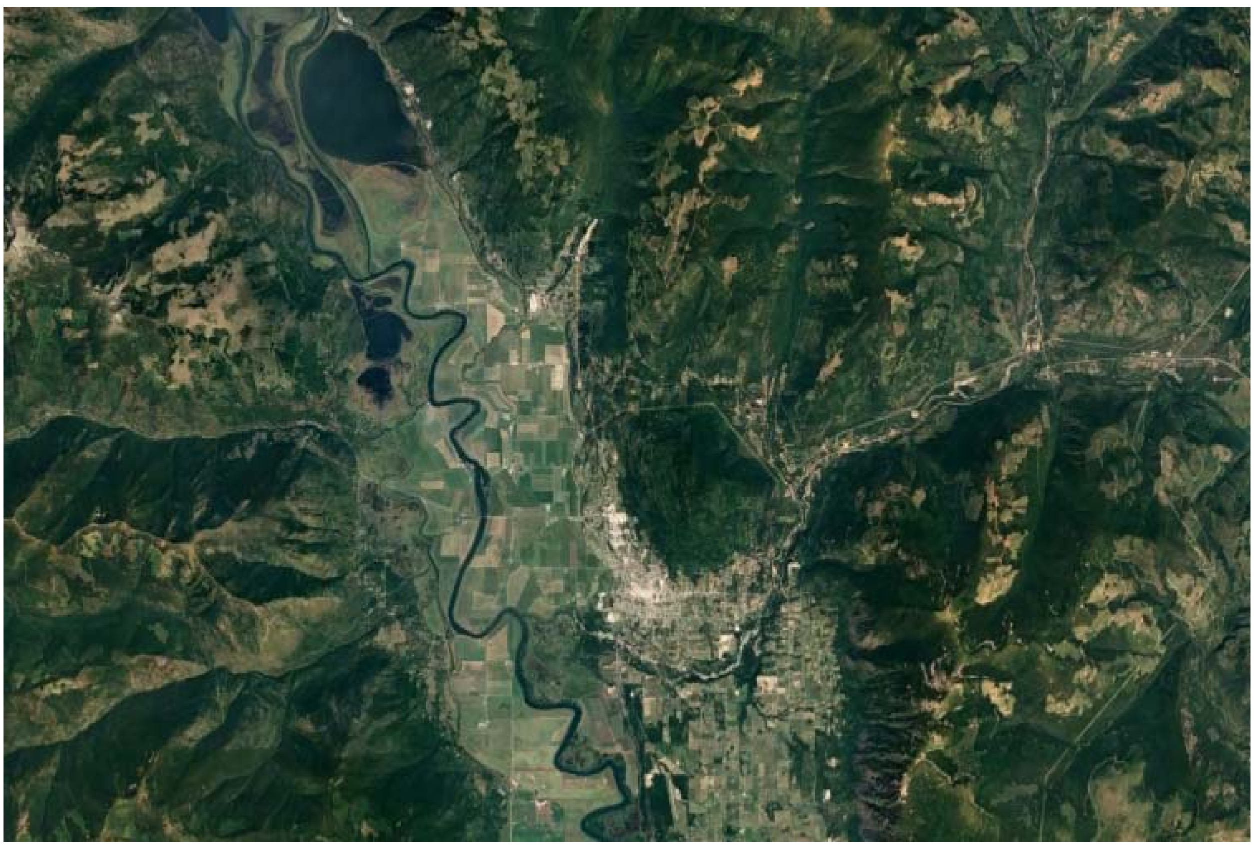
# PROFESSIONAL ENGINEERING SERVICES FOR THE CRESTON VALLEY FLOOD RISK ASSESSMENT

## STRATEGIC PLAN DEVELOPMENT

TOWN OF CRESTON

APRIL 2023



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## STRATEGIC PLAN DEVELOPMENT

TOWN OF CRESTON

FINAL VERSION

PROJECT #: 221-08591-00
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WSP CANADA INC.
840 HOWE STREET, #1000
VANCOUVER, BRITISH COLUMBIA V6Z 2M1

PHONE: +1 604-685-9381

WSP.COM

Engineers & Geoscientists BC Permit #1000200

# SIGNATURES

PREPARED BY


Ana Hosseinpour, Water Resource Engineer
P.Eng., Ph.D.

REVIEWED BY


Vincent Cormier, Project Manager
P.Eng., M.Sc.

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| Preliminary | Town Of Creston | March, 10, 2023 |
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# PRODUCTION TEAM

TOWN OF CRESTON

| | |
|---|---|
| Town of Creston Representatives | Avery Deboer-Smith<br>John Cathro |

WSP CANADA INC. (WSP)

| | |
|---|---|
| Project Manager | Vincent Cormier |
| Deputy Project Manager | Curtis Vanwerkhoven |
| Water Resource Engineers | Ana Hosseinpour<br>Winston Wade |
| ArcGIS Specialist | Pierre-André Bastin |
| Edition | Sophie Auclair<br>Nancy Paquet |

**Reference to mention:**

WSP. 2023. *Professional Engineering Services for the Creston Valley Flood Risk Assessment – Strategic Plan Development*. Report from WSP Canada Inc. to Town Of Creston. 45 p. and Appendices.

# EXECUTIVE SUMMARY

The Town of Creston has retained WSP to develop an updated flood risk assessment and a flood action plan based on prioritized flood mitigation options for about 92 km of the dikes within the Kootenay River floodplain, from the U.S. 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.

Stage 1 has been completed, and a risk assessment report has been prepared and submitted to the client in January 2023. The main focus of the current report is to summarize the analysis carried out to complete Stage 2.

As part of Stage 2, WSP collected and reviewed background information to learn about the previously recommended flood risk mitigation options at the project site. This report provides a summary of recommendations by NHC (1999), BGC (2014), and RHL (2018).

In this study, some of the most relevant flood risk mitigation options were reviewed to identify the appropriate ones for the study area. The options include a wide range of mitigation measures, including various structural and non-structural measures. The corresponding advantages, disadvantages, general range of applicability, geomorphic response, engineering effectiveness, and habitat characteristics of these options were analysed.

Then, the suitability of the options was evaluated based on several criteria for the dikes in the study area to select the most appropriate one for each dike.

The retained options include riprap protection on the riverside of the dike, setback dikes, and vegetated riprap protection on the riverbank at the dike.

Finally, a Strategic Plan for the next 10 years was developed based on the outcomes of the project in Stage 1 (priority of the dikes), Stage 2 (risk mitigation options), and a high-level cost estimate. The plan outlines the actions that should be taken and recommended timelines for each task to achieve the final goal of flood risk mitigation in the study area.

The Yaqan Nukiy perspective on flood management was included in the decision process and reflected in the Strategic Plan (Table 7.3).

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# 1 INTRODUCTION

The Kootenay River, flowing from south to north, and its tributaries, including the Goat River that flows from east to west, run through Creston Valley, which has been historically prone to flooding until a diking system was built on the banks and within the floodplains of the Kootenay River and Goat River. Currently, Creston Valley is protected by about 92 km of dike network protecting residential areas and agricultural lands along the Kootenay River and Goat River. The floodplain area protected by these dikes now provides rich agricultural lands. Construction of the Libby Dam in the USA has significantly reduced the Kootenay River's peak discharges and the Creston Valley's flood risk.

However, dike failure and consequent flooding are still a potential hazard that needs to be managed by maintaining and upgrading the existing dike system. The Town of Creston has retained WSP to update the existing 2014 Creston Valley Floodplain Management Study (BGC, 2014a) flood risk assessment and develop a Strategic Plan to identify and prioritize potential flood mitigation options.

In Stage 1 of this project, WSP reviewed the 2014 BGC hydrological and hydraulic analysis (BGC, 2014a), completed an erosion assessment of the dike network by conducting a site inspection, evaluated the likelihood and consequence of dike failure, and assigned flood risk rating to each section of the dikes. A risk rating of Negligible, Very Low, Low, Moderate, High, Very High, or Extreme was assigned to different parts of the dikes in the Risk Assessment Update report (WSP, 2023). These ratings were then used to prioritize the required dike upgrades.

In Stage 2 of the project, the outcome of Stage 1 is used to develop an Action Plan, as explained in the current report. The objective of the Action Plan is to reduce the flood risk by lowering their likelihood of failure. The detailed scope of work for Stage 2 is listed in Section 1.1.

## 1.1 SCOPE OF WORK

The scope of work for this stage (Stage 2) of the project includes the following:

- Review existing flood management documentation developed for the study area;
- Review a variety of potential flood risk mitigation measures;
- Determine the most appropriate risk mitigation option for each section of the dike;
- Conduct cost estimate evaluations for the recommended options; and
- Develop a Strategic Plan.

## 1.2 REPORT STRUCTURE

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

**Chapter 2: Background Review.** Summarizes the flood risk reduction recommendations provided in the previous studies.

**Chapter 3: Flood Risk Assessment Summary.** Provides the summary of the final outcome of the analysis from Stage 1.

**Chapter 4: Stakeholder Feedback.** Summarizes the feedback from stakeholders.

**Chapter 5: Flood Mitigation Measures.** Provides information on the available options to reduce the flood risk and explains the methodology and the results of applied techniques to select the most appropriate option for each dike.

**Chapter 6: Cost Estimate.** Delivers the high-level cost estimate for the recommended options.

**Chapter 7: Strategic Plan.** Describes the proposed Strategic Plan.

**Appendix A** provides overview maps of the dikes, **Appendix B** summarizes the dike risk assessments, and **Appendix C** provides the field inspection and reporting template.

# 2 BACKGROUND REVIEW

WSP was given access to previous studies providing flood risk reduction measures within the Creston Valley. WSP reviewed the content of each study and developed a summary of flood risk reduction recommendations from these three studies, presented below.

## 2.1 NHC – 1999

NHC report was not available to WSP for review, but BGC provided a summary of the mitigation measures proposed by NHC (BGC, 2014a). According to BGC – 2014a, NHC provided the following general recommendations for stabilizing the Kootenay River bank.

- Conduct site surveys of the eroded river banks and collect information along the cross-section of the dike.
- Clear the bank from vegetation and re-slope the dike to 2H:1V or flatter at both sides.
- Place a gravel-cobble blanket on the bank between the elevation of 528 m (about 2 m below the minimum lake level recorded since 1973) and 537 m, which is about 2 m below the dike crest.
- The blanket should be at least 600 mm and consist of a well-graded mixture of cobble, gravel and coarse sand with a D50 of 75 mm and grain diameters less than 200 mm.
- The blanket should be placed by an excavator, not end dumped, to ensure uniform coverage.
- As a more economical alternative, NHC also proposed to use blasted rock from local quarries with the following riprap gradation:
  - 100% smaller than 450 mm (or 130 kg);
  - 20% larger than 350 mm (or 70 kg);
  - 50% larger than 300 mm (or 40 kg);
  - 80% larger than 200 mm (or 10 kg).
- Where it is not feasible to place the blanket down to an elevation of 528 m, a thicker berm (minimum thickness of 1,000 mm) will be placed at the base of the slope to armor the toe of the slope in the event of future scour (self-launching armor) and provide a platform for construction. The river side of the berm should have a slope of 2H:1V and a top width of 1.7 m.
- The bank protection should form a smooth transition into the natural bank at the upstream and downstream ends of the works.

## 2.2 BGC – 2014

As part of the Creston Valley Floodplain Management Study, BGC investigated the following dike management alternatives:

- *Status Quo: Maintain the status quo with dikes repaired on an as-needed basis and with no setback;*
- *Option 1: Do not maintain the dikes and accept that damages will occur;*
- *Option 2: Maintain the dikes, but implement setback criteria (where appropriate) when dike repairs are required. Also, implement other environmental mitigation works;*
- *Option 3: Remove the dikes (or select areas with breaches) and raise all buildings on the floodplain and Highway #3 above the 200-year flood level.*

These options were compared using a multiple-criteria analysis and a cost-benefit analysis. As a result, Option 2 was selected as the most desirable option from an economic perspective, with the status quo option being the second best. This option was recommended as the basis of the flood management plan for the Creston Valley (BGC, 2014b).

The advantage of the setback dike is that less rock is required compared to the typical dike repair method, and the restored floodplain provides some environmental benefits. The challenge of this method is that land must be purchased for the setback and the dike structure. Therefore, the property owner must agree with the sale of the land. Also, if there is infrastructure (buildings, roads, and pump stations) to be moved, the relocation can significantly increase the dike upgrade cost. The report also states that "if there are outside bends where the river is aggressively eroding the bank, then it is possible that setback dike repairs are not feasible" (BGC, 2014a).

Where the floodplain area is graded so that there is a long flat slope between the setback dike and the river bank, BGC proposed that the floodplain area could be planted with trees and shrubs, eliminating the riprap cost.

Based on the 2009 costs for the 420 m long IR2 typical dike repair, the costs of Typical Dike Repair, Setback Dike Repair, and Sloped Setback Dike Repair are $990, $850, and $751 per meter, respectively.

The total cost was calculated based on the 4.35 km of the dikes with High erosion hazards and 6.41 km of the dikes with Moderate erosion hazards in the BGC report, and assuming that half the repairs will use typical dike repair costs and half the repairs will use setback dike repair costs. The cost estimates for the dikes with High and Moderate erosion hazards were $4,009,000 and $5,901,000, respectively. The total annual maintenance cost for 95.7 km of the dikes was estimated to be $37,300.

## 2.3 RHL – 2018

Rodman Hydrotechnical Ltd (RHL) prepared a report in 2018 containing the recommended dike repairs for the Reclamation Diking District at three locations. According to RHL, the setback dikes are not applicable at the locations of interest due to their location on abrupt bends and/or adjacent infrastructure. Recommended repairs include:

— Re-sloping of the dike flanks to 2H:1V at site 1 (at the end of Christenson Road) and add riprap blanket;

— Re-sloping of the dike flanks to 1.5H:1V at site 2 (upstream of Old Ferry Crossing of Kootenay River) and add riprap blanket;

— Re-sloping of the dike flanks to 2H:1V at site 3 (east of existing farm building) and add riprap blanket.

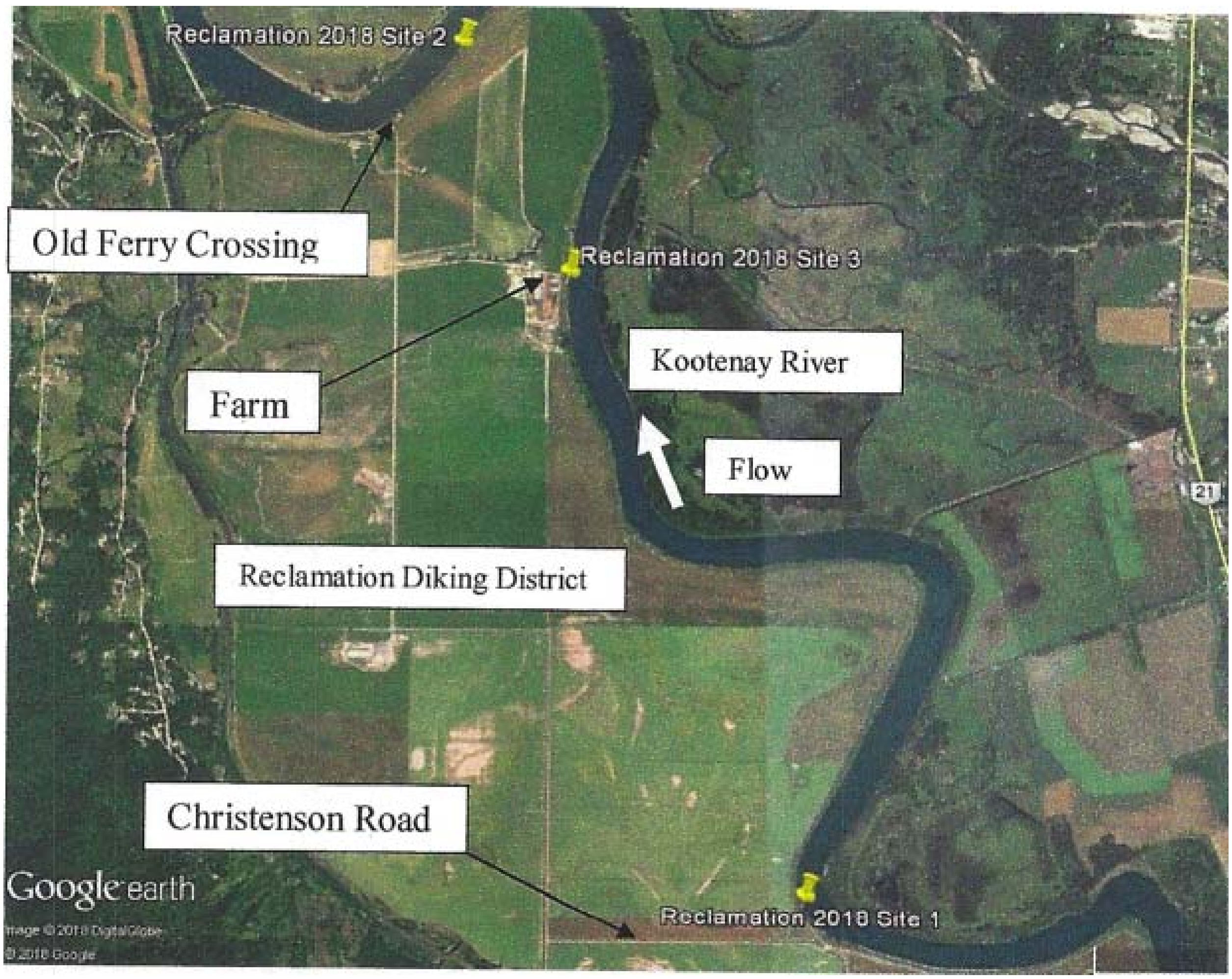



**Figure 2.1 Reclamation Diking District Repair Sites by RHL (RHL, 2018)**

The recommended riprap is a 600 mm blanket consisting of cobble, gravel, and coarse sand with a D50 of 75 mm and a maximum grain diameter of 200 mm. Where cobble/gravel material is not available, it might be more economical to use blasted rock from local quarries. The proposed riprap gradation is similar to NHC study as follows:

- 100% smaller than 450 mm (or 130 kg);
- 20% larger than 350 mm (or 70 kg);
- 50% larger than 300 mm (or 40 kg);
- 80% larger than 200 mm (or 10 kg).

# 3 FLOOD RISK ASSESSMENT SUMMARY

In Stage 1 of this project, a risk rating of Negligible, Very Low, Low, Moderate, High, or Very High was assigned to each dike within the study area, as shown in Table B-1 (Appendix B) and illustrated in Maps A-1, A-2, and A-3 (Appendix A) of Stage 1 report (WSP, 2023) and this report.

The defined risk ratings were then used to sort the dikes in order of priority. 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. Also, 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. As well, 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.

Table 3.1 shows this table for the dikes with the risk rating of High and Very High, which are the main focus of this Strategic Plan. In this table, 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, and a sub-priority number was assigned to each dike. The priority score and sub-priority of the dikes within the study area define the recommended order of implementing a risk reduction measure. Dikes with the same sub-priority have the same precedence for being upgraded.

## Table 3.1 Dike Hazard Ratings and Priorities

| DIKE NO. | DIKING AUTHORITY | VULNERABLE LOCATION (km)* | CONCERN NATURE | EROSION LIKELIHOOD | EROSION SCORE | CONSEQUENCE | HAZARD RATING | PRIORITY SCORE | SUB-PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| 120 | Creston Diking District (LKB:17.45 to 17.57) | 17.45-17.95 | Erosion | High | 46 | Major | Very High | 1 | 1.1 |
| 37 | Creston Diking District | 27.1-27.25 | Erosion | High | 46 | Major | Very High | 1 | 1.1 |
| 120 | Creston Diking District (LKB) | 16.55-17.03 | Erosion | High | 44 | Major | Very High | 1 | 1.2 |
| 120 | Creston Diking Distric (LKB) | 20.02-20.75 | Erosion | High | 44 | Major | Very High | 1 | 1.2 |
| 266 | Reclamation Farm Diking District | 17.07-17.83 | Erosion | High | 42 | Major | Very High | 1 | 1.3 |
| 120 | Duck Lake Diking District (LKB) | 30.93-31.2 | Erosion | High | 40 | Major | Very High | 1 | 1.4 |
| 37 | Creston Diking District (LKB : 20.75 to 20.84) | 20.75-21.95 | Erosion | High | 38 | Major | Very High | 1 | 1.5 |
| 142 | Nick's Island Diking District | 24.05-24.39 | Erosion | High | 40 | Moderate | High | 2 | 2.1 |
| 142 | Nick's Island Diking District | 20.6-20.9 | Erosion | High | 38 | Moderate | High | 2 | 2.2 |
| 120 | Nick's Island Diking District | 24.78-25 | Erosion | High | 36 | Moderate | High | 2 | 2.3 |
| 37 | Creston Diking District | 18.3-18.36 | Erosion | Moderate | 34 | Major | High | 2 | 2.4 |
| 37 | Creston Diking District | 18.5-18.68 | Erosion | Moderate | 34 | Major | High | 2 | 2.4 |
| 37 | Creston Diking District | 26.8-27.1 | Erosion | Moderate | 34 | Major | High | 2 | 2.4 |
| 37 | Creston Diking District | 27.25-27.4 | Erosion | Moderate | 34 | Major | High | 2 | 2.4 |
| 266 | Reclamation Farm Diking District | 16.02-16.68 | Erosion | Moderate | 32 | Major | High | 2 | 2.5 |
| 120 | Creston Diking District (LKB) | 24.75-24.95 | Erosion | Moderate | 30 | Major | High | 2 | 2.6 |
| 37 | Creston Diking District | 27.4-27.65 | Erosion | Moderate | 28 | Major | High | 2 | 2.7 |
| 37 | Creston Diking District | 26.55-26.8 | Erosion | Moderate | 26 | Major | High | 2 | 2.8 |
| 120 | Creston Diking District | 24.44-24.51 | Erosion | Moderate | 26 | Major | High | 2 | 2.8 |
| 266 | Reclamation Farm Diking District | 13.83-14.1 | Erosion | Moderate | 26 | Major | High | 2 | 2.8 |
| 266 | Reclamation Farm Diking District | 9-9.85 | Erosion | Moderate | 26 | Major | High | 2 | 2.8 |
| 37 | Creston Diking District | 18.68-19.1 | Erosion | Moderate | 24 | Major | High | 2 | 2.9 |
| 120 | Creston Diking District (LKB) | 17.03-17.45 | Erosion | Moderate | 24 | Major | High | 2 | 2.9 |
| 48 | Duck Lake Diking District | 28.05-28.2 | Erosion | Moderate | 24 | Major | High | 2 | 2.9 |
| 266 | Reclamation Farm Diking District | 4.36-6.5 | Erosion | Moderate | 24 | Major | High | 2 | 2.9 |
| 266 | Reclamation Farm Diking District | 12.45-12.95 | Erosion | Moderate | 22 | Major | High | 2 | 2.10 |
| 266 | Reclamation Farm Diking District | 16.68-17.07 | Erosion | Moderate | 22 | Major | High | 2 | 2.10 |

* Map A-1, A-2 (Appendix A).

# 4 YAQAN NUKIY PERSPECTIVE

The Lower Kootenay Band (Yaqan Nukiy) has been a very active proponent of improved dike management strategies within the study area. The dike network built along the Kootenay and Goat Rivers significantly altered the ecological function of these streams and the Yaqan Nukiy has put forward strong arguments to reconcile flood protection with ecological restoration. The Yaqan Nukiy perpestive on flood management is currently being compiled and summarised in a separate report (prepared by others).

The main principles supported by the Lower Kootenay Band are listed below:

- Improving riprarian management practices along the stream banks and bank lines by implementing setbacks;
- Limit the footprint of dike stabilization methods (such as bank hardening) within the riverbeds;
- Limiting uncontrolled cattle access to the streams;
- Compensate for dike requiring repairs and upgrades, but that cannot be a setback by implementing compensation projects aiming at restoring critical off-channel habitats.

WSP acknowledges these core principles and included them, where possible, in this Flood Risk Management Plan.

# 5 FLOOD MITIGATION MEASURES

## 5.1 STRUCTURAL AND NON-STRUCTURAL MEASURES

Some dikes are adjacent to the river and need structural or non-structural maintenance, while others have a setback from the river bank. Even though the later dikes might not be in immediate danger of erosion, river bank migration could eventually reach and destabilize them. Therefore, the river bank might need to be stabilized in that area. This section summarizes some of the known flood risk mitigation and stabilization options for river banks or the dikes in the riparian environment, extracted from available guidelines and handbooks. In addition, the pump stations are an essential component of the flood mitigation system in Creston Valley. Pumps are critical for surface flood management and prevent water accumulation behind the dike network, especially during the spring freshet. According to the BGC report (BGC, 2014a), there are eleven pumps across all the diking districts, including three pumps within the Reclamation Farm Diking District, one in Lower Kootenay Band, two in Creston Diking District, two in Nick's Island Diking District, two in Duck Lake Diking District, and one in Creston Valley Wildlife Management Area. These pumps were not inspected as part of Phase 1 of this study, but annual inspection and testing are recommended.

These options were reviewed to identify the appropriate ones for the study area. The options with corresponding advantages, disadvantages, the general range of applicability, geomorphic response, engineering effectiveness, and habitat characteristics are listed in Table 5.2. A short explanation of each option is provided below. Refer to Table 5.2 for a typical cross-section or plan view of each option.

### *5.1.1 DIKE STABILIZATION METHODS*

#### RIPRAP

Riprap is loose rocks placed on the slope against the water to protect the bank against erosion caused by ice, wave, and high velocities.

#### VEGETATED RIPRAP

Vegetated riprap is riprap with one or more rows of vegetation that provides bank stability by combining both rock and live root systems protection (AMEC, 2012). Refer to the "Vegetation Control" section below for the type and location of the vegetation allowed near a dike.

#### SETBACK DIKE AND VEGETATION BUFFER ZONES

This option includes keeping or removing the existing dike partially or entirely (depending on each case), building a new one further from the river bank, and creating a buffer zone between the river bank and the new dike. The buffer zone could be vegetated. The vegetation buffer zones preserve and/or enhance the riverine corridor and allow fluvial processes and more natural river movement (i.e., erosion and deposition) to continue. The vegetation buffer zones between the active river channel and the new dike can reduce the need for future bank stabilization. A side channel could be built within the setback zone to improve the fish habitat in the area where geometry allows. More land is required for this alternative. Riparian lands provide ecological benefits and promote valuable areas of riparian habitat (Bank Stabilization Design Guidelines, U.S. Department of Interior, 2015).

### *5.1.2 BANK STABILIZATION METHOD*

**LONGITUDINAL STONE TOE WITH BIO-ENGINEERING ON BANKS**

A rock toe is placed along shorelines to provide erosion protection, and a brush layer is installed above the rock toe. The brush layer consists of a row of live cuttings placed in between layers of soil, with tips protruding beyond the face of the fill (AMEC, 2012). Refer to the "Vegetation Control" section below for the type and location of the vegetation allowed near a dike.

**SPUR DIKE**

A spur dike is a structure projected from the bank into the current to protect eroding banks by slowing down the flow and creating stable pools that enhance aquatic habitats. The dike should be monitored regularly for subsidence and loss of the stones, especially from the crest and tip.

**LARGE WOODY DEBRIS (LWD)**

This option includes large logs and tree trunks properly anchored to provide stream bank protection by redirecting the flow from the stream bank and lowering the flow velocity. The woody debris could create a more diverse aquatic habitat and perching sites for reptiles and birds.

**RETAINING WALL**

Retaining walls are engineered walls that help prevent erosion and keep the soil on a slope from falling into the river. They allow for a steeper slope and are typically considered when the allowable footprint of the bank stabilization is restrained. Retaining walls come in various forms, such as rock baskets, gabions, lock blocks, bin walls, concrete gravity or cantilever walls, and segmental walls.

### *5.1.3 NON-STRUCTURAL MEASURES*

**DIKE MAINTENANCE**

According to the Dike Operation and Maintenance Manual, early identification of dikes issues is a significant part of their maintenance because it helps to recognize the areas requiring improvements before major problems develop (BC MELP, 2001). Some main dike maintenance actions include vegetation control, dike inspection, and dike survey, as described below.

**VEGETATION CONTROL**

Only trimmed grass shall be established on dike slopes to the toe of the dike fill to facilitate the inspection of dikes and future upgrades or repairs. Trimmed grass reduces surface erosion due to rain, currents, and waves.

### DIKE INSPECTION

Frequent periodic inspection is essential to identify ongoing issues before major problems develop. Under the Dike Maintenance Act, the Inspector of Dikes requires Diking Authorities to complete annual dike inspection report throughout the dike life cycle (BC MELP, 2000b). All the dikes should also be inspected following major flood events or following major seismic events as well.

### PUMP STATION MAINTENANCE

Pumping stations play a critical role in flood prevention within the study area by pumping excess water from low-lying areas behind the dikes and directing it to nearby rivers or other drainage systems. Table 5.1 summarizes the existing pumping stations within the study area, based on the BGC report (2014a) information. The pumping capacity, reproduced in Table 5.1, was calculated by BGC based on the rated power of each pump and the differential head to overcome.

**Table 5.1 Summary of Existing Pumps**

| DIKING DISTRICT | PUMP NO | DRAINAGE BASIN AREA (ha) | TOTAL CALCULATED POWER (HP) | FLOW ($m^3/s$) |
|---|---|---|---|---|
| Reclamation Farm Diking District | RF1 | 1,100 | 50 | 0.8 |
| | RF2 | 1,960 | 100 | 1.5 |
| | RF3 | 770 | 60 | 0.9 |
| Lower Kootenay Band | LKB1 | 1,760 | Unknown | Unknown |
| Creston Diking District | CD1 | 1,670 | 145 | 2.2 |
| | CD2 | 3,430 | 75 | 1.1 |
| Nick's Island Diking District | NI1 | 430 | 40 | 0.6 |
| | NI2 | 420 | 40 | 0.6 |
| Duck Lake Diking District | DL1 | 515 | 75 | 1.1 |
| | DL2 | 550 | 60 | 0.9 |
| Creston Valley Wildlife Management Area | CW1 | 11,700* | 300 | 3.8 |

* DL1, DL2, and CD1 stations discharge into Duck Lake and have not been included in the total basin area values for CW1.

Although a comprensive flood risk assessment associated with a pump station failure was not completed as part of Phase 1 of this study (WSP, 2023), a malfunction of the pumping station listed in the previous table could result in upland flooding. The consequences of such an event would depend on the timing of the pump failure and the severity of the concurrent snowmelt/storm event. However, dike failures during a flood event are expected to have much greater consequences than a pump malfunction due to the larger flood volume from the Kootenay River or Goat River. For example, a Kootenay River dike failure during a reasonably large flood event could result in flood depths in excess of 3 meters in certain areas protected by the dikes. In comparison, the 100-year, 24-hour precipitation depth in the study area is 60 mm[1]. In the event of a pump station malfunction occurring at the beginning of such a storm event, runoff would converge into low laying areas behind the dikes. However, the flood depths are

[1] Based on IDF CC tool at Creston Campbell Scientific Station.

expected to be relatively small compared to a dike failure given the low runoff volumes over the upland drainage area. Therefore, the consequence of a dike failure during a flood event far exceeds the consequence of a pump failure. Moreover, the likelihood of having a pump failure occurring at the onset of a large rain/snowmelt event is relatively low if the pumps are regularly inspected and properly maintained. It is also unlikely to have more than one pump failure within a diking district occurring at the same time.

A good flood action plan can help mitigate the consequences of a pump station failure during an extreme rain/snowmelt event. For instance, a flood action plan could list local mobile pump suppliers that could be mobilized on site to pump some of the runoffs on the other side of the dikes. Even though mobile equipment typically don't have enough capacity to completely replace the pumping station capacity, listed in Table 5.1, they can provide temporary relief until the pumping stations are operating again. However, this kind of temporary measures is a last line of defense and can't replace proper maintenance and testing of the pumping equipment.

Proper maintenance of pumping stations is essential to ensure their reliable operation during times of flooding. Some of the maintenance activities required for pumping stations for flood prevention include:

- Regular inspections: Regular inspections should be carried out to identify any signs of wear and tear, leaks, or other issues that could affect the performance of the pumping station. Inspections should be conducted by qualified personnel;
- Cleaning and debris removal: The pumping station should be kept clean, and any debris or vegetation that could clog the pumps or block the flow of water should be removed;
- Pump maintenance: The pumps should be inspected regularly and maintained if required to ensure that they are functioning properly. This includes checking the impeller, bearings, and seals;
- Electrical system maintenance: The electrical system should be inspected and maintained regularly to ensure that it is functioning properly. This includes checking the electrical panels, motors, and controls;
- Emergency backup power: Backup power sources can ensure that the pumps remain in operation in case of power outages. This can include generators or battery backups;
- Alarm systems: The pumping station should be equipped with an alarm system that can alert personnel in case of an emergency or malfunction;
- Record keeping: It is important to keep accurate records of maintenance activities, inspections, and repairs. This helps to identify any recurring issues and ensures that maintenance is carried out on a regular schedule.

By following these maintenance procedures, pumping stations for flood prevention can operate efficiently and effectively, reducing the risk of flooding in low-lying areas.

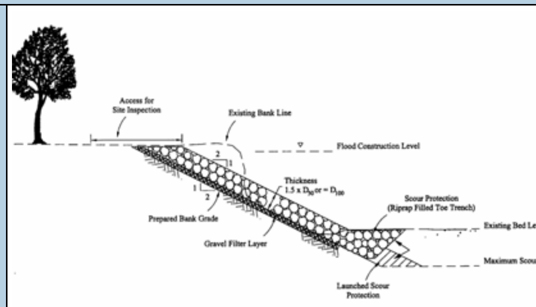
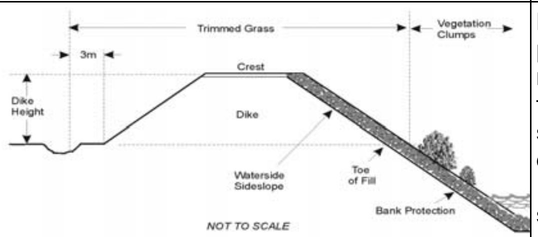
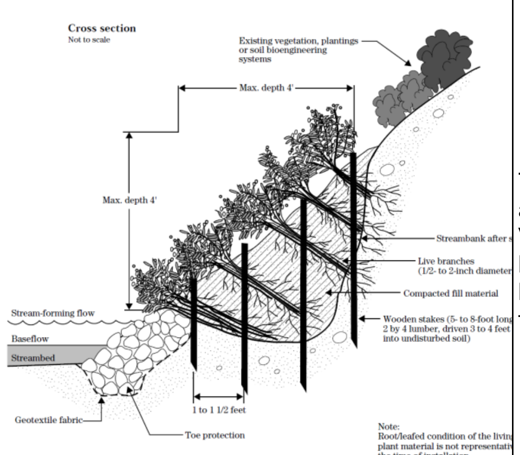
## CATTLE FENCES

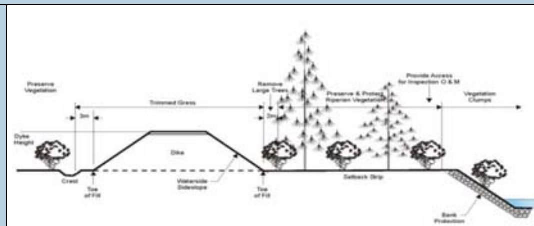
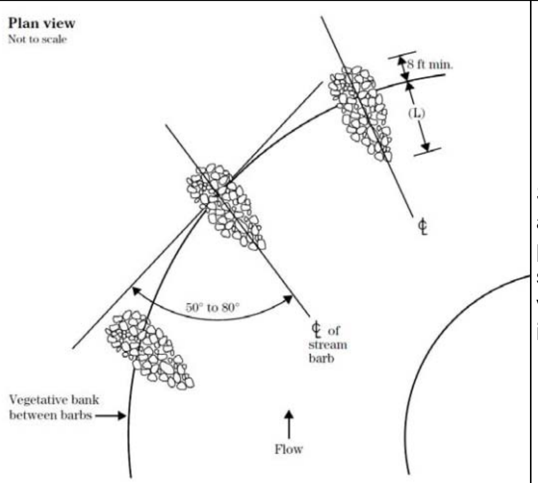
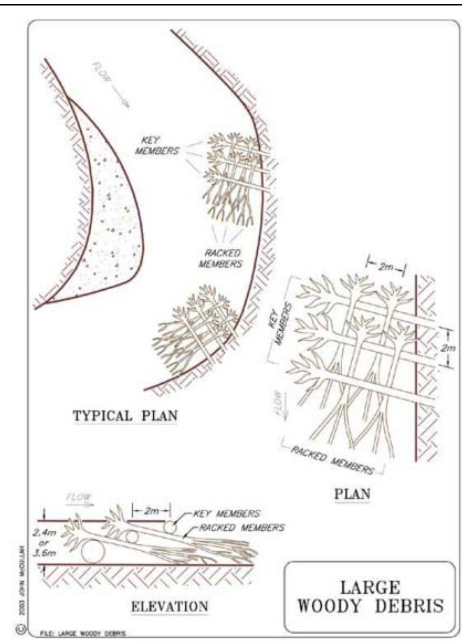
Superficial erosion and damage were observed at certain dike sections due to cattle accessing the Kootenay River. Although this damage is generally limited, they can reduce the dike's ability to sustain erosive forces of the Kootenay River during flood events. To improve the dikes resiliency, it is recommended to install cattle fences at specific locations to prevent cattle traffic over the dikes' crest and slopes.

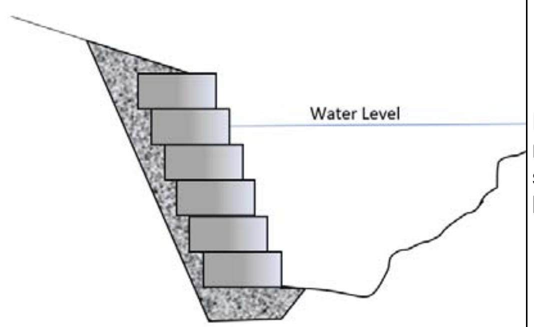
## DIKE SURVEY

Surveying the dike crest profile every three to ten years and comparing it to the design profile helps to identify the low areas that should be raised (BC MELP, 2001).

**Table 5.2 Dike/Bank Stabilization Options**

| DIKE OR BANK STABILIZATION METHOD | | ADVANTAGES | DISADVANTAGES | GENERAL RANGE OF APPLICABILITY | GEOMORPHIC RESPONSE | ENGINEERING EFFECTIVENESS | HABITAT CHARACTERISTICS |
|---|---|---|---|---|---|---|---|
| STRUCTURAL OPTIONS | | | | | | | |
| Riprap | <br>(Source: BC MELP, 2000a) | In general, these methods are widely tested and used, while deformable bank lines are less well understood. Riprap has proven to be extremely resilient and effective at protecting dikes against erosion mechanisms. | Can cause the channel width to decrease, creates a static bank line, and can in some cases, but not all, lead to acceleration of bank erosion in downstream bends. | Generally applicable to all types of channels. | Stops local bank erosion; causes local scour and channel deepening. Can be susceptible to flanking if upstream channel migration occurs. | Durable, high level of confidence in method. Provides long-term bank protection. | Same as longitudinal stone toe except without minimal benefits to riparian community (no bio-engineering). |
| Vegetated Riprap | <br>(Source: BC MWLA, 2003) | More natural and aesthetically pleasing than traditional rock riprap. It provides habitat for fish and wildlife by creating shade, cover and small organic debris input to the watercourse. It is flexible and not affected by slight movements from ground settlement, shifting, frost heave or toe erosion. It is cost-effective in comparison to other hard erosion control techniques. Can negate or reduce the amount of habitat alteration compensation required by regulators. It has minimal maintenance requirements. * | Requires local supply of rock riprap, otherwise it would be very expensive to haul in materials. It requires local supply of suitable native live materials. Need to ensure that navigability of the channel is not impeded. Specialized equipment might be required if there are access restrictions.*<br>Needs watering during dry periods until vegetation has been established.* | In case of having a dike, it is only applicable to an overwidth dike or below the toe for the regular dikes. | Same as Riprap. | Same as Riprap. | Same as longitudinal stone. |
| Longitudinal Stone Toe with Bio-Engineering on Banks | <br>(Source: U.S. Department of Interior, 2015) | Thoroughly tested and used in a wide range of conditions. Vegetation provides aesthetic benefits, shading, and reduces bank line velocity during high flows. | Decreased channel width and increased depth. Creates a local static bank line. In some cases, longitudinal stone toe can lead to accelerated bank erosion of downstream bends. In arid climates, Koir fabric or bio-D blocks are needed to provide suitable conditions for vegetation to grow, and vegetation may need to be replanted to provide the desired benefits.<br>Needs watering during dry periods until vegetation has been established.* | Well suited to protect against toe erosion where mid and upper banks are fairly stable due to vegetation and cohesion. All types of channels throughout the U.S. | Same as Riprap. | Durable, high level of confidence in method provided that the elevation of the top of the riprap stone toe is adequately established to provide complete toe protection. | Prevents lateral migration and the establishment of new depositional zones where vegetation could become established. Reduces local sediment supplied from bank erosion. The steep bank angle on the outside of the bend limits fish cover, except for the riprap interstitial spaces. The point bar remains connected to the main channel and remains static. The flow velocity and depth are greater than typically found in natural channels along the outside bank of a river bend. Bio-Engineering provides shading and minimal benefits to riparian community. |

| DIKE OR BANK STABILIZATION METHOD | | ADVANTAGES | DISADVANTAGES | GENERAL RANGE OF APPLICABILITY | GEOMORPHIC RESPONSE | ENGINEERING EFFECTIVENESS | HABITAT CHARACTERISTICS |
|---|---|---|---|---|---|---|---|
| STRUCTURAL OPTIONS | | | | | | | |
| Setback Dike and Vegetation Buffer Zones | <br>(Source: BC MWLA, 2003) | Greater area for lateral migration. Infrastructure is protected by relocation. | Can be a higher cost than other methods; lateral migration may continue to new infrastructure location with the same erosion issue as before. | Applicable to all ranges of river conditions, except at sharp meanders where aggressive bank migration is observed. | Can encourage current geomorphic processes to continue, such as lateral migration and the creation of new flood plain and riparian areas. Opportunity to connect to historical channels and oxbows. For incised channels, this may provide an opportunity to establish new inset flood plain and riparian zones. | Effectively protects riverside infrastructure by moving it from the erosion zone. Level of confidence is medium to high and depends on the amount of setback. | Lateral river movement creates broader flood plain and a more favorable riparian zone habitat. Lateral bank movement should result in deposition of sediment downstream. The river will establish bars and low surfaces, where vegetation can become established. Longer meander bends may establish greater pool depth and eroding banks with vegetation falling into the channel, providing fish cover and habitat complexity.<br>The vegetation promotes greater area of undisturbed habitat. |
| Spur (Vane) Dike | <br>(Source: AMEC, 2012) | Spur dikes modify channel alignment and provide erosion protection for riverside structures. Provides variable velocity and depth habitat. Can induce sediment deposition. | The bank line between spur dikes can erode when the spur dike spacing is too large. Over time, the channel deepens, increasing flow capacity. Local channel narrowing can occur. The extent of channel deepening and narrowing cannot be predicted with great reliability. The bank line is fixed, thus interrupting fluvial processes. | Most commonly used in shallow, wide streams with moderate to high suspended sediment load. Spur dikes are used widely for protecting highway bridge crossings in the United States.<br>Usually used on outer banks along long radius bends.** | Spur dikes block the flow up to bank height, thus shifting the thalweg alignment to dike tips. Peak flow capacity can be reduced initially until the channel adjusts. The channel adjusts to the presence of spur dikes by forming a deeper, narrower cross section with additional scour downstream from each spur dike. Sediment deposition can occur between spur dikes. | Level of confidence is medium. Can halt local bank erosion. Spur dikes are more durable than bendway weirs and can remain functional if there are small changes to the upstream entrance conditions. Future maintenance (adding riprap on the spur dike tips) may be required, especially in gravel and sand bed streams. | Sediment deposition between structures may allow establishment of riparian vegetation and backwater areas. Channel deepening and tip scour could locally lower the riverbed. Depending on site-specific conditions, transverse features could allow for overbank flooding conditions improving the health of the riparian zone. Local scour could provide habitat diversity and deep habitat during low-flow conditions. |
| Large Woody Debris (LWD) | <br>(Source: U.S. Department of Interior, 2015) | Can create in-stream cover, pool formation, deflect flows, retain gravels, and create complex hydraulics. LWD is a natural material. | The length of benefit is usually between 5 and 15 years, depending upon the durability of the available tree species.<br>They can also create hazards to boaters and other recreationalists when still attached to the bank, or when washed downstream with trailing cable.<br>They can cause some erosion issues downstream if they are washed away.<br>They may cause changes to the opposite bank. | LWD is used in many areas of the world, but is not used much in the arid Southwest, where tree species do not last more than about 5 years.<br>Mostly applicable on long uniform bends in alluvial channels to prevent toe erosion or scour.** | Creates pools, generates scour and substrate sorting, and increases depth and velocity complexity. Can promote side channel formation and maintenance. Can lead to sediment deposition, including formation of islands, in rivers with large sand loads. | Level of confidence is medium. Some design guidelines are available. Short design life span for some southwestern U.S. tree species such as cottonwood. | Adds complexity to the system. Sediment deposition can create areas where new riparian vegetation becomes established. Can create variable depth and velocity habitat. Reliability for providing fish habitat is high for a while logs/root wads remain intact (5-25 years). Can provide structure and habitat for fish. Can provide low-flow refugia habitat during low-flow periods. |

| DIKE OR BANK STABILIZATION METHOD | | ADVANTAGES | DISADVANTAGES | GENERAL RANGE OF APPLICABILITY | GEOMORPHIC RESPONSE | ENGINEERING EFFECTIVENESS | HABITAT CHARACTERISTICS |
|---|---|---|---|---|---|---|---|
| STRUCTURAL OPTIONS | | | | | | | |
| Retaining Wall |  | Effective for limited space or near structures/slopes that are sensitive to movement and loading. | Generally, an expensive option and may require some in-stream work. | Applicable to shallow rivers where the stabilization work footprint must be minimized at the top of slope. | Stops local bank erosion; causes local scour and channel deepening.<br>Can be susceptible to flanking if upstream channel migration occurs. | Durable, high level of confidence in method. Provides long-term bank protection. | No benefits to riparian community. |
| NON-STRUCTURAL OPTIONS | | | | | | | |
| Dike Maintenance | | These options are not as expensive as other options while playing a significant role in dike failure risk mitigation. | They usually involve personal judgment, continuous effort, and owner cooperation. Landowners should be educated for an effective result. | Essential for all dikes. | N/A | Provides long-term bank protection. | Removing the vegetation from the dike or discouraging burrowing animals has adverse effect on habitat. |

Information is mostly from the Bank Stabilization Design Guidelines (U.S. Department of Interior, 2015).
* AMEC, 2012
** Washington Dept of Fish & Wildlife, 2003.

## 5.2 MULTICRITERIA ANALYSIS

In this section, the suitability of the flood risk mitigation and stabilization solutions introduced in Section 5.1 was evaluated for the dikes in the study area to select the most appropriate one for each case. The approach is to carry out a comparative analysis based on several criteria, including:

- The technical efficiency/relevance of the option;
- The sustainability of the option;
- Implementation/Construction;
- The cost of the work;
- Maintenance;
- Regulations;
- Environmental impact.

The evaluation criteria are rated on a scale of 1 to 5. A favorable criterion receives a score of 5, and an unfavorable one receives a score of 1, as shown in Table 5.3. Although this table helps assign the scores, an engineering judgment is still required. The final score is calculated based on the sum of scores for various criteria without considering any weighting. Thereby all criteria are considered equally important.

The cost estimates provided in Table 6.2 correspond to the approximate cost of implementing one linear meter of the flood mitigation option. For the spur dikes and woody debris, it is assumed that the spacing is about 150 m and 30 m, respectively, based on which the unit cost per linear meter is calculated. The height of the retaining wall is assumed to be 4 m, which corresponds to the approximate average river bank height along Kootenay River. Other assumptions for the cost estimates are provided in Section 6.

**Table 5.3 Evaluation Score Description**

| SCORE | TECHNICAL EFFICIENCY / RELEVANCE | SUSTAINABILITY | IMPLEMENTATION/CONSTRUCTABILITY | COST* ($/L.M.) | MAINTENANCE | REGULATIONS | ENVIRONMENTAL IMPACT |
|---|---|---|---|---|---|---|---|
| 1 | Not efficient | < 5 years | Not feasible at the site | >4,000 | High maintenance | Possibly unacceptable from a regulation point of view. | Adverse impacts on the environment. |
| 2 | Low efficiency | 5-10 years | Major challenges | 3,000-4,000 | Moderate-high maintenance | Major regulation requirements. | Neutral |
| 3 | Medium efficiency | 10-25 years | Moderate challenges | 2,000-3,000 | Moderate maintenance | Moderate regulation requirements. | Minor positive impacts. |
| 4 | Medium-high efficiency | 25-50 years | Minor challenges | 1,000 – 2,000 | Minor maintenance | Minor regulation requirements. | Moderate positive impacts. |
| 5 | High efficiency | > 50 years | Almost no challenges | < 1000 | No Maintenance | No regulation involved. | Major positive impacts. |

* Excluding land acquisition cost.

Not one option is applicable or suitable for all the dikes. Selecting a method for each dike depends on various parameters, such as the hydraulic characteristics of flow at the location, the morphology of the river, and the distance between the dike and the riverbank.

The dikes with risk ratings of Very High and High are categorized into three groups as follows:

- **Group 1:** Dikes in this group exhibit little or no setback. There is no development or significant constraints behind the dike and a setback dike is a possible option. A span of 6.16 km of the dikes, including 1.69 km of LKB dikes, are included in this group;
- **Group 2:** Dikes in this group exhibit little or no setback. Challenging location for a setback dike due to some developments behind the dike. Also, 0.4 km of the dikes are included in this group;
- **Group 3:** There is enough setback between the dike and riverbank to restore riparian habitat without moving the dikes. As well as 5.65 km of the dikes are included in this group.

The list of the dikes that fit in each group is shown in Table 5.4, and the multicriteria analysis for the dikes in each group is presented in Table 5.5 to Table 5.7.

**Table 5.4 Group Categories for Dikes with Risk Ratings of Very High and High**

| GROUP | DIKE NO. | DIKING AUTHORITY | LOCATION (km)* - RISK RATING |
|---|---|---|---|
| 1 | 266 | Reclamation Farm Diking District | 16.02 to 16.68 - High |
| | 142 | Nick's Island Diking District | 20.6 to 20.9 - High<br>24.05 to 24.39 - High |
| | 120 | Creston Diking District | 16.55 to 17.03 (LKB-IR1C) - Very High<br>17.03 to 17.45 (LKB-IR1C) - High<br>17.45 to 17.57 (LKB-IR1C) – Very High<br>17.57 to 17.95 – Very High<br>20.02 to 20.75 (LKB-IR1C) – Very High<br>24.44 to 24.51 – High |
| | 37 | Creston Diking District | 18.3 to 18.36 - High<br>20.75 to 20.84 (LKB-IR1C) – Very High<br>20.84 to 21.95 – Very High<br>26.67 to 27.1 – High<br>27.1 to 27.25 – Very High<br>27.25 to 27.65 - High |
| | 48 | Duck Lake Diking District | 28.05 to 28.2 - High |
| | 120 | Duck Lake Diking District | 30.93 to 31.2 (LKB-IR5) – Very High |
| 2 | 37 | Creston Diking District | 18.50 to 18.68 – High |
| | 120 | Nick's Island Diking District | 24.78 to 25 - High |
| 3 | 266 | Reclamation Farm Diking District | 4.36 to 6.5 – High<br>9 to 9.85 - High<br>12.45 to 12.95 - High<br>13.83 to 14.1 – High<br>16.68 to 17.07 – High<br>17.07 to 17.83 – Very High |
| | 37 | Creston Diking District | 18.68 to 19.1 – High<br>26.55 to 26.67 – High |
| | 120 | Creston Diking District | 24.75 to 24.95 (LKB-IR3)- High |

* Map A-1, A-2 (Appendix A).

**Table 5.5 Multicriteria Analysis for Dikes in Group 1**

| DIKE STABILIZATION OPTION | TECHNICAL EFFICIENCY/ RELEVANCE | LIFESPAN | IMPLEMENTATION / CONSTRUCTION | COST* | MAINTENANCE | PERMITTING | ENVIRONMENTAL IMPACT | TOTAL SCORE |
|---|---|---|---|---|---|---|---|---|
| Riprap | 5 | 5 | 5 | 3 | 5 | 2 | 2 | 27 |
| Vegetated Riprap | 4 (only trimmed grass is allowed on the dikes) | 5 | 5 | 3 | 4 (watering the vegetation until they establish) | 2 | 3 | 26 |
| Longitudinal Stone Toe with Bio-Engineering on Banks | 1 (only trimmed grass is allowed on the dikes) | 2 | 4 | 4 | 4 (watering the vegetation until they establish) | 2 | 4 | 21 |
| Setback Dike and Vegetation Buffer Zones | 5 (assuming enough setback) | 4 (becomes ineffective once the river reaches the dike) | 2 (Landowners might not be willing) | 3 | 5 | 5 | 5 | 29 |
| Spur (Vane) Dike | 2 (mostly suitable for shallow streams, it might cause erosion on the opposite bank) | 3 | 2 (work in the deep sections of the river) | 4 | 3 (needs regular monitoring) | 2 | 4 | 20 |
| Large Woody Debris (LWD) | 1 (mostly suitable for alluvial channels, it causes erosion on the opposite bank) | 3 (5-15 years life cycle) | 2 (work in the deep sections of the river) | 5 | 4 (following the floods greater what they were designed for) | 3 | 5 | 23 |
| Retaining Wall | 5 | 4 | 1 (involves many heavy machinery works) | 1 | 2 | 1 | 1 (removal of natural conditional in the water and bank) | 15 |

* Excluding land acquisition cost.

**Table 5.6 Multicriteria Analysis for Dikes in Group 2**

| DIKE STABILIZATION OPTION | TECHNICAL EFFICIENCY/ RELEVANCE | LIFESPAN | IMPLEMENTATION / CONSTRUCTION | COST* | MAINTENANCE | PERMITTING | ENVIRONMENTAL IMPACT | TOTAL SCORE |
|---|---|---|---|---|---|---|---|---|
| Riprap | 5 | 5 | 5 | 3 | 5 | 2 | 2 | 27 |
| Vegetated Riprap | 4 (only trimmed grass is allowed on the dikes) | 5 | 5 | 3 | 4 (watering the vegetation until they establish) | 2 | 3 | 26 |
| Longitudinal Stone Toe with Bio-Engineering on Banks | 1 (only trimmed grass is allowed on the dikes) | 2 | 4 | 4 | 4 (watering the vegetation until they establish) | 2 | 4 | 21 |
| Setback Dike and Vegetation Buffer Zones | 3 (assuming that enough setback is not possible due to existing structures behind the dike) | 4 (might become ineffective once the river reaches the dike) | 1 | 3 | 5 | 5 | 5 | 26 |
| Spur (Vane) Dike | 2 (mostly suitable for shallow streams, it might cause erosion on the opposite bank) | 5 | 2 (work in the deep sections of the river) | 4 | 3 (needs regular monitoring) | 2 | 4 | 22 |
| Large Woody Debris (LWD) | 1 (mostly suitable for alluvial channels, it causes erosion on the opposite bank) | 3 (5-15 years life cycle) | 2 (work in the deep sections of the river) | 5 | 4 (following the floods greater what they were designed for) | 3 | 5 | 23 |
| Retaining Wall | 5 | 4 | 3 (needs heavy machinery works) | 1 | 2 | 1 | 1 (removal of natural conditional in the water and bank) | 17 |

* Excluding land acquisition cost.

**Table 5.7 Multicriteria Analysis for Dikes in Group 3**

| DIKE STABILIZATION OPTION | TECHNICAL EFFICIENCY/ RELEVANCE | LIFESPAN | IMPLEMENTATION / CONSTRUCTION | COST* | MAINTENANCE | PERMITTING | ENVIRONMENTAL IMPACT | TOTAL SCORE |
|---|---|---|---|---|---|---|---|---|
| Riprap | 5 | 5 | 5 | 3 | 5 | 2 | 2 | 27 |
| Vegetated Riprap | 5 | 5 | 5 | 3 | 4 (watering the vegetation until they establish) | 2 | 3 | 27 |
| Longitudinal Stone Toe with Bio-Engineering on Banks | 3 (not so efficient above the vegetation and in case vegetation are dead or washed away) | 2 | 4 (challenges with the required excavation shape and planting) | 4 | 4 (watering the vegetation until they establish) | 2 | 4 | 23 |
| Setback Dike and Vegetation Buffer Zones | 2 (there is already a setback) | 4 (might become ineffective once the river reaches the dike) | 2 | 3 | 5 | 5 | 4 (the existing setback dike is already environmentally effective if it is vegetated) | 25 |
| Spur (Vane) Dike | 2 (mostly suitable for shallow streams, it might cause erosion on the opposite bank) | 5 | 2 (work in the deep sections of the river) | 4 | 3 (needs regular monitoring) | 2 | 4 | 22 |
| Large Woody Debris (LWD) | 1 (mostly suitable for alluvial channels, it causes erosion on the opposite bank) | 3 (5-15 years life cycle) | 2 (work in the deep sections of the river) | 5 | 4 (following the floods greater what they were designed for) | 3 | 5 | 23 |
| Retaining Wall | 5 | 4 | 3 (needs many heavy machinery works) | 1 | 2 | 1 | 1 (removal of natural conditional in the water and bank) | 17 |

* Excluding land acquisition cost.

As the total scores in Table 5.5 show, the most appropriate options for the dikes in Group 1 are riprap protection on the riverside of the dike and setback dikes. Figure 5.1 and Figure 5.2 show the typical cross-section of these two options. According to the Bank Stabilization Design Guidelines (U.S. Department of Interior, 2015), stabilization techniques preserving the floodplain, such as setback dikes, are the most preferred options since it reconnects and expands the floodplain and maintains sediment continuity. However, the choice between typical riprap protection and setback dikes depends on the available budget and the inclination of the landowners to change the land use of their property.

Based on the total scores in Table 5.6 and Table 5.7, the most appropriate option is riprap protection on the riverside of the dike for the dikes in Group 2 (Figure 5.1). For dikes in Group 3, the total score of riprap and vegetated riprap is the same. However, vegetated riprap protection on the riverbank is preferred since it provides more environmental benefits (Figure 5.4).

Longitudinal stone toe with bio-engineering on banks, spur dikes, large woody debris, and retaining walls were not retained for any of the dikes mainly because longitudinal stone toe with bio-engineering on banks loses its efficiency significantly if the vegetation dies or gets washed away. Spur dikes and large woody debris are mostly recommended for shallow waters, and retaining walls are not environmentally and economically desirable.

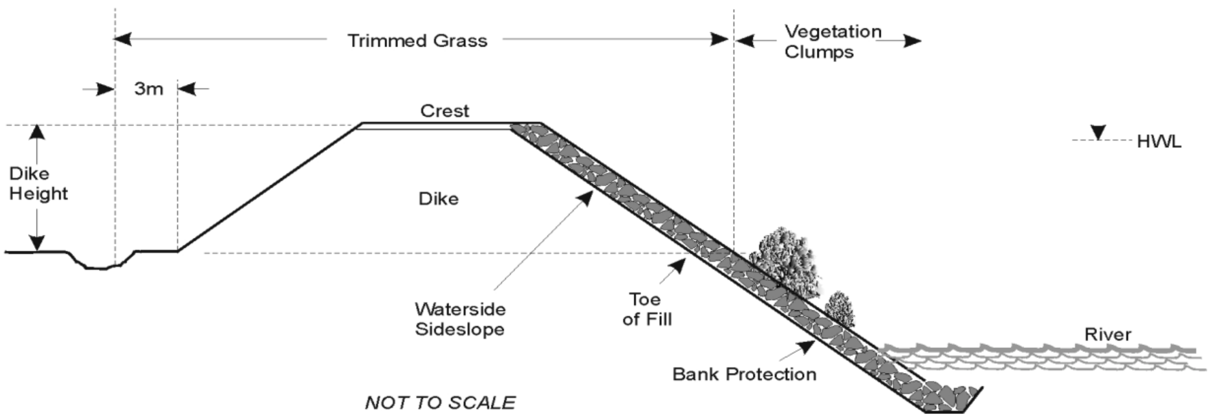



**Figure 5.1 Typical Cross-Section of Riprap Protection for Riverside of the Dikes**

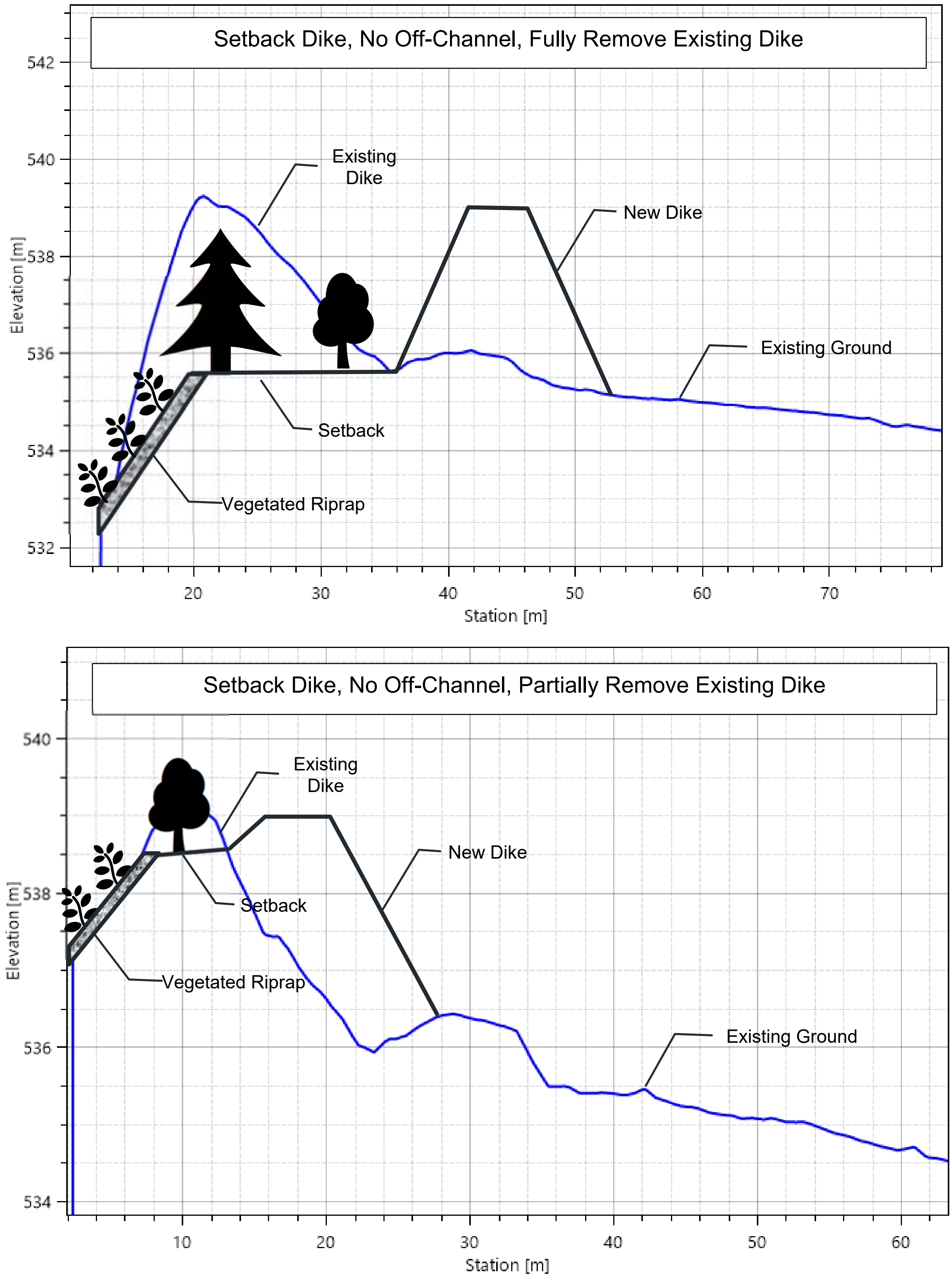



**Figure 5.2 Typical Cross-Section of a Setback Dike – No Off-Channel**

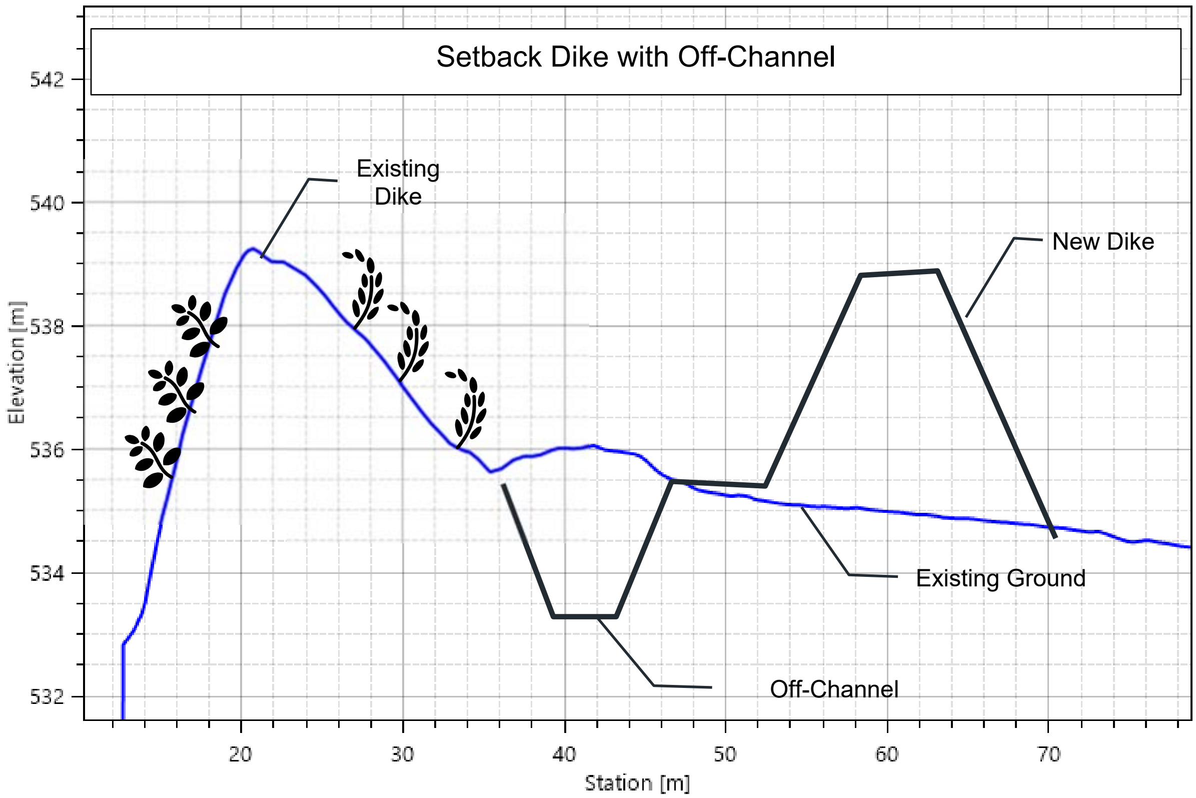



**Figure 5.3 Typical Cross-Section of a Setback Dike – With Off-Channel**

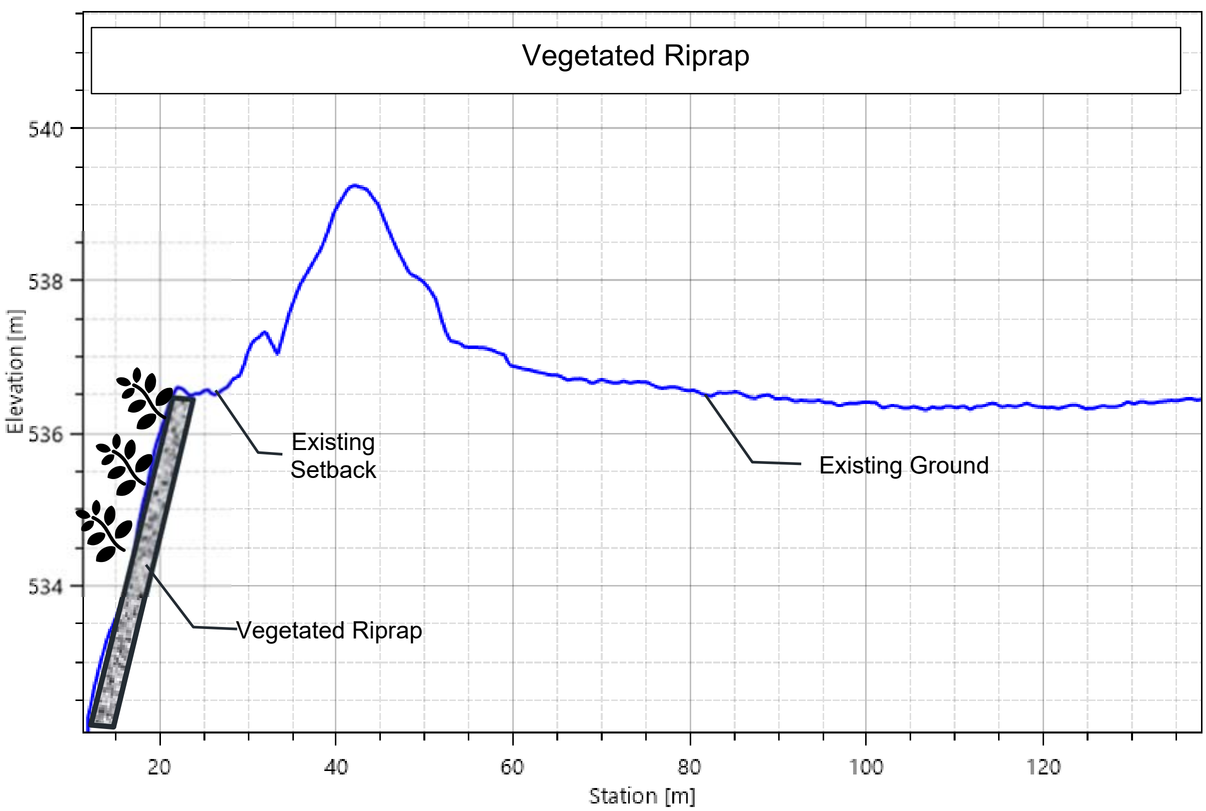



**Figure 5.4 Typical Cross-Section of Vegetated Riprap Protection for Riverbank at the Dikes**

# 6 COST ESTIMATE

This section provides a high-level (Class D) cost estimate for the four options of riprap, vegetated riprap, setback dike without side channel, and setback dike with side channel selected in Section 5.2 as the most appropriate options for the dikes with High and Very High hazard ratings. Also, the cost of regular dike maintenance, including vegetation control, dike inspection, and dike survey for the dikes with risk ratings of Moderate and Low, is provided in this section. Similar dike maintenance should be applied to dikes with High and Very High hazard ratings after implementing the proposed dike stabilization options.

The cost estimates are calculated assuming that:

— The riprap design characteristics are as follows: Class 50 kg ($D_{50}$ = 340 mm) riprap with a thickness of 550 mm and an average height of 9 m (5 m dike and 4 m river bank) on the riverside of the dike. The length of the riprap at the toe of the bank is 2 m. These characteristics shall be refined during the detailed design. It should be noted that regulatory agencies might reject toe stabilisation methods within the riverbed, such as rock key or apron, but for the purpose of these cost estimates, they were included in the calculations;

— For vegetated riprap, the vegetation applies to 2 m of the slope height (2 m out of the 4 m riverbank);

— The setback in the setback dike option is 20 m, on average, when there is no side channel and about 34 m when there is a side channel. This number might change from one location to another depending on the agreements with the landowner and the detailed design;

— For the setback dike, the old dike to be removed is, on average, 5 m high and 4 m wide at the top, with a 2H:1V side slope. Similar characteristics are assumed for the new dike. It is assumed that the old dike will not be removed for the setback dike with the side channel;

— For the setback dike with an off channel, the channel depth is 2 m, and the bottom width is 2 m, on average, with a 2H:1V side slope. The depth of gravel bedding is 0.3 m;

— The setback dike would be applied to the dikes in Group 1 assuming the landowners will accept and facilitate their implementation. Setback dikes could be replaced by riprap if budgetary constraints arise;

— For the setback dike, the riprap design characteristics at the river back are as follows: Class 50 kg riprap with a thickness of 550 mm on the riverbank and its toe. These characteristics shall be refined during the detailed design;

— When the proposed option involves vegetation planting, they should be regularly watered until they establish;

— All the quantities used for the cost estimate shall be refined during the detailed design;

— The engineering works, including detailed design and regulatory approval, are 15% of the construction cost and environmental protection are 10% of the cost for in-water works.

Table 6.1 and Table 6.2 shows the cost estimates for the recommended options for the dikes with a hazard rating of Very High and High, respectively. The cost estimate for the dike maintenance for the dikes with a hazard rating of Low and higher is tabulated in Table 6.3. The cost estimate for special inspections (explained in Section 7.6) is not included.

### Table 6.1 High-Level Cost Estimate for the Recommended Options for the Dikes with Hazard Rating of Very High

| OPTION | COST PER METER (CND) | TOTAL LENGTH (KM) | TOTAL COST (CND)* |
|---|---|---|---|
| Riprap (Group 1) | 2,300 | 0 | - |
| Riprap (Group 2) | 2,300 | 0 | - |
| Vegetated riprap (Group 3) | 2,800 | 0.76 | 2,128,000 |
| Setback dike – No side channel (Group 1) | 2,800 | 1.67 | 4,676,000 |
| Setback dike – With side channel (Group 1) | 3,000 | 1.67 | 5,010,000 |
| Total cost (excluding tax) | - | 4.09 | 11,814,000 |
| Contingency (25%) | - | - | 2,953,500 |
| GST (5 %) - rounded | - | - | 738,400 |
| Total- rounded | - | 4.09 | 15,505,900 |

* Numbers are rounded up.

### Table 6.2 High-Level Cost Estimate for the Recommended Options for the Dikes with Hazard Rating of High

| OPTION | COST PER METER (CND) | TOTAL LENGTH (KM) | TOTAL COST (CND)* |
|---|---|---|---|
| Riprap (Group 1) | 2,300 | 0 | - |
| Riprap (Group 2) | 2,300 | 0.40 | 920,000 |
| Vegetated riprap (Group 3) | 2,800 | 4.89 | 13,692,000 |
| Setback dike – No side channel (Group 1) | 2,800 | 1.42 | 3,976,000 |
| Setback dike – With side channel (Group 1) | 3,000 | 1.42 | 4,260,000 |
| Total cost (excluding tax) | - | 8.12 | 22,848,000 |
| Contingency (25%) | - | - | 5,712,000 |
| GST (5 %)- rounded | - | - | 1,428,000 |
| Total- rounded | - | - | 29,988,000 |

* Numbers are rounded up.

### Table 6.3 High-Level Cost Estimate for Dike Maintenance Activities

| OPTION | REQUIRED WORK | AVERAGE ANNUAL TOTAL COST (CND) |
|---|---|---|
| Dike maintenance | Vegetation control | 35,000 (Annual Work) |
| | Dike and appurtenances inspection | 15,000 (Annual Work) |
| | Cattle fencing | 5,000 (Annual Work) |
| | Dike topographic survey | 50,000* (Every 5-10 years) |
| Average Annual Cost for appropriate action in case of any problem (Section 7.6) | | 30,000 |
| Estimated cost (excluding tax) | | 85,000 |
| Contingency (25%) | | 106,300 |
| GST (5%) | | 5,300 |
| Total cost (including tax) | | 111,600 |

* Excluded from the total cost since the province has historically conducted topographic surveys of regulated dikes.

# 7 STRATEGIC PLAN

The analysis findings from Stages 1 (WSP, 2022) and 2 (current study) are used to develop a Strategic Plan for the next 10 years. This Strategic Plan is the final outcome of the current project, but it is also a start for a series of actions that should be taken to achieve the final goal of flood risk mitigation in the study area. The scope of work, description of actions to be taken, and recommended timelines for each task are provided below.

## 7.1 STAKEHOLDER AGREEMENT

The first step to proceed is to make sure that the proposed plan in this report is clear to all stakeholders, they agree with the plan, and are ready to contribute and cooperate where needed.

WSP has collected feedback from the stakeholders throughout the project and tried to reflect them in the developed Strategic Plan. We also solicited feedback on recommended actions from the stakeholders.

Although the Town will be primarily responsible for implementing the Strategic Plan, a collaboration between the Town, residents and regional stakeholders will be crucial for successful implementation. Some actions can be taken by landowners, and some require their consent and inclination.

**RECOMMENDED TIMELINE**

— Continuous effort.

## 7.2 FUNDING

The outcome of this report can be used to apply for available governmental funds. Some of the potential sources of funding currently open are shown in Table 7.1. The committee responsible of implementing the strategic plan should actively find the available source of government funds and apply for them where applicable.

**RECOMMENDED TIMELINE**

— Continuous. The available fundings are usually limited and must be spent in a limited time. Therefore, the client should keep applying for funding for the following years.

**Table 7.1 Available Fundings**

| PROGRAM | PROJECT ELIGIBILITY | ELIGIBLE APPLICANT | MAX FUND | MORE INFORMATION |
|---|---|---|---|---|
| UBCM Disaster Risk Reduction-Climate Adaptation | – A new project (retroactive funding is not available) or a subsequent phase of a DRR-CA related project;<br>– Located on publicly owned land or First Nations land;<br>– Capable of completion by the applicant within two years from the date of grant approval;<br>– Inclusive of engagement with impacted and affected parties, including First Nations, local governments, and equity-denied populations;<br>– Able to show that climate change is integrated into project methodology and deliverables to adapt to the impacts of climate change. While a range of scenarios are recommended, at a minimum the use of Emissions Scenarios RCP 8.5 or SSP5_8.5. Structural projects should use scenarios (or equivalent amount of global warming) appropriate for the design life. | All local governments (municipalities and regional districts) and all First Nations (bands and Treaty First Nations) in BC can submit one application per intake, including regional applications or participation as a partnering applicant in a regional application. | The combined total is limited to $2.3 million:<br>– Category 1 (Foundational Activities): $150,000;<br>– Category 2 (Non-Structural Activities): $150,000;<br>– Category 3 (Small-Scale Structural Activities): $2 million. | https://www.ubcm.ca/cepf/disaster-risk-reduction-climate-adaptation |
| Green Infrastructure: Adaptation, Resilience and Disaster Mitigation Sub-Stream | A proposal will be deemed eligible if the project:<br>– A new project (retroactive funding is not available) or a subsequent phase of a DRR-CA related project;<br>– Is a new project (retroactive funding is not available);<br>– Builds, modifies or reinforces public infrastructure (including natural infrastructure) to prevent, mitigate or protect against floods and flood-related hazards;<br>– Starts by October 7, 2024 and is completed by March 31, 2027. | Indigenous recipients, municipalities and regional districts. | Up to $10 million for individual communities and $20 million for joint proposals submitted by two or more neighbouring communities, for their flood mitigation project. Cost-sharing system between the applicant, federal government and the provincial government. | https://www2.gov.bc.ca/gov/content/safety/emergency-management/local-emergency-programs/financial/ardmp |
| Disaster Mitigation and Adaptation Fund | New construction of public infrastructure and/or modification or reinforcement of existing public infrastructure including natural infrastructure that prevents, mitigates or protects against the impacts of climate change, disasters triggered by natural hazards, and extreme weather. | – A municipal or regional government established by – or under –provincial or territorial statute;<br>– An Indigenous governing body including, but not limited to:<br>a. A band council within the meaning of Section 2 of the Indian Act;<br>b. A First Nation, Inuit or Métis government or authority established pursuant to a Self-Government Agreement or a Comprehensive Land Claim Agreement between Her Majesty the Queen in right of Canada and an Indigenous Peoples of Canada, that has been approved, given effect and declared valid by federal legislation; or<br>c. A First Nation, Inuit or Métis government that is established by or under legislation whether federal, provincial or territorial legislation that incorporates a governance structure.<br>– An Indigenous Development Corporation; and<br>– A not-for-profit organization whose central mandate is to improve Indigenous outcomes.<br>Eligible projects could include bundled sub-projects if it is demonstrated that each of the multiple mitigation/adaptation investments work systematically as a whole to reduce the same risk within the same time period. | $1 Million to $20 Million for small-scale projects, and $20 Million + for large-scale projects, maximum federal contribution is 40% for municipalities. | https://www.infrastructure.gc.ca/dmaf-faac/applicant-guide-demandeur-eng.html#_Toc77262269 |
| Nature Smart Climate Solutions | The portion of the Nature Smart Climate Solutions Fund administered by ECCC is a ten-year fund focused on reducing greenhouse gas emissions using natural climate solutions, which also support human well-being and biodiversity. This fund is intended to support projects which focus on conserving, restoring, and enhancing wetlands, peatlands and grasslands to store and capture carbon. The 2021 application process included three streams:<br>– Place-based actions stream (focused on restoration projects and enhanced land management activities and/or projects that prevent GHG emissions from degradation/loss of carbon-rich habitat);<br>– Sector-based policy stream (focused on advancing policies, programs, and tools to support nature-based solutions); and<br>– Reverse auction pilot stream (piloting a reverse auction for agricultural land to reduce GHG emissions or increase carbon sequestration). | – Provinces, territories, Indigenous organizations, governments and groups, municipal and local governments, not-for-profit organizations, academic institutions, Canadian individuals, domestic or international for-profit organizations, local organizations. | Total budget of $1.4 billion, over ten years. Funding limit for individual projects is uncertain. | https://www.canada.ca/en/environment-climate-change/services/environmental-funding/programs/nature-smart-climate-solutions-fund.html |

# 7.3 DETAILED DESIGN

An eligible engineering team shall be hired to prepare detailed designs of the proposed risk reduction options for the dike with a risk rating of High and Very High. The detailed design may involve survey, hydraulic, structural, geotechnical, and environmental services. The summary of recommended options to be designed is shown in Table 7.2.

Designing should be done based on the priority shown in Table 7.2. Dikes with a hazard rating of Very High have the highest priority for construction (Priority 1 in Table 7.2), and dikes with a hazard rating of High have second priority for construction (Priority 2 in Table 7.2). For the dikes with the same priority, a sub-priority is defined in Table 3.1. The designing team is advised to start from the top of this list in Table 3.1 and follow the defined sub-priority order to address the dikes' issues based on their priority.

**Table 7.2 Summary of the Recommended Options**

| GROUP | DIKE NO. | DIKING AUTHORITY | LOCATION (KM) | CONSTRUCTION PRIORITY | RECOMMENDED RISK REDUCTION OPTION |
|---|---|---|---|---|---|
| 1 | 266 | Reclamation Farm Diking District | 16.02 to 16.68 | 2 | Setback dike |
| | 142 | Nick's Island Diking District | 20.6 to 20.9<br>24.05 to 24.39 | 2<br>2 | |
| | 120 | Creston Diking District | 16.55 to 17.03 (LKB-IR1C)<br>17.03 to 17.45 (LKB-IR1C)<br>17.45 to 17.57 (LKB-IR1C)<br>17.57 to 17.95<br>20.02 to 20.75 (LKB-IR1C)<br>24.44 to 24.51 | 1<br>2<br>1<br>2<br>1<br>2 | |
| | 37 | Creston Diking District | 18.3 to 18.36<br>20.75 to 20.84 (LKB-IR1C)<br>20.84 to 21.95<br>26.67 to 27.1<br>27.1 to 27.25<br>27.25 to 27.65 | 2<br>1<br>2<br>2<br>1<br>2 | |
| | 48 | Duck Lake Diking District | 28.05 to 28.2 | 2 | |
| | 120 | Duck Lake Diking District | 30.93 to 31.2 (LKB-IR5) | 2 | |
| 2 | 37 | Creston Diking District | 18.5 to 18.68 | 2 | Riprap |
| | 120 | Nick's Island Diking District | 24.78 to 25 | 2 | |
| 3 | 266 | Reclamation Farm Diking District | 4.36 to 6.5<br>9 to 9.85<br>12.45 to 12.95<br>13.83 to 14.1<br>16.68 to 17.07<br>17.07 to 17.83 | 2<br>2<br>2<br>2<br>2<br>1 | Vegetated riprap |
| | 37 | Creston Diking District | 18.68 to 19.1<br>26.55 to 26.67 | 2<br>2 | |
| | 120 | Creston Diking District | 24.75 to 24.95 | 2 | |

The following considerations are recommended for the detailed design:

- The bank protection work should be uniform and form a smooth transition into the natural bank at the upstream and downstream ends of the works;
- The riprap blanket should be designed considering the minimum and maximum expected water levels at the location of concern;
- Generally, dike slopes without seepage control measures shall be no steeper than 3H:1V, and with adequate seepage control, no steeper than 2H:1V. For the waterside slope, the slopes shall be no steeper than 2.5H:1V; unless it is equipped with erosion control, then it may be steepened to 2H:1V. Dikes with heights between 2 m and 3.5 m shall be sloped at 3H:1V, or flatter, even under the most favorable conditions. Higher dikes require further analyses (BC MWLA, 2003);
- For dikes higher than 2 m, or when the adequacy of available embankment materials or foundation conditions is concerning, dike embankment design requires detailed analysis (BC MWLA, 2003);
- No new planting of trees or shrubs is to be undertaken on the dikes without the written approval of the Inspector of Dikes (IOD) (BC MWLA, 2003);
- The setback strip in the setback dike option should be flat with no downward slope toward the dike;
- The flow characteristics and stream morphology should be considered to define the setback strip's width.

**RECOMMENDED TIMELINE**

- Hire the designing engineering team after receiving funding approval (approximately in the fourth quarter of 2023).
- Completing the detailed design of the proposed option is a continuous work that must be done upon the availability of funds until all the dikes with hazard ratings of Very High and High are updated. For the purpose of this planning, it is assumed that the detailed design could be completed each year for the following year's construction or upon the availability of the required fund.

## 7.4 APPROVALS

The required regulatory approval and permitting should be identified during the detailed design. The process of acquiring approvals and permitting should be started as soon as the detailed design is complete.

**RECOMMENDED TIMELINE**

- Obtaining regulatory approvals is a continuous work that has to be done following a detailed design. For the purpose of this planning, it is assumed that the approvals could be obtained each year for the following year's construction.

## 7.5 CONSTRUCTION

Construction should be done based on the priority shown in Table 7.2, but it can proceed in parallel at more than one location.

### RECOMMENDED TIMELINE

- Start the construction in 2025 for the dikes with a risk rating of Very High and aim to finish it by the end of the year 2033 (on average, 0.45 km or less than 1.7 million dollars of design and construction per year).
- With a construction pace of 0.45 km per year, updating the dikes with a risk rating of High could not start until 2034.

## 7.6 MAINTENANCE

For all the dikes, regular dike maintenance actions, including vegetation control, dike inspection, and dike survey, is recommended. These actions are explained below in more detail.

### VEGETATION CONTROL

Only trimmed grass shall be established on dike slopes to the toe of the dike fill to facilitate the inspection and future upgrades or repairs. Trimmed grass reduces surface erosion due to rain, currents, and waves.

Tree and shrub planting are not recommended on dike slopes. Trees affect dikes by root penetration, causing seepage and piping at high river levels, cracking, and loosening. Falling trees can take a large ball of soil from the dike slope leading to slope failure. Trees can also displace riprap bank protection, leading to holes where erosion and instability may occur. Trees, brush, and tall vegetation on dike slopes can displace riprap bank protection and obstruct the inspector's view to detect ongoing issues. No new planting of trees or shrubs is to be undertaken on the dikes without the written approval of the Inspector of Dikes (IOD) (BC MWLA, 2003).

Vegetation with a trunk/stem diameter greater than 300 mm shall be removed from an additional 2 m strip measured horizontally (BC MELP, 1999).

Figure 7.1 illustrates the vegetation control on overwidth dikes. Overwidth dikes are dikes with a minimum of 9 m crest width measured from the landside edge of the crest formed by roads or dikes constructed beside natural levees. On these dikes, vegetation can be kept on the side slopes of the dikes to maintain or enhance environmental values (BC MELP, 1999). The following considerations apply:

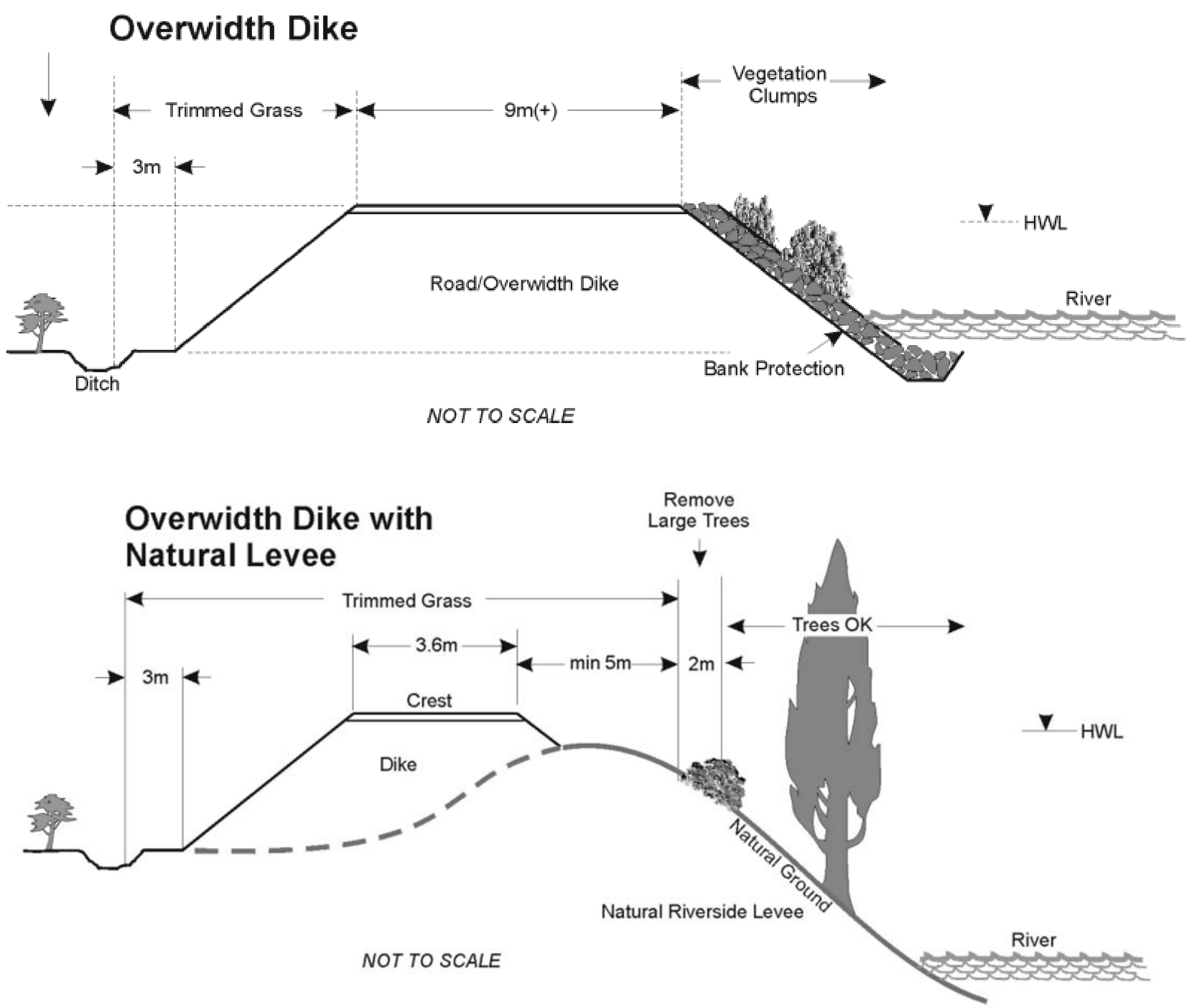
- As long as dike safety is not affected, trees may be retained on the side slopes of overwidth dikes without bank protection if they are spaced and pruned;
- Trees should be thinned, topped, or removed (especially if higher than 15 m);
- The lower 1.5 m of trees should be regularly pruned to maintain inspection possibility;

— Trees are not recommended in the freeboard range (0.6 m vertical) to facilitate possible emergency works;

— Natural riverbanks and overwidth dikes may contain clumps of controlled vegetation. “In sensitive habitat areas, consideration may be given to selective topping, pruning, thinning or stabilization of existing large vegetation provided the bank protection is not compromised" (BC MELP, 1999).

Dike maintenance activities might negatively impact the fish habitat if undertaken without the appropriate care. The Department of Fisheries and Oceans (DFO) requires "no net loss" of fish habitat, which may be achieved by relocation, redesign, and/or mitigation measures. If all measures are impossible or ineffective, fish habitat compensation may be considered an option. The setback dikes could be part of the compensation plan.

Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment Guideline (BC MELP, 1999) is the appropriate source for more vegetation control information.




*Source: BC MELP, 1999.*

**Figure 7.1 Vegetation Control for Overwidth Dikes**

### DIKE INSPECTION

A short description of dike inspection frequency and technique is provided below.

### INSPECTION FREQUENCY

Annual inspections: Annual inspections should be completed prior to the high-flow season. The inspection should be completed early enough to allow adequate time for any potential required work to be done before the flood season. The appurtenances of the flood protection system (such as the pumps, pump station, and flood box) may require more frequent checks to confirm the operationality of the system (BC MELP, 2001).

According to the Dike Operation and Maintenance Manual (BC MELP, 2001), the annual dike inspection shall be conducted to:

- Check crest, slopes, and toe for:
  - Settlement, depressions, sinkholes;
  - Cracking, slides, sloughing;
  - Erosion;
  - Seepage, piping, boils;
  - Loss of freeboard, low spots.
- Check for areas where vegetation hampers inspection and/or may weaken the dike;
- Look for rodent activity – paths and burrows. (Beavers can cause serious sinkholes. One or more inspections annually to be done at low water to include toe.);
- Check for unauthorized excavation or construction on or adjacent to the dike;
- Check river flow pattern for changes, deposition, scour, debris jams, etc.;
- Check the condition of scour or erosion around bridges or other structures in the vicinity.

Appropriate action must take place in case any problem is detected. For example, burrowing animals whose burrows are detrimental to dike stability shall be discouraged, and the holes and tunnels should be completely excavated and backfilled. The malfunctioning appurtenances of the flood protection system shall be fixed or replaced (such as replacing pumps if required) before the flooding season starts.

<u>Low water inspection</u>: A low water inspection should be conducted yearly during the annual low water level when the normally underwater infrastructures are exposed.

<u>High water patrol inspections:</u> High water patrol inspections should be carried out during high water events to check the performance of the flood control works and detect early signs of increased hydraulic pressure, increased potential for erosion of materials, and increased chance of reduced freeboard. The frequency of dike patrol should increase as flow and/or water levels approach critical conditions.

<u>Special inspections</u>: Special inspections may be needed to monitor and react to particular situations, such as storms, earthquakes, ice or debris jamming, significant sedimentation or degradation, reports of vandalism, or construction activity on or near the dike (BC MELP, 2001). After flood events, a post-flood inspection and evaluation should be undertaken to collect

information on the high water profile along the dike, new locations of log jams, streambed aggradation and degradation areas, weakened or damaged areas, and the condition of all appurtenant works. A post-earthquake inspection should be integrated with local emergency plans (BC MELP, 2000b).

### INSPECTION METHODS

The usual method of inspecting the dike fill is to walk along both crest edges and toes. The inspections are recommended to be conducted by a qualified professional engineer. The riverside toe of dikes adjacent to the stream may be done from a boat or using binoculars from across the river in the presence of erosion protection works (BC MELP, 2000b).

The appurtenant structures usually require hands-on inspection. A few examples are checking that locks work, pumps run properly, and flood box gates open fully and easily. It is recommended to keep a record of the location and photographs of the malfunctioning structures for future reference and obtain repair funds.

"Use the **SMPL** (pronounced Simple) rule for all inspection reporting: **S** (Sketch the deficiency and note its important characteristics), **M** (Measure the deficiency), **P** (Photograph the deficiency or describe its characteristics in writing), and **L** (Locate the deficiency relative to some standard point)," (BC MELP, 2000b).

Examples of inspection forms are provided in Section 6 (Field Guides for Inspection and Reporting) of the Flood Protection Works Inspection Guide (BC MELP, 2000b) and Appendix C of this report. The dike inspection forms should be well archived for future reference.

### DIKE SURVEY

A topographic survey of the crest of the dikes is recommended to be conducted periodically to ensure that the dikes' crest has not moved significantly and still provides sufficient freeboard.

### RECOMMENDED TIMELINE

Dike maintenance is an ongoing process:

- Vegetation control should be done based on an as-needed base;
- For the dikes with a risk rating of High and Very High, the inspection should start during construction and continue annually throughout its operation;
- Other dikes shall be inspected annually. Appropriate action must take place in case any issue is detected. Implementing the general risk reduction options should be considered if resources allow;
- Surveying the dike crest profile shall be completed every three to ten years.

**Table 7.3 Strategic Plan**

| Strategic Plan Development | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2023 | | 2024 | | 2025 | | 2026 | | 2027 | | 2028 | | 2029 | | 2030 | | 2031 | | 2032 | | 2033 | |
| Quarter | Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 | Q1, Q2 | Q3, Q4 |
| **Stakeholder Agreements** | | | | | | | | | | | | | | | | | | | | | | |
| | Finalize agreements with landowners and stakeholders | | | | | | | | | | | | | | | | | | | | | |
| **Funding** | | | | | | | | | | | | | | | | | | | | | | |
| | Apply for government funds | | | | | | | | | | | | | | | | | | | | | |
| **Detail Design** | | | | | | | | | | | | | | | | | | | | | | |
| | | Hire eligible design engineers | | | | | | | | | | | | | | | | | | | | |
| | | Detailed design | | | | | | | | | | | | | | | | | | | | |
| **Approvals** | | | | | | | | | | | | | | | | | | | | | | |
| | | | Obtain the regulatory approvals | | | | | | | | | | | | | | | | | | | |
| **Construction** | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Construction for berms with a hazard rating of Very High | | | | | | | | | | | | | | | | | |
| **Maintenance** | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | Watering the planted vegetation until established | | | | | | | | | | | | | | | | |
| | Vegetation control | | | | | | | | | | | | | | | | | | | | | |
| | Dike and appurtenances inspection at the recommended frequency | | | | | | | | | | | | | | | | | | | | | |
| | Dike survey at the recommended frequency | | | | | | | | | | | | | | | | | | | | | |

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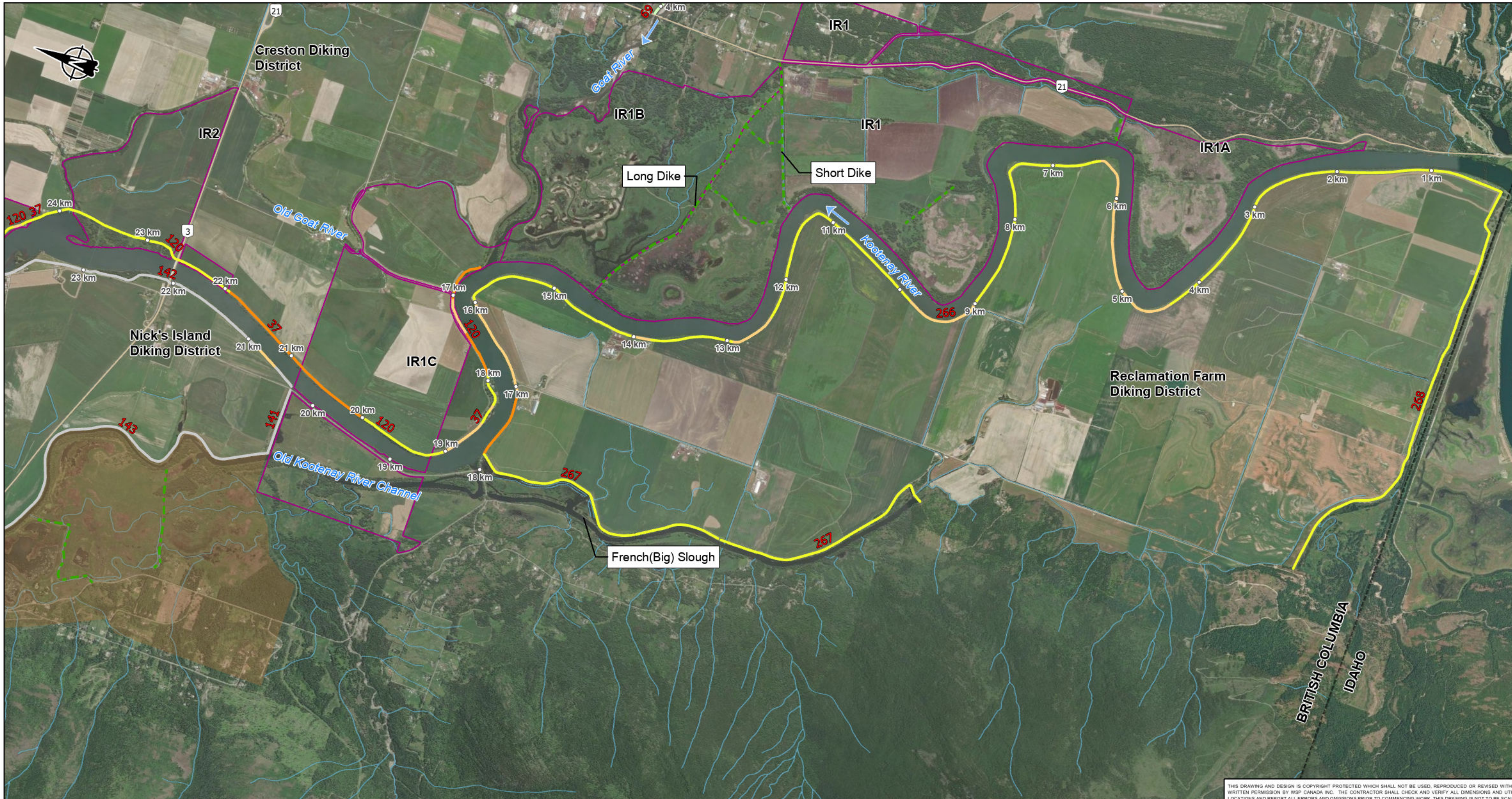
# APPENDIX

# A OVERVIEW MAPS



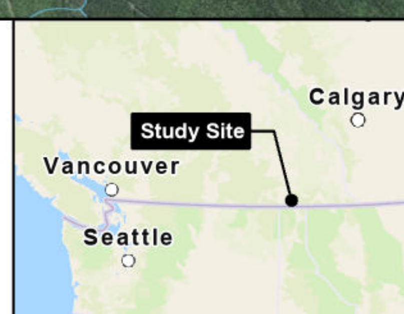



**Risk Rating**

- 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

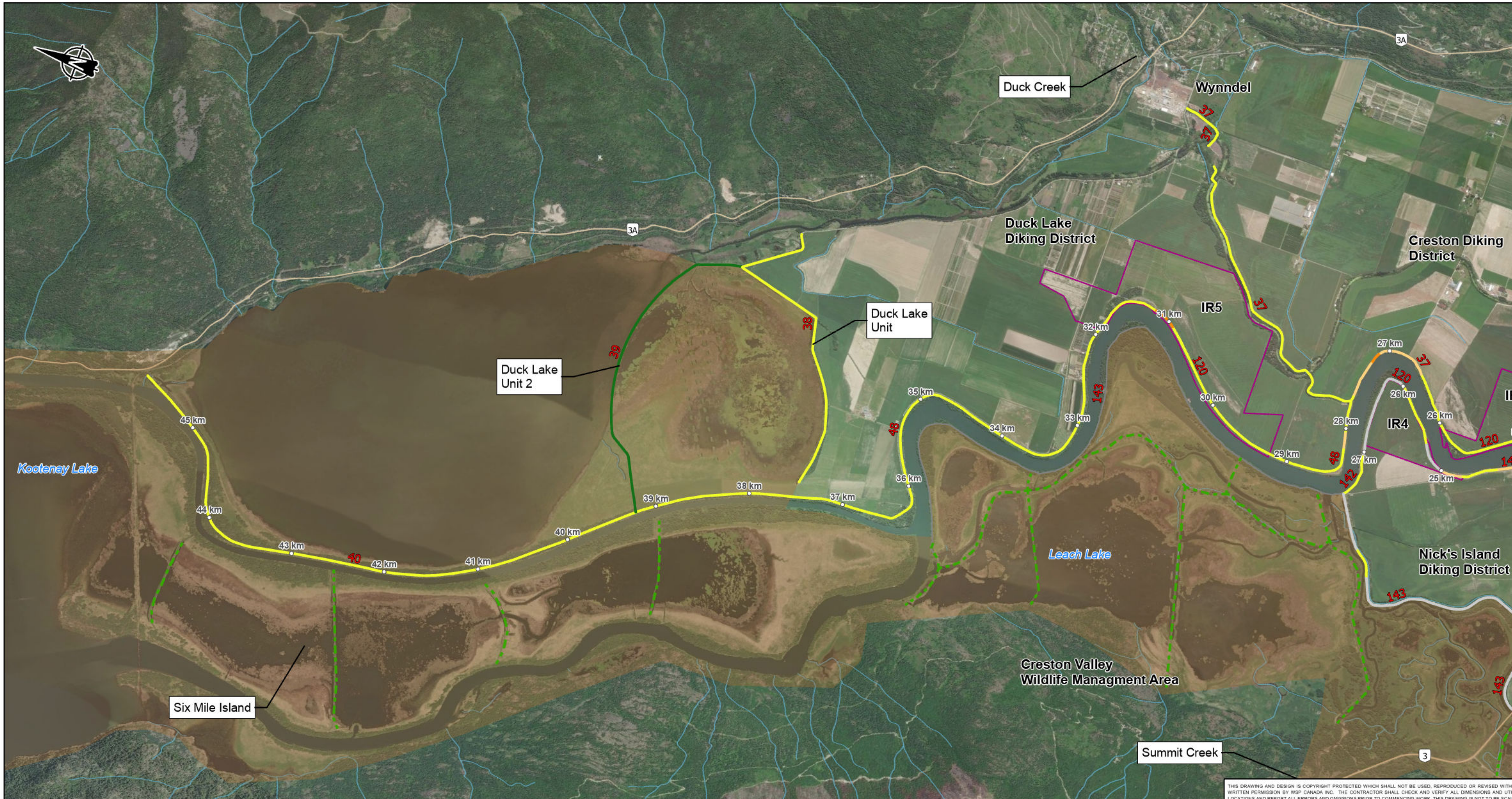
WSP CANADA INC.
SUITE 1000, 840 HOWE STREET
VANCOUVER, BC V6Z 2M1
PHONE: 604 685-9831 - FAX: 604 736-1519
WWW.WSP.COM

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 1:40,000 |
| 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
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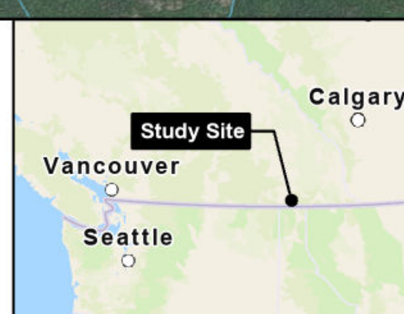


NOTES:
1. ALL UNITS IN METERS UNLESS NOTED OTHERWISE
2. COORDINATES SHOWN IN UTM NAD83 ZONE 11

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

0 400 800 1,200 1,600 m

wsp

WSP CANADA INC.
SUITE 1000, 840 HOWE STREET
VANCOUVER, BC V6Z 2M1
PHONE: 604 685-9831 - FAX: 604 736-1519
WWW.WSP.COM

| | |
|---|---|
| TITLE: | OVERVIEW MAP OF CRESTON VALLEY |
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| CLIENT: | TOWN OF CRESTON |

| | |
|---|---|
| DES. AH | DR. PAB |
| CH. AH | SCALE 1:40,000 |
| APP. VC | DATE FEB 2023 |
| DWG. NO. Map 2 | |
| FILE NO. 221-08591-00 | SHEET 2 OF 3 |

# APPENDIX

# B DIKE RISK ASSESSMENT SUMMARY

| 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<br><br>People: Major 4<br>Economy-Building: Moderate 3<br>Economy-Infrastructure: High 5<br>Environment: High 5<br>Culture: High 5 | Moderate, 18.3-18.92 | 11.13 / 24.27<br><br>Building: 4.05<br>Building Content: 4.74<br>Crops: 1.45<br>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<br><br>People: Major 4<br>Economy-Building: Moderate 3<br>Economy-Infrastructure: High 5<br>Environment: High 5<br>Culture: NA 0 | Moderate, 0.65-0.81 | 10.98 / 17.37<br><br>Building: 3.52<br>Building Content: 2.13<br>Crops: 4.32<br>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<br><br>Building: 0.80<br>Building Content: 0.63<br>Crops: 0.67<br>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<br><br>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)** | | Consequence of Failure | Hazard Rating |
| | | | | | | | Overtopping, 200-year Flood | Erosion | | |
| | | | | Economy-Building: Moderate 3<br>Economy-Infrastructure: Major 4<br>Environment: Major 4<br>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<br><br>People: Moderate 3<br>Economy-Building: Minor 2<br>Economy-Infrastructure: High 5<br>Environment: High 5<br>Culture: High 5 | - | 3.51 / 5.17<br><br>Building: 0.77<br>Building Content: 0.68<br>Crops: 0.66<br>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<br><br>People: Moderate 3<br>Economy-Building: Minor 2<br>Economy-Infrastructure: High 5<br>Environment: High 5<br>Culture: High 5 | - | - | - | Low | Major 4 | Moderate |
| 39 | Creston Valley Wildlife Management | 1971 | 4.6 | Insignificant 1<br><br>People: NA 0<br>Economy-Building: NA 0<br>Economy-Infrastructure: Moderate 3<br>Environment: High 5<br>Culture: NA 0 | - | - | - | Low | Insignificant 1 | Negligible |
| 40 | Creston Valley Wildlife Management | | 27.4 | Major 4<br><br>People: Moderate 3<br>Economy-Building: Moderate 3<br>Economy-Infrastructure: High 5<br>Environment: High 5<br>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*<br><br>People: Moderate 3<br>Economy-Building: Minor 2<br>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 | | 1960s-1970s | | Moderate 3*<br><br>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<br>Economy-Infrastructure: Moderate 3<br>Environment: Moderate 3<br>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)

# APPENDIX

# C FIELD INSPECTION AND REPORTING TEMPLATE

# 6. Field Guides for Inspection and Reporting

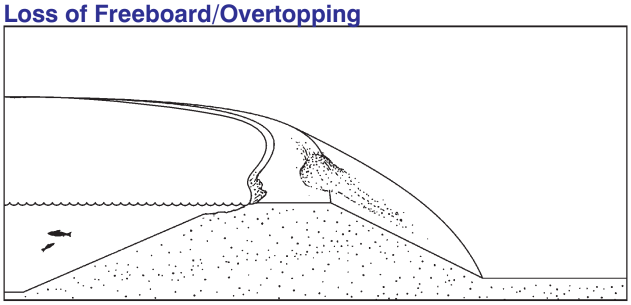
## 6.1 Flood Protection Works Basic Inspection Checklist

| Item❑ | Yes | No |
|---|---|---|
| **A) Pre-inspection activities** | | |
| 1. Review all safety requirements | ❑ | ❑ |
| 2. Ensure all necessary safety equipment is in place for the inspection | ❑ | ❑ |
| 3. Ensure safety check-in procedures are in place | ❑ | ❑ |
| 4. Review pertinent office materials such as plans, reports, previous inspections etc. | ❑ | ❑ |
| 5. Inform all necessary contacts (e.g. adjacent landowners) about when the inspection will take place and to ensure access | ❑ | ❑ |
| **B) Inspection of the dike** | | |
| Walk along both shoulders of the crest and record details and mark location of any of the following deficiencies: | | |
| 1. Check for loss of freeboard, recent high water marks and their relationship to the crest elevation | ❑ | ❑ |
| 2. Check for signs of settlement/depressions/sinkholes | ❑ | ❑ |
| 3. Check for signs of seepage/piping/boils | ❑ | ❑ |
| 4. Check for cracking | ❑ | ❑ |
| 5. Check for slides, sloughs, scarps and bulges | ❑ | ❑ |
| 6. Check for surface erosion (rutting, scars, tracks, water pools) | ❑ | ❑ |
| 7. Check for signs of unauthorized activity (construction, excavation, vandalism) | ❑ | ❑ |
| 8. Check for areas where vegetation hampers inspection | ❑ | ❑ |
| 9. Check for signs of rodent/beaver activity | ❑ | ❑ |
| Walk along the landside toe and where possible the riverside toe and record details and mark location of any of the following deficiencies: | | |
| 11. Check for changes in the river flow pattern, existence of log jams, gravel build up or scour holes | ❑ | ❑ |
| 12. Check for signs of seepage/ piping / boils | ❑ | ❑ |
| 13. Check for signs of toe bulges | ❑ | ❑ |

| Item | Yes | No |
|---|---|---|
| **C) Inspection of erosion protection works** | | |
| Choose the most efficient and safe method of inspection, i.e. vantage points, boat or from across the river using binoculars | | |
| 1. Look for evidence of toe scour | ❑ | ❑ |
| 2. Check for signs of weakness in the protective cover, i.e. riprap loss, unusually steep slopes, beaching, scarping | ❑ | ❑ |
| 3. Check for riprap material degrading (weathering) | ❑ | ❑ |
| 4. Check for bed degradation (e.g. riprap perched on a ledge) | ❑ | ❑ |
| 5. Check for indications of outflanking at the upstream end of the erosion protection works | ❑ | ❑ |
| 6. Check for changes in river flow patterns (log jams, gravel bars, and imminent problems etc.) | ❑ | ❑ |
| 7. Check for rock displacement due to ice, logs etc. | ❑ | ❑ |
| 8. Check for areas of reduced overbank - unprotected bank erosion | ❑ | ❑ |
| 9. Check for areas where vegetation hampers inspection | ❑ | ❑ |
| 10. Check for signs of rodent / beaver activity | ❑ | ❑ |
| **D) Inspection of appurtenant works** | | |
| 1. Check condition of access roads | ❑ | ❑ |
| 2. Check water level gauges for damage, elevation change, readability | ❑ | ❑ |
| 3. Check condition of floodboxes, operation of control gates, intakes and outlets | ❑ | ❑ |
| 4. Check for seepage at all interfaces between structures and dike fills | ❑ | ❑ |
| 5. Check pump station building for signs of deterioration, settlement, or vandalism. | ❑ | ❑ |
| 6. Check maintenance records of pumps | ❑ | ❑ |
| 7. Check condition of pump intake and outlets areas including trash racks for debris buildup, etc. | ❑ | ❑ |
| 8. Check condition of pump power source (fuel tanks, electrical transmission lines, etc.) | ❑ | ❑ |
| 9. Run pump(s) - check for excessive vibration, etc. | ❑ | ❑ |
| 10. Check condition of relief wells | ❑ | ❑ |
| 11. Check all concrete structures for signs of deterioration and/or settlement | ❑ | ❑ |
| 12. Check for areas where vegetation hampers inspection | ❑ | ❑ |
| 13. Check for signs of beaver activity at intakes to floodboxes and pump station | ❑ | ❑ |
| 14. Test switching | ❑ | ❑ |
| 15. Check alignment of floats and sensors | ❑ | ❑ |
| 16. Test operation of gates | ❑ | ❑ |

## 6.2 Guide for Identifying Problems in Dike Fill

### Loss of Freeboard/Overtopping

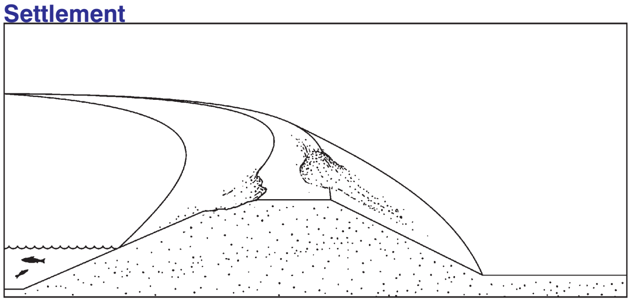

Loss of Freeboard/Overtopping

**Observation:**
- High water surface profile is within the freeboard allowance
- Evidence of slumps, sinkholes, slides

**Causes:**
- Aggradation of the channel bed
- Channel blockages; logs, ice, etc.
- Settlement of dike

**Concerns:**
- Reduced freeboard creating a potential for overtopping

### Settlement

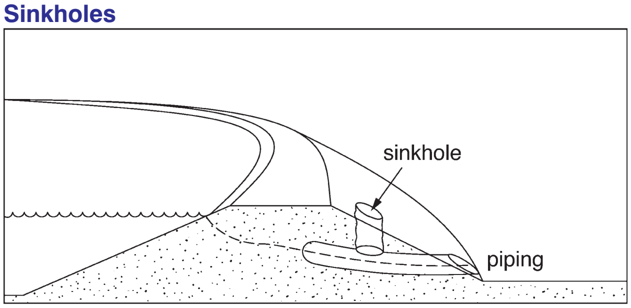

Settlement

**Observation:**
- Uneven surface of the crest or slopes
- Depressions with gently sloping bowl-like sides

**Causes:**
- Internal erosion of the embankment material
- Prolonged erosion from wind or water
- Poor construction practices, poorly compacted fill, organic material in fill
- Foundation consolidation

**Concerns:**
- Creates areas of structural weakness
- Loss of freeboard from settling can create the potential for overtopping

### Sinkholes



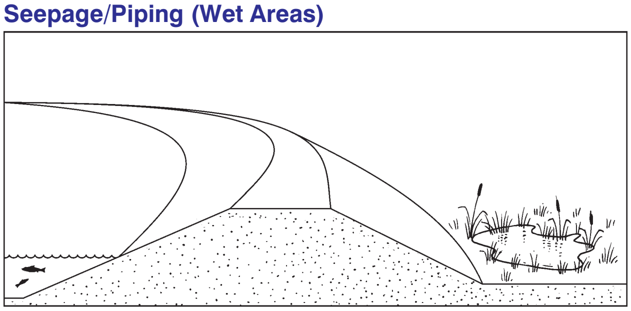
Sinkholes

**Observation:**
- Hole in the dike surface
- Depression with steep bucket-like sides

**Causes:**
- Animal burrows
- Internal erosion from seepage piping or a hole in a floodbox conduit
- Foundation problems such as rotting stumps or other wood debris

**Concerns:**
- Weakens the dike fill by decreasing the length of the seepage path
- Provides an entrance point for surface water
- Can pose a danger to vehicular and pedestrian traffic
- May signal collapse and/or instability

### Seepage/Piping (Wet Areas)

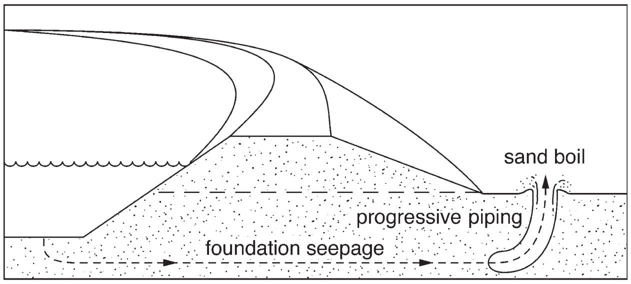

Seepage/Piping (Wet Areas)

**Observation:**
- Turbid (dirty) or cloudy seepage water
- Water or wet areas near the toe or on dike slope
- Localized or lush vegetation on dike slopes or adjacent to the dike
- Increase in seepage flow rates different from past patterns

**Causes:**
- Excessive flow of water through the dike fill or through the foundation material
- Surface water entering through cracks, sinkholes, animal burrows, along the outside surface of conduits

**Concerns:**
- May cause slope instability which can lead to failure
- Turbid (dirty) seepage water is an indication that piping may be occurring and may result in a piping failure of the foundation and ultimately the embankment

## Boils



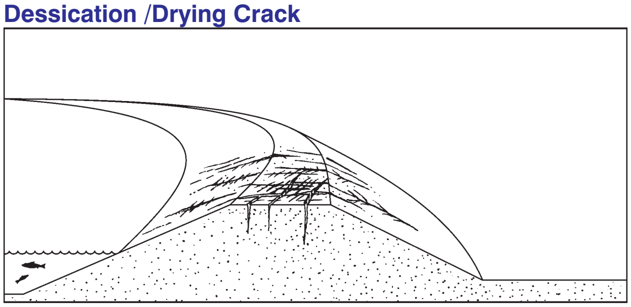

### Boils

**Observation:**
- Water upwelling on landside of dike, near toe or further away
- Upwelling may form cone-shaped ‘volcanoes’

**Causes:**
- A weak layer of sand or gravel in the foundation material is being charged by hydraulic pressure produced during high water conditions
- A concentrated seepage path or pipe has developed through the foundation

**Concern:**
- May be an early sign of piping

## Dessication /Drying Crack



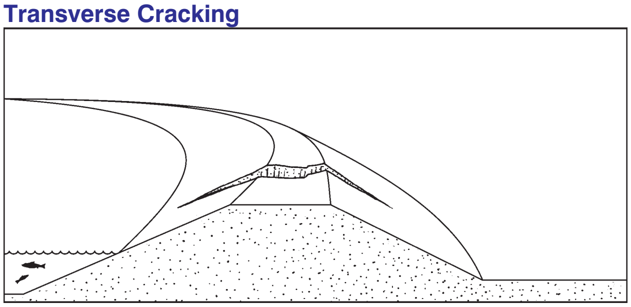
### Dessication/Drying Crack

**Observation:**
- Random, honeycomb pattern of cracks along the embankment

**Causes:**
- Embankment material expands and contracts with alternating wet and dry weather
- Embankment fill with high fines content and/or inadequate compaction

**Concerns:**
- Provides an entrance point for surface water which can saturate the crest material
- May affect durability of the crest in wet weather

## Transverse Cracking



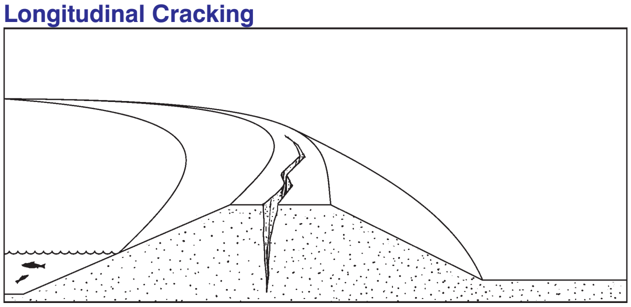
### Transverse Cracking

**Observation:**
- Cracks extend across the crest perpendicular to the dike length

**Causes:**
- Uneven movement between two adjacent segments of the embankment
- Instability of the embankment or foundation material
- Differential settlement

**Concerns:**
- Provides an entry point for surface water
- Creates an area of structural weakness which could result in further movements or failure
- May create a seepage path and/or a potential piping failure

## Longitudinal Cracking



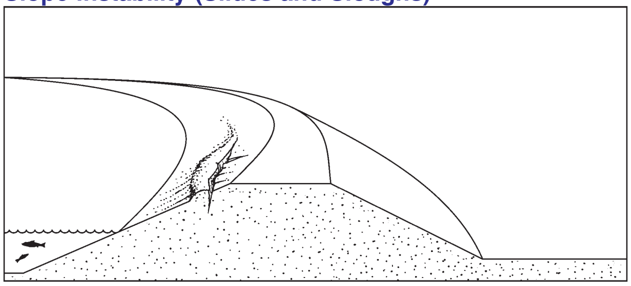
### Longitudinal Cracking

**Observation:**
- Cracks extend roughly parallel to the length of dike

**Causes:**
- Uneven settlement within the foundation or embankment
- Initial stage of a slope failure or embankment slide

**Concerns:**
- Possible instability
- Can lead to future movements or failure (breach)
- Provides an entry point for surface water which can promote movement
- Often reduces the effective crest width

Slope Instability (Slides and Sloughs)



## Slope Instability (Slides and Sloughs)

**Observation:**

- Displaced material on dike slope
- Bulges along the embankment slope or toe
- Area above the bulge shows cracking or scarps
- Excessive moisture or softness upon probing the bulge
- Arc-shaped crack (beginning of a slide)
- Evidence of settlement
- Slides (shallow or deep-seated)

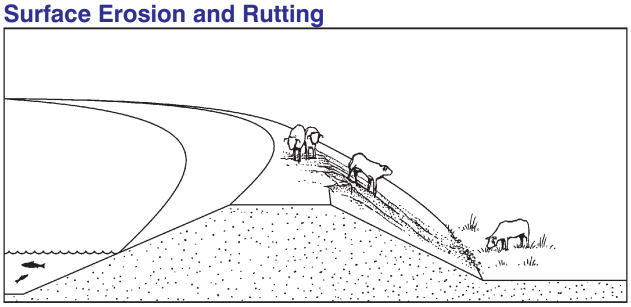
**Causes:**

- Ice action and wave erosion creating vertical slopes
- Steep slopes left unsupported by erosion
- Embankment fill becomes saturated during high water followed by a rapid drop in water levels
- Slope too steep for type of embankment material to allow free draining

**Concerns:**

- Direct threat to the integrity of the dike - possible breaching
- Provides an entry point for surface water which can promote movement
- Often reduces the effective crest width

Surface Erosion and Rutting



## Surface Erosion and Rutting

**Observation:**

- Evidence of material loss from dike surface
- Wheel tracks, animal tracks
- Scarring of dike surface
- Pooling of water on crest

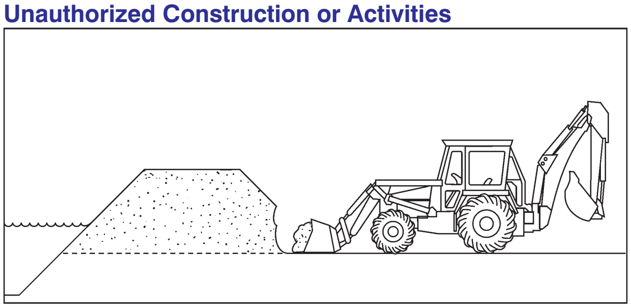
**Causes:**

- Livestock or human traffic
- Surface runoff over erodible material

**Concerns:**

- Encourages further erosion
- Can decrease cross-sectional width and weaken the embankment

Unauthorized Construction or Activities



## Unauthorized Construction or Activities

**Observation:**

- Embankment material disturbed or removed
- New ponds, holes or foundations dug close to the dike

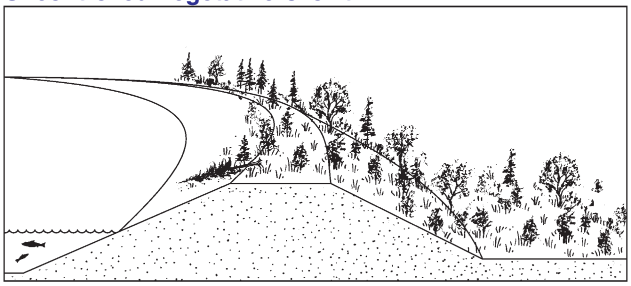
**Cause:**

- Uninformed or illegal construction practices

**Concerns:**

- Otherwise competent system can be compromised by a single unauthorized action
- Can block or hamper access
- Often hides defects such as poorly compacted fill around a newly placed or repaired conduit increasing the chance of seepage
- Can encourage boils or slumping and reduce top width
- Can encourage boils and failure from piping

### Uncontrolled Vegetative Growth



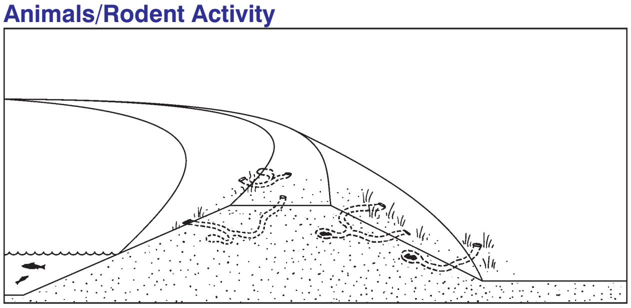
### Uncontrolled Vegetative Growth

**Observation:**
- Vegetation obscures ability to detect cracks, seepage or other problems

**Causes:**
- Lack of maintenance

**Concerns:**
- Root systems can provide seepage conduits
- Rotting root systems weaken the embankment
- May prevent emergency access
- Provides a habitat for unwanted burrowing animals
- Windthrow or uprooting of trees can create holes and weakness

### Animals/Rodent Activity



### Animals/Rodent Activity

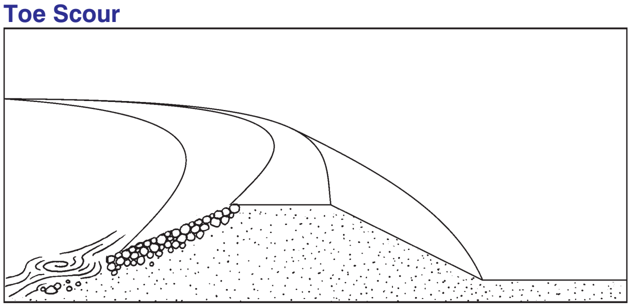
**Observation:**
- Rodent holes, burrows and tunnels
- Animal trails
- Fallen trees (beaver activity)

**Causes:**
- Burrowing animals including bank beavers

**Concerns:**
- Can weaken the embankment - cause sinkholes and piping
- Potential vehicle access restrictions if unchecked

## 6.3 Guide for Identifying Problems in Erosion Protection Works

### Toe Scour



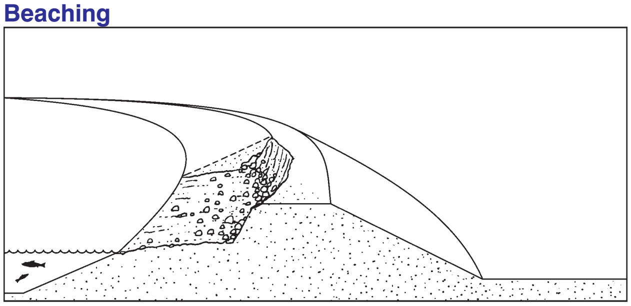
### Toe Scour

**Observation:**
- Loss of riprap from dike slope
- Loss of riprap starting at the toe
- Undermining of the dike slope
- Eddying at the dike toe

**Causes:**
- Inadequate riprap toe design/material size
- Shift in flow impact angle due to formation of log jams, ice jams, shifting river bed materials or man made obstacles

**Concern:**
- Loss of erosion protection material leaving the embankment materials vulnerable to erosion and possible breaching

### Beaching



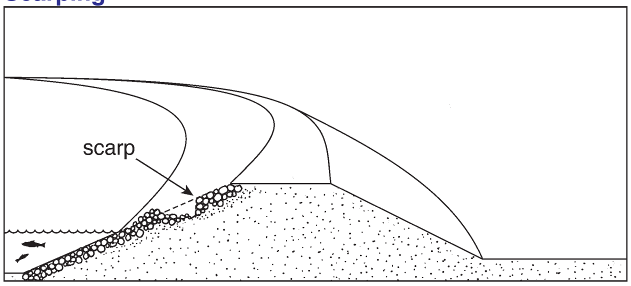
### Beaching

**Observation:**
- Riprap on dike slope slumping and forming a horizontal beach near the water level

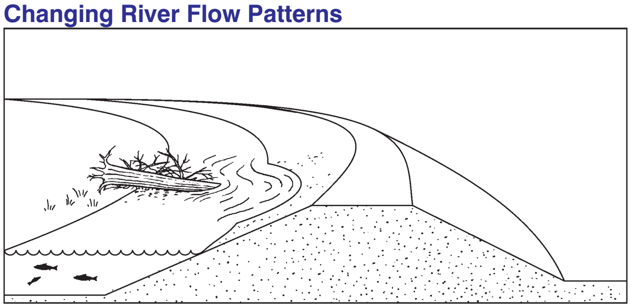
**Cause:**
- Wave action removing a portion of the riprap slope and depositing it further down the slope
- Insufficient riprap rock size

**Concern:**
- Loss of erosion protection material leaving the embankment materials vulnerable to erosion and possible breaching

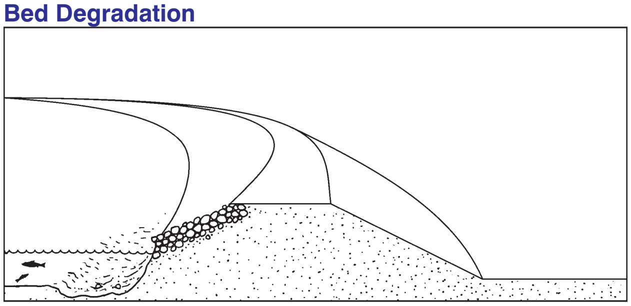
## Scarping



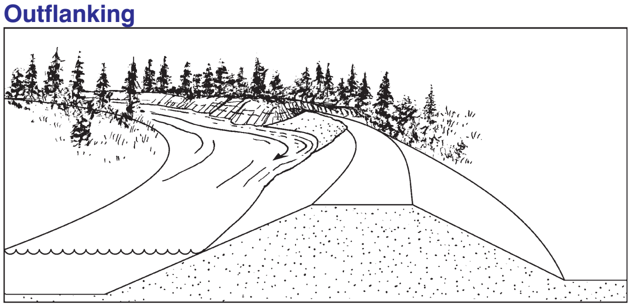

## Changing River Flow Patterns



## Bed Degradation



## Outflanking



## Scarping

**Observation:**

- Riprap undermined and sliding down the slope
- Cracking, spalling of riprap material
- Oversteepened riprap slope

**Cause:**

- The removal of bedding material (filter material) from beneath riprap due to ice, wave action, internal erosion or local settlement

**Concern:**

- Riprap slides to lower part of the slope causing scarps to form which could reduce the cross-sectional width of the dike

## Changing River Flow Patterns

**Observation:**

- Dramatically altered flow pattern of the river
- Areas of impingement on the dike altered
- Channel obstructions in the vicinity

**Cause:**

- Landslides
- Ice and log jams
- Gravel accumulations
- Man made obstructions
- Natural meander progression and/or formation of cutoffs

**Concern:**

- Additional erosive forces applied against existing bank protection works increasing the chance of its failure
- Direct flow against sections of the flood protection system not previously subjected to erosion . If not already armoured, could lead to rapid loss of embankment fill
- Outflanking of existing works at upstream end

## Bed Degradation

**Observation:**

- River channel scouring adjacent and roughly parallel to the erosion protection
- Riprap perched on a ledge

**Cause:**

- Changing river currents and high water levels
- Deepening of the riverbed in the reach near the dike
- Insufficient toe protection design or construction

**Concern:**

- The erosion protection material is vulnerable to undermining and collapse exposing the bank

## Outflanking

**Observation:**

- River erosion upstream of hardpoint or key trench

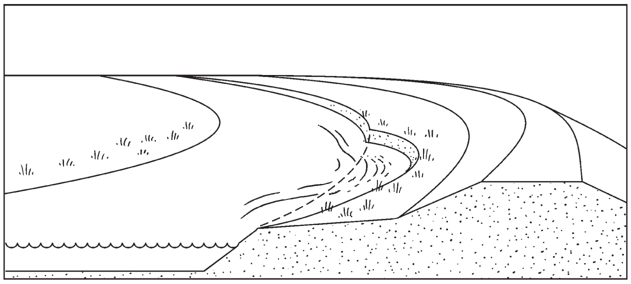
**Cause:**

- Erosion protection not extending far enough upstream
- Erosion protection not extended to a hardpoint at the upstream end
- Weak upstream key (poor design)
- Sudden change in river flow pattern

**Concerns:**

- Rapid loss of erosion protection material leaving the embankment fill vulnerable to erosion
- Exposure of unprotected fill to erosive forces

## Overbank Erosion



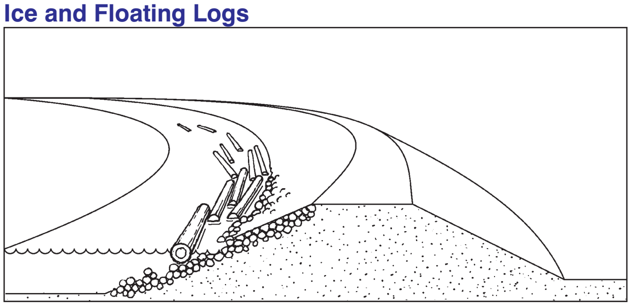
## Overbank Erosion

**Observation:**
- Reduced riverbank area
- Progressive erosion

**Cause:**
- Reduced distance from the dike fill to the river channel due to changing river currents
- Natural meander progression
- Lack of erosion protection on set-back area

**Concerns:**
- Threat to embankment stability
- Undermining of embankment

## Ice and Floating Logs



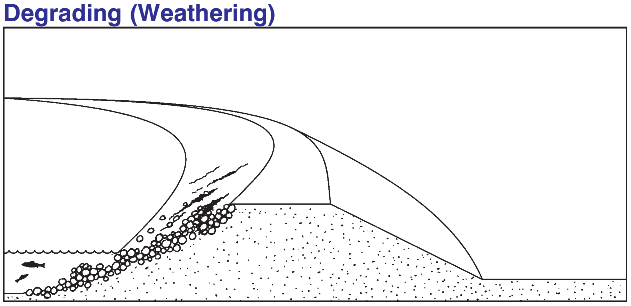
## Ice and Floating Logs

**Observation:**
- Dislodged riprap pieces on riverside slope, holes in riprap
- Riprap damaged
- Impingement on dike of uprooted trees

**Cause:**
- Loss of erosion protection due to forces exerted by flowing ice and floating logs (trees)
- Moving ice grinding or displacing riprap

**Concern:**
- Weakening or complete loss of erosion protection material

## Degrading (Weathering)



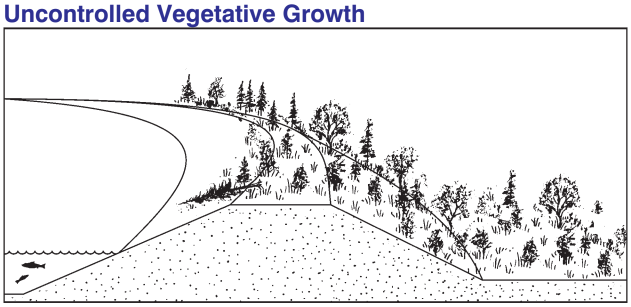
## Degrading (Weathering)

**Observation:**
- Disintegration of riprap material
- Cracks, spalling, crumbling of riprap material
- Hollow sound on rock hammer testing

**Cause:**
- Chemical or mechanical deterioration of the erosion protection material often accelerated by wave action and ice flows and freeze and thaw cycle

**Concern:**
- Widespread weakening of erosion protection material leaving the embankment fill more susceptible to erosion

## Uncontrolled Vegetative Growth



## Uncontrolled Vegetative Growth

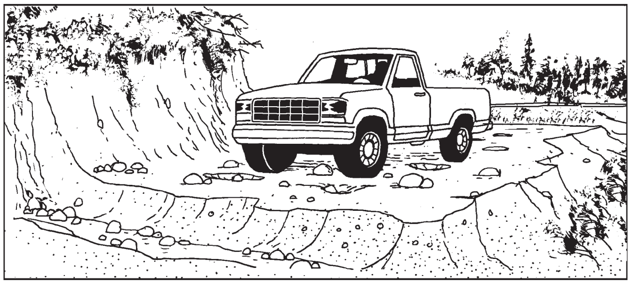
**Observation:**
- Vegetation obscuring inspection
- Large vegetation and trees on fill
- Tree uprooting on riprap
- Tree blowdown across dike

**Cause:**
- Lack of regular vegetation management
- Poor maintenance procedures

**Concerns:**
- Can obscure serious problems which may exist
- Tall trees with large root systems can displace large amounts of erosion protection material when forced over by wind, ice flows or high water
- Provides a habitat for unwanted burrowing animals

## 6.4 Guide for Identifying Problems in Appurtenant Works

### Access Roads



### Access Roads

**Observation:**

- Poor road conditions
- Blocked access

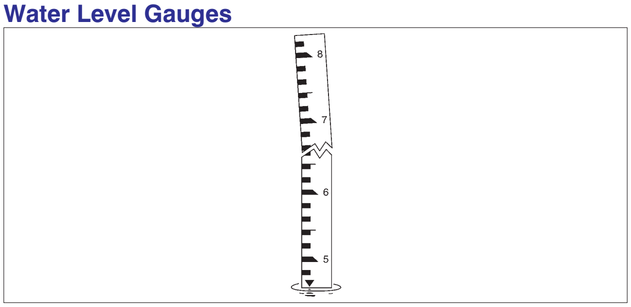
**Causes:**

- Lack of proper gates and controlled access
- Poor construction practices
- Poor maintenance
- Jurisdictional problems regarding access and maintenance of access

**Concerns:**

- Blocked access during emergencies
- Unnecessary delays

### Water Level Gauges




### Water Level Gauges

**Observation:**

- Gauge is broken, bent or missing
- Gauge is unreadable (paint gone)
- Gauge is obscured from view

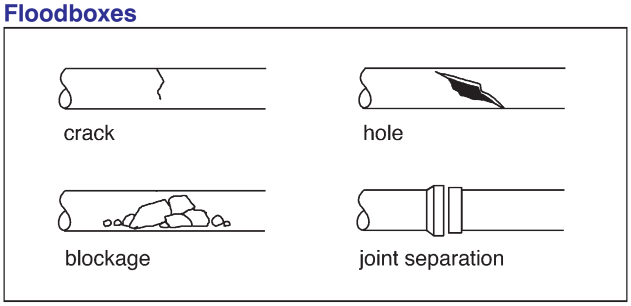
**Causes:**

- Ice, high water, floating debris, vegetation growth
- Poor installation
- Vandalism
- Deterioration due to weathering

**Concerns:**

- Loss of a vital information tool for operation, maintenance and flood fighting activities
- Unnoticed elevation change resulting in incorrect reading

### Floodboxes




### Floodboxes

**Observation:**

- Cracks/holes/joint separation
- Concrete deterioration
- Gates not opening easily
- Gates blocked (woody debris, slumping, siltation)
- Evidence of rusting at culvert joints

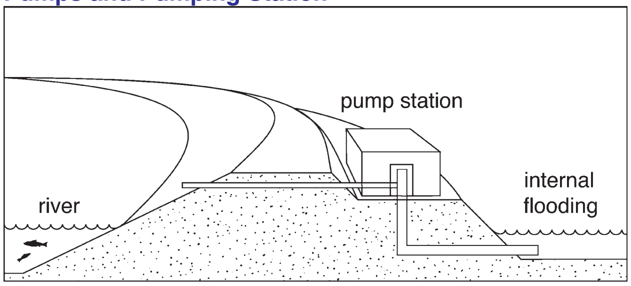
**Causes:**

- Poor construction practices
- Internal settlement, separation
- Corrosion
- Lack of maintenance
- Beaver activity
- Damage from ice, floating debris, etc. to the gate and its supports (guides)
- Vandalism

**Concerns:**

- Internal flooding from debris blockage or improperly or partially closed gates
- Seepage along outside of conduit resulting in piping and ultimately embankment failure

## Pumps and Pumping Station



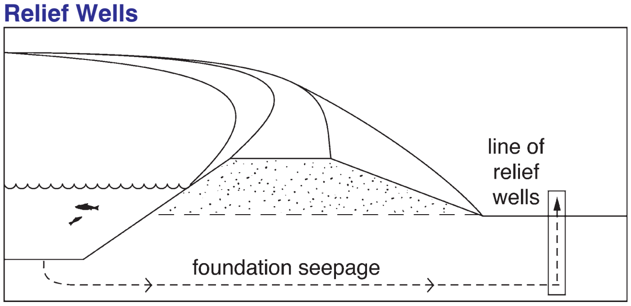

## Pumps and Pumping Stations

**Observation:**
- Pumps not working to specifications
- Rust on pipes or pumps
- Power source not operative
- Switching devices not working to specifications
- Walls, doors, gates, etc. out of alignment
- Scouring or undermining near the footing or foundation of the structure

**Causes:**
- Lack of a proper maintenance schedule
- Power outages
- Vandalism

**Concern:**
- Failure causing internal flooding

## Relief Wells



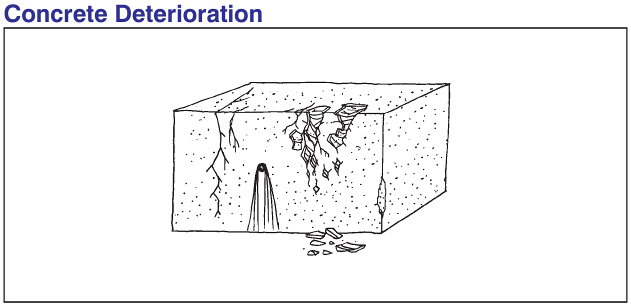

## Relief Wells

**Observation:**
- Turbid water in wells
- Concrete deterioration

**Causes:**
- Piping of foundation materials

**Concerns:**
- Piping leading to weakening of embankment

## Concrete Deterioration



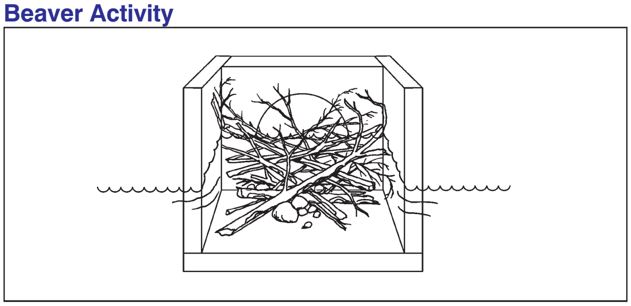
## Concrete Deterioration

**Observation:**
- Cracking, spalling, disintegration
- Evidence of rust
- Hollow sound on rock hammer test

**Causes:**
- Poor construction practices
- Corrosion of reinforced steel from salt content
- Forces of erosion and weathering

**Concern:**
- Loss of ability to carry out the designed functions of the appurtenant works

## Beaver Activity



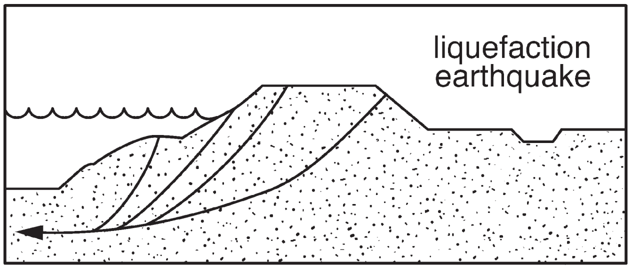
## Beaver Activity

**Observation:**
- Beaver dam and/or wood debris blocking intakes

**Cause:**
- A favourable habitat

**Concern:**
- Beaver activity may block intakes to floodboxes and pump stations causing internal flooding

## 6.5 Post-Earthquake Problems




**Observation:**
- Slumping of the fill
- Bulges at lower elevations on the dike
- Liquefaction of ground
- Collapse of fills
- Cracking in the embankment
- Damage to appurtenant works

**Cause:**
- Seismic activity

**Concerns:**
- Widespread damage to the flood protection system is possible
- If widespread, complete repair might not be possible before high water conditions
- Areas affected by tides are of special concern
- Functionality of pumps, gates and structures
- Damages may not be visible immediately

*Inspections by Boat*

Sheet No. __________
File No. __________

## 6.6 Flood Protection Inspection Report

Dike Length: __________

DIKE: ____________________________________________________________

REACH: ____________________________________________________________

DATE INSPECTED: ____________________________ Signed: ______________________________________

The condition of the flood protection works is as reported below:

1. DIKES: (access, gates, locks, vegetation growth, gravel surface, height, slopes, erosion, animal burrows, seepage, trash, berms, relief wells)

2. BANK PROTECTION: (loss of rock, settlement, slumping)

3. FLOODBOXES/PUMP STATIONS: (inlet and outlet channels, gate operation, trash racks, debris, erosion, corrosion, structure, discharge structure, electrical and mechanical components)

4. WORK REQUIRED:

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

5. ADDITIONAL INFORMATION (see below) (sketch, photos, etc.)

6. WORK COMPLETED: Date: _____________________ Signed: ____________________________________

## 6.7 High Water Patrol Log

Date: ______________________________ Inspector: ______________________________

Time Commenced: ______________________ Time Completed: ______________________

**1. Gauges Height** | **Design WL** | **Time** | **Water Level**

| Gauges Height | Design WL | Time | Water Level |
|---|---|---|---|
| Gauge ________ | ________ | ________ | ________ |
| Gauge ________ | ________ | ________ | ________ |

**2. Landside Seepage**

| | Yes | No | Comments/Location |
|---|---|---|---|
| Boils | ☐ | ☐ | **Clear:**__________**Dirty:**__________**Piping:**__________ |
| Ponding | ☐ | ☐ | ______________________________ |

**3. Landside Slope**

| | Yes | No | Comments/Location |
|---|---|---|---|
| Cracking | ☐ | ☐ | ______________________________ |
| Sloughing | ☐ | ☐ | ______________________________ |
| Seepage | ☐ | ☐ | ______________________________ |

**4. Dike Crest**

| | Yes | No | Comments/Location |
|---|---|---|---|
| Accessible | ☐ | ☐ | ______________________________ |
| Cracking | ☐ | ☐ | ______________________________ |
| Settlement | ☐ | ☐ | **Sinkholes:**______________________________ |
| Freeboard | ☐ | ☐ | ______________________________ |

**5. Riverside Slope**

| | Yes | No | Comments/Location |
|---|---|---|---|
| Erosion | ☐ | ☐ | **Dike Fill:**______________**Riprap:**______________ |
| Instability | ☐ | ☐ | ______________________________ |
| Underwater | ☐ | ☐ | ______________________________ |

**6. Floodboxes**

| | Yes | No | Comments/Location |
|---|---|---|---|
| Gates | ☐ | ☐ | **Leakage:**______________**Flow Estimate:**______________ |

**7. Pumps**

| | Yes | No | Comments/Location |
|---|---|---|---|
| Inlet/Outlet | | | **Open:**______________**Obstructed:**______________ |
| Operating | ☐ | ☐ | **Flow Estimate:**______________________________ |

**8. Required Action:** ______________________________

**Notification:**______________________**To Whom:** Time:______

***Refer to System Operation & Maintenance Manual***