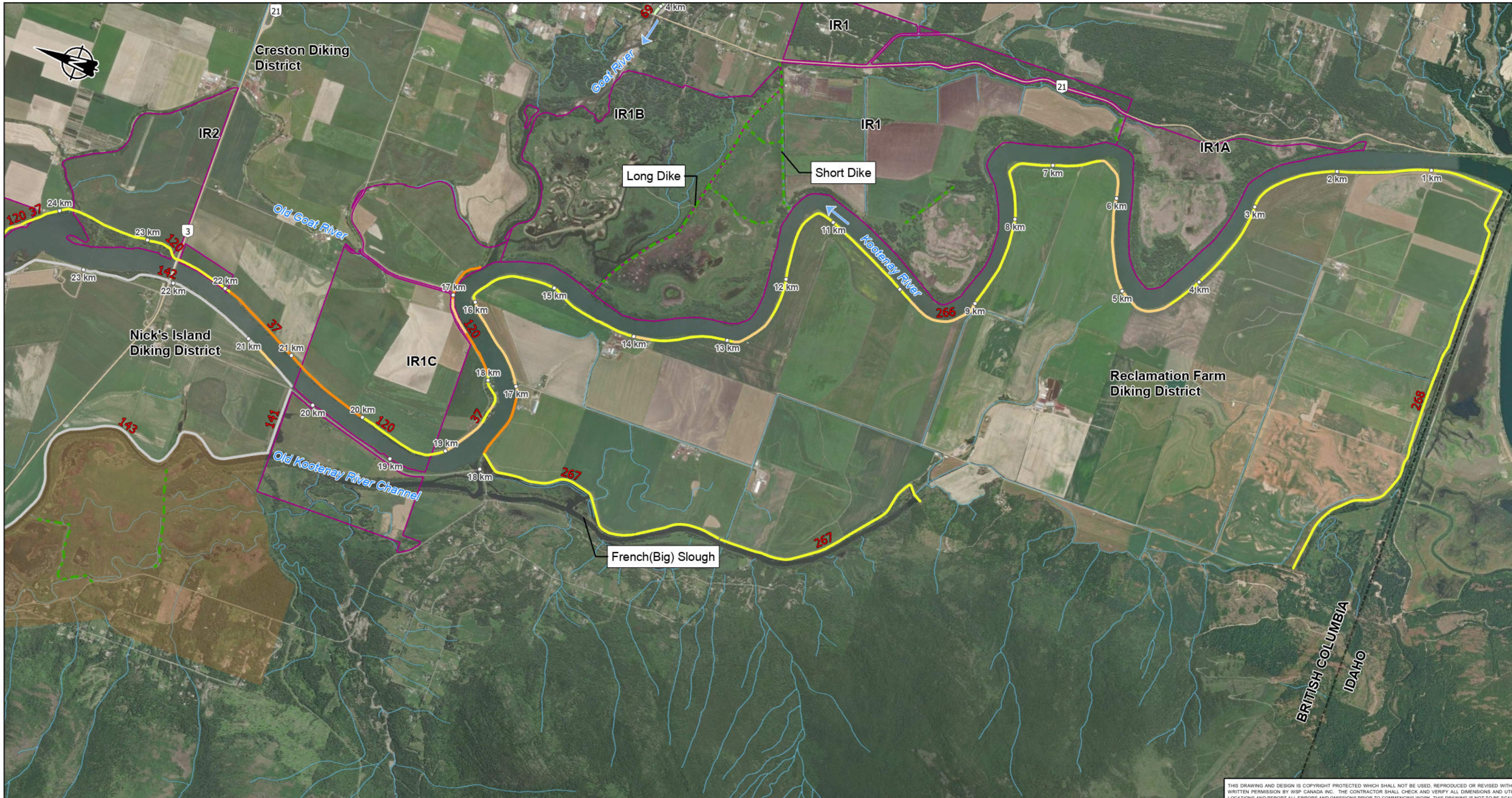
The dikes were then ranked based on their risk ratings, as shown in Table 5.6. It is recommended that the risk reduction measures for dikes with a priority score of 1 and 2 be carried out within the next five to eight years, respectively. The recommended risk reduction measures will be provided in a separate report (under preparation).

REFERENCES

- AMEC Earth & Environmental. (2005). *Goat River South Channel Geomorphic Assessment and Conceptual Design of Inlet*. Report prepared for Goat River Residents Association, June 2005.
- Bonneville Power Administration, US Bureau of Reclamation, US Army Corps of Engineers. (2019). *Draft 2020 Water Management Plan*.
- BC HYDRO POWER SMART. (2022). *Columbia River Operations Summary*.
- BGC. (2014a). *Lower Kootenay Band, Creston Valley Floodplain Management Study, Baseline Study, Stage 1*.
- BGC. (2014b). *Lower Kootenay Band, Creston Valley Floodplain Management Study, Risk Assessment, Stage 2*.
- BGC. (2014c). *Lower Kootenay Band, Creston Valley Floodplain Management Study, Flood Management Plan, Stage 3*.
- BGC. (2020a). *High Level Assessment of a Proposed Dam, Lake Koocanusa, Ministry of Energy, Mines and Petroleum Resources.*
- BGC. (2020b). *RDCK Floodplain and Steep Creek Study, Goat River*. Prepared by BGC Engineering Inc. for: Regional District of Central Kootenay.
- Higginson, Alana. Contributed by Norm Allard and Neil Fletcher. (2022, July 27). *Watershed Renewal Project at BC First Nation Bearing Fruit as Wildlife Returning.* Source: Opinion: Watershed Renewal Project at BC. First Nation Bearing Fruit as Wildlife Returning - The Globe and Mail.
- Klohn Crippen. (2002). *Goat River Flood Protection Planning Study*. Report prepared for Regional District of Central Kootenay.
- Kerr Wood Leidal Consulting Engineers (KWL). (2020). *Risk Assessment of BC's Orphan Dikes*, Summary Report, December 9 2020.
- US Army Corps of Engineers – Northwestern Division, Bureau of Reclamation – Columbia-Pacific Northwest Region, and Bonneville Power Administration. (2020, September). *Environmental Impact Statement Record of Decision*.
- US ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT. (2004). *Hydrologic Analysis of Upper Columbia Alternative Options: Local Effects of Alternative Flood Control and Fish Operations at Libby Dam*.
- US ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT. (2005). *Bonners Ferry Flood Level Study Report*.
- NORTHWEST HYDRAULIC CONSULTANTS. (2019). *BC Dike Consequence Classification Study*. Prepared for Ministry of Forests, Lands, Natural Resource Operations and Rural Development.
- NORTHWEST HYDRAULIC CONSULTANTS. (1999, August). *Kootenay River Erosion Study*. Report prepared for Association of Kootenay Valley Drainage Districts.

APPENDIX

A OVERVIEW MAPS

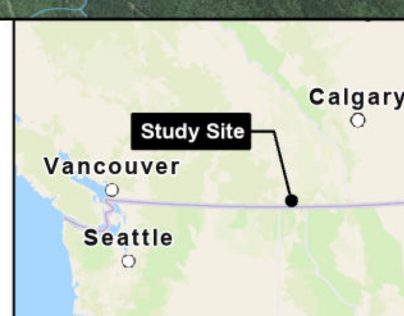


Risk Rating

- Negligible
- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Legend

- Wetland Management Dike
- Lower Kootenay Bank Reserve
- Creston Valley Wildlife Management Area
- 266 Dike Number



NOTES:
1. ALL UNITS IN METERS UNLESS NOTED OTHERWISE
2. COORDINATES SHOWN IN UTM NAD83 ZONE 11

REFERENCES:
1. CANVEC, NRCAN, GOVERNMENT OF CANADA
2. ESRI BASEMAP, WORLD TOPOGRAPHY MAP

0 400 800 1,200 1,600 m

WSP CANADA INC.
SUITE 1000, 840 HOWE STREET
VANCOUVER, BC V6Z 2M1
PHONE: 604 685-9831 - FAX: 604 736-1519
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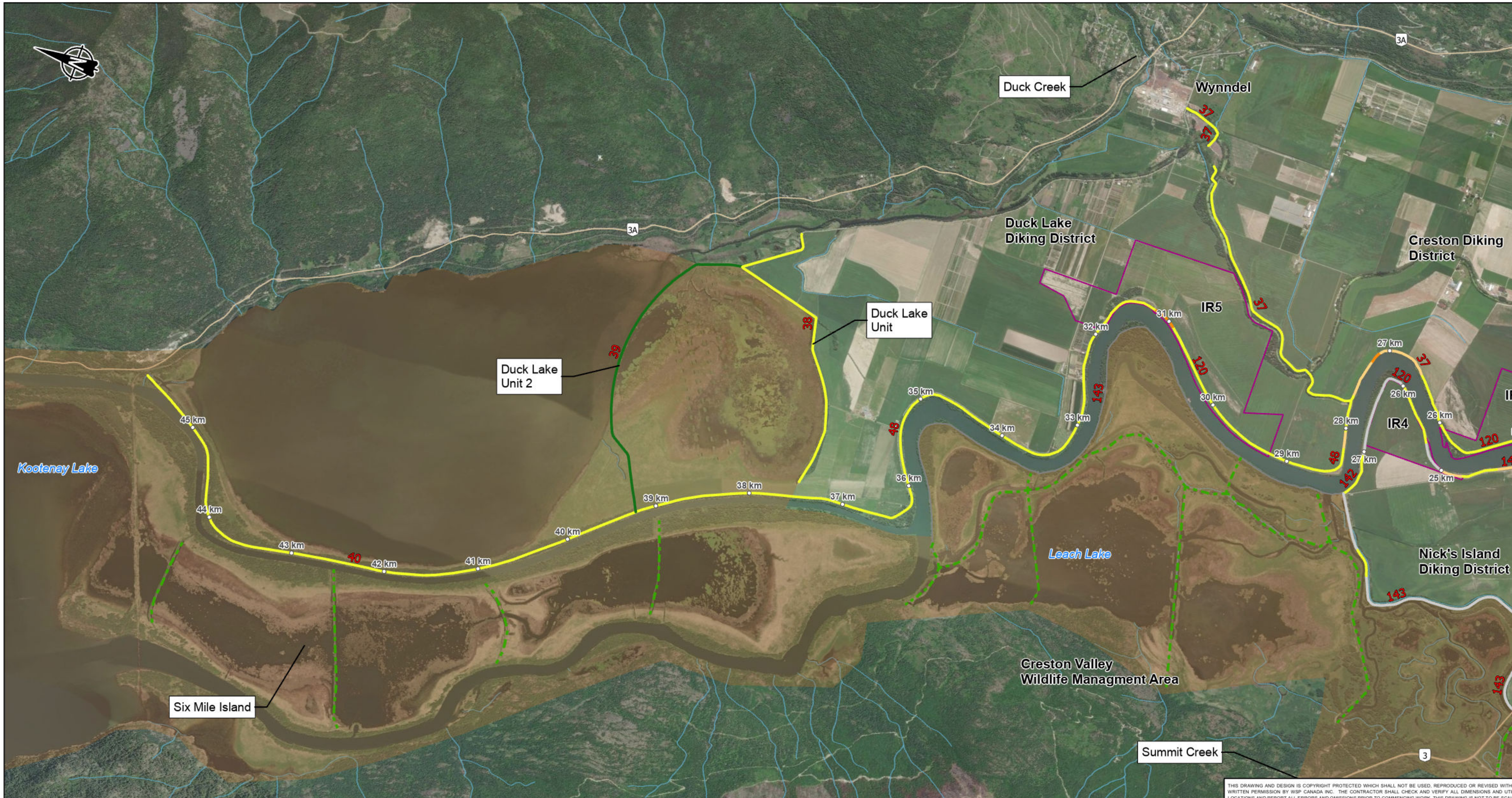
TITLE: OVERVIEW MAP OF CRESTON VALLEY

PROJECT: PROFESSIONAL ENGINEERING SERVICES FOR THE CRESTON VALLEY FLOOD RISK ASSESSMENT

CLIENT: TOWN OF CRESTON

DES.	DR.
AH	PAB
CH. AH	SCALE 1:40,000
APP. VC	DATE FEB 2023
DWG. NO. Map 1	
FILE NO. 221-08591-00	SHEET 1 OF 3

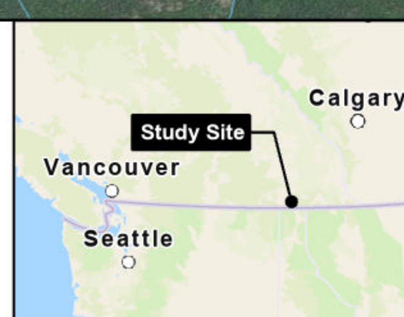


Risk Rating

- Negligible
- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Legend

- Wetland Management Dike
- Lower Kootenay Bank Reserve
- Creston Valley Wildlife Management Area
- 266 Dike Number



NOTES:
1. ALL UNITS IN METERS UNLESS NOTED OTHERWISE
2. COORDINATES SHOWN IN UTM NAD83 ZONE 11

REFERENCES:
1. CANVEC, NRCAN, GOVERNMENT OF CANADA
2. ESRI BASEMAP, WORLD TOPOGRAPHY MAP

0 400 800 1,200 1,600 m

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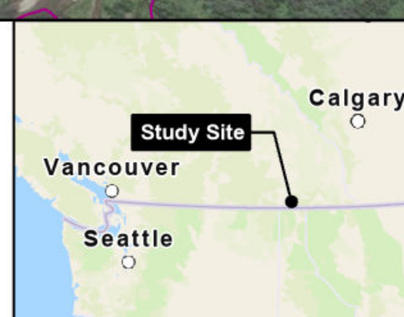
TITLE: OVERVIEW MAP OF CRESTON VALLEY		DES. AH	DR. PAB
		CH. AH	SCALE 1:40,000
PROJECT: PROFESSIONAL ENGINEERING SERVICES FOR THE CRESTON VALLEY FLOOD RISK ASSESSMENT		APP. VC	DATE FEB 2023
		DWG. NO. Map 2	
CLIENT: TOWN OF CRESTON		FILE NO. 221-08591-00	SHEET 2 OF 3

Risk Rating

- Negligible
- Very Low
- Low
- Moderate
- High
- Very High
- Extreme

Legend

- Wetland Management Dike
- Lower Kootenay Bank Reserve
- Creston Valley Wildlife Management Area
- 266 Dike Number



NOTES:
1. ALL UNITS IN METERS UNLESS NOTED OTHERWISE
2. COORDINATES SHOWN IN UTM NAD83 ZONE 11

REFERENCES:
1. CANVEC, NRCAN, GOVERNMENT OF CANADA
2. ESRI BASEMAP, WORLD TOPOGRAPHY MAP

0 400 800 m

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TITLE:	OVERVIEW MAP OF CRESTON VALLEY
PROJECT:	PROFESSIONAL ENGINEERING SERVICES FOR THE CRESTON VALLEY FLOOD RISK ASSESSMENT
CLIENT:	TOWN OF CRESTON

DES. AH	DR. PAB
CH. AH	SCALE 1:20,000
APP. VC	DATE FEB 2023
DWG. NO. Map 3	
FILE NO. 221-08591-00	SHEET 3 OF 3

APPENDIX

B DIKE RISK ASSESSMENT SUMMARY

wsp

Dike Number	Dike Authority	Year of Construction*	NHC - 2019		BGC - 2014		WSP - 2022			
			Total Protected Floodplain Area (km2)	Consequence classification	Erosion Failure Likelihood Rating & Vulnerable Location (km)**	Consequence of Failure / Value (Million $)	Failure Likelihood Rating & Vulnerable Location (km)**		Consequence of Failure	Hazard Rating
							Overtopping, 200-year Flood	Erosion		
37	Creston Diking District	1930s -Dike between Creston Diking District from the Duck Lake Diking District	30.1	Major 4 People: Major 4 Economy-Building: Moderate 3 Economy-Infrastructure: High 5 Environment: High 5 Culture: High 5	Moderate, 18.3-18.92	11.13 / 24.27 Building: 4.05 Building Content: 4.74 Crops: 1.45 Business: 0.89	Very Low	Low, 17.95-18.25	Major 4	Moderate
					Moderate, 20.67-21.16		Very Low	Low, 18.25-18.30		Moderate
					High, 25.71-25.94		Very Low	Moderate, 18.30 -18.36		High
					High, 26.65-26.98		Very Low	Low, 18.36-18.5		Moderate
					High, 27.27-27.39		Very Low	Moderate, 18.50-18.68		High
					-		Very Low	Moderate, 18.68-19.1		High
							Very Low	High, 20.75-21.16		Very High
					-		Very Low	High, 21.16-21.95		Very High
					-		Very Low	Low, 23.6-24.39		Moderate
							Very Low	Low, 25.68-26.55		Moderate
					-		Very Low	Moderate, 26.55-27.1		High
					-		Very Low	High, 27.1-27.25		Very High
							Very Low	Moderate, 27.25-27.65		High
					-		Very Low	Low, Remaining		Moderate
120	Creston Diking District		-	-	Moderate, 16.71-16.84		Very Low	High, 16.55-17.03		Very High
					High, 16.84-16.97		Very Low	Moderate, 17.03-17.45		High
					High, 17.16-17.42		Very Low	High, 17.45-17.95		Very High
					Moderate, 19.6-20.09		Very Low	Low, 19.1-20.02		Moderate
					High, 20.09-20.23		Very Low	High, 20.02-20.75		Very High
					Moderate, 20.23-20.67		Very Low	Low, 21.95-23.6		Moderate
					Moderate, 24.34-24.54		Very Low	Low, 24.39-24.44		Moderate
					High, 24.99-25.35		Very Low	Moderate, 24.44-24.51		High
					High, 25.51-25.71		Very Low	Low, 24.51-24.75		Moderate
							Very Low	Moderate, 24.75-24.95		High
					-		Very Low	Low, 24.95-25.68		Moderate
266	Reclamation Farm Diking District		28.7	Major 4 People: Major 4 Economy-Building: Moderate 3 Economy-Infrastructure: High 5 Environment: High 5 Culture: NA 0	Moderate, 0.65-0.81	10.98 / 17.37 Building: 3.52 Building Content: 2.13 Crops: 4.32 Business: 1.00	Very Low	Low, 0.21-4.4	Major 4	Moderate
					Moderate, 6.83-7.31		Very Low	Moderate, 4.36-6.5		High
					Moderate, 9.43-9.91		Very Low	Low, 6.5-9		Moderate
					Moderate, 11.25-11.7		Very Low	Moderate, 9-9.85		High
					Moderate, 13.33-13.65		Very Low	Low, 9.85-12.45		Moderate
					High, 17-17.68		Very Low	Moderate, 12.45-12.95		High
					-		Very Low	Low, 12.95-13.83		Moderate
					-		Very Low	Moderate, 13.83-14.1		High
					-		Very Low	Low, 14.1-16.02		Moderate
					-		Very Low	Moderate, 16.02-17.07		High
					-		Very Low	High, 17.07-17.83		Very High
267	Reclamation Farm Diking District		28.7		-		-	Low	Major 4	Moderate
268	Reclamation Farm Diking District	1892-1893	28.7		-		-	Low	Major 4	Moderate
120	Nick's Island Diking District		-	-	Moderate, 24.57-24.8	2.16 / 4.24 Building: 0.80 Building Content: 0.63 Crops: 0.67 Business: 0.05	Very Low	Moderate, 24.39-24.78	Moderate 3	Moderate
					Moderate, 25.25-25.85		Very Low	High, 24.78-25		High
					-		Very Low	Low, 25-25.35		Low
					-		Very Low	Moderate, 25.35-26		Moderate
					-		Very Low	Low, 26-27.05		Low
141	Nick's Island Diking District		8.6	Moderate 3 People: Moderate 3	-		-	Low		Low
142	Nick's Island Diking District		8.6		High, 20.48-20.77		Very Low	Low, 20.32-20.6		Low
					Moderate, 20.77-21.61		Very Low	High, 20.6-20.9		High

Dike Number	Dike Authority	Year of Construction*	NHC - 2019		BGC - 2014		WSP - 2022			
			Total Protected Floodplain Area (km2)	Consequence classification	Erosion Failure Likelihood Rating & Vulnerable Location (km)**	Consequence of Failure / Value (Million $)	Failure Likelihood Rating & Vulnerable Location (km)**: Overtopping, 200-year Flood	Failure Likelihood Rating & Vulnerable Location (km)**: Erosion	Consequence of Failure	Hazard Rating
				Economy-Building: Moderate 3 Economy-Infrastructure: Major 4 Environment: Major 4 Culture: Moderate 3	High, 23.76-24.12		Very Low	Low, 20.9-24.05		Low
					-		Very Low	High, 24.05-24.39		High
							Very Low	Moderate, 27.05-27.52		Moderate
143	Nick's Island Diking District		8.6		Moderate, 0.28 km along the north channel		-	Moderate, 0.28 km along the north channel		Moderate
								Low, remaining		Low
48	Duck Lake Diking District		16.2	Major 4 People: Moderate 3 Economy-Building: Minor 2 Economy-Infrastructure: High 5 Environment: High 5 Culture: High 5	-	3.51 / 5.17 Building: 0.77 Building Content: 0.68 Crops: 0.66 Business: 1.40	Very Low	Low, 27.65-28.05	Major 4	Moderate
							Very Low	Moderate, 28.05-28.2		High
							Very Low	Low, 28.2-29.02		Moderate
							Very Low	Low, 31.85-35.9		Moderate
							Very Low	Low, 35.9-36.2		Moderate
							Very Low	Low, 36.2-38.95		Moderate
120	Duck Lake Diking District		-	-	High, 30.97-31.28		Very Low	Low, 29.02-30.93		Moderate
					-		Very Low	High, 30.93-31.2		Very High
					-		Very Low	Low, 31.2-31.85		Moderate
38	Creston Valley Wildlife Management	1953	11.6	Major 4 People: Moderate 3 Economy-Building: Minor 2 Economy-Infrastructure: High 5 Environment: High 5 Culture: High 5	-	-	-	Low	Major 4	Moderate
39	Creston Valley Wildlife Management	1971	4.6	Insignificant 1 People: NA 0 Economy-Building: NA 0 Economy-Infrastructure: Moderate 3 Environment: High 5 Culture: NA 0	-	-	-	Low	Insignificant 1	Negligible
40	Creston Valley Wildlife Management		27.4	Major 4 People: Moderate 3 Economy-Building: Moderate 3 Economy-Infrastructure: High 5 Environment: High 5 Culture: High 5	-	-	Very Low	Low, 38.95-45.44	Major 4	Moderate
-	Goat River Residents Associates	2006-2007		-	-	1.94 / 7.19	Very Low	Very Low, 0-0.31	Moderate 3	Very Low
69***					-		Very Low	Very Low, 0.31-0.49		Very Low
				Moderate 3* People: Moderate 3 Economy-Building: Minor 2 Economy-Infrastructure: Moderate 3			Moderate, 0.49-0.65	-		Moderate
					-		Very Low	Low, 1.0-1.6		Low
					-		Very Low	Very Low, 1.6-1.68		Very Low
-		2006-2007		-	-		Very Low	Low, 1.68-1.83	Insignificant 1	Negligible
					-		Very Low	Very Low, 1.83-1.93		Negligible
					-		Very Low, 1.93-2.26	Very Low, 1.93-2.26		Negligible
					-		Very High, 2.26-2.47	Very Low, 2.26-2.47		Moderate
					-		Very Low	Very Low, 2.47-2.59		Negligible
69		1960's-1970's		Moderate 3* People: Moderate 3	-		Very Low	Low, 2.59-2.81	Moderate 3	Low
					-		Very Low	Very Low, 2.81-2.9		Very Low
					-		Very Low	Moderate, 2.9-3.03		Moderate

Dike Number	Dike Authority	Year of Construction*	NHC - 2019		BGC - 2014		WSP - 2022			
			Total Protected Floodplain Area (km2)	Consequence classification	Erosion Failure Likelihood Rating & Vulnerable Location (km)**	Consequence of Failure / Value (Million $)	Failure Likelihood Rating & Vulnerable Location (km)**		Consequence of Failure	Hazard Rating
							Overtopping, 200-year Flood	Erosion		
				Economy-Building: Minor 2 Economy-Infrastructure: Moderate 3 Environment: Moderate 3 Culture: NA 0	-		Very Low	Very Low, 3.03-3.05		Very Low
					-		Very Low	Low, 3.05-3.14		Low
					-		Moderate, 3.14-3.2	Low, 3.14-3.2		Moderate
					-		Very Low	Moderate, 3.2-3.4		Moderate
					-		Very Low	Low, 3.4-3.97		Low
					-		Very Low	Very Low, 3.97-4.1		Very Low

* From BGC – 2014 or Provided by the Client

** Refer to Appendix A

*** km 0.65 to 1 is a gravel berm (not classified as a dike)