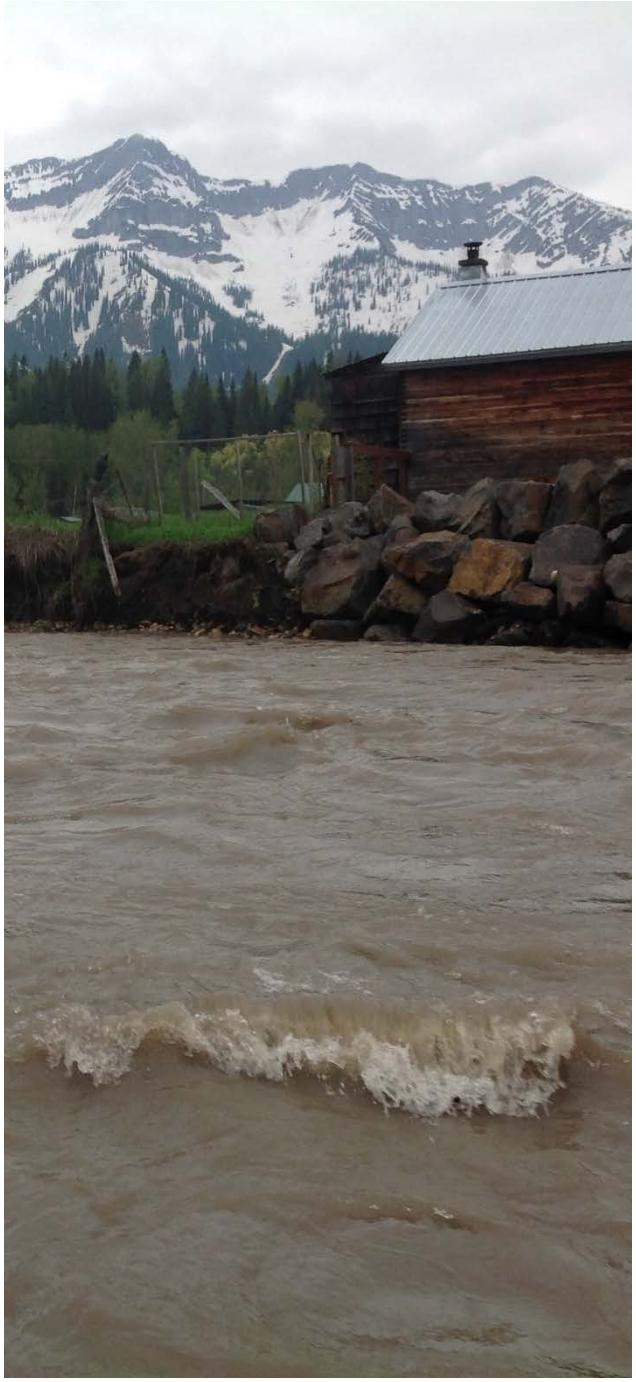

ELK RIVER
FLOOD HAZARD MITIGATION

FINAL REPORT

Prepared for:

Regional District of East Kootenay

Regional District of East Kootenay
19-24th Avenue, Cranbrook, BC, V1C 3H8

06 February 2019

NHC Ref. No. 3003761

nhc
northwest hydraulic consultants
water resource specialists

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Prepared by:

Northwest Hydraulic Consultants Ltd.
North Vancouver, BC

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DISCLAIMER

CREDITS AND ACKNOWLEDGEMENTS

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- Kara Zandbergen, Engineering Technician

The following NHC personnel were part of the study team and participated in the identification and assessment of mitigation measures.

• Dale Muir, M.Eng. P.Eng.	Project management and technical support
• Vanessa Bennett, MASc, EIT	Project engineering and modelling
• Julie Van De Valk, EIT	Project engineering and Risk Assessment
• Josef Dreschler, GISP	Spatial data manipulation, management, and mapping.
• Dwain Boyer, M.Eng. P.Eng.	Engineering support.
• Neil Peters, MASc. P.Eng.	Technical review.

EXECUTIVE SUMMARY

The Elk River flows from the east through the Regional District of East Kootenay (RDEK) in the southeast corner of the British Columbia. The area is in the Rocky Mountains and due to the high relief and sometimes inclement weather, there is a risk from hydrotechnical hazards. These hazards include flood inundation, sediment deposition, erosion, channel migration, as well as avulsion. To better understand the flood hazard, the RDEK updated the 1979 floodplain maps (NHC, 2019). Results from the updated floodplain maps have since been used to identify and assess potential structural and non-structural flood mitigation measures along the Elk River from the District of Sparwood to Morrissey.

The identified and assessed structural mitigation measures are centred at locations of known problems, dense population, and where issues became evident from the floodplain mapping project. The mitigation measures include:

- Elk River diking and improvements to tributary channels at the Town of Hosmer.
- Sediment management and improvements in conveyance at Hartley Creek, and
- Elk River diking and new erosion protection downstream of the City of Fernie at Cokato and Riverside.

Approximate "planning level" costs were estimated for each mitigation measure. The benefits and feasibility were assessed and compared qualitatively using a rating system.

Non-structural mitigation measures presented included emergency response planning, regulatory controls on land use within the floodplain, awareness and education, and monitoring and maintenance of structural flood protection. Costs, benefits, and qualitative ratings were not developed for the non-structural measures; however, they are likely to have the greatest reduction in risk to cost ratio as they can benefit large numbers of people. They are also typically substantially lower cost than construction and on-going monitoring and maintenance of structural measures. Therefore, it is recommended that the non-structural measures be implemented with the highest priority.

Specific non-structural mitigation measures should be considered as soon as practical. This includes:

- Development or application of land use regulation for properties within the floodplain using the recently developed floodplain maps.
- Consideration of developing an early warning protocol with the existing Elk River at Natal gauge, and potentially additional real-time gauges.
- Establishing a monitoring protocol for the Elk River at the Hosmer exfiltration ponds.
- Review of the Emergency Response Plan with respect to the new floodplain maps.

In addition, the RDEK should incorporate on-going education for flooding and monitoring and maintenance of flood protection infrastructure.

Structural flood mitigation measures are costly to construct and maintain and frequently blocked by the difficulty in obtaining property rights. Therefore, structural mitigation measures are rarely practical except for areas where the hazard and consequent are great. Of the structural mitigation measures identified, the greatest risk avoidance or benefit is expected to occur from constructing a dike around

the upstream portion of the Town of Hosmer, maintaining Mine Creek conveyance (dredging) through Hosmer, and reconstruction of the existing downstream Hosmer dike. These three measures range in cost from one of the most expensive mitigations to one of the least expensive, as presented in the following table of highest ranked structural mitigation measures.

An option downstream of the City of Fernie exists to reduce flood damage risk in the Cokato area, that is to armour or set back the existing Hill Road dike. The Hill Road project protects a smaller community than Hosmer, yet armouring would have high costs, similar to that of diking around Hosmer. However, protection of an existing dike asset through set back or armouring may be easier to accomplish than developing new infrastructure.

A dike at Riverside would protect a number of homes along Vanlerberg Road, many of which seem to be at the highest risk in the study. However, a dike at this location is expected to be costly, requiring substantial fill and armouring as well as being constrained between the river and waterfront homes. The flood inundation benefit of a Riverside dike is contingent on completion of upstream diking within the City of Fernie. The City of Fernie is not expected to proceed with such a project, unless it is lead by development of Riverside. A dike at Riverside, in the RDEK or City of Fernie, is not expected to proceed in the foreseeable future.

The following table represents the recommendations for mitigation measures for the Elk River based on criteria outlined in the report. It is recommended that this report and attachments be read in entirety prior to applying any of the findings.

Location	Structural Mitigation Measure	Purpose	Cost
Elk River at Hosmer	Dike construction along Elk River	Protects against through flooding from Elk River and Mine Creek.	$2,860,000
Mine Creek at Hosmer	Downstream Mine Creek conveyance improvement	Improve Mine Cr conveyance (widen / deepen channel) through Hosmer.	$520,000
Hosmer Bridge	Upgrade existing dike (downstream right bank)	Protects properties north of Hwy 3 downstream of bridge. Upgrade to current standards.	$280,000
Cokato	Setback Hill Road Dike	Protect existing structure from erosion & homes from Elk River floodplain flow.	$3,230,000

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

1 INTRODUCTION

1.1 Background and Purpose

The Regional District of East Kootenay (RDEK) covers the southeast corner of the province. It can be characterized by the surrounding mountain ranges and the large river systems that flow along the valley bottoms; most notably, Columbia River to the north, Kootenay River flowing south, and the Elk River flowing from the east. The steep surrounding mountain slopes provide beauty and recreation, but also confine much of the development to the bottom of the valley; where there is often risk from flood and debris hazards.

The region has experienced a number of large floods with the largest on the Elk River occurring on June 21, 2013 (approximately a 1-in-500-yr event) (Photo 1) and many of the tributaries experiencing an equally extreme event on June 7, 1995. Northwest Hydraulic Consultants Ltd. (NHC) was retained by the RDEK to update the floodplain maps for the Elk River from the District of Sparwood downstream to Morrissey. Potential measures to mitigate the flood risk have been subsequently identified and evaluated based on the work done in preparation of the floodplain maps.

Photo 1. Hosmer during the June 2013 flood (Looking at Mine Creek crossing at 3rd Avenue with backwatering up King St, and Victoria St.

1.2 Scope

This report presents the identification and evaluation of potential structural and non-structural mitigation measures for the Elk River and tributaries within the RDEK between the District of Sparwood and Morrissey. Approximate "planning level" costs were estimated for each mitigation measure. Benefits and feasibility were assessed and compared qualitatively for each structural mitigation measure.

1.3 Definitions

Following are definitions of key terms used in this work.

1.3.1 Design Flood Level

In British Columbia, the design flood level is typically taken as the water level associated with a 200-year design flood event, that is a flood event with an expected annual exceedance probability (AEP) of 1:200 (MWLAP, 2003) (MWLAP, 2004). Where an event has exceeded the 200-year event, the largest flood recorded, referred to as the flood of record, is often used as the basis for the design event; examples of this include the lower Fraser River and the Elk River. The water level is typically calculated through simulation of the design flood event using a numerical hydraulic model. In some instances, the design flood level may be from observations from the flood of record or from a physical hydraulic model.

1.3.2 Flood Construction Level

The flood construction level, or FCL, is the design level used for buildings within the floodplain to limit risk of damage from flood waters. The FCL is determined by adding a freeboard to the design flood level. The risk of flooding is reduced through enforcing that living space, areas used for the storage of goods damageable by floodwaters, and any electrical switchgear are above the FCL. Specifically, the FCL defines the minimum level for the underside of a wooden floor system or top of a concrete slab.
As stated in *Section 3.6* of the provincial guidelines, residential, commercial, and institutional developments already protected by dikes are required to also meet these criteria; *"Buildings and manufactured homes in areas protected by standard dikes should meet minimum FCLs".* This perceived duplication of protection has been adopted in BC (unlike Alberta) to account for potential failure of dikes, seepage through or under dikes, and internal flooding from stormwater and inflow trapped on the landside of the dike. Dikes are used in addition to building floodproofing where there is a high flood risk, to limit frequency of flooding, inundation of low-lying infrastructure (such as roads and garages), high velocity flow, and potential inflow of sediment, debris, and contaminants into the town. Conversely, areas not densely populated or not at high risk to flooding, rarely warrant dikes.
Provincial guidance for design crest elevation for dikes does not specifically refer to the FCL. However, the definition of the design crest elevation in BC is the same as the definition of the FCL[1] (MWLAP, 2003). This report therefore presents them synonymously.

[1] Exception is dikes for agricultural land, which are often limited to an AEP of 1:50, (MWLAP, 2003).

A community may determine that a greater or different level of protection is warranted for dike design than for structures within the floodplain. Typically, this would be achieved by further increasing the design event (i.e. AEP of 1:500 or 1:1000) or considering alternative freeboard. In some cases, this may result in exemptions being defined for buildings protected by the dike, potentially in contradiction to the provincial land use guidelines. Some communities have adopted exceptions to the FCL for specific areas protected by dikes. For example; the City of Chilliwack *Floodplain Regulation Bylaw 2018 No. 4519* states in *Section 20.3* and *20.4* that some commercial uses are exempt from the FCL requirement provided that they are constructed to a specified minimum elevation above the crown of adjacent roads. No such variances were immediately evident for the current study area.

1.3.3 Flood Risk

Flood risk is the probability of loss resulting from a flood. The loss can be direct, such as loss of a home or business, or indirect, such as the impact of changed perception of the community. Assessment of potential loss or consequence generally includes identification of hazards, potential receptors susceptible to the hazards (i.e. people, economy, environment, cultural values), and exposure and vulnerability of the receptors with respect to the hazard; as depicted in the following figure. The resulting flood risk is the probability of the flood event occurring and leading to the identified impacts.

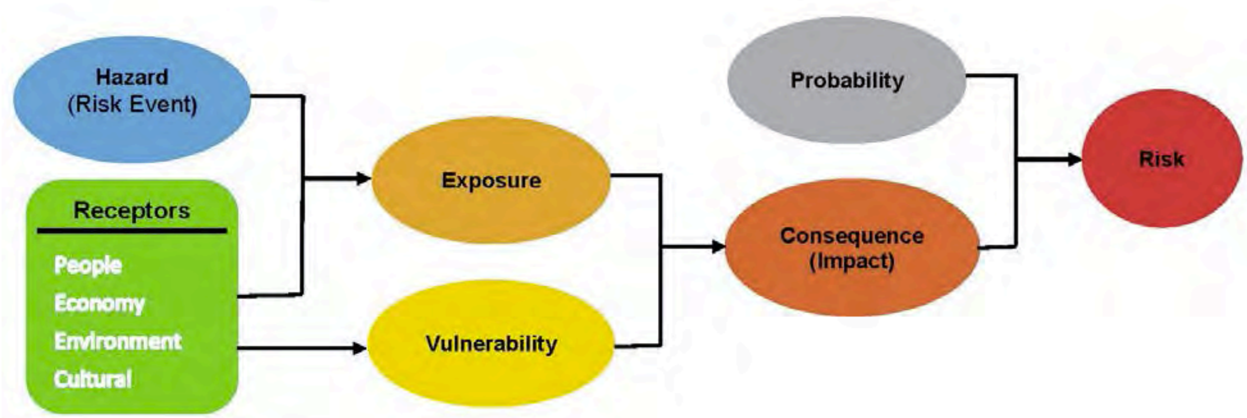


Figure 1. Components of risk assessment

Detailed assessment of flood risk can require extensive definition of flood risk events and consequences for the range of receptors and probabilities. This can be time consuming and difficult to ascertain, requiring a variety of specific data for the area and assessment by a wide range of experts. Most flood risk assessments are simplified through:

- Reducing the number of hazard events considered,
- Reducing the number of receptors considered (i.e. number of homes),
- Limiting analysis to direct impacts, and
- Using exposure as a proxy for impact instead of directly considering vulnerability (i.e. number of homes impacted versus damage caused by flood inundation).

1.3.4 Flood Risk Mitigation

Flood risk mitigation is the reduction of the risk to flooding. This is generally accomplished through reducing the exposure and vulnerability to the hazard. In a few circumstances, mitigation may also include flood hazard reduction, such as through diverting floods around the community (i.e. Red River diversion at Winnipeg and Assiniboine River diversion near Portage la Prairie). Flood risk mitigation measures are often categorized as structural and non-structural; the terminology used within this report. However, alternative characterization has been used by other studies; such as 'protect' (similar to the structural measures presented within this report), 'adapt' (similar to the non-structural measures presented within this report), and 'retreat' (i.e. relocation of infrastructure, homes, or communities).

2 FLOOD HAZARD

Flood hazard along the Elk River and the tributaries can result from flood inundation, erosion, scour, sediment deposition, aggradation, degradation, channel migration, and channel avulsion. The hazards can threaten populations, infrastructure, environment, economy, and cultural values along the river (Photo 2). The hazards imposed by clear water flow can be exacerbated with the transport of debris and sediment. This is particularly the case as the steep, confined tributaries as they reach the flatter, less confined Elk River Valley. The current assessment of mitigation measures is based on investigation of the Elk River from the downstream of the District of Sparwood to Morrissey (with exclusion of the City of Fernie) including Hosmer Creek and Mine Creek at the town of Hosmer, as well as Hartley Creek (located on the right bank of the Elk River 5 km downstream of the town of Hosmer). Other similar studies are being conducted by the local communities of Elkford, Sparwood, and Fernie.

Photo 2. Erosion hazards on the Elk River from previous flooding (structure location upstream of Morrissey on right bank)

2.1 Elk River Flood Hazard

The Elk River throughout the study reach can be characterized as a wandering gravel bed river. Characteristic of this typology are wider multi-channel sedimentation zones separated by narrower, steeper, sinuous single-thread reaches. The Elk River transports a large quantity of suspended and bedload sediment during spring freshet and rainstorm flood events. The numerous sedimentation zones within the study area, are often locally unstable with ongoing sediment deposition which can lead to redirection of flow, bank erosion, channel migration, and occasionally avulsion (Photo 3). As a result, these reaches exhibit low-order braiding with many lateral, point, and mid-channel bars.

Photo 3. Bank erosion of the Elk River (downstream of Hosmer on right bank)

As part of the floodplain mapping project, a one-dimensional hydraulic model of the Elk River was developed. Simulation results from the model were used to map flood construction level (FCL) and inundation extents based on the design flood event. The design flood event was taken as the peak instantaneous flow from the 2013 flood with a 10% allowance to account for climate change to the year-2100.Flood construction levels (FCL) were mapped as the resulting water level from the hydraulic analysis with the addition of a 0.6 m freeboard to account for local variations and uncertainty.

In addition, the model was used to analyse the impact of potential floodway encroachment; particularly to identify bounds where further encroachment is expected to have the potential to transfer flood risk to adjacent or upstream properties (that is, simulation suggests complete floodplain encroachment to the bound would increase upstream flood levels by 0.3 m or more during the design flood). Area within the bounds is referred to as the floodway, whereas inundated area beyond the bounds is referred to as the flood fringe. Within the floodway, depth of flow is typically 1 m or more and velocity is 1 m/s or more. The FCL map illustrates FCL isolines along the Elk River, approximate extent of inundation, the floodway, and the flood fringe.

Areas exposed to fluvial geomorphic hazards and alluvial fan hazards have also been identified based on review of past studies, historic and current air photos, site inspection, and the hydraulic flood model. Erosion hazard areas were mapped along the Elk River to illustrate locations where there is active or high potential for bank erosion, and where such erosion could lead to dike breach, avulsion. In addition, areas at risk to channel migration were identified, delineating where the channel may migrate over time across the floodplain.

2.2 Elk River Tributary Flood Hazards

Mine Creek, Hosmer Creek, and Hartley Creek within the Elk River Valley were also considered in the hazard assessment. These tributaries were selected based on their history of past flooding. The selected design flood for these tributaries is based on the peak instantaneous 1-in-200-year design flood from the Hosmer Water Survey of Canada (WSC) gauge. These three watersheds are relatively small and steep, with evidence of past sediment and debris concerns, suggesting a high likelihood to experience debris flood events. Past studies show that debris flood events can have total discharge in the order of 1.5 to 2.0 times the 200-year clear water flow; the 200-year flow was therefore increased by 50%. This resulted in a flow on Hosmer Creek slightly greater than that estimated for 1995 flood event (based on the Water Survey of Canada Hosmer Creek gauge data). Analysis of the projected impacts of climate change for the tributaries indicated potential for flood flows to increase more than 10% over the next 80 years. Therefore, the calculated flood was increased by an additional 20% to account for potential changes to the year-2100. Design flow was transposed from the Hosmer gauge to the three tributaries and simulated using a two-dimensional hydraulic model.

Inspection of the existing crossings in spring of 2018 indicated that many of the crossings were partially blocked by debris (roughly 25% blocked with some crossing showing further blockage up to 60%) (Photo 4). During a flood event it is expected that the crossings would be further blocked, and hence were simulated assuming 75% blockage. Since they are simulated in two dimensions, overbank flow is allowed to flow perpendicular to the channel and flooding extends along and over the roadway and railway embankments to adjacent low-lying areas.

Photo 4. Culvert inlet under Highway 3 on Hartley Creek – single arch culvert with 4.3 m span and 1.45 m rise partially blocked (roughly 60%) with sediment and almost flooding the highway during Spring 2018 freshet.

Geomorphic hazards were also considered where the tributaries join the Elk River Valley. The most prominent geomorphic hazard zones associated with the tributaries were alluvial fans. Alluvial fans were delineated for several the tributaries along the study reach, not only Mine, Hosmer, and Hartley Creek. Past studies were used as the initial bases for mapping of the alluvial fans (MWLAP and Fraser Basin Council, 2004, and BGC, 2013). Alluvial fans are the accumulation of sediment from steep channels that transported substantial sediment and debris entering an unconfined reach of flatter gradient. The sediment accumulation "fans out" forming a wedge or cone. The channel often incises into the deposited material over time and can give the illusion of a stable channel alignment. However, future events may bring additional debris which can lead to rapid channel aggradation, local blockage, and channel avulsion. The hydraulic hazards associated with alluvial fans have specific considerations within the hazards' assessment guidelines (EGBC, 2018), and should be assessed specifically for each individual site and project.

3 POTENTIAL FLOOD HAZARD MITIGATION MEASURES

There are multiple approaches to mitigate the potential damages from flood hazards. Mitigation methods are often categorized as structural and non-structural measures. Examples of these are presented in the following sub-sections.

3.1 Structural Mitigation Measures

Structural mitigation measures are measures that are physically constructed to limit the probability and consequences of floods. Examples of some of the most common structural flood mitigation measures are presented below.

3.1.1 Dikes

Dikes have been used extensively to provide protection from high water by providing a barrier to hold back ponding or flowing water. Dikes are generally earthen embankments, consisting (from water to land side) of an armouring layer, a filter layer, impermeable core, and drain layers. The armouring layer can vary from rock riprap to grass depending on the erosive potential of the adjacent water.

Dikes are often seen as a desirable form of flood protection as they can block water, sediment, and debris from entering a community protecting it from the flood event. Cost is a major challenge with dikes; this includes acquiring the land, constructing the dike, monitoring the dike, and maintaining the dike. Dikes can limit riparian habitat, act as a barrier between terrestrial and aquatic habitat, limit space for the river to migrate and store sediment and debris, and when encroaching on the floodway potentially increase local velocities, increase upstream water levels, and decrease in-channel storage (which can, but generally only to a non-observable extent, increase downstream flow). Dikes block flow from the flood source (i.e. the Elk River), but also prevent outflow from local stormwater and tributaries; therefore, suitable drainage has to be provided for channels that flow through dikes which may also require provisions for fish passage. Some of the adverse environmental aspects and costs can be reduced if the dike is setback from the river floodway and erosion protection costs can be reduced if the armouring is set back from the active channel.

When dikes and to some extend bank erosion protection works are designed it is important to consider their effects on adjacent and upstream and downstream properties. The construction of dikes can result in increases in adjacent and upstream water level. Dikes can also increase water levels within a diked floodplain when there is an upstream dike breach. These potential changes need to be considered when considering construction of new or extended dikes.

Furthermore, dikes can fail. There are numerous failure mechanisms for dikes, such as failure from overtopping flow, surface erosion, internal erosion (piping), or seismic destabilization. Following appropriate design, construction, monitoring, and maintenance methods, such as defined by the Dike Design and Construction Guide (MWLAP, 2003), the Seismic Design Guidelines for Dikes (Golder Associates Ltd., 2014), and the Dike Operation and Maintenance Manual (MELP, 2001) can reduce the probability of failure, but can not eliminate the risk. A typical cross-section of a dike along the channel bank is shown below. Dikes are owned and maintained by local diking authorities (usually local governments) and are regulated by the province under the *Dike Maintenance Act* (MFLNRORD, 2017). "Orphan dikes" are existing flood protection works that are not being maintained by an owner or diking authority. Prior to approval of construction of a new dike, or the upgrading of an existing orphan dike, the local government (i.e. RDEK) must acquire legal access to the land on which the dike is to be located, must agree to become the legal diking authority, and must agree to be fully responsible for the operation and maintenance of the dike. Projects to upgrade existing orphan dikes, and to construct new dikes must fully meet provincial design and construction standards in order to receive funding for construction or maintenance.

Dikes are generally most suited to address flooding of dense communities where the tax base is sufficient to fund both construction and ongoing maintenance. In the Elk River Valley, dikes exist on the right bank of the Elk River near Hosmer (extending north from the Highway 3 bridge embankment) and along the left bank of the Elk River at Hill Road (downstream of Fernie). The City of Fernie owns and maintains dikes along Elk River and Coal Creek within the City's municipal boundaries. The RDEK inspects and maintains the Hill Road dike. However, the dike on the right bank extending north from the Hosmer Hwy 3 bridge has no Diking Authority and is not inspected and maintained.

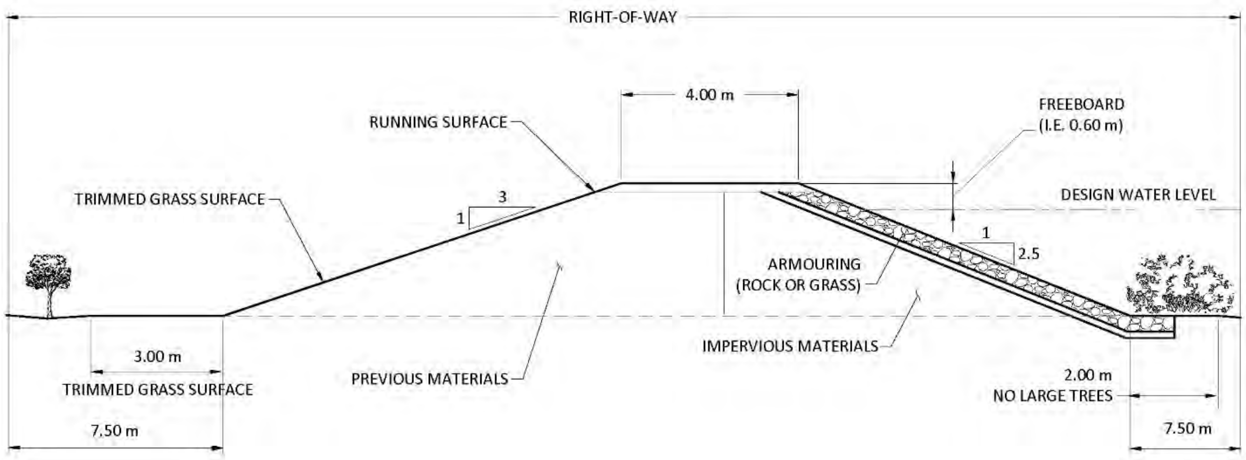


Figure 2. Idealized dike cross-section based on MWLAP standards.

3.1.2 Erosion Protection

Erosion protection is typically the armouring of banks with angular rock riprap. Erosion protection on its own does not provide protection from high water levels but can limit erosion and channel migration which can threaten dikes, homes, and other infrastructure located near fast flowing water. Detailed design standards for design of erosion protection features such as riprap size, gradation, and thickness are provided by the BC Ministry of Environment, Land and Parks (MELP) (2000). A typical cross-section of a bank protected by riprap is shown below. Armouring orphan dikes is considered an upgrade and triggers approval under the *Dike Maintenance Act* and full requirements for dikes.

Erosion protection has similar challenges to dikes, predominantly the cost of land acquisition, construction, monitoring, and maintenance, impact to riparian vegetation, provide a barrier between terrestrial and aquatic habitat, and potentially constrict the natural width and migration of the river resulting in local scour or increased probability of lateral migration on the opposite bank. Some of the adverse environmental aspects of erosion protection can be reduced if the armouring is set back from the active channel or by incorporating planting of shrubs in benches, pockets, or riprap voids.

Riprap spurs (also referred to as groynes) and bendway weirs can be used in conjunction or as an alternative to linear bank armouring. These structures extend rock roughly perpendicular to the bank instead of parallel to the bank. When working properly, these structures reduce the velocity along the bank and can direct flow towards the centre or opposite bank. Often these structures require similar or more rock than linear bank armouring, however effective redirection of flow can limit the length of bank armouring required and potentially reduced maintenance along the bank. Furthermore, such structures create variable hydraulic conditions and can incorporate large wood debris (LWD) and planting; all of which is often seen as beneficial to aquatic habitat and can therefore support permit acquisition.

To remain functional, erosion control measures require annual inspections and maintenance (especially when LWD is incorporated). There are no regulations to ensure the operation and maintenance of bank erosion works similar to those found in the Dike Maintenance Act for dikes. Typically, within a municipality the municipality will inspect and maintain erosion control works. In unincorporated areas there may be a need to implement a local services area bylaw process to ensure operation and maintenance of erosion control works where there is no Diking Authority established.

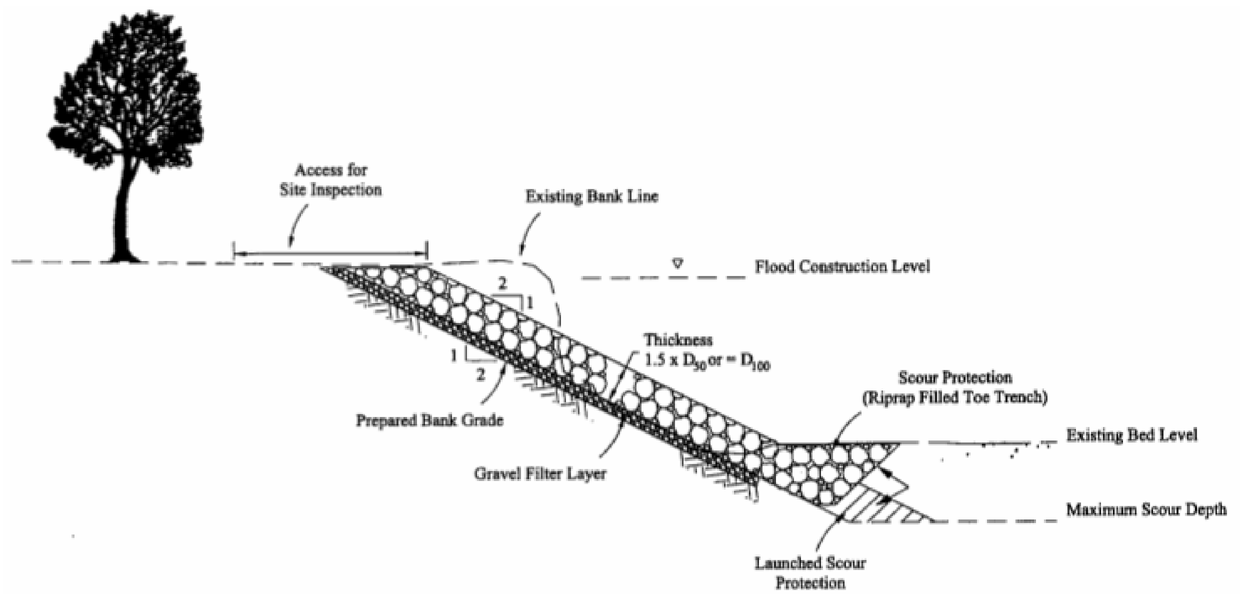


Figure 3. Typical riprap cross-section (Source: MELP (2000)).

3.1.3 Upstream Storage

Upstream storage can be used to attenuate flood flows. Storage to mitigate flood flows is typically done either through large dams and reservoirs or smaller scale such as community or site-specific retention and detention ponds. The size and general gradient of the Elk River and its major tributaries would require substantial amounts of storage to substantially mitigate the design flood event, such as through construction of a large dam and reservoir. Such an approach has substantial economic and environmental costs as well as adds additional risk of dam failure to the downstream community. This mitigation measure was not considered in any detail for this study.

3.1.4 Increased Conveyance Through Dredging and Diversion Channels

Conveyance can be increased through a particular reach and reduce the flood elevation within that reach and immediately upstream. Dredging of accumulated sediment and removal of debris is often done where channel gradients decrease, and sediment accumulates. Large scale dredging projects have occurred along the Fraser River (Hope to Mission), along the lower Chilliwack River (Vedder), and Cowichan River. Localized dredging has been considered along the Elk River, but primarily to address redirection of flows from localized deposition. Localized dredging and debris removal are also an effective strategy to maintain conveyance at culverts and bridges along smaller channels, such as tributaries to the Elk River. Larger scale diversion of flow is typically only suitable when protecting a large community and where there is room to route flood flows (such as the Red River floodway around Winnipeg). Such opportunities for large scale dredging or floodway construction are not expected to be feasible along this study reach Elk River and have not been investigated this study.

3.2 Non-Structural Mitigation Measures

3.2.1 Flood Emergency Response Planning

Emergency response planning (ERP) is critical to identify what actions, when, and by whom need to occur during an emergency to ensure public safety. The ERP may be on a community or district scale. The existing floodplain map can help guide the ERP in identifying areas at risk to flooding and high ground safe areas. Of particular interest should be access routes (highways, railways, airports), emergency centres (RCMP, fire halls, hospital), and large social spaces such as schools and libraries that may be at risk to flooding. Preparation of emergency response plans (ERP) by local authorities is mandated by the BC *Emergency Program Act* (BC, 1996). The province provides guidance on planning for various aspects of flood emergency response including plan preparation, pre- and during-flood actions, and post-flood management. (BC, 2016; PEP, 1999).

3.2.2 Education

Education about the flood risk can help inform property owners to help them be more prepared. Flood risk education can include:

- Presenting flood hazard that potentially threatens the community (i.e. floodplain FCL, depth, velocity, or hazard maps);
- How to prepare for and be aware of the timing and seasonality of floods;
- Where to find sources for information on floods and flood preparedness;
- Where to find real time forecasts of water level, water flow, and what it means;
- Location of nearest high ground;
- Local evacuation routes and procedures.

Local governments can help improve flood awareness by posting information on their websites with definitions of flood hazard and emergency resources for the general public (for example,

Photo 5. Sandbagging competition in Skagit County

https://www.chilliwack.com/main/page.cfm?id=1912). Community outreach can also take the form of handouts, community meetings, or poster and booth presentations at community events (i.e. county fair). Some diking districts hold spring sandbag competitions to build awareness of the upcoming flood season (i.e. Photo 5, courtesy Skagit County).

3.2.3 Land-use Management

The province provides guidelines to help local governments develop and implement land-use management plans and make development decisions for flood hazard areas (MFLNRORD, 2018). Development decisions may include limiting land use and density within certain hazard zones and or requiring site specific hazard assessment and mitigation measures for development within hazard zones (i.e. EGBC, 2018). Part 14 of the *Local Government Act* (BC, 2015) provides local governments with several land-use management tools to promote flood safety. For example, the Act empowers local authorities to establish development permit areas, designate certain lands as floodplains through bylaws, enact zones to promote safe developments in floodplains, and implement measures such as setback from the rivers edge and preventing disturbance of riparian vegetation.

Within regional district lands, land use regulation requires coordination with the provincial Ministry of Transport and Infrastructure subdivision approval officer who is responsible for the review and approval of subdivision of land outside of municipal boundaries.

3.2.4 Flood Proofing of Local Assets

This often includes constructing or raising buildings to the FCL but can also include waterproofing of the portion of structures located below the FCL. Local government adoption of a floodplain bylaw under Section 524 of the *Local Government Act* and construction of the habitable areas of new homes to the FCL is the most common non-structural mitigation approach applied in BC. Elevation of habitable areas is an effective mitigation measure regardless of the presence of dikes to account for the potential for dikes to fail as well as any seepage or stormwater inflows that may raise water levels on the landside of the dike.

3.2.5 Relocation or Retreat

Land-use management approaches typically deal with future development. Existing homes and infrastructure can relocate or gradually retreat with time. Relocation of individual homes may be warranted when homes are located within an area at risk to erosion and channel migration. On going maintenance and repair of bank armouring can be costly and difficult to reduce the risk to an acceptable level, particularly if the channel is actively migrating towards a house (in comparison to local erosion), if there is little bank remaining between the home and the river, or where the site is along a deep scour hole. Relocation of one or more homes may be the least costly and most long-term approach to address the flood hazard.

4 ASSESSMENT APPROACH

As mitigation measures are identified they can be evaluated using a qualitative risk and feasibility assessment. The risk component of the assessment assigns a score of the severity of risk avoided by the proposed mitigation. The feasibility component of the assessment assigns a score to represent the ease of implementation of the proposed mitigation. These two scores can then be combined into a risk: feasibility ratio.

4.1 Scoring of Risk Avoidance

To identify the level of risk avoided through each mitigation, a risk score was assigned based on the likelihood of the flood event overwhelming existing defences and the consequence of the flood event. Flood risk as defined by EGBC is a measure of the likelihood and severity of an adverse effect to health, property, or the environment. Risk is often estimated by the product of likelihood and consequence. (EGBC, 2018). For this project, risk is determined through the matrix shown in Figure 4.

The likelihood of the adverse effect is evaluated based on the probability that a flood event will overwhelm existing defences and impact an area. The consequence is described for the area that would be defended by the mitigation. Consequence, as defined by EGBC (2018) is “the outcomes or potential outcomes arising from the occurrence of a flood, expressed qualitatively or quantitatively in terms of loss, disadvantage or gain, damage, injury, or loss of life”. Consequence is estimated by an assessment of the people and assets directly exposed to the flood hazard and the potential extent of damage associated with the flood hazard which would be eliminated by the mitigation measure. Assessment of consequence generally includes consideration of injury or loss to humans, economy, social and cultural values, intangibles (personal suffering), and ecology (i.e. flora and fauna). This assessment has focussed on exposure of homes and associated structures. Such an approach is common for flood hazard analysis of this scale and often acts as a reasonable proxy for other values except for ecologic values.

Based on the risk assessment, each feature is assigned a risk score between 1 to 5, based on the matrix shown in Figure 4. A score of 5 indicates highest risk avoided or greatest benefit of the mitigation measure.

Likelihood of Reducing Hazard		Risk Score		
High – 3	Very likely to be highly effective	3	4	5
Medium – 2	Likely to be highly effective	2	3	4
Low – 1	Likely to be moderately effective	1	2	3
	Estimated Consequence Without Proposed Mitigation	Minimal exposure of people, economic sociocultural, & ecological assets/areas Low – 1	Some exposure of people, economic sociocultural, & ecological assets/areas Medium – 2	High exposure of people, economic sociocultural, & ecological assets/areas High – 3

Figure 4. Scoring matrix for risk avoidance.

4.2 Feasibility Score

To identify the feasibility associated with each mitigation, a feasibility score was estimated. A low feasibility score represents a project which is easy to implement. The feasibility score was determined by applying the matrix (Figure 5) to the two feasibility factors:

- Ease of execution; and
- Cost of implementation.

The ease of execution factor includes consideration of design complexity, environmental constraints, land acquisition or easements needed, and impacts on property-owners or other stakeholders. The cost of implementation factor includes consideration of the estimated costs of the proposed works. Category descriptions are provided in the following table. Values assigned can be refined through stakeholder or community discussion and progressing the design and costing. Additional feasibility factors may also be identified through stakeholder consultation.

Rating	Cost of implementation	Feasibility Factor		
High – 3	>$700,000	**3**	**4**	**5**
Medium – 2	$100,000 to $700,000	**2**	**3**	**4**
Low – 1	<$100,000	**1**	**2**	**3**
	Ease of Execution	Straightforward design and implementation. Minimal environmental impact. Does not require significant changes in land ownership. Minimal impact to stakeholders.	Somewhat complex design and implementation. May include moderate environmental impact. May require minor changes in land ownership. May have moderate impact on other stakeholders.	Complex design. May include substantial environmental impact. May require significant changes in land ownership. May impact other stakeholders significantly.
	Rating	High – 1	Medium – 2	Low – 3

Figure 5. Scoring matrix for feasibility factor.

4.3 Approach for Cost Estimation

Cost estimation for structural mitigation measures was performed at a 'planning' level of estimating which is defined by BC Ministry of Transportation and Infrastructure (MOTI) (2013b) as being "based on sufficient knowledge of site conditions adequate to identify high level risk". The expected accuracy range for this level of estimating is +/- 35%. Unit prices for construction items were obtained from recent NHC projects in the region.

Soft costs are typically 15% to 35% of construction costs. This is supported by provincial documentation by MOTI which suggests 25% (2013a). However, for this project we have adopted soft costs at the low end of this range, assuming some service costs, such as environmental monitoring, surveying, and material testing, is incorporated with the contractor's scope. The distribution of this is as follows:

- Project management and planning: 2%
- Design: 6%
- Construction supervision and inspection: 7%

Costs were inflated to reflect the uncertainty of the estimate by a contingency rate of 35% of construction cost. This contingency rate is commensurate with the accuracy range of this project as per MOTI (2013b). Costs for non-structural mitigation measures were not estimated. The presented cost estimates only include construction costs. On-going monitoring and maintenance have not been included but should be budgeted for.

5 IDENTIFIED MITIGATION MEASURES

The following sub-sections present the structural and non-structural mitigation measures identified and assessed within previous and the current study.

5.1 Previously Considered Strategies

A number of flood mitigation measures have been identified through a number of recent projects. Particularly the Elk River Alliance (ERA) has been proactive in identifying opportunities in two recent reports. The mitigation measures presented by these reports are briefly noted in the following subsections.

5.1.1 Elk River Flood Strategy, (ERA 2016)

The ERA 2016 report presents the following strategies for mitigating flood hazards:

- Retention and regeneration of riparian vegetation and wetlands,
- Changes in land use,
- Setting dikes back from the river,
- Lowering river bed and floodplain elevation, and
- Use of dikes where other options are not available.

These recommendations have been considered in the preparation of this report and have been incorporated where appropriate.

5.1.2 Lotic Environmental and ERA Flood and Erosion Mitigation (Lotic and ERA, 2016)

The Lotic Environmental (Lotic) and ERA, 2016 report presents conceptual mitigation measures. The measures that are within the current study reach are summarized below:

- Hosmer exfiltration ponds (located 11.5 km south of Sparwood); previous estimates for cost on this work ranged from $450,000 (relocation) to $1,500,000 (dike around site).

  NHC does not consider the ponds at imminent threat of channel migration and does not recommend that they be armoured at this time. Furthermore, the ponds are not expected to be inundated during the design event, and therefore do not require further diking. Despite no works being recommended, annual monitoring of the river near the ponds – such as by RCDC – is recommended. The figure below (from NHC's Floodplain Mapping Report, 2019) illustrates the migration of the banks over the last 50 years. Armouring may be warranted if the channel begins to trend towards this site.

Figure 6. Bankline comparison and channel migration zone near Hosmer exfiltration ponds.

- Hosmer townsite flooding, is reported by Lotic as one of the highest priorities for the RDEK to address flooding, but that it requires additional study.

  Flooding in Hosmer has been investigated by the current floodplain mapping project (NHC, 2019) with suggested mitigation measures presented below. Part of the Lotic and ERA (2016) study suggest increasing capacity through the Hosmer Highway 3 bridge. During the design flood, the hydraulic model (NHC, 2019) suggests that the difference in water level through the crossing is only 15 cm, suggesting the potential benefit is likely not worth the cost.

- Hosmer Highway 3 set-back dike is the orphan dike that extends north to the valley wall from the right bank bridge abutment of the Hosmer bridge. Two options were presented, one to raise the dike (previously estimated at $276,000), and the second to relocate the dike to include the two properties outside of the dike (previously estimated at $1,200,000).

  NHC considers this site in the current study and both options are assessed.

- Elk River at McLean Street is presented by Lotic as a project armouring 150 m of the left bank of the Elk River downstream of Fernie to protect the single home (cost reported at $440,000).

  This site was not considered by NHC in the current study, as it protects a single property.

- Elk River at Vanlerberg Road is presented by Lotic as a project to armour 200 m of the right bank of the Elk River at the end of Vanlerberg Road (cost reported as $633,000).

  This site was considered by NHC with inclusion of diking to limit inundation as well as erosion.

- Elk River at Hill Road is presented by Lotic as a project armour 450 m of the left bank of the Elk River along the water side of the Hill Road dike (cost reported as $1,551,000).

  This site was considered by NHC within the current study.

5.1.3 Undocumented Strategies

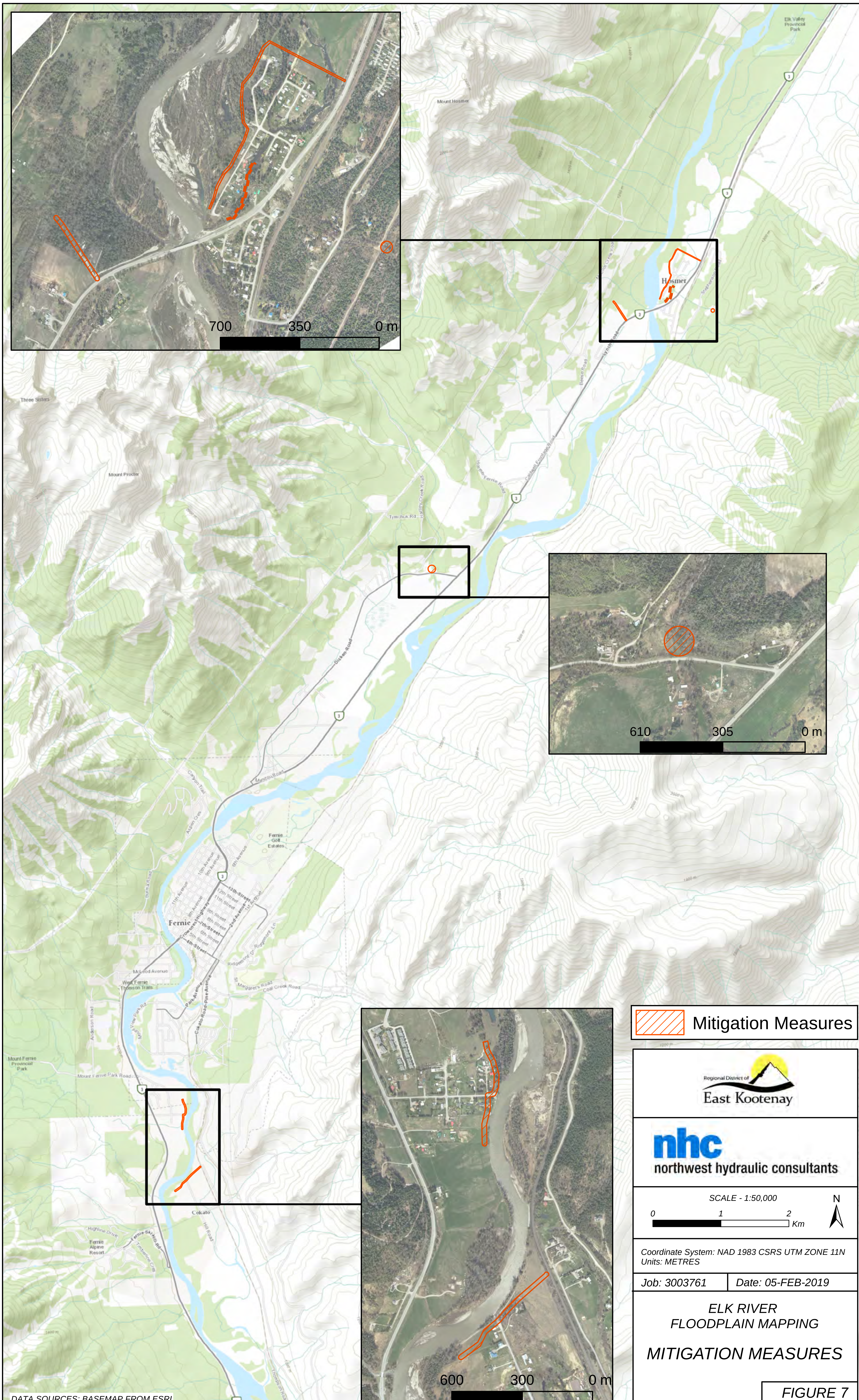
Through discussions with RDEK a number of other strategies have been considered. These are discussed below:

- It is our understanding that a dike or berm may have previously existed along the left bank of the Elk River at the upstream end of the town of Hosmer. This structure was constructed following the 1995 flood event, and primarily consisted of cobble and gravel placed at the mouth of the overflow channels to limit flood flows down these channels. This material has since been washed through, likely during the 2013 flood. A structure at this location could limit overflow down the numerous side channels that approach Hosmer. However, a structure at this location was not considered in detail during the current study, because i) flooding of the town of Hosmer is expected to initiate both upstream as well as at this site requiring substantial expansion of this structure to protect the town, ii) any remaining structure is understood to be in poor condition and would require substantial reconstruction, iii) being located along the bank such a structure would require extensive armouring to resist erosion. Due to the limited benefit of this site, an alternative dike alignment, set back from the active channel, is preferential for future diking.
- Bank armouring or spurs in the Elk River at this same location have been suggested (left bank of the Elk River at the upstream end of the town of Hosmer). Such structures could help to protect the dike as well as encourage the river to maintain a channel alignment along the right side of the valley reducing the potential of migrating towards the town of Hosmer. Although protection for the historic structure is not considered a high priority, maintaining channel alignment does have some benefit to the town of Hosmer and hence is presented further in the following sections.
- Channelization of the Elk River through Hosmer bridge crossing (under Hwy 3) was historically attempted through removal of sediment along the channel alignment. Removal of sediment can reduce the local migration and erosion pressures as well as reduce water levels during low to moderate flows. However, the localized increased depth provided from dredging is expected to have little impact on flood levels during extreme flood events and likely to infill during such events as large sediment loads typically accompany large floods. Furthermore, due to potential or perceived harm to fish and fish habitat, and potential to cause property damages[2] it should be expected that regulatory agencies, interest groups, and the public would oppose such work.

5.2 Structural Flood Hazard Mitigation

Potential for flood mitigation measures were identified from the floodplain mapping. Areas were targeted that had a number of homes, in relatively close proximity, that appeared to be at high risk to flood or erosion hazards. Figure 7 shows the locations of suggested structural mitigation measures, presented from upstream to downstream.

[2] Past correspondence suggests that the local sentiment is that properties downstream of the dredging suffered loss of land due to the dredging.



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5.2.1 Town of Hosmer - Upstream Dike

A) Overview

The portion of the town of Hosmer located on the left bank, upstream of the Highway 3 bridge has experienced substantial flooding in the past (such as 1995 and 2013 event) (Photo 6). From the floodplain mapping project, it became apparent that much of this flooding is coming from the Elk River with additional contribution from Mine Creek. A number of options were considered to improve the flooding that included; i) improvements to the existing railway berm to establish it as a dike, ii) construct a dike around this portion of Hosmer, and iii) improve drainage through the town of Hosmer along Mine Creek. The second option was selected to investigate further over the first due to the increased length of project required for the railway embankment option. This alignment is shown in Figure 8.

A similar dike alignment was proposed in 1996 by MFLNRORD and the RDEK following the 1995 flood (MFLNRORD, 1996).

Photo 6. Photo of flooded Mine Creek in Hosmer (Elk Street and 3rd Avenue) during the 2013 flood (from CBC website, courtesy A. Hanson).

The proposed dike would be set back from the river to locate the structure on higher ground, leaving it less at risk to erosion (and hence less likely to need for armouring), and minimizing the impacts to river conveyance, river processes, and riparian vegetation. The proposed alignment is to avoid houses where possible, however the dike is close to existing homes, which may interfere with views towards the river and potentially even use of the existing properties. These values will have to be considered prior to proceeding with this option.

The dike would need to include a culvert at the upstream end to maintain the current connectivity of Mine Creek and possibly a culvert would also be required for an existing side channel of the Elk River (depending on habitat value/use within this channel). The culvert could be sized to act as an orifice and limit flow from upstream to the town of Hosmer during flood flows, or potentially a gate could be added to the culvert. The gate could be manually operated or automated through the use of floats or level sensors and electrical actuators (i.e. SRT or self-regulating tide gate). Such structures are potentially costly to operate and maintain. It is expected a CSP of 1.8 m to 2.0 m diameter is the appropriate size to limit flow through town during flood events without substantially increasing upstream water levels or impeding normal flow of Mine Creek. The downstream end of the dike can be left open, allowing free discharge from the town of Hosmer (i.e. Mine Creek and Hosmer Creek) as flooding from the Elk River at this location is not a hazard at the design flood event.

Alternative to the culverts through the dike, would be to re-route Mine Creek west to the Elk River upstream of the dike. This would be a better hydraulic solution, but is expected to result in reduce aquatic habitat, and hence require greater compensation.

Figure 8. Proposed dike to protect the upstream left bank (south) side of Hosmer from Elk River & Mine Creek.

B) Cost Estimate

The quantities and cost for this work has been estimated based on rough geometry over the existing terrain. Volumes and cost can be refined with site survey. The cost estimate includes culverts and manually operated sluice gates (which may be needed) at both the secondary and primary channel crossings over Mine Creek, as well as some riprap armouring to protect the structure where high velocity is expected (i.e. the northwest bend in the dike and midway downstream where the historic side channel is near the dike).

A substantial cost for this dike is the acquisition of right-of-way for the structure plus an offset of 7.5 m on either side of the dike. The cost of obtaining the ROW has not been included. Cost share funding for design and construction may be available from senior levels of government, however there are few if any grants that will fund property acquisition

Table 1. Town of Hosmer upstream dike, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length	1,200 m	-	
Average Height	1.3 m	-	
Fill	12,300 m^3	85 $/$m^3$	$1,045,500
Armouring (300 m x 3 m high)	3,000 m^3	185 $/$m^3$	$555,000
Culvert Crossing – blind channel (0.6 m dia.)	22 m	600 $/m	$13,200
Culvert Flood Gates – blind channel	1	$7,000	$7,000
Culvert Crossing - Mine Creek (2 m dia.)	22 m	1,700 $/m	$37,400
Culvert Flood Gates – Mine Creek	1	$50,000	$50,000
Supplementary Construction	1	$200,000	$200,000
Soft Costs	+15%	-	$286,215
Contingency	+35%	-	$667,835
Total			$2,860,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000.

C) Risk : Feasibility Ratio Scoring

The following table presents the risk to feasibility ratio for developing a dike along the north and west side of the upstream left bank portion of the town of Hosmer. A high risk avoided score and a low feasibility score indicates the best scenario. This project received both a high-risk avoidance score and a high cost to implement score, resulting in a 5:5 ratio of benefit to cost.

Table 2. Risk : feasibility ratio for town of Hosmer upstream dike

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer U/S Dike	Likelihood	3	5	Ease of execution	3	5	5 : 5
	Consequence	3		Cost of implementation	3		

5.2.2 Town of Hosmer – Downstream Mine Creek Conveyance Improvements

A) Overview

As stated for the previous mitigation measure, the portion of the town of Hosmer located on the left bank, upstream of the Highway 3 bridge is subjected to flooding from the Elk River as well as Mine Creek and Hosmer Creek. In addition, or as an alternative to blocking off flow from the Elk River and Mine Creek at the upstream end of town (with a dike or diversion of Mine to the Elk River), increasing flow capacity within the town would help to alleviate flooding coming from Mine Creek. The culverts crossing under 3rd Ave (partially blocked 2 x 0.7 m dia, 1.2 m dia, 1.4 m dia culverts) may be adequately sized based on MOTI design standards (100-year flow for low occupancy roads) but appears to be inadequate for the design flood event. Flooding is evident upstream and at this crossing. Flooding is also evident downstream of the crossing; therefore, any increase in capacity upstream should be accompanied with increases in channel capacity downstream, such as increasing the width and or depth of the downstream channel. The following figure illustrates the existing flooding condition at this site under the design event (NHC, 2019).

Figure 9. Existing flood extents (blue hatch) under the design flood event through Hosmer with 3rd Avenue culvert circled (Mine Creek and Elk River over flow is from top to bottom).

B) Cost Estimate

The quantities and cost for this work has been estimated based on rough geometry over the existing terrain. Volumes and cost can be refined with site survey. An embedded CSP of 3.3 m diameter has been assumed for this estimate. However, the size should be designed based on local survey with consideration for elliptical or arch culvert as an alternative to reduce the required excavation depth. Channel dimensions have been assumed to have been increased by addition of roughly 6 m channel width for the downstream most 350 m of channel.

Table 3. Town of Hosmer 3rd Ave culvert and downstream channel improvements, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length of Channel Excavation	350 m	-	
Excavation Volume	4,200 m^3	35 \$/m^3	\$147,000
Channel Complexing/Restoration	350 m	250 \$/m	\$87,500
Culvert Crossing for Mine Creek (3.3 m dia.)	20 m	3700 \$/m	\$74,000
Supplementary Construction	1	\$ 40,000	\$40,000
Soft Costs	+15%	-	\$52,275
Contingency	+35%	-	\$121,975
Total			\$520,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000.

C) Risk: Feasibility Ratio Scoring

The following table presents the risk to feasibility ratio. A high risk avoided score and a low feasibility score indicates the best scenario. This project received a high-risk avoidance score and a moderate cost to implement score, resulting in a 5:4 ratio of benefit to cost.

Table 4. Risk : feasibility ratio for town of Hosmer 3rd Ave culvert and downstream channel improvements.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer D/S channel	Likelihood Consequence	3 3	5	Ease of execution Cost of implementation	3 2	4	5 : 4

5.2.3 Hosmer Creek Sediment Trap

A) Overview

In addition to Elk River and Mine Creek the upstream left bank portion of the town of Hosmer experiences flooding from Hosmer Creek, particularly at the railway and Highway 3 crossings. The crossings may be appropriately designed for current standards (100-year or 200-year flow), however under the design flood event the crossings do not have adequate capacity and flooding is expected along the embankments to adjacent properties. This will be particularly acute when debris and sediment accompany a flood event and potentially block these crossings. The following figure shows the extent of flooding with varying levels of blockage of the railway and Highway 3 crossings. Additional crossings under the embankments may exist other than the creek crossings which may reduce the extent of flooding, however such crossings were not found during the site inspection. The Hosmer Creek crossings were both partially blocked at the time of site inspection (NHC, 2019).

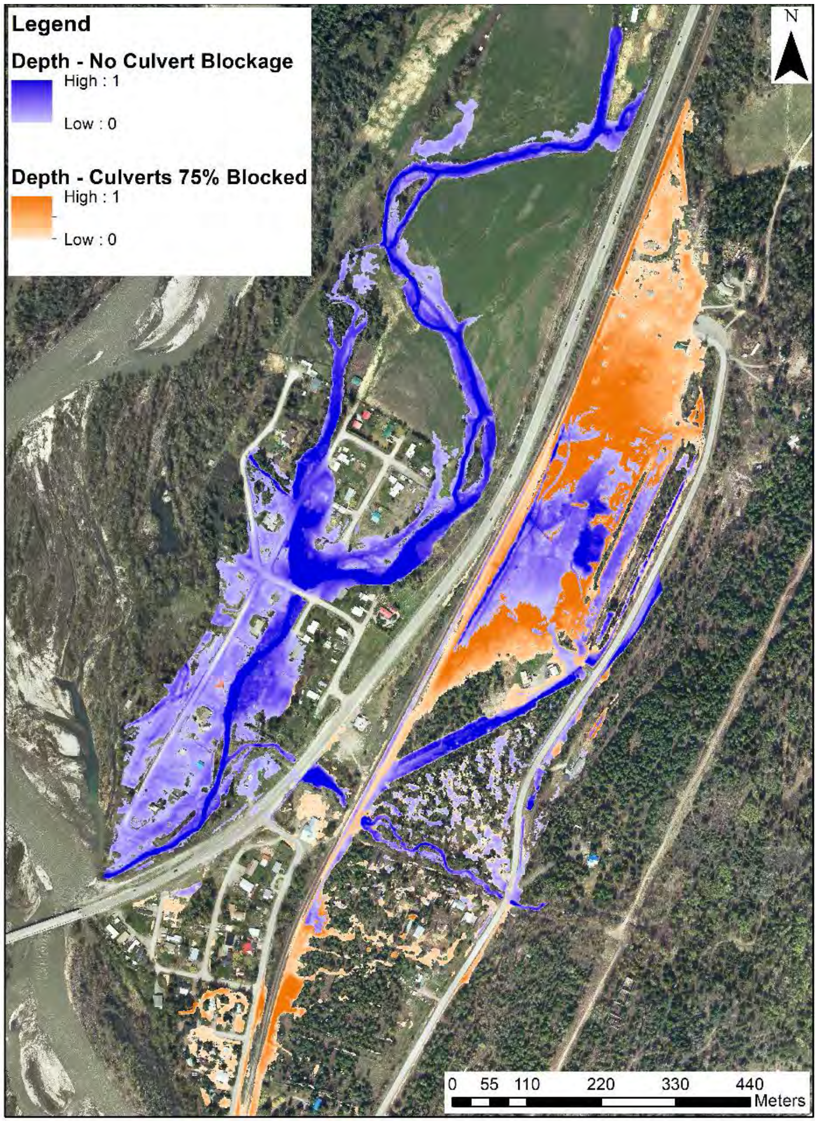

Figure 10. Hosmer Creek flooding at town of Hosmer for the design event with varying degree of blockage of the existing crossings.

To reduce the likelihood and extent of flooding these crossings should be routinely monitored and maintained to limit the likelihood of blockage from debris and sediment. Larger crossings may be warranted when the crossings are to be replaced, however in the interim a sediment trap upstream of the crossings (such as upstream of Stephenson Road or the upstream forestry road) may help to reduce the likelihood of blockage and frequency of sediment and debris removal. The largest challenge will to find adequate low gradient ground to develop such a basin. Removal of sediment and debris upstream of the upper most crossing will limit the rate of channel aggradation downstream of the sediment trap and may simplify permitting for ongoing sediment removal. Sizing and design of the sediment trap should be made based on record of past removals but is likely limited by the steepness off the terrain.

B) Cost Estimate

The quantities and cost for this work has been estimated based on rough geometry over the existing terrain. Volumes and cost can be refined with site survey and appropriate siting based on site inspection. Channel dimensions have been assumed as a series of ponds roughly 5 to 10 m wide by 20 m long.

Table 5. Hosmer Creek sediment trap, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length of Channel Excavation	60 m	-	
Excavation Volume	12,000 m^3	35 $/$m^3$	$420,000
Armouring	200 m^3	185 $/$m^3$	$37,000
Access	720 m^3	50 $/m	$36,000
Supplementary Construction	1	$ 70,000	$70,000
Soft Costs	+15%	-	$84,450
Contingency	+35%	-	$197,050
Total			$840,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000. In order for sediment traps to remain functional, sediment has to be periodically removed. The frequency of removal varies based on size of the sediment trap and the sediment load experienced in any given year. It is not uncommon that sediment is removed each year, which can be a sizable maintenance cost. A study of the sediment load and potential markets for the sediment would help define the design as well as the expected maintenance effort and cost.

C) Risk Scoring

The following table presents the risk to feasibility ratio. A high risk avoided score and a low feasibility score indicates the best scenario. This project received a moderate risk avoidance score and a moderate cost to implement score, resulting in a 4:3 ratio of benefit to cost.

Table 6. Risk : Feasibility ratio for Hosmer Creek sediment trap.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer Sediment Trap	Likelihood	2	4	Ease of execution	2	3	4 : 3
	Consequence	3		Cost of implementation	2		

5.2.4 Spurs Upstream of Hosmer

A) Overview

A substantial deposition zone exists along the Elk River upstream of the Hwy 3 bridge at the Town of Hosmer. The deposition causes overland flow, as experienced during the 1995 and 2013 flood, as well as channel widening and extensive lateral migration of the channel. This is evident when comparing the historic banklines at this site and noting the variable channel width and extensive migration over the past 50 to 60 years (Figure 11). During a site inspection at the site following the 2013 flood event (2013 September 4, Dale Muir), the low banks, extensive bank erosion, and suspended debris was noted (Photo 7). Gravel deposition upstream along the right bank and point bar growth directly across from the site was directing flow towards the left bank and the remnant channels that flow towards Hosmer.

It is probable that with time the channel will once again migrate along an alignment closer or towards the Town of Hosmer, as it appears to have from 1962 to 1979. Hosmer is located above the lower terrace where the channel would likely flow. However, such an alignment could require extensive armouring to ensure protection of town. As a pre-emptive measure spurs located along this bank could help direct flow towards the right bank and help to maintain the current alignment (located at the red oval in Figure 11). Typically, such structures are constructed out of angular rock but can potentially also be constructed out of wood (such as an engineered log jam, ELJ) or a combination of wood and rock. However, use of wood is potentially not suitable for this site, due to the power of the Elk River and proximity to the downstream bridge.

Spurs would help to maintain the channel alignment limiting the risk of channel migration but does not reduce the flood inundation risk. Reliance of the spurs for a dike near Hosmer may be limited, due to the existing overbank channels; that is, the spurs would not substantially reduce the cost of a dike. Furthermore, the spurs may impose a navigation challenge, permitting challenge (instream work), and reduce riparian vegetation; access road and ROW are likely to be required to access the spurs for monitoring and maintenance.

Photo 7. Downstream looking view of a) the erosion (evident by undercut banks and recent fallen trees) and b) debris transported during past flood flows (NHC, 2013 September 04).

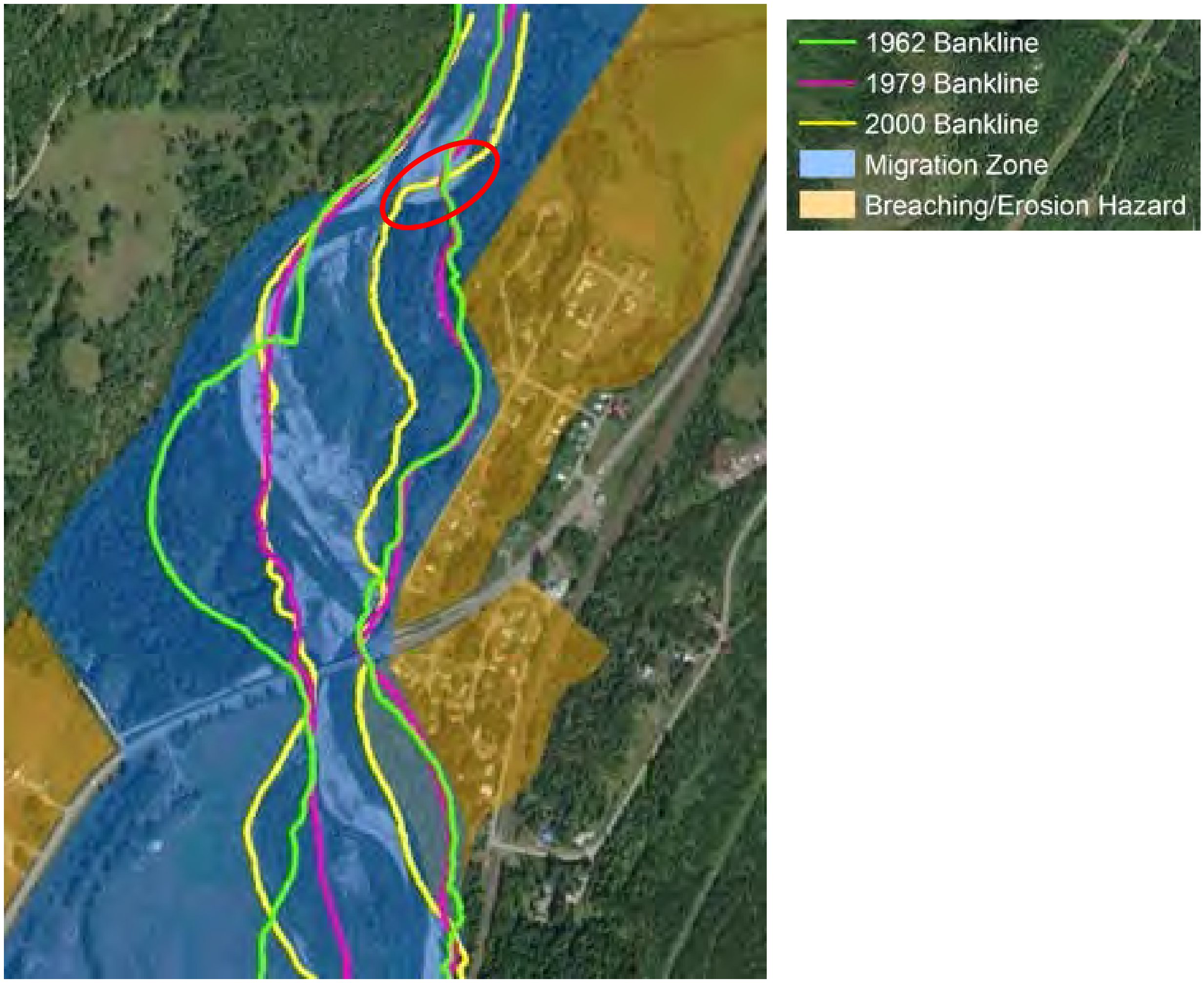

Figure 11. Bankline comparison of the Elk River at Hosmer.

B) Cost Estimate

It is estimated that 4 to 5 structures would be required, each 5 to 10 m long, spaced 15 to 30 m apart. Design of such structures is typically done using detailed 2D o 3D hydraulic modelling to confirm length and spacing. The following cost estimate is based on 4 structures, each 10 m long, constructed of angular rock riprap (Table 9). This estimate has been developed without the benefit of a recent site inspection or detailed site survey. The cost and potential challenges of obtaining the access to the land has not been included.

Table 7. Town of Hosmer upstream spurs, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length	10	-	
Average Height	2	-	
Number	4		
Rock Fill	550 m^3	185 $/$m^3$	$101,750
Supplementary Construction	1	$ 70,000	$70,000
Soft Costs	+15%	-	$25,763
Contingency	+35%	-	$60,113
Total			$260,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000. Access road development and habitat compensation may also be required adding to the cost.

C) Risk Scoring

The following table presents the risk to feasibility ratio. A high risk avoided score and a low feasibility score indicates the best scenario. This project received a moderate-risk avoidance score and a moderate cost for improvements to implement score, resulting in a 3:4 ratio of benefit to cost. The cost of ROW acquisition is somewhat accounted for in the ease of execution value selected but is not directly reflected in the cost.

Table 8. Risk : feasibility ratio for town of Hosmer downstream dike improvements.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer U/S Spurs	Likelihood	1	3	Ease of execution	3	4	3 : 4
	Consequence	3		Cost of implementation	2		

5.2.5 Town of Hosmer Downstream Dike

D) Overview

An existing orphan dike extends from the right bank approach road of the Highway 3 Hosmer bridge to the north side of the Elk River Valley. The dike was apparently constructed in 1948 and failed during the 2013 flood event. The mechanism of failure is not known; however, it is reported that the structure did not fail from being overtopped. Failure of this structure allows higher elevation floodwaters from upstream of the bridge to flow along the Highway 3 embankment and flood the properties north of Highway 3. When floodwaters reach development through this path, they have a high consequence to people and assets in the area, impacting approximately 70 structures. This flooding can be mitigated through a number of potential options; i) improving the existing dike, ii) improving drainage through the Highway 3 road embankment, iii) floodproofing future and existing structures within this floodplain.

The third option should be incorporated with any suggestion, at least for new and substantially renovated buildings. The second option should be considered by MOTI when the road is next substantially improved. The first option is the mitigation measure considered in further detail in this section of the report including upgrading the dike, rebuilding the dike and relocating the dike. Improvement of the dike is expected to require ROW acquisition, dike widening, dike raising, dike side slope improvements, and establishment of an ongoing maintenance and monitoring plan.

Figure 12 illustrates the location of the dike, the location of the potential setback dike and part of the downstream community sheltered by the dike. Two properties are located upstream of the current dike. Relocation of the dike to help protect these two homes has been considered.

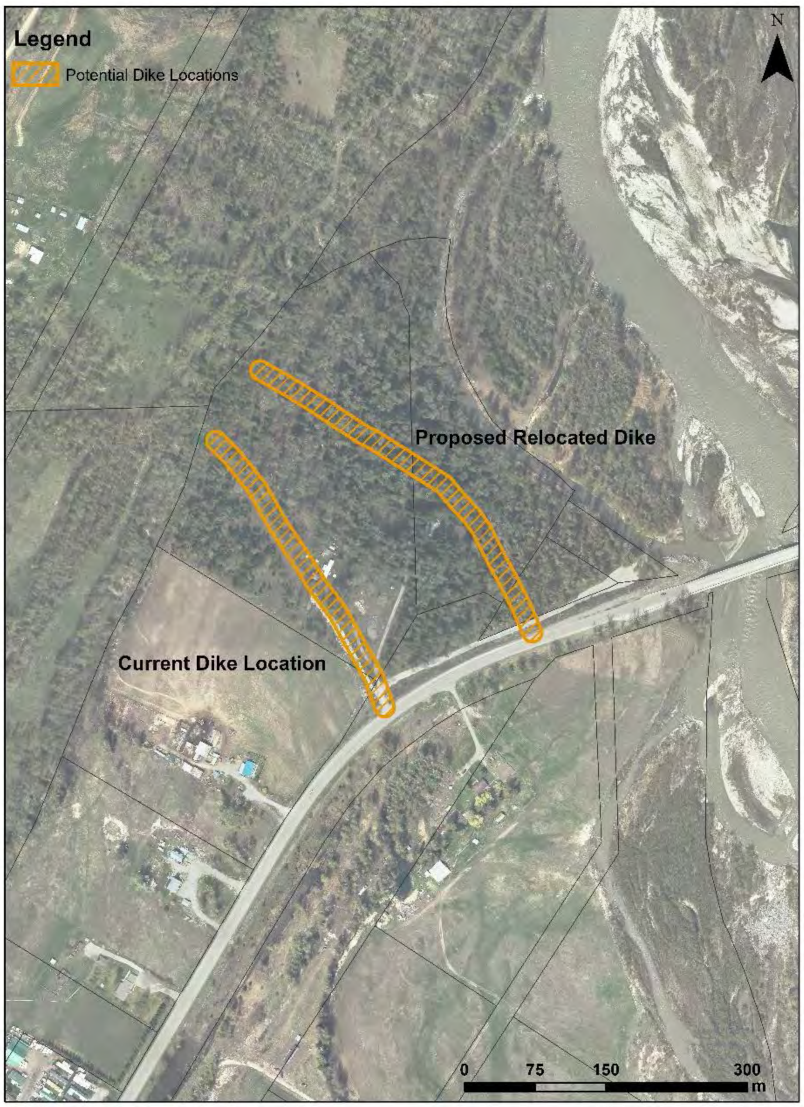

Figure 12. Hosmer downstream dike

E) Cost Estimate

The following cost estimate is based on the assumed requirements for improving this structure (Table 9). This estimate has been developed without the benefit of a site inspection, site survey, past as-built drawings, or detail photo documentation of the existing structure or its construction. Table 10 and Table 11 estimates are based on the assumed requirements for rebuilding the dike. Since, the dike has not been visually inspected, there are no drawings for the dike, no recent inspection reports, and since the dike failed during the 2013 event; it is felt that limited modification of the existing dike may not be possible and a rebuild may be required. The cost and potential challenges of obtaining the ROW has not been included.

Table 9. Town of Hosmer downstream dike upgrade, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length	320 m	-	
Average Height	1.7 m	-	
Fill	1,310 m^3	85 $/$m^3$	$111,350
Supplementary Construction	1	$ 75,000	$75,000
Soft Costs	+15%	-	$27,953
Contingency	+35%	-	$65,223
Total			$280,000

Table 10. Town of Hosmer downstream dike rebuild, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length (m)	320 m	-	
Average Height (m)	1.7 m	-	
Fill (m^3)	5260 m^3	85 $/$m^3$	$447,100
Supplementary Construction	1	$ 100,000	$100,000
Soft Costs	+15%	-	$82,065
Contingency	+35%	-	$191,485
Total			$820,000

Table 11. Town of Hosmer downstream dike offset, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length (m)	420 m		
Average Height (m)	1.5 m		
Fill (m^3)	5360 m^3	85 $/$m^3$	$455,600
Supplementary Construction	1	$100,000	$100,000
Soft Costs	+15%	-	$83,340
Contingency	+35%	-	$194,460
Total			$830,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000.

F) Risk Scoring

The following table presents the risk to feasibility ratio. A high risk avoided score and a low feasibility score indicates the best scenario. This project received a high-risk avoidance score and a low cost for improvements to implement score, resulting in a 5:3 ratio of benefit to cost. The cost of ROW acquisition is somewhat accounted for in the ease of execution value selected but is not directly reflected in the cost. Rebuilding and relocating the dike are both more expensive and more difficult to execute and therefore, were given a 5:5 ratio of benefit to cost.

Table 12. Risk : feasibility ratio for town of Hosmer downstream dike improvements.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer D/S Dike Upgrade	Likelihood	3	5	Ease of execution	2	3	5 : 3
	Consequence	3		Cost of implementation	2		
Hosmer D/S Dike Reconstruction	Likelihood	3	5	Ease of execution	3	5	5 : 5
	Consequence	3		Cost of implementation	3		
Hosmer D/S Dike Relocation	Likelihood	3	5	Ease of execution	3	5	5 : 5
	Consequence	3		Cost of implementation	3		

5.2.6 Hartley Creek Improvements

A) Overview

During high flow events, Hartley Creek can overflow its bank and cause flooding in the surrounding area. Hartley Creek has a high sediment and debris load, and without frequent monitoring and maintenance, the sediment and debris can block the crossing at Dicken Road and result in flooding. Flows from Hartley Creek have a medium consequence and can directly impact approximately 10 structures.

Constructing a sediment trap or basin upstream of Dicken Road could reduce flooding by reducing the frequency of sediment removal. This is relatively easy to implement other than challenges with siting a suitable location and acquiring ROW. This project would likely be done by MOTI which would therefore have to meet MOTI's priorities instead of RDEK's.

Upgrades to existing culvert conveyance under both Dicken Road and Highway 3 along Hartley Creek would reduce flooding by removing flow constrictions and potentially reducing the extent of sediment and debris deposition and blockage. Such improvements are likely only warranted when the roads are scheduled for substantial improvements. Despite such improvements ongoing monitoring and sediment removal is expected to be required. This work would be done by MOTI if deemed by MOTI to be warranted, and hence not further assessed.

Overbank flow from upstream of the Dicken Road – Hartley Creek crossing is expected to flow south along the Dicken Road embankment until it reaches the Highway 3 embankment. Adequate drainage is required at this location to limit the flood risk to the properties at this location. Site inspection of this location has not been conducted. If drainage at this location is not adequate, then it should be improved. Drainage likely to consist of culvert under Hwy 3. This work would be done by MOTI if deemed by MOTI to be warranted; and hence not further assessed.

B) Cost Estimate

The cost of improving conveyance capacity at the Dicken Road-Hartley Creek crossing at the junction of Highway 3 and Dicken Road have not been made. Such projects would need to be led by MOTI not RDEK. An estimate for the potential addition of a sediment trap upstream of Dicken Road is provided below, however this project may also be scoped to MOTI. This estimate should be considered coarse in nature as it was done without survey or detailed site inspection for this purpose. The cost of land acquisition is not included. Channel dimensions have been assumed as a series of ponds roughly 20 m long and 10 m wide.

Table 13. Hartley Creek sediment trap, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length of Channel Excavation	60 m	-	
Excavation Volume	15,000 m^3	35 $/$m^3$	$525,000
Armouring	300 m^3	185 $/$m^3$	$55,500
Access	720 m^3	50 $/m	$36,000
Supplementary Construction	1	$ 70,000	$70,000
Soft Costs	+15%	-	$102,975
Contingency	+35%	-	$240,275
Total			$1,030,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000.

C) Risk Scoring

The following table presents the risk to feasibility ratio. A high risk avoided score and a low feasibility score indicates the best scenario. These potential projects received a moderate risk avoidance score and a moderate cost to implement score.

Table 14. Risk : Feasibility ratio for Hartley Creek improvements.

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Dicken Road Sediment Trap	Likelihood Consequence	3 2	4	Ease of execution Cost of implementation	2 3	4	4 : 4
Increased Hartley Creek Crossing Conveyance	Likelihood Consequence	3 2	4	Ease of execution Cost of implementation	3 3	5	4 : 5
Improved conveyance at Hwy 3 and Dicken Road	Likelihood Consequence	3 2	4	Ease of execution Cost of implementation	3 3	5	4 : 5

5.2.7 Riverside

A) Overview

South of Fernie, there are approximately 40 buildings along Vanlerberg Road which are impacted by high water levels in the Elk River as simulated and mapped for the design flood event. In addition, the right bank of the Elk River at the end of Vanlerberg Road has been eroding and potentially threatens the road and homes. Figure 14 provides a comparison of historic banklines. The comparison shows that there has been some migration towards Vanlerberg Road. The distance of past migration does not appear to be large, however there was never much of a buffer between the river and development. Construction of a dike here is likely to require the purchase of property and homes along the river to provide a location for the dike.

Two sizable challenges for this area are; i) the limited space to construct a dike between the river and the existing homes, and ii) the large distance to extend the dike upstream (and downstream) to reach high ground. The RDEK boundary with the City of Fernie is 150 m upstream of Vanlerberg Road. A dike in this area would be expected to include an extension of the dike upstream around Riverside (through the City of Fernie) to high ground at the Highway 3 embankment.

The City of Fernie is not considering developing a dike in the Riverside area but may be open to a dike being constructed as condition of further development of the Riverside area. There are no indications that such a project is likely to proceed. If this dike is to go forward within the City of Fernie, it would be reasonable for the RDEK to then consider extending the dike to and potentially beyond Vanlerberg Road. Where the dike is not set back a substantial distance from the riverbank (the majority of the portion within the RDEK) armouring would be required. Typically, rock riprap is used for armouring critical infrastructure such as flood prevention dikes.

The dike portion upstream of Vanlerberg Road is expected to reduce the flood level by as much as 1 m for the properties near the upstream end of this dike. Vanlerberg Road could subsequently be raised and further protect the properties upstream of the road as well as improve safe egress from the area. Downstream extension of the dike would further lower the flooding level within this area. Vanlerberg Road would then be at or close to the resulting flood level. However, yards and likely homes downstream of Vanlerberg Road would still be below the FCL. To further improve flood protection the dike could continue downstream or bear west and tie into high ground at the Highway 3 embankment.

Alternative to diking in this area, the bank could be armoured. This would reduce the threat of erosion and channel migration, but not address potential flood inundation. The bankline downstream of Vanlerberg Road appears armoured already, but armouring could potentially be extended upstream or improved. Access road on top of the bank is generally required for construction, monitoring, and maintenance. The cost of armouring the bank is expected to be similar magnitude to diking, but primarily benefit the properties closest to the river.

Figure 13. Riverside dike, proposed alignment.

Figure 14. Bankline comparison at Riverside (NHC, 2019).

B) Cost Estimate

The quantities and cost for this work have been estimated based on rough geometry over the existing terrain. Volumes and cost can be refined with site survey. A substantial cost for this dike, as with all dikes is the acquisition of right-of-way for the structure plus an offset of a minimum 7.5 m beyond the landside dike toe. The cost and potential challenges of obtaining the ROW has not been included. Funding may be available from senior levels of government to support construction of the dike, however there are few if any grants that will fund property acquisition.

Table 15. Riverside dike, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length (upstream of Vanlerberg Rd)	150 m	-	
Ave. Height (upstream of Vanlerberg Rd)	1 m	-	
Fill (upstream of Vanlerberg Rd)	2,000 m^3	85 $/$m^3$	$170,000
Armouring (upstream of Vanlerberg Rd)	1,815 m^3	185 $/$m^3$	$335,775
Length (downstream of Vanlerberg Rd)	200 m	-	
Ave. Height (downstream of Vanlerberg Rd)	1 m	-	
Fill (downstream of Vanlerberg Rd)	1,800 m^3	85 $/$m^3$	$153,000
Armouring (downstream of Vanlerberg Rd)	2,420 m^3	185 $/$m^3$	$447,700
Supplementary Construction	1	$ 90,000	$90,000
Soft Costs	+15%	-	$179,471
Contingency	+35%	-	$418,766
Total			$1,790,000

Table 16. Riverside bank armouring, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length	150 m	-	
Ave. Height of bank	3 m	-	
Armouring	1,310 m^3	185 $/$m^3$	$242,350
Supplementary Construction	1	$ 70,000	$70,000
Soft Costs	+15%	-	$46,853
Contingency	+35%	-	$109,323
Total			$470,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000. The RDEK would have to assume the role as the Diking Authority to operate and maintain the dike or make arrangements with the City of Fernie.

C) Risk : Feasibility Ratio Scoring

The following table presents the risk to feasibility ratio for developing a dike along the riverside. This portion of dike is only applicable if and when the City of Fernie develops a dike upstream. A high risk avoided score and a low feasibility score indicates the best scenario. This project received both a high risk avoidance score and a high cost to implement score, resulting in a 5:5 ratio of benefit to cost.

Limiting the project to bank armouring changes the risk : feasibility ratio to 3:4.

Table 17. Risk : feasibility ratio for Riverside dike

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer U/S Dike	Likelihood	3	5	Ease of execution	3	5	5 : 5
	Consequence	3		Cost of implementation	3		

Table 18. Risk : feasibility ratio for bank armouring at Vanlerberg Road

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hosmer U/S Dike	Likelihood	2	3	Ease of execution	3	4	3 : 4
	Consequence	2		Cost of implementation	2		

5.2.8 Cokato Area (Hill Road Dike)

A) Overview

There are approximately 30 structures in the Cokato area which are in the Elk River floodplain and/or are at risk from bank erosion. The properties are located on the outside of an eroding right bend. The Hill Road dike (an orphan dike) is located along the top of this bank and has been reported as being threatened by erosion. Comparison of historic bank lines (see Figure 16 below) illustrates ongoing erosion at this site. The distance of channel migration is relatively small, but as the structure was built close to the top of bank there was little room to accommodate erosion before the structure was threatened. This structure was damaged during the 2013 flood from channel migration eroding the floodplain that was supporting the dike. The dike was subsequently repaired but remains at threat to erosion.

It is proposed that this structure be raised to the current FCL, extended upstream to tie into high ground, and armoured to protect it from erosion. Rock riprap is the typical armouring used to protect critical structures such as dikes. Spurs could potentially also be used as a bank armouring strategy; however, they may increase the cost and impact navigation. The dike does not tie into high ground at the downstream end. It does however limit flow and velocity across the area behind the dike as well as reduce the water level at the upstream end of the dike by as much as 2 m.

Constructing a new setback dike was also considered as an alternative. Ideally the dike would be set a minimum of 30 to 60 m from the top of bank, however some locations are likely to constrain a set back of closer to 20 m (i.e. where houses exist). Armouring may be reduced (limited to the area near the existing homes) or postponed by setting back the dike. However, depending on the velocity expected at the dike, armouring may still be required along the face of the dike. The dike could also be extended downstream to tie into the west end of Robinson Road and this portion of road raised to the FCL to further improve flood protection. This additional extension has not been assessed under the current study. Flooding in this area has high consequences due to the relatively high density of structures and population.

Figure 15. Hill Road dike

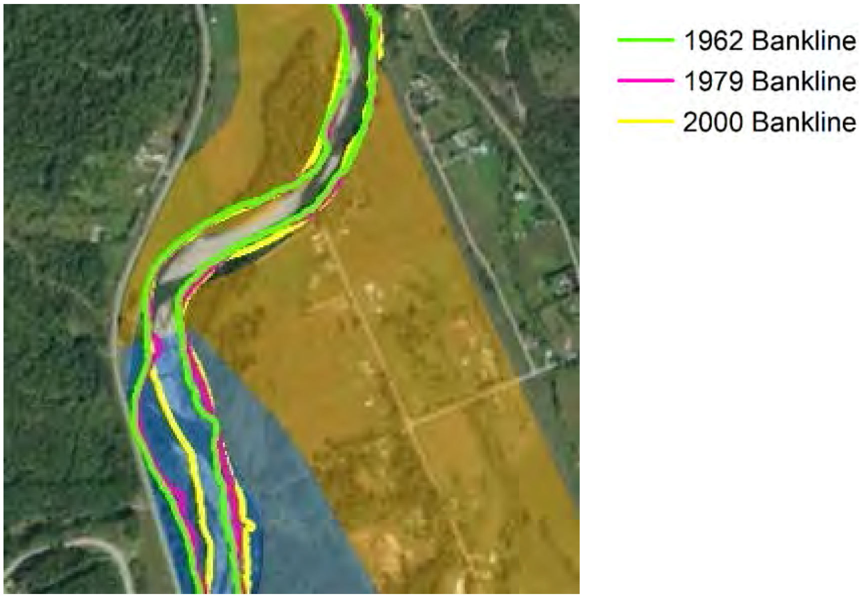

Figure 16. Bankline comparison at Hill Road dike (NHC, 2019).

B) Cost Estimate

The quantities and cost for this work has been estimated based on rough geometry over the existing terrain. Volumes and cost can be refined with site survey. A substantial cost for this dike, as with all dikes is the acquisition of right-of-way for the structure plus an offset of a minimum 7.5 m from the dike toe. The cost and potential challenges of obtaining the ROW has not been included. The setback cost estimate assumes roughly 300 m of armouring would still be required where the dike cannot be set back due to existing homes. Funding may be available from senior levels of government to support construction of the dike, however there are few if any grants that will fund property acquisition.

Table 19. Hill Road dike upgrade, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length	500 m	-	-
Average Height	0.5 m	-	-
Fill	2,200 m^3	85 $/$m^3$	$187,000
Armouring	11,880 m^3	185 $/$m^3$	$2,197,800
Supplementary Construction	1	$ 275,000	$275,000
Soft Costs	+15%	-	$398,970
Contingency	+35%	-	$930,930
Total			$3,990,000

Table 20. Hill Road dike setback, estimate of quantities and costs.

Item	Quantity	Unit Rate	Cost
Length	500 m	-	-
Average Height	1.6 m	-	-
Fill	7,040 m^3	85 $/m³	$598,400
Armouring	7,200 m^3	185 $/m³	$1,332,000
Supplementary Construction	1	$ 225,000	$225,000
Soft Costs	+15%	-	$323,310
Contingency	+35%	-	$754,390
Total			$3,230,000

Supplementary construction cost has been included to account for cost of testing, surveying, water and erosion control, mobilization, clearing, grubbing, demobilization and other costs beyond the bulk material supply and placement. The total cost has been rounded to the nearest $10,000.

C) Risk : Feasibility Ratio Scoring

The following table presents the risk to feasibility ratio for improving and setting back the Hill Road Dike. A high risk avoided score and a low feasibility score indicates the best scenario. The upgrade received a high-risk avoidance score and a moderate cost to implement, primarily due to the structure already being in place, resulting in a 5:4 ratio of benefit to cost. The cost of this structure is, however, fairly high due to the length and extent of armouring expected to be required. The actual quantity may substantially change depending on site survey. The setback option is more difficult to execute because it requires obtaining ROW but is less expensive than the upgrading option. The benefit to cost ratio is 5:5.

Table 21. Risk : feasibility ratio for Hill Road dike

Proposed Measure	Risk Avoided Score			Feasibility Score			Risk : Feasibility Ratio
	Factor	Factor Score	Overall Score	Factor	Factor Score	Overall Score	
Hill Rd Dike Upgrade	Likelihood Consequence	3 3	5	Ease of execution Cost of implementation	2 3	4	5 : 4
Hill Rd Dike Setback	Likelihood Consequence	3 3	5	Ease of execution Cost of implementation	3 3	5	5 : 5

5.3 Non-structural Mitigation

Cost of implementation and risk : feasibility scoring was not conducted for the non-structural mitigation measures. It is however expected that the non-structural measures are likely to have highest benefit to cost ratio as they can benefit large numbers of people are typically substantially lower cost than construction and on-going monitoring and maintenance of structural measures.

5.3.1 Flood Emergency Response Planning and Warning

The updated floodplain maps should be used to update the ERP. Contacts within an ERP should be reviewed and updated annually with a more thorough review every 7 to 10 years; this update schedule aligns with that required for dams under the *Dam Safety Regulation*.

As a rain-on-snow derived event, floods along the Elk River can peak quickly. Both the 1995 and 2013 flood events experienced a substantial increase in flow over a relatively short period of time. Average daily flow for the days surrounding the 2013 flood event are plotted in Figure 17. During this flood, flow increased from an average daily flow of just over 500 m^3/s on June 20th to a peak flow of 1060 m^3/s on June 21st. This substantial spike in flow illustrates the limited warning prior to flood flows. Following the peak, flows receded slightly more gradually over the following two or three days.

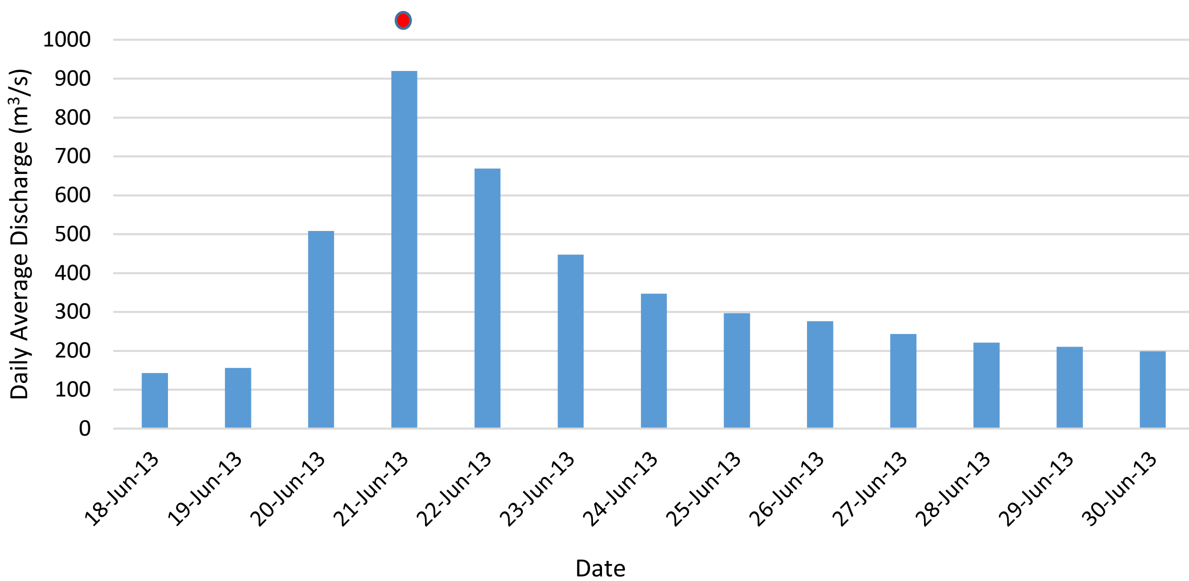

Figure 17. Daily average discharge for the days surrounding the June 21, 2013 flood event, with a dot representing the peak flow.

Currently, there is only one active gauge on the Elk River upstream of the study reach and no active gauge on Elk River tributaries near the study reach. These gauges along with existing real time snow pack information (such as the BC Hydro alpine station operated by NHC), and weather forecasts provide information to help forecast floods. The BC River Forecast Centre provides flood forecasting during flood season (http://bcrfc.env.gov.bc.ca/warnings/index.htm).

Based on the recent floodplain mapping model, it is estimated that the peak flow of 2013 reached the City of Fernie roughly 4 hours after it passed the Elk River near Natal gauge. This estimate is supported by comparison of the 2018 peak flow, which suggests a delay of roughly 4 hours (hourly flow data from the Elk River near Natal gauge is not available for the 2013 flood event). Based on watershed scaling, flow as observed at the Elk River near Natal gauge is expected to be roughly 60% of that observed at Elk River at Fernie gauge. In other words, if a flow of 400 m^3/s or more is observed near Natal than flows in excess of 700 m^3/s can be expected at Fernie; roughly a 50-year event.

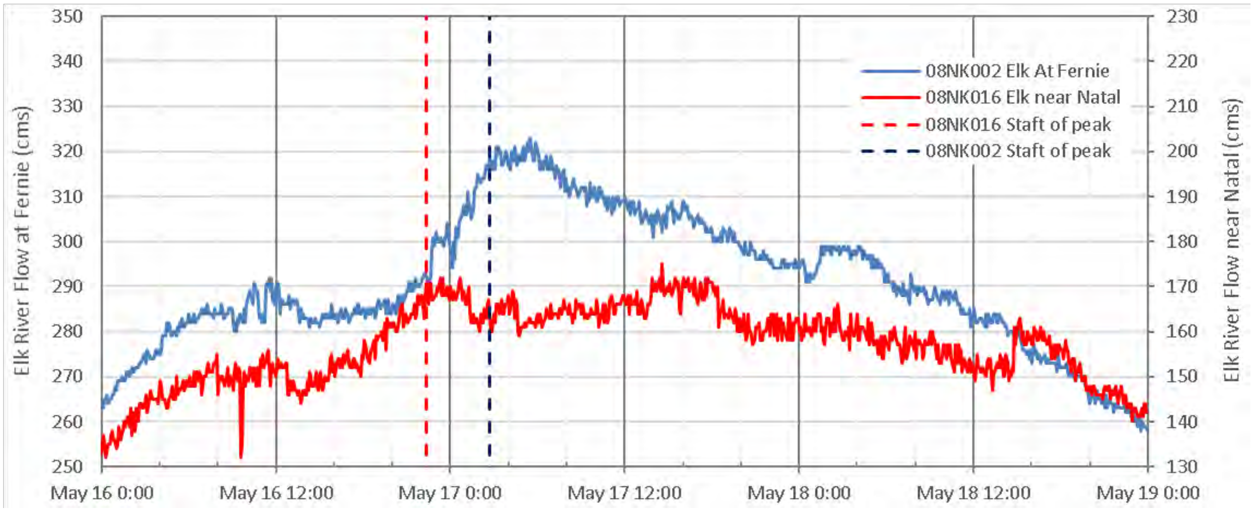

Figure 18. Comparison of flow reported for Elk River near Natal with Elk River at Fernie during the 2018 freshet

Prior to 1996, Water Survey of Canada (WSC) also operated gauges upstream of Sparwood which, if reinstated, could further inform flood forecasts for communities along the Elk River. Real-time data on the existing or additional tributaries could further help inform communities along tributaries of increasing flood risk; such as communities along Mine Creek, Hosmer Creek, and Hartley Creek.

Below is a table of existing and historic gauges. The drainage area to each of the gauges (as reported by WSC) is also presented to allow comparison between the gauges.

Table 22. Existing and historic WSC gauges near the study reach.

Location	Number	Area (km^2)	Record	Status
Hosmer Creek at Diversions	08NK026	6.4	1981+	Active
Elk River Below Weary Creek	08NK027	334	1982-1996	Historic
Michel Creek below Natal	08NK020	637	1970-1996	Historic
Elk River Near Natal	08NK016	1,840	1950+	Active
Elk River at Fernie	08NK002	3,090	1925+	Active

5.3.2 Regulatory Controls

The most obvious mitigation measure, due to relatively minor cost and effectiveness at reducing flood risk, is the development of regulatory controls on development within the floodplain. Although such measures do not help existing structures and infrastructure, they do limit potential threats for future development.

As granted in the provincial *Local Government Act* the RDEK has general powers to regulate the development in floodplains similar to municipalities where they act in the interest of the public safety:

- Sections 472-473 empowers regional districts to adopt an official community plan through which restrictions may be placed on the use of land that is subject to "hazardous conditions".

- Section 479 empowers regional districts to "divide the district into zone and regulate or prohibit any use or uses in a zone."
- Section 491 empowers regional districts to establish development permit areas where subject to flooding and regulate development in those areas.
- Section 524 states that if a regional district considers that flooding may occur on land, it may designate the land as a floodplain, specify an FCL and setback for the area, and enforce new development to be built in accordance to the standard.

In addition, *Land Title Act* states:

- Section 86, the regional district may refuse to approve the subdivision plan "if the approving officer considers that the land is subject, or could reasonably be expected to be subject, to flooding."

It is our understanding that the BC Ministry of Transportation and Infrastructure (MOTI) subdivision approval officer currently exercises this authority in the RDEK. Either MOTI or RDEK should consider applying regulatory control on development within the floodplain. As an example, the maps could be used to help this guide control such as:

- Floodway – land within the floodway could be designated as areas not suitable for further development. The floodway is illustrated on the FCL designation map and signifies the region of the floodplain that conveys the majority of the flow. This area typically has depth in excess of 1 m and or velocity greater than 1 m/s. Furthermore, through encroachment analysis, it was determined that encroachment of fill or structures within this area has the potential to transfer the flood risk to other properties by increasing flood levels upstream by 0.3 m or more.

  Some communities have allowed limited development within the floodway for specific land use (i.e. agriculture and recreation) or on pre-existing lots that otherwise would not be buildable. Such allowances should be reviewed and only approved if deemed safe for use and do not transfer flood risk to other properties. Covenants and occasionally other communications (such as signage, or warnings in lease agreements) are typically a condition of such developments to ensure future land owners and users are aware of the risk. Evacuation planning for humans, animals, and potentially goods of value and potentially damaged by floodwaters should be considered prior to development.

- Flood fringe – designates land within the flood inundation zone that may be deemed acceptable for development provided adequate mitigation measures are adhered to. The flood fringe is illustrated on the FCL designation map.

  Building to the FCL provides a primary mitigative measure. Typically, mitigation measures also include set back from the top of bank or water's edge by a defined amount; for this scale and form of river a setback of 60 m is typically adopted. Some communities further limit the density of new development within the flood fringe and or place other requirements such as inclusion of an evacuation plan prior to approving development. Setback as a mitigation measure should also consider remnant side channels that may reactivate during high flow events. Identification of such features has been used to define the migration hazard zone, but such features and hazards should be considered on a site-specific basis.

- Fan hazard zone – are lands designated to be within an alluvial fan. Active alluvial fans can be more susceptible to aggradation, channel migration, and avulsion than areas within the floodplain adjacent to the fan.

  Due to the potential for increased hazard and vulnerability of development within active alluvial fans, a site-specific flood hazard assessment completed by a Qualified Professional is usually required as a condition of development approval. Relevant professional practice guidelines are published by Engineers and Geoscientists of BC (EGBC, 2018). Site specific mitigation measures may be more extensive than normally considered for other areas on the floodplain.

- Erosion hazard zone – as designated on the attached geomorphic hazard maps, signify areas that have increased hazard derived from bank erosion. The erosion can directly affect the property – such as erosion of the bank along the edge of a property – or indirectly affect the property – such as erosion and failure of an existing dike could lead to increase flood hazard at downstream properties. Changes in the hazard as erosion progresses can be gradual as erosion encroaches a few meters further each event of high flow season or can be relatively sudden such as failure of an existing dike.

  Erosion hazard zones have been identified to help ensure that development approvals within such zones account for this hazard. Potential mitigation measures include increased setbacks from the water's edge, monitoring and maintenance programs, erosion protection at the river bank and foundation fills, setback dikes, or reduced density of development.

- Migration hazard zone – as designated on the attached geomorphic hazard maps, signify areas that have increased hazard derived from potential lateral migration of the channel. Channel migration may occur over decades or during one or two large floods. Migration hazard zones have been identified to ensure development within such zones account for this hazard when determining if development is safe or what mitigation measures are required. Potential mitigation measures include, increased set back from the water's edge, erosion protection near the building site (i.e. foundation fill), setback dikes, or reduced density of development.

Any development within the floodplain should only be done following a site-specific flood hazard assessment conducted by a registered professional following the EGBC guidelines for such assessments (2018). Assessments may be waived by regulators if the flood risk and any mitigation measures are well known; for example, development within an existing community, behind a regulated dike, with current floodplain mapping.

The hazard zones identified by in NHC's Floodplain Mapping Study (2019) are based on a specific design event with a relatively low probability of occurrence and has included an allowance for the projected change in climate to the year 2100 associated with global climate change. However, changes in climate, land use, river form, or societies' risk tolerance may limit the usefulness of this work in time. Historically, floodplain maps in British Columbia are expected to need replacement every 25 to 30 years. Climate change is expected to increase the rate of change in the future; these maps may therefore need replacement or review every 10 to 15 years.

5.3.3 Awareness and Education

Education around flood awareness should focus on broadcasting:

- Community resources with respect to flooding (such as information from Elk River Alliance, BC Flood Forecast Centre, RDEK website, Fernie website, evacuation information)
- Existing ERP (particularly procedures, areas and transportation routes potentially inundated, local safe areas)
- Floodplain mapping
- Mechanism and timing of flooding (such as ice jams in the winter and rain-on-snow floods in the spring)
- Household emergency planning and rapid response (such as having emergency food supply of non-perishable goods and water for all family members and pets, have emergency kits with essential items and go bags prepared, have plans to meet family members caught away from home in emergency, etc.)

A provincial review of floods and wildfires (BCFWR, 2018) identified dissemination of awareness and education as one of the key pillars of a complete flood mitigation plan. Flood mapping is identified as the first step of awareness of the hazard (NRC/PSC, 2018). Despite preparation of the floodplain map, distribution and education should shortly follow.

The 2019 floodplain mapping is based on a flow that is nearly 60% greater than the previous 1979 maps, this results in increased inundation extents and higher FCLs; people that may have once considered themselves safe from a flood may now be within the designated flood boundary and should be made aware of the risk. In addition, the datum has changed, and must be considered when comparing the two maps.

5.3.4 Monitoring and Maintenance

Many of the tributary flood conditions are exasperated by blockage of crossings, such as the 3rd Avenue crossing on Mine Creek, the railway and Highway 3 crossings at Hosmer Creek, and the Dicken Road and Highway 3 crossings on Hartley Creek. Monitoring and subsequent removal of debris and sediment from these culverts and their entrances should be done routinely throughout the high flow season to ensure flow is not further restricted at these locations. In addition, any dikes or other flood protection infrastructure should be inspected annually and maintained as needed. Operation, maintenance, and surveillance (OMS) documents should exist for key flood mitigation infrastructure to help guide this process.

Another example of recommended monitoring is that for the Hosmer exfiltration ponds (located 11.5 km south of Sparwood). These ponds are not currently at threat from channel migration or inundation during the design flood event, however the river should be monitored as the level or risk may change with changes in the river.

6 CONCLUSION

The recently produced floodplain hazard maps were used to identify and assess potential flood mitigation measures within the RDEK along the Elk River between the District of Sparwood and

Morrissey. Options for structural and non-structural mitigation measures were identified and the structural options were scored for their feasibility, cost, and risk avoidance.

It is recommended that the specific non-structural mitigation measures should be considered and implemented as soon as practical because of the large benefit versus reasonable costs. This includes:

- Development or application of land use regulation for properties within the floodplain using the recently developed floodplain maps.
- Consideration of developing an early warning protocol with the existing Elk River at Natal gauge, and potentially additional real-time gauges.
- Establishing a monitoring protocol for the Elk River at the Hosmer exfiltration ponds.
- Review of the Emergency Response Plan with respect to the new floodplain maps.

In addition, the RDEK should incorporate on-going education for flooding and monitoring and maintenance of flood protection infrastructure.

Structural flood mitigation measures are costly to construct and maintain and frequently blocked by the difficulty in obtaining property rights. Therefore, structural mitigation measures are rarely practical except for areas where the hazard and consequent are great. Table 23 describes the recommended structural mitigation measures for the Elk River based on the criteria and scoring.

Table 23. Recommended mitigation measures.

Location	Structural Mitigation Measure	Purpose	Cost
Elk River at Hosmer	Dike construction along Elk River	Protects against through flooding from Elk River and Mine Creek.	$2,860,000
Mine Creek at Hosmer	Downstream Mine Creek conveyance improvement	Improve Mine Cr conveyance (widen / deepen channel) through Hosmer.	$520,000
Hosmer Bridge	Upgrade existing dike (downstream right bank)	Protects properties north of Hwy 3 downstream of bridge. Upgrade to current standards.	$280,000
Cokato	Setback Hill Road Dike	Protect existing structure from erosion & homes from Elk River floodplain flow.	$3,230,000

Table 24 describes all the structural mitigation measures considered in this report and their scoring with the measures expected to result in the greatest reduction in flood risk presented first. Of the structural mitigation measures identified, the greatest risk avoidance or benefit is expected to occur from constructing a dike around the upstream portion of the Town of Hosmer, maintaining Mine Creek conveyance (dredging) through Hosmer, and reconstruction of the existing downstream Hosmer dike. These three measures range in cost from one of the most expensive mitigations to one of the least expensive, as presented in the following table of highest ranked structural mitigation measures.

Table 24. Summary of structural mitigation measures.

Location	Structural Mitigation Measure	Purpose	Risk : Feasibility Score	Cost
Elk River at Hosmer	Dike construction along Elk River	Protects against through flooding from Elk River and Mine Creek.	5:5	$2,860,000
Mine Creek at Hosmer	Downstream Mine Creek conveyance improvement	Improve Mine Cr conveyance (widen / deepen channel) through Hosmer.	5:4	$520,000
Hosmer Bridge	Upgrade existing dike (downstream right bank)	Protects properties north of Hwy 3 downstream of bridge. Upgrade to current standards.	5:3	$280,000
Hosmer Bridge	Reconstruct existing dike (downstream right bank)	Protects properties north of Hwy 3 downstream of bridge. Reconstruct dike assuming current structure is not repairable.	5:5	$820,000
Hosmer Bridge	Relocate existing dike upstream (downstream right bank)	Relocation dike to protect houses upstream as well as downstream of existing structure.	5:5	$830,000
Riverside	Construction of Riverside dike at Vanlerberg Road	Protect from Elk River overbank flooding and ongoing erosion.	5:5	$1,790,000
Riverside	Riverside bank armouring	Alternative protection against erosion and channel migration, does not address inundation.	3:4	$470,000
Cokato	Armour and raise Hill Road Dike	Protect existing structure from erosion & homes from Elk River floodplain flow.	5:4	$3,990,000
Cokato	Setback Hill Road Dike	Protect existing structure from erosion & homes from Elk River floodplain flow.	5:5	$3,230,000
Hosmer Creek	Hosmer Creek sediment trap	Remove sediment from Hosmer Creek to prevent blockage of culverts and aggradation of channel.	4:3	$840,000
Hartley Creek	Dicken Road sediment trap	Define location and operations for sediment removal, increase volume for sediment storage.	4:4	$1,030,000
Hartley Creek	Increase Hartley Creek crossing conveyance at Dicken Rd and Hwy 3	MoTI replace crossings to limit frequency of crossing blockage and subsequent overland flooding.	4:5	NA
Hartley Creek	Verify or improve drainage through Hwy 3 east of Dicken Road	Current conveyance capacity is unknown. Overland flow from Hartley Cr. would pond here if drainage is inadequate.	4:5	NA
Hosmer Upstream	Spurs along the Elk River	Maintain current channel alignment away from town	3:4	$260,000

Other options with high risk avoidance scores are protecting or setting back the Hill Road dike in the Cokato region and armouring and diking the downstream end of Riverside. The Hill Road project protects a smaller community and has similarly high cost to that of diking around Hosmer. However, protection of an existing dike asset through set back or armouring may be easier to accomplish than developing new infrastructure.

The Riverside dike option also protects a sizable community and similar cost to the proposed Hosmer dike. However, this project unlikely to progress as the City of Fernie does not intend to build the upstream connection of this dike. The Riverside dike is also challenged by the limited space between existing buildings and the river, and the diking portion has limited benefit until diking is constructed upstream.

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