Elk River
FLOOD STRATEGY

Final Report
June, 2016

PREPARED FOR

Regional District of East Kootenay
Real Estate Foundation of BC
Columbia Basin Trust
Teck Coal

PREPARED BY THE PARTNERSHIP OF

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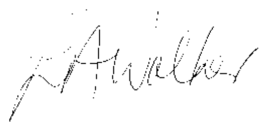
Contact Information

On behalf of the project team, I appreciate the opportunity to complete this valuable assessment and to provide recommendations for proactive solutions that keep citizens safe from flooding, protect key infrastructure, and increase watershed resiliency. Together, this information is intended to contribute to sustainable development within the Elk River watershed.



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- RDEK Area A Flood Mitigation Service Area Contribution
- Columbia Basin Trust Environmental Initiatives Grant
- Real Estate Foundation BC Grant
- RDEK Community Initiatives Grant
- Teck
- Mitacs Inc. University of British Columbia (provided funding to the University of Lethbridge).

In-kind services were also generous and fundamental to the project's success:

- The University of Lethbridge provided Ph.D. and post Doctorate candidates, and graduate and undergraduate students in hydrology and geography to complete the hydrological assessment and the Elk River flood model
- Teck provided a data sharing agreement with the Elk River Alliance for use of 2011 and 2012 orthophoto and LiDAR imaging
- The Regional District of East Kootenay, District of Sparwood, and Government of BC also provided in-kind contributions (e.g. LiDAR, orthophotos and maps).

We are grateful to the time and contributions provided by the public, government and other stakeholders during the flood outreach and technical review workshop components of this project.

Valuable peer review was provided by Kara Zandbergen (Engineering Technician, RDEK), Brian Funke (Manager, Engineering Services, RDEK), Stella Swanson (PhD, Aquatic Biologist, ERA Director) of Swanson Environmental Strategies Ltd, Jim Miller (PEng - retired, ERA Director), and Bruce Elson (PEng - retired).

Errors and Omissions

The attached report ('the Report') was prepared in accordance with the Agreements between the Elk River Alliance (ERA) and the Funding Partners (see Acknowledgements) and the subsequent agreements between the ERA and the Project Team.

The information, data, analysis, results, recommendations and conclusions contained in the Report:

- Is subject to the scope, schedule, and other constraints and limitations in the Agreements;
- Represents the Project Team's professional judgement using standards, where available, for the preparation of similar reports;
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- Has not been updated since the date of issuance of the Report, and its accuracy is limited to the time period and circumstances in which it was collected, processed, and made; and,
- Is intended to be read as a whole, and sections thereof should not be read out of context.

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Executive Summary

A group of Elk Valley local government officials and staff, industry representatives, and community members met at a critical meeting hosted at the City of Fernie chamber in July following the June 2013 flood. Participants agreed that the following were needed: 1) a better understanding of the current and future condition of the Elk River and its flooding behaviour; and, 2) a holistic flood strategy protecting residents, community infrastructure, as well as watershed function and wildlife.

The Elk River Watershed Alliance (ERA) is an independent, non-profit community-based water group formed in 2010 that promotes a holistic approach to management of human actions in the Elk River watershed. ERA took on the challenge to coordinate the collection of the above requested information, and community input for proactive flood management. The Elk River Flood Strategy report (Flood Strategy) provides a review of how the local watershed functions within the larger environment, current and forecasted streamflow and flooding in the Elk Valley, effects of flooding on community, fish and wildlife, and effective measures available to help mitigate against future flood risk.

The Flood Strategy team had substantive professional and local Elk River watershed experience, and included: the ERA, contractors, academics, local government staff, and dedicated ERA board members as a review team. Team backgrounds were diverse, including: environmental management, aquatic biology, municipal and water engineering, hydrology, hydraulics, and computer modelling. Elk Valley residents who experienced past flooding, provided critical observations and analysis of our local response, as well as suggestions for moving forward as a resilient, prepared citizenry and community.

Analysis of flooding in the Elk River (Section 3)

Flooding on the Elk River was analyzed first by discussing the conceptual framework of a watershed. A quantitative analysis was then completed of the hydrology of the Elk River and tributaries, with particular emphasis on the conditions that result in flooding and how these are affected by land use and climate change.

Watershed function and the interconnectedness between hydrology, ecology, and water quality were investigated. This addressed how changes to one element invariably affects the others, and that while a watershed can withstand a certain degree of change, dramatic or cumulative disturbance can eventually lead to a shift in watershed response. Effective watershed management going forward must recognize that natural and human activity within the Elk Valley invariably affects watershed function and can cause fragmentation and a loss of diversity, both of which can further reduce the watershed's resiliency to future disturbances.

The hydrologic regime of the Elk River at Fernie was examined. A review of the three largest floods on record in the Elk Valley (2013, 1995 and 1974), showed that flooding occurs almost exclusively during this peak flow period, and that extreme floods are typically preceded by extreme rainfall events coinciding with near-peak snowmelt. A statistical evaluation of the observed changes to the hydro-meteorological drivers of flooding in the Elk Valley suggests that there has been an increase in spring rainfall and winter snowpack since 1970, although this does not appear to have manifested itself as an increase in average streamflow in the valley.

Effects of flooding on community (Section 4)

To provide a comprehensive picture of the history of flooding in the Elk Valley, archived photos and documents were reviewed from the Fernie Free Press (1902-present), the Fernie and District Historical Society, and the Sparwood Public Library archives. Flood history was obtained from various local and regional media, local government notices, and flood hazard assessment reports from mid 1990s to present. Using this information, the chronology of floods in the watershed, resulting damage, emergency actions deployed, and responses of the communities were summarized.

From May to September 2015, two community outreach flood educators attended 23 events, where they reached over 1,400 residents about flooding in the Elk Valley. Surveys were solicited at these events and on-line through the ERA website, which 200 people completed. Survey respondents were spread approximately in proportion to populations of Elk Valley communities. Additionally, eighteen oral history interviews were conducted with residents of the Elk Valley. These anecdotal impressions of past flooding events were valuable in framing the picture of community experience and attitude to flooding, and in compiling past experiences of flood mitigation and community response.

During January and February 2015, Lee-Anne Walker, ERA Executive Director delivered an Elk River Flood Strategy overview presentation to the Districts of Elkford and Sparwood, City of Fernie, Elk Valley Cumulative Effects Management Framework (CEMF) working group and Elk Valley Integrated Resource Task Force. The main goal of these presentations was to gather input from municipal leaders about their key questions with regards to flooding in the Elk Valley, and how ERA's Flood Strategy could best support their decision making. ERA hosted 40 participants at the Elk River Flood Strategy Technical Review Workshop on October 14, 2015 and the same number at the Solutions Symposium for Flooding in the Elk River Watershed April 12, 2016. The objectives of these two workshops were to check back with the community on key findings and outcomes throughout the process and obtain critical feedback and advice on how to implement the Flood Strategy recommendations.

Effects of flooding on fish and wildlife, and mitigation options that improve habitat (Section 5)

A literature review was completed on the effects of flooding and flood mitigation works on fish and wildlife. The floodplain of the Elk River Valley provides important habitat for many fish and wildlife species, including many sensitive species. Riparian areas are the transition area between aquatic and upland habitats; these areas support distinct plant species, and provide many essential watershed, aquatic life, and wildlife functions. Black cottonwood riparian stands and wetlands are specific habitats of importance in the Elk River floodplain. These areas all have the greatest potential to be influenced by flood and flood mitigation practices.

Floods often have positive effects on fish populations (e.g., by stimulating invertebrate production, and triggering spawning for certain species), but can also potentially have negative impacts on fish populations, particularly recently hatched and juvenile life-stages, which can be overtaken by high flows. Maintaining hydraulically complex streams through responsible land management practices, is important to increase the ability of fish and habitats to positively respond to flood events.

The morphology of the Elk River in the study area is riffle-pool channel type. The value of fish habitat in this channel type is determined largely by channel pattern, bar type, large woody debris, and stability. These habitats can become negatively impacted under aggrading or degrading sediment supply conditions, as a more uniform channel is created. In addition to immediate direct riparian habitat losses, traditional flood mitigation such as dike and rip rap installations, can result in channel degradation (sediment supply being limited). Examples of channel degradation impacts include: extensive riffles and runs; decreased pool frequency, size and depth; cut off side channel and off-channel habitats; cobble and courser texture sediment size; and limited large woody debris, with those present oriented parallel to the banks. These changes can impact fish diversity and abundance.

Smart land use planning, which considers preserving the natural floodplain as a priority, should be a precursor to installation of traditional flood mitigation measures for the protection of fish and wildlife habitats. When planning for flood mitigation, the following over-riding principles were suggested: 1) use traditional hard approaches only when necessary, 2) limit footprint size, 3) limit narrowing, straightening and cutting off the floodplain, 4) set-back installations, and 5) incorporate natural habitat elements. Visual examples of habitat features incorporated into traditional flood mitigation works were provided (e.g., setback dike, vegetated dike and rip rap, rock groins, and bioengineering).

Simulating floods in the Elk Valley (Section 6)

Historical streamflow for the Elk River at Fernie was simulated using process-based hydrological modelling. The model represented daily average streamflow conditions for the Elk River reasonably well, and was subsequently used to evaluate streamflow response to land use and climate change. The Climate BC version 5.21 tool (Wang et al. 2012) was used to obtain two future climate change scenarios (RCP 4.5 and RCP 8.5) for one general circulation model (Can ESM2) for the period from 2011 to 2041. These future climate change scenarios represent greenhouse gas concentration pathways (RCP) that are focused on when greenhouse gas concentrations will stabilize. The RCP 4.5 assumes radiative forcings will stabilize at 4.5 Watts per meter squared (W m^2) by the year 2100, while RCP 8.5 is comparatively higher at 8.5 W m^2 by 2100. In general air temperatures are projected to increase under these scenarios, and so is winter precipitation. Summer precipitation is projected to decrease. Land use change was simulated as a 3,100 hectare (ha) forest harvest scenario, representing approximately 5 years of timber harvest at the current annual allowable cut in the Elk Valley. It was also assumed that harvest area would not exceed 10 ha and would be distributed randomly below an elevation of 2000 m above sea level.

Future streamflow simulations suggest that climate change has an over-arching effect relative to land use change, and that runoff is expected to be earlier in the spring period. Simulations also suggest that higher snowpack in the winter could result in higher spring streamflow on average. Land use change scenarios resulted in slight streamflow increases early in the spring and slight decreases during June. The effect of land use change is largely due to desynchronization of snowmelt runoff from lower elevations where forest cover was removed.

In addition to hydrologic modelling, a hydraulic model was developed for the Elk River between the townsite of Hosmer and Coal Creek. This model was based on high resolution digital elevation data and field surveys and provides a means of evaluating the relative differences in inundation between different flood events. It is important to recognize that this model is not intended to be an exact replication of particular events, nor is it meant to provide exact information on inundation. This is a screening-level tool that provides value in assessing relative effects of events. A web-based visualization tool was developed (elkriveralliance.watersimulation.ca) to help facilitate the delivery of this information to a broad audience.

Recommended non-structural and structural flood management strategies (Section 7)

Flooding is only a problem when it affects people and properties. A qualitative overview was undertaken of the major non-structural and structural flood management strategies that have been employed in Western Canada and internationally, with a particular emphasis on methods with demonstrated effectiveness that also preserve watershed function and diversity. Widely-used non-structural flood management measures including emergency planning and response, homeowner preparedness such as flood-proofing, and municipal planning were reviewed.

Structural mitigation options, including storage infrastructure (dry-dams and reservoirs), floodwalls, diversions, and channelization projects, can span a wide range of costs and environmental impacts. Given the current scientific understanding of the interconnectedness between watershed hydrology, ecology and water quality, it is important that flood mitigation measures aim to maintain the natural integrity of the watershed. It was recommended that planning occur with the erodible corridor concept in mind to leave a wide belt which within the river channel can freely move and flood, for ecological conservation and to minimize future conflicts between human settlement and bank erosion processes. Non-structural measures, such as renaturation of the floodplains, restoration of riparian areas and wetlands, and land use best management practices, provide flood mitigation options that are both effective at reducing flood damage and promoting natural hydrological processes.

There are several properties in the RDEK, situated in the Elk River floodplain with potential flood and/or erosion issues. Sites were identified by the consulting team and RDEK staff as key areas to investigate. Concept designs and associated cost-estimates were developed to further prioritize the sites, identify additional study requirements, and seek infrastructure funding. These concept designs are in a separate report.

Informing local decision makers and community with flood strategy tools (Section 8)

An analysis of flood planning and management from the 1990s throughout the Elk River watershed revealed that communities have actively studied the issue of flood hazard and mitigation, raised money for flood protection, and modified planning to keep in step with changing land use and climatic conditions. This Elk River Flood Strategy recognizes the value of this past work and wishes to integrate and build on these previous efforts.

The Solutions Symposium on Flooding in the Elk Watershed was held on April 12, 2016 at the Fernie Arts Station. The symposium was attended by 40 key decision makers and residents. Key findings from the Flood Strategy were presented. Participants provided direct input on specific actions or recommendations toward proactive, holistic watershed scale flood management and protection in the Elk River Watershed.

Specific recommendations stemming from this report and associated community input are:

1. **Continue to build on this flood strategy, using an integrated, collaborative and coordinated approach to flood management and mitigation.**
   - Encourage all levels of government, industry and community to continue to collaborate on holistic, watershed wide flood strategies.
   - Adopt the Elk River Flood Strategy as a first step toward an integrated *Elk River Watershed Flood Management Plan.*
   - Form an *Elk River Flood Management Committee,* empowering local watershed governance as stated in the new BC *Water Sustainability Act*. This Committee could be initially facilitated by the Elk River Alliance.
   - Exercise existing regulations, policy and political will to limit, where possible, development in the floodplain.
   - Work with private land owners in the Elk Valley to address community concerns about flood impacts from private land.
   - Continue with hydraulic modeling in high priority areas in the Elk River Watershed, similar to that which the Flood Strategy produced between the townsite of Hosmer and Coal Creek mouth. This product provides a tool to aid decision makers and residents in visualizing various flood inundation scenarios.

2. **Keep people safe from flood risks.**
   - Recognize the impacts of flooding on individual homeowners and educate watershed residents with practical solutions that they can take to be prepared for future flood impacts.
   - Talk with residents about their local knowledge and experience with flooding and consider this input throughout the decision-making process.
   - Continue to increase our collective watershed literacy about flooding.

3. **Protect key infrastructure.**
   - Employ proactive flood management and mitigation approaches that are effective, use tax resources wisely, increase watershed resilience, and protect habitat. Avoid reactive 'quick fix/non-strategic' actions.
   - Monitor and maintain existing flood infrastructure (e.g., dikes, and streambank erosion protection) in good working condition to protect citizens.
   - Restrict dredging, as the cost to the river ecology outweighs the perceived short-term benefits.
   - Where diking and riprap are required to protect key infrastructure, incorporate natural habitat elements to offset impacts to fish and wildlife habitat.

- Where possible, protect and re-establish riparian areas, wetlands and off-channel habitats.

4. Respect the natural function of the watershed to provide a buffer of resilience to climate change.

- Use the understanding of Elk River hydrology, geomorphology, and effects of flooding on fish and wildlife to guide flood management and mitigation decisions.
- Recognize that natural and human activity in the Elk Valley affects watershed function, and can cause fragmentation and a loss of diversity. Therefore, limit development in the erodible corridor (valley bottom) to the furthest extent possible, to maintain ecological function.
- When implementing structural flood mitigation, limit narrowing, straightening and cutting off the floodplain from the Elk River and tributaries.
- Promote best flood management practices for developers and private landowners in flood prone areas.
- Promote best management practices with municipalities regarding stormwater management, riparian protection, and erosion protection to reduce sediment in the Elk River and its tributaries, in order to protect aquatic habitat.
- Acknowledge that crisis in the watershed can oscillate between floods and droughts; therefore, plan for mitigation measures to address both extremes.

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1. Background

The Elk River Flood Strategy (Flood Strategy) is intended to provide decision makers and the public with information, data analysis, and recommended strategies to minimize flooding impacts in the Elk River watershed. The Elk River Watershed Alliance (operating as Elk River Alliance or ERA) is a community-based water group that promotes a holistic approach to management in the Elk River watershed. The ERA applied for funds and in-kind contributions and coordinated resources from partners (government, industry, academics, non-government organizations, and the public) and consultants (MacDonald Hydrology, Lotic Environmental Ltd.) to prepare the Flood Strategy. The Flood Strategy has been funded by the Real Estate Foundation of BC, Regional District of East Kootenay (RDEK), Mitacs, Teck and the Columbia Watershed Trust. In kind services were provided by the University of Lethbridge, and Teck Resources Ltd (Teck).

As evidenced by floods in 1995, 2005 and 2013, severe floods occur regularly in the Elk River watershed. Flooding can impact economic activity, displace human populations, and cause risk to human safety. Recovery efforts can be lengthy and have economic impacts, both in loss of revenue and cost of repair. Additionally, recovery efforts can change the physical stream characteristics and hydraulics, potentially impacting fish and wildlife, and downstream users. To date, the usual responses to address flooding issues has been to construct rip rap armoured dikes. While these structures may be suited to many situations, they have potential limitations (e.g., high cost, not fail proof) may impact watershed function and aquatic ecosystems and other alternatives may exist.

Following the 2013 flood, the City of Fernie held a meeting, which was attended by elected officials, government staff, industry, and community representatives. Participants identified limitations in current planning and expressed a desire to:

- Be proactive;
- Collaborate between local governments;
- Think holistically on a watershed scale;
- Share mapping data, information, and resources that explore both hard (e.g., engineered dikes) and soft (e.g., zoning regulations, riparian protection, and wetland reconstruction) approaches to flood preparedness and mitigation; and
- Integrate this strategy with other ongoing initiatives and flood hazard/mitigation efforts.

The Flood Strategy follows up on these ideas, to benefit residents and communities in the Elk River Watershed. The Flood Strategy investigates existing conditions in the watershed, and models a range of potential future climate and land use scenarios to identify potential future hydrological flooding outcomes. Using this information, flood mitigation strategies are provided, aimed at: providing personal safety by protecting homes and community infrastructure, providing increased resilience, being cost effective, being timely, and protecting watershed function and wildlife habitat the environment. Through extensive public education and outreach, flood literacy was raised and public input obtained. The project integrates existing initiatives/policies, to compliment rather than duplicate efforts.

Objectives

1. Provide an understanding of Elk River hydrology.
2. Model future scenarios of flood frequency/severity and the effects on communities.
3. Provide a cost/benefit analysis of flood mitigation options.
4. Promote a watershed approach to flood mitigation, to integrate government policies, industrial practices, and community efforts.
5. Support decision makers in implementing the best flood mitigation practices throughout the Elk River watershed.
6. Increase community watershed literacy of the past, current and future impacts of flooding.
7. Provide information to help regional and municipal governments prepare future flood protection funding applications.

2. Methods

The Flood Strategy was completed from April 2015 through May 2016. Report preparation involved providing several defined outputs, using both scientific assessment/analysis and public/government consultations. The methods employed are summarized below.

Output 1: Analysis of flooding in the Elk River Valley

Author: MacDonald Hydrology - Ryan MacDonald (Hydrologist, PhD) and Matthew Chernos (MSc).

Methods: Available literature and data were used to prepare an Elk River hydrology report on flood mitigation and adaptation alternatives. Analyses were completed as outlined below.

Streamflow in the Elk River Watershed

- To manage the Elk River watershed and mitigate against flood risks, an understanding of the hydrologic regime was required. Using available streamflow data from the Elk River and major tributaries up-river of the City of Fernie, the magnitude and variability in streamflow was quantified. This was completed to provide a better prediction of the timing and magnitude of peak flows, as well as an understanding of the main drivers of streamflow in the Elk River watershed.
- Streamflow data were obtained from the Water Survey of Canada Historical Hydrometric datasets (Water Survey of Canada 2015) for several locations on the Elk River, Fording River, Line Creek, and Hosmer Creek (Table 1, Figure 1). All hydrometric trend analyses were carried out using data from 1970 (1971 for Line Cr.) to 2014.

Table 1. Elk Valley Water Survey of Canada gauge stations used in this study.

Station Name	Station Code	Period of record	Record Length (years)	Drainage Area (m^3/s)
Elk River Near Natal	08NK016	1951-2013	62	1840
Elk River at Fernie	08NK002	1925-1927; 1970-2013	46	3090
Elk River at Phillips Bridge	08NK005	1925-1996	72	4450
Fording River at the Mouth	08NK018	1970-2013	44	621
Fording River Below Clode Creek	08NK021	1971-1995	24	104
Line Creek at the Mouth	08NK022	1971-2012	42	138
Hosmer Creek Above Diversions	08NK026	1982-2013	32	6.4

- Climate data were obtained from Environment Canada for weather stations at Sparwood (49°44’43”°N, 114°52’58”°W, 1138 masl) and Fernie (49°29’19”°N, 115°04’24”°W, 1001 masl), in the Elk Valley (Environment Canada, 2015). The Fernie station has data from 1970-2014, while Sparwood only has data from 1980 onwards. In order to fill in the gaps in the record, missing data from both stations were in-filled using other weather station data in close proximity. Sparwood missing data are first replaced with data from a weather station at Natal Kaiser Resources (500 m from the current Sparwood site) from 1970-1980. Remaining data-gaps for Sparwood are filled using Fernie and Beaver Mines stations, and statistical models (linear regression). Fernie data-gaps are infilled using data from Elko, Sparwood and Beaver Mines weather stations, and linear regression models to account for air temperature and precipitation gradients in the region.
- Snowpack data were obtained from the British Columbia River Forecast Centre (British Columbia Ministry of Environment, 2015). Automatic snow pillow data in the Elk Valley region were available for Floe Lake (51° 03’ N, 116° 08’ W, 2110 m) from 1998-2014, Morrissey Ridge (49° 27’ N, 114° 58’ W, 1966 m) from 1979-2014 (excluding 1982-84,

1990-97), and Moyie Mountain (49° 15’ N, 115° 46’ W, 1840 m) from 1971-2014 (excluding 1982-84, 1990-97). All three sites collect daily snow water equivalent measurements. Additional data were obtained using the BC River Forecast Centre’s manual snow survey data for several sites in the Elk River headwaters.

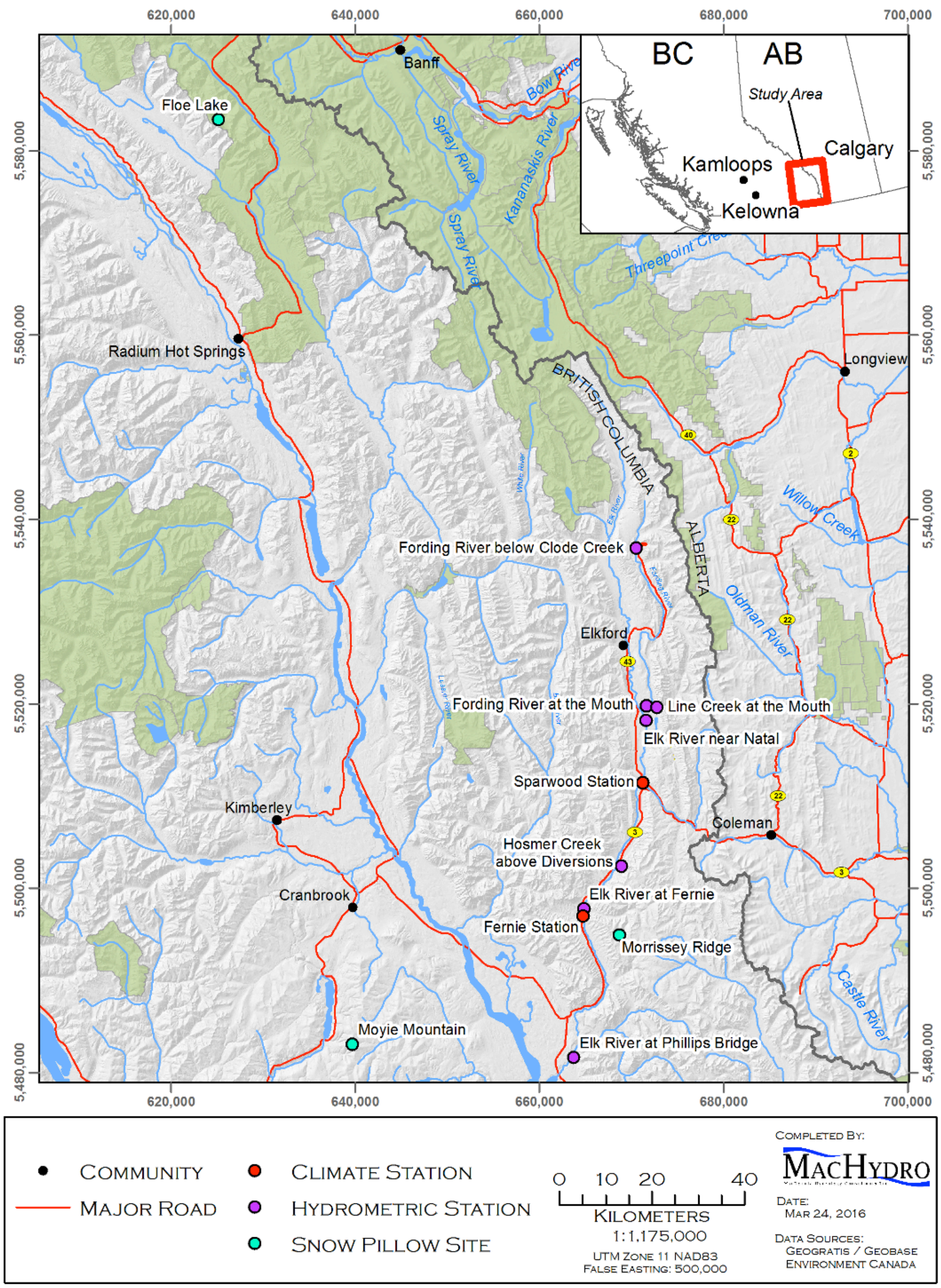


Figure 1. Hydrometric, climate, and snow pillow monitoring locations used for data analysis.

<u>Conditions driving extreme flows</u>

- In order to examine the driving causes of flooding in the Elk Valley, the three largest flood events on record during the last 40 years were examined – they were all in June 1974, 1995, and 2013. The largest floods were found by ranking the largest peak annual flows for Water Survey of Canada gauges on the Elk River (Below Natal, at Fernie), Hosmer Creek, Line Creek, and Fording River (at Clode Creek, at the Mouth).

Output 2: Effects of flooding on community

Authors: Elk River Alliance - Lee-Anne Walker (Executive Director, MA Environment and Management), Marsha Clarke (Program Coordinator Restoration and Stewardship), and Chiara Cipriano and Graham Preston (Outreach Educators).

Methods:

- The chronology and history of flooding in the Elk River watershed was provided from 1890s to present. This involved researching historical articles from newspaper archives at the Free Press, which were stored on microfiche at the Fernie Heritage Library. Flood dates were confirmed using the Fernie Heritage Museum photo archives, Sparwood Library archives, personal conversations noted in other research documents, and historical data from the Water Survey of Canada gauges on the Elk River (Output 1).
- An education and outreach program was developed to raise water literacy, watershed awareness and provide flood education. Two ERA Community Outreach Educators (educators) attended community events throughout the Elk Valley, over the spring and summer of 2015. Residents were asked to share their flood related experiences, concerns and ideas. The educators provided flooding information and summarized strategies identified in the hydrology report. Public input was collected using a survey with an added incentive of a 'fish carabiner' if completed on site. Most of the surveys were hand-written on clipboards and later entered by the educators online, although some residents responded directly using the web-based tool at surveymonkey.net.
- Oral history interviews were conducted with Elk Valley residents. Participants were asked to share their personal experiences with flooding in the watershed and recollections of community response. These interviews were transcribed.
- In January and February 2015, the Flood Strategy concept was presented to council and staff of the Districts of Elkford, Sparwood, and City of Fernie; as well as Elk Valley Cumulative Effects Management Framework (CEMF) Working Group, and Elk Valley Integrated Resource Task Force. During these presentations input was collected on key questions to answer regarding flooding in the Elk River watershed.

Output 3: Effects of flooding on fish and wildlife and mitigation options that improve habitat

Author: Lotic Environmental - Sherri McPherson (Aquatic Biologist, BSc, RPBio).

Methods:

- A desktop study of available literature was conducted to research and analyze the effects of floods on native fish species and their habitat in the Elk River watershed.
- Through the literature review, the effects of traditional flood mitigation strategies on fish and wildlife were explained.
- Fish friendly flood mitigation options were provided, including mechanisms to enhance traditional approaches.

Output 4: Simulating floods in the Elk Valley

Authors: Ryan MacDonald, Urban Systems – Christina Hopkinson (EIT), Jeff Rice (PEng), MacDonald Hydrology – Devin Cairns (MSc, PGeol), and University of Lethbridge - Celeste Barnes (PhD candidate).

Methods:

- Historical hydrologic conditions were assessed using hydrological and hydraulic modelling.
- The hydrological model used was the Generate Earth Systems Science Input (GENESYS) modelling tool (MacDonald et al. 2009). GENESYS has been applied in a number of previous studies to simulate hydrological processes in mountain environments, and was used here as the basis for hydrological simulations of the Elk River watershed. The model was calibrated and verified against historical data.
- Hydraulic modeling was completed with an industry standard software package, the U.S. Army Corps of Engineers' "HEC-RAS"; this is a one-dimensional, steady state hydraulic model suitable for computing flood profiles along rivers such as Elk River. The model was developed using channel survey data collected in August of 2015 and a 2012 LiDar Digital Elevation Model (DEM) provided by Teck Coal. Cross sections were "cut" at approximately 50 m along the length of the Elk River in a perpendicular manner.
- The model was parametrized to account for channel roughness and slope, and parameter sensitivity analysis was conducted in order to determine model sensitivity to channel roughness. Bridge crossings and road elevations were also accounted for in the model.
- The hydraulic model was used to simulate the 1:200 event based on the Water Survey Canada gauge at Fernie (see Appendix for analysis), the 1995 event, and the 2013 event. Inputs from Hosmer Creek and Mine Creek, as well as Little Fairy Creek were accounted for using linear scaling by watershed area.
- Hydraulic model outputs were imported to a web-based mapping system that enables rapid evaluation of areas of interest under a range of hydrologic conditions
- The potential effects of land use and climate change on flood magnitudes were examined:

Future climatic conditions

- Future climate scenarios for Sparwood and Fernie, BC were used to evaluate future hydrology in the Elk Valley. Climate projections were taken from ClimateBC (Wang *et al.* 2012), which downscales General Circulation Models (GCM's). GCM's represent Earth's climate and can be used to examine how climate can be affected by a range of factors, including changes in greenhouse gases. The models were run under 2 greenhouse gas concentration scenarios (RCP 4.5, RCP 8.5), which are based on the possible range of radiative forcing by the year 2100, relative to pre-industrial values (at 4.5, 8.5 W m^{-2}). The models and emission scenarios are based on the most current IPCC Fifth Assessment (AR5) (Intergovernmental Panel on Climate Change 2014).
- A simple "delta" approach was applied here, where historical climate records were scaled based on future climate scenarios. Scaling factors were calculated by comparing monthly climate normals (1981 to 2010) obtained from Climate WNA (Wang et al. 2012) to monthly climate change projections for 2011 to 2041. This time period is not meant to reflect actual years between 2011 and 2041, rather a relative difference when compared to the historical 1981 to 2010 period. This newly scaled air temperature and precipitation dataset was used as an input to the GENESYS model in order to simulate the potential effects of future climate change on streamflow.

Land use change

- Land use change was simulated as a 3,100 hectare (ha) harvest scenario, representing approximately 5 years of timber harvest at the current annual allowable cut in the Elk Valley. It was also assumed that harvest area would not exceed 10 ha and would be distributed randomly below an elevation of 2000 meters above sea level. This level of forest harvest is assumed to be an upper bound on harvest, and represents a reasonably sizeable forested landscape disturbance. The land use change scenario was only evaluated for a 10 year period given that minimal hydrologic recovery would be expected during this period, and this provides a reasonable length of record for analysis.

Output 5: Recommended flood management strategies

Authors: Lee-Anne Walker, Ryan MacDonald, MacDonald Hydrology - Danielle Marcotte (MSc, BIT), Lotic Environmental - Mike Robinson (Aquatic Ecologist, MSc, RPBio), Sherri McPherson, Jim Miller (PEng. Retired), Stella Swanson (PhD, Aquatic Toxicologist), Bruce Elson (PEng. Retired).

Methods: Non-structural and structural flood management strategies to address flood concerns were outlined using the results of a literature review. Management strategies detailed are as follows:

Non structural

- Emergency flood procedures to ensure human safety;
- Flood protection mechanisms for homeowners;
- Community plans and bylaws;
- Policies to prohibit development in the floodplain and possibility for infrastructure; and
- Maintenance/restoration of riparian vegetation, wetlands and beaver dams.

Structural measures

- Diversion, storage, conveyance, and protection.

Output 6: Informing local decision makers and community with flood strategy tools

Lead: Lee-Anne Walker, Celeste Barnes, and Ryan MacDonald

Methods:

- A comprehensive review was conducted of 15 relevant flood hazard/water/land use planning initiatives completed by the Elk Valley municipal governments and Provincial government and their relevance to the Flood Strategy report and tools.
- A *Technical Review Workshop* was hosted with community and stakeholders midway through the project in October, 2015.
- A workshop was hosted with realtors and developers to inform them of the content of the report, and to encourage accurate advice to home sellers, buyers, developers and renovators with regards to flood hazards, mitigation, and flood proofing of properties.
- An analysis of flood hazard and mitigation planning was completed to ensure the Flood Strategy is integrated with existing and ongoing initiatives and reports.
- The *Solutions Symposium on Flooding in the Elk Watershed* April 2016 was hosted to finalize recommendations and discuss next steps for implantation of the Flood Strategy.

3. Analysis of Flooding in the Elk Valley

3.1 *The Elk Valley Watershed*

3.1.1 Watersheds and their natural functions

That area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community.

— John Wesley Powell 1879

A watershed, also referred to as a drainage divide, is often defined as an extent or area of land where surface water converges to a single point. For example, the British Columbia Forest Practices Code defines a watershed as: "*the drainage area above the most downstream point of diversion on a stream for a water use that is for human consumption*" (BC Ministry of Environment 1995). Although these utilitarian definitions have been used for centuries (Powell et al. 1879), treating a watershed solely as the physical transport of water through a system ignores much of the important functionality and habitat that it provides for numerous organisms (Black 1997).

Watershed 'functions' can be broadly characterized into three major groups, comprising effects on watershed hydrology, ecology, and water quality. Hydrologically, a watershed functions as a source and sink for water resources. Water is collected from rainfall and snowmelt, stored in lakes, rivers, and the ground, and is transported out of the system either as streamflow or evaporation. Ecologically, these water flows create habitat such as wetlands, rivers and lakes, and promote forest and riparian growth (Creed et al. 2011b). The interaction between the hydrologic and ecological functions of a watershed play an important role in maintaining water quality. As water travels through ecologically rich areas, or geologic units, it is filtered, vital chemical reactions take place, and nutrients and sediment are transported throughout the watershed (Creed et al. 2011b). These processes serve to enhance water quality, further promote ecological functionality, and also affect the hydrologic regime of the watershed, creating a complex, highly coupled system.

One of the defining features of natural watersheds is a high degree of connectivity and resilience, where hydrologic, ecological, and water quality functions are highly interconnected and interdependent. Changes to the ecological composition within the watershed will invariably affect hydrologic response and water quality, while the inverse also holds true. As such, changes to watershed land use and landscape, such as a forest fire, logging, and mining (among others) extend well beyond the event's spatial and temporal extent. These effects range from changes in downstream hydrology and forest composition, to upstream sediment storage and landslide risk, and vary in both in space and time.

However, this spread and magnitude of change due to land use changes can be somewhat buffered by the natural resilience of the watershed (Creed et al. 2011b), where the degree of resiliency is a product of the redundancy and diversity of ecological, hydrologic and water quality functions. Resilient watersheds (Figure 2) are able to withstand disturbances without major changes in ecology, hydrology, or water quality because the system is not reliant on a small number of functional units. This resiliency is dependent on the preservation of the number and diversity of watershed functional units. Conversely, the reduction, destruction, or fragmentation of these functional units serve not only to reduce the effectiveness of the watershed's functionality as a whole, but also reduce its ability to withstand and recover from future disturbances. As such, watersheds that lack diversity, redundancy, and connectivity are significantly more sensitive to changes in land use alterations, as well as changes in climate.

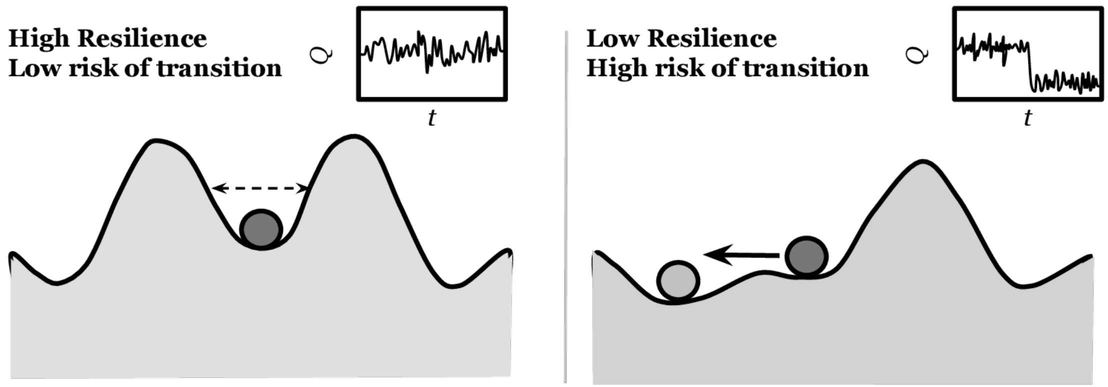


Figure 2. Resilient watersheds are able to withstand moderate changes to their environment without significant changes to downstream hydrology and function. Conversely, small changes in conditions can be enough to trigger large changes in watersheds lacking redundancy and diversity. This figure demonstrates a resilient watershed on the left, and shows how the system remains in one state. The figure on the right demonstrates a system that has low resilience and can be shifted into a new state when a disturbance occurs. Adapted from Creed et al. (2011b).

As human settlement and resource development encroach on watersheds worldwide, decision-makers are required to effectively manage watersheds. Watershed management approaches must seek to minimize infrastructure from the hydrologic risk of flooding and drought as well as regulate water resources, all while attempting to maintain environmental functionality (Creed et al. 2011a). However, in order to achieve effective environmental management, a holistic consideration of the range and connectivity of watershed functions is essential.

3.1.2 Natural history of the Elk Valley

Watershed management predominantly focuses on streamflow, considered as surface water flowing through stream channels within a watershed. However, streamflow itself is a product of the complex interactions between climate, vegetation, soils, geology, and topography as water moves through the watershed. As such, an evaluation of current watershed functionality requires a strong understanding of its environmental context. This context, in turn, is a product of the watershed's natural history, meaning watershed functionality is strongly defined by its natural history. Similarly, changes to the landscape, both in ecology and forest cover, and in soils and surficial geology, invariably affect a watershed's current and future hydrologic response.

The Elk Valley was fully glaciated approximately 13 000 – 11 000 years ago (Ferguson and Osborn 1981, Clague 1982). A large valley glacier extended from its headwaters near Mount Joffre to below Elko, BC, where the glacier would have joined with a much larger glacier extending down the Rocky Mountain Trench (Osborn and Luckman 1988). At the end of the Last Glacial Maximum, the Elk Valley glacier thinned and retreated as it separated from the much larger Rocky Mountain Trench glacier. During this sequential retreat, meltwater was dammed by the Rocky Mountain Trench glacier, which led to the formation of a large glacial lake (George et al. 1987). Blockage originally occurred near Morrissey and later near Elko, and successive lakes drained first through the Crowsnest Pass, and then through Bean Creek, and eventually Elko with the retreat of the Rocky Mountain Trench glacier. As of September 2014, measurements using Landsat imagery (U.S. Geological Survey 2015) indicate that the Elk Valley glacier has retreated 142 km, and has fragmented, with the Pétain, Castleneau, Elk, and Abruzzi glaciers covering only a combined 7.7 km^2 of the watershed.

More recently, changes to the Elk Valley landscape have been related to industry and natural disturbances. Mountain-top coal mining is prevalent throughout the eastern side of the valley, while forestry practices within the watershed, in particular clear-cutting, has visibly altered the landscape. However, modern landscape change is not uniquely related to industrial development; recent outbreaks of mountain pine beetle within the valley have had a large effect on the state of the watershed's forest and fire hazard, while forest fires themselves have had an effect on a substantial portion of the valley.

While the legacy of these changes on the landscape shape both the surface geology and ecology in the region, they also play a critical role in defining the hydrologic regime, controlling how water moves through the watershed (Figure 3), and ultimately how the watershed functions within the landscape. A fraction of the water that enters the watershed either as rainfall or snowfall is first intercepted by the forest canopy. Water that is not either absorbed by plants or evaporated travels towards the stream either as surface flow or through groundwater pathways. Once water enters streamflow, it is transported downstream, with the potential for some of that water to be lost to evaporation or groundwater. The relative influence and magnitude of each of these hydrologic pathways is defined by the properties of the watershed's ecology, geology and climate. As such, watershed function is largely defined by its natural history.

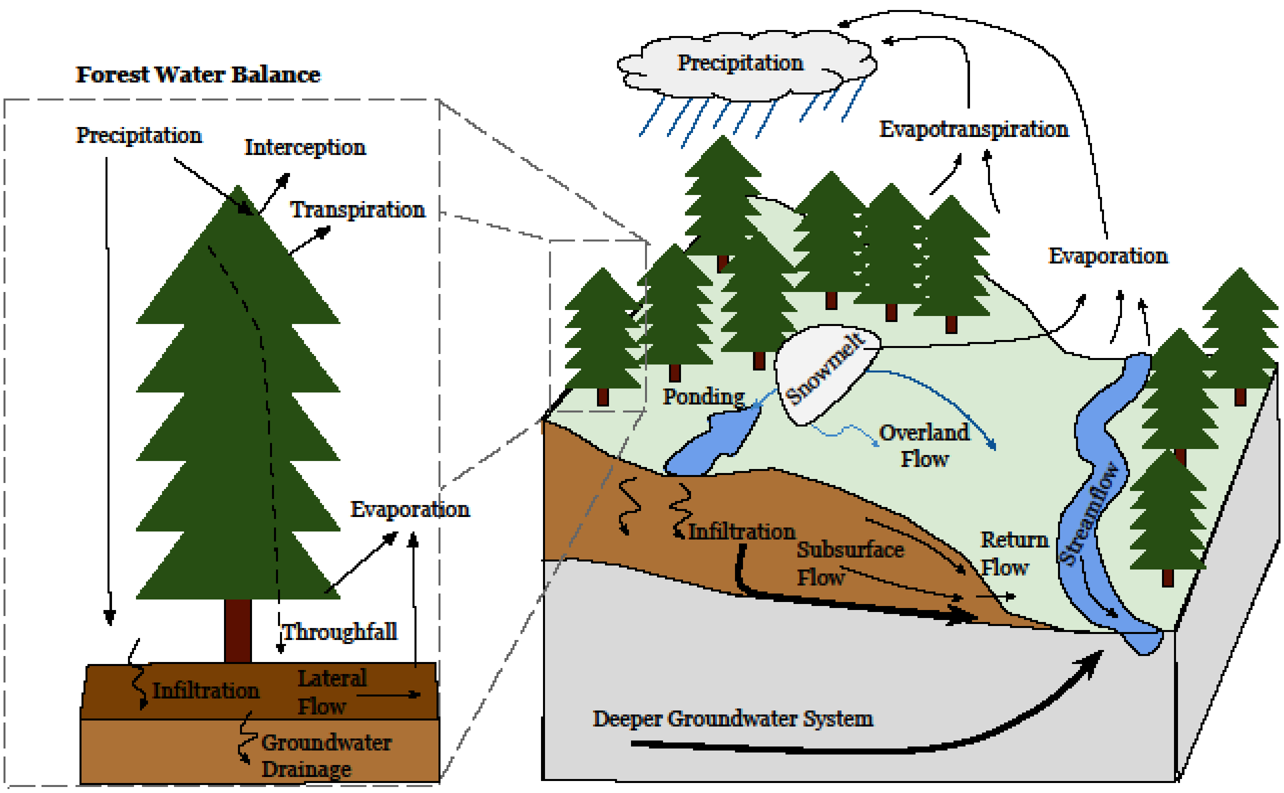


Figure 3. Water pathways within a forested watershed. Adapted from USGS

A legacy of glaciation has shaped the valley, both in form, creating steep U-shaped valleys, moraine-dammed lakes, and defining river-channel morphology (Montgomery and Buffington 1997), and in top-soil, depositing glacial debris (till) along the length of the valley (Fulton 1995). The presence of glacial till strongly affects groundwater flows, and hence the responsiveness and peakedness of streamflow. The depth at which groundwater can travel is limited by the location of basal till (Hutchinson and Moore 2000). Since basal till has been subject to intense pressure due to glaciation, it is relatively impervious and restricts the downward flow of groundwater, instead forcing water to travel near-surface pathways into river networks. Additionally, in quaternary environments, groundwater flows are predominantly through shallow, coarse debris (ablation till), allowing for water to travel more quickly into streamflow relative to denser soils (Hinton et al. 1994). The combination of these two quaternary features create conditions for a more rapid and intense streamflow response to storm events. There are also lacustrine deposits (clay) in the Elk Valley that were formed by the large glacial lake (George et al. 1987). These deposits can direct water and store large amounts of water. These deposits can be found throughout the Elk Valley, for example along Lizard Creek.

The quaternary history of the valley has also shaped, in part, the forest composition and structure of the Elk Valley, which has large implications for the hydrology of the watershed. Forests create and amplify many hydrologic pathways in a watershed, acting as both a storage medium, and a conveyor of water through the system. Initially, a fraction of precipitation inputs from rain and snow are intercepted by the forest canopy, reducing the volume of overland flow contributing to streamflow (Bond et al. 2008). Of the fraction intercepted by the canopy, some of the water is stored in the canopy, while some is lost via evaporation or sublimation and transpiration from plant leaves (Varhola et al. 2010). The remaining water slowly falls through the forest canopy, eventually reaching the ground as throughfall.

Once rain and snow reaches the ground surface, the forest still exhibits a strong influence on how water moves. Spring snowmelt, which provides substantial streamflow inputs, is slowed by heavy tree shading, limiting the rate at which energy is transmitted from the sun to snowpack (Winkler et al. 2005, Jost et al. 2009). Tree roots have also been shown to enhance soil infiltration rates by creating larger soil pore spaces, in turn allowing for larger volumes of water to be transported through groundwater channels (Sidle 1985). As Figure 3 demonstrates, these are complex interactions that all play a role in governing how water eventually reaches our rivers, lakes, and wetlands.

3.1.3 The free stone Elk River

The Elk River is a “free stone” or gravel bed river. The term “gravel” is applied broadly to any sediment material in river systems with a diameter greater than 2 mm, encompassing “pebbles”, “cobbles”, and “boulders”. While this suggests that a gravel bed river is composed entirely of larger material, a quantitative examination of river sediment reveals that smaller material is always present, sometimes accounting for as much as 30% of the total sediment by weight (Church 2010). The character of a gravel bed river is such that the bed and lower banks of the stream are composed of larger grains (gravel), while smaller material (such as sand, silt, and clay) is hidden in the gaps between larger grains, and sometimes deposited along the tops of banks. Gravel bed rivers are sometimes referred to as “freestone rivers”, and occur primarily in montane and upland valleys and mountain forelands where the channel slope has decreased as the river moves out of steep, headwater streams.

The sediment deposited in gravel bed rivers originates in steep headwater channels. In the steepest and furthest upstream channels of a river system, rock is weathered and eroded through a variety of processes. Material that is eroded by glacial activity, frost cracking, and other forms of mechanical weathering is then transported into headwater channels by landsliding and runoff, where steep slopes allow for fast flowing streams to carry the sediment downslope and downstream.

When the river has moved out of steep, mountainous terrain, and into upland valleys, the channel slope decreases. As the slope decreases, the river loses power (termed ‘competence’, or ‘stream power’), and is unable to continue transporting larger particles, leading to the deposition of gravels. Although this would suggest that smaller sediment grains (sands, silts, clays) would continue to be transported downstream, a significant percentage of those grains become entrained between larger grains. This sediment is deposited in localized areas of low stream power, and is classified as ‘bedload’, while non-entrained suspended sediment quickly vacates the system, and is termed ‘washload’.

The deposition pattern of gravel bed rivers is primarily determined by the slope of the channel and streamflow. Given the relatively consistent channel slope of most gravel bed systems, sediment in gravel bed rivers (bedload) is able to self-organize, forming predictable bed structures, the most common of which is called imbrication. Since sediment deposition occurs when the stream power becomes too small to continue to transport grains of a specific size, bedload tends to be well sorted, and have a relatively uniform grain size (termed size-selective transport). These larger grains tend to orient downstream due to the stream current, and form a bed structure that deflects current. This structure tends to form on top of smaller grains deposited during lower streamflow, in effect sheltering them from further transport, termed ‘armouring’.

Given that stream reaches in gravel bed rivers tend to be self-organizing, size-selective, and form armoring imbrication structures which resist bed erosion, sediment transport is limited much of the time. In order to mobilize sediment, stream power must be great enough to first mobilize the larger grains, which form the structure of the stream bed. These conditions may not occur every year, and are only achieved infrequently through unusually large episodic events.

When an extreme flood does occur, the erosion-resistant bed structure is quickly dismantled, allowing for a large amount of transported material, and dramatic changes to channel morphology. Once larger grains are mobilized, underlying material, much of which is smaller and more mobile, is no longer protected, and can be easily transported. This mechanism demonstrates that sediment transport in gravel bed rivers is stochastic: sediment accumulates within low-slope reaches over several years, and is flushed out by large flood events, initiating a downstream pulse of sediment.

3.1.4 How do humans affect sediment in gravel bed rivers?

An underlying concept fundamental to understanding the function and character of gravel bed rivers is that of connectivity. A growing body of scientific research (see Wohl 2006) has shown that changes to one location within a watershed can have a cascade effect, leading to changes upstream and/or downstream. This concept implies that effective river management must pay particular attention to the connections between hillslope and channel, upstream and downstream, and hydrology, geomorphology, and ecology. Although there are limitless potential ways in which humans (as well as natural disturbances) can affect river morphology, some of the most common and best understood direct and indirect effects are summarized below.

One of the most prevalent direct ways in which the sediment budget in gravel bed rivers is altered by humans is by building in-stream structures such as dams and levees, diversions or culverts, and bank reinforcements. Structures that regulate the flow of rivers, such as dams and levees, fundamentally alter the hydrologic regime of the river, in particular leading to a decrease in flood frequency and magnitude, as well as changes to the spatial location and transport of sediment. Dams create an area of low stream power immediately upstream, allowing for significant sediment deposition that would otherwise have travelled further downstream. Reinforcing river banks can also lead to a measurable reduction in the river's sediment budget. While natural river banks are erodible and contribute sediment to streams, reinforcing the banks, or protecting them completely from erosion eliminates the sediment source. In addition to structures, many streams (including the Elk River) have experienced dredging. Dredging is a short-term mitigation measure to lower water levels by removing stream sediments and has potential to disrupt aquatic organisms. Luckily, dredging is no longer considered standard practice.

Indirectly, anthropogenic (or human influenced) changes to land use can have an effect on the sediment budget of gravel bed streams. The clearing of vegetation, through deforestation and agricultural land use changes the hydrologic regime of the watershed. Due to a combination of changing snowmelt dynamics, and precipitation runoff routing, flows are expected to increase in peakedness, and magnitude, creating more frequent and more severe flooding, in turn allowing for more sediment mobilization and transport. Likewise, a reduction in forest cover also allows for more out-of-stream erosion, and a reduction in river bank strength, both of which increase the input of sediment into the stream. Much of the same fundamental changes can also be expected from increased urbanization, due to much higher runoff rates. Increased industrial activity, such as mining, forestry, and even road construction, in the watershed can also increase sediment yields. While additional sediment inputs can be expected due to the construction and disturbance of surface materials, indirect effects, such as increased propensity for landslides, stream constriction or bank fortification, and channel re-routing, all lead to enhanced erosion, and higher sediment loads.

3.1.5 Disturbances and their effect on streamflow

> *Nature, left undisturbed, so fashions her territory as to give it almost unchanging permanence of form, outline and proportion, except when shattered by geologic convulsions; and in these comparatively rare cases of derangement, she sets herself at once to repair the superficial damage, and to restore, as nearly as practicable, the former aspect of her dominion.*
>
> *— George Perkins Marsh 1865*

As we have known for over a century and a half, disturbances are relatively frequent events within watersheds (Marsh, 1865), and although they vary in scale and cause, they are a natural, cyclical part of ecosystems. A healthy forest goes through the natural processes of aging, disturbance, and renewal, and this process is an essential component of maintaining biodiversity and complexity within an ecosystem. Many organisms have adapted to this natural forest disturbance regime and therefore, depend on these disturbances for survival (BC Ministry of Water, Land and Air Protection, nd). For example, certain species of forest birds depend on dead stands to provide appropriate habitat, and even seeds of certain tree species (lodgepole pine) germinate in response to fire disturbance (BC Ministry of Water, Land and Air Protection, nd). Just as forests depend on disturbance, certain floodplain vegetation depends on the disturbance of large-scale flooding for its persistence. Periodic flooding within the floodplain provides an influx of nutrients and sediment, both of which create critical habitat for certain vegetation as well as aquatic species (Ben-David 1998).

In modern times, these disturbance regimes are also affected by human intervention. Human action on fire suppression and flood mitigation, among many other anthropogenic actions, has affected the rate and magnitude of natural disturbances. Conversely, industrial and urban development has also created new localized disturbances, such as forest harvesting, mining, and urban expansion, as well regional and global disturbances such as the spread of invasive species and climate change (e.g. Buttle et al. 2005, Intergovernmental Panel on Climate Change 2014). Whether natural or human influenced, large or small, disturbances within a watershed invariably alter hydrologic processes, affecting water quality and quantity, and potentially modifying watershed function.

Forestry

Forest disturbance can potentially affect watershed function. Given the role trees play, shaping the pathways of water through a forested watershed (Figure 3), changes to their coverage and distribution invariably affect a miriad of hydrologic processes, ranging from evaporation, to snowmelt, to groundwater flows. The change in the magnitude and responsiveness of these pathways, in turn, can have significant effects on the magnitude, variability, and responsiveness of streamflow downstream.

Forest harvesting directly affects the watershed hydrologic regime through the removal of a forest canopy, effectively removing the interception of precipitation. While a thick forest canopy can intercept a sizeable fraction of precipitation and delay its delivery to the forest floor, allowing for some of the intercepted precipitation to evaporate, areas without forest cover receive the full brunt of precipitation immediately. This direct delivery allows for an immediate, elevated input of water to the forest floor, promoting faster runoff, and a more rapid saturation of soils (Winkler et al. 2010b). In aggregate, studies have shown that annual water yield generally increases (with disturbance levels greater than 20% of a watershed) as a result of reduced forest cover (Stednick 1996, Buttle 2011).

Of particular importance to the Elk Valley, given that much of the streamflow is generated through snowmelt, is that a reduction in forest cover enhances snowmelt. The reduction in forest cover brings about a reduction in shading (Jost et al. 2009, Winkler et al. 2005), which in turn results in more rapid snowmelt. This increased rate of snowmelt is further exacerbated by the fact that the lack of forest reduces snow interception losses, and allows for higher amounts of snow accumulation (Moore and Scott

2005). In aggregate, this allows for a more rapid, transient peak in spring streamflow in forested sites (Buttle et al. 2009). However, the opposite effect (a less-peaked, longer-lasting freshet) has been shown in watersheds where only certain tributaries or areas are harvested, due to a desynchronization of spring runoff (Schnorbus and Alila 2013). While watersheds that have been significantly disturbed will have a more rapid runoff response due to enhanced snowmelt, peak flows from a logged sub-watershed will no longer coincide with peak flows from the rest of the forested watershed. However, this finding does not necessarily imply a reduction in flood potential. Studies have found that some partially-logged watersheds exhibit higher baseflow conditions, and a higher water table (Zhang and Wei 2012), while others find an increase in extreme events (Schnorbus and Alila 2013), due predominantly to faster response times to large rain events, and the lack of forest canopy to intercept a fraction of precipitation.

Although forest disturbance can have significant effects on the volume and timing of streamflow, it can also have significant effects on stream temperatures, which in turn affect aquatic habitat. The reduction in riparian (near-stream) vegetation can significantly reduce stream shading (Moore and Scott 2005). This increase in solar radiation can have large implications for the energy balance of streams, and result in significantly elevated water temperature (Leach and Moore 2010). Interestingly, these effects are contrasted by where stream water is coming from, and with high proportions of groundwater in stream water it is possible that riparian forests play less of a role (Wagner et al. 2014). Nevertheless, increases in summer stream temperature have been shown to have detrimental effects to fish populations, in particular rocky mountain trout (Isaak et al. 2012).

General forest harvesting effects on streamflow in watersheds

- Higher flows (due to less canopy interception and evaporation);
- Faster response to storms;
- A more rapid and potentially higher spring freshet due to faster snowmelt (particularly in heavily-harvested watersheds);
- Potentially higher late season streamflow due to increased infiltration and reduced evapotranspiration; and,
- Elevated stream temperatures (particularly in areas where riparian vegetation is not protected).

Forest fires

Forest fires are common in almost all types of forested ecosystems, and they play a substantial role in the formation and regrowth of dry continental forests, with potentially substantial implications for hydrology. Among the other implications attributed to the loss of forest coverage, detailed above, forest fires create additional effects which influence the geomorphology, runoff potential, and flood risk in forested watersheds.

Similar to clear-cut watersheds, post-fire watersheds in snow-melt dominated watersheds tend to exhibit earlier freshets, due predominantly to a decrease in shading, allowing for earlier and more rapid snowmelt (Eaton et al. 2010). Additionally, wildfires also induce soil hydrophobicity, leading to a decrease in soil infiltration, and an increase in overland flow. This, in turn, allows for a more intense response in streamflow to storm events (Huffman et al. 2001). The magnitude and spatial extent of this soil hydrophobicity seems to vary with fire intensity and location (Woods et al. 2007). In general, post-fire watersheds exhibit higher peaked flows, which are further exacerbated by enhanced runoff.

Forest fires also exhibit a substantial effect on slope and channel stability. Observations have also been made that indicate that channel morphology becomes less stable following fires, due to the loss of root strength (Eaton et al. 2010, Phillips and Eaton 2009). Similarly, the loss of stabilizing forest roots on steep mountain slopes allows for significantly elevated rates of mass movement (Sidle 1985). Enhanced landslide and debris flow activity within the watershed also supply additional sediment into streams, allowing for elevated rates of sediment transport (Benda and Dunne 1997).

Furthermore, in watersheds where forest fires do not completely incinerate trees, falling trees can provide large woody debris inputs to streams over the subsequent decade. Although results vary depending on the size and distribution of both falling tree and stream, inputs of large woody debris (LWD) to streams can provide habitat and create zones of scour and sediment deposition (Eaton et al. 2012, Davidson and Eaton 2013). Additionally, preliminary work suggests that LWD have the potential to attenuate flood waves by reducing the streamflow speeds (Wenzel et al. 2014).

A forest fire disturbance also produces certain benefits for a forest ecosystem. Fire releases nutrients that are stored in the litter layer of the forest floor. Fallen trees also open the tree canopy to more sunlight, and for certain tree species, fire allows for germination of seeds. These factors are essential to maintaining forest diversity, itself a primary goal for effective watershed management, which serves to test the resilience of a watershed. In cases where much of the watershed has already been disturbed, either through natural means (e.g. fires or insect outbreaks), or through development (e.g. urban encroachment or forestry), any additional disturbance may be sufficient to upset the equilibria in watershed function, and trigger long-term changes to the hydrologic regime.

General effects of forest fires on streamflow

- Effects listed above for forest harvesting (elevated baseflow, faster storm response, enhanced snowmelt, elevated stream temperatures)
- Elevated storm-flow response due to enhanced runoff rates;
- Reductions in channel stability;
- Enhanced landslide/debris flow potential leading to increased sediment supply and transport; and,
- Increased input of large woody debris (creating habitat, scour zones, and sediment deposition zones, as well as potentially allowing for some reduction in flood intensity).

Mining

Coal mining has been a major industrial activity in the Elk Valley over the last 100 years. While it has played a significant role in the economic and social development of the valley, it has also likely played a role in shaping the hydrologic response of the Elk Valley watershed. As of 2012, the valley contains 5 of the 6 largest mines in British Columbia, and some estimates put the total disturbed area in the valley at over 11 000 ha (Komnenic 2013). The magnitude of area that is disturbed makes it likely that this change in land use has substantial effects on the valley's hydrology.

Although research examining hydrologic responses has been overshadowed by examinations of water quality and sediment inputs, conceptually there is a substantive framework in understanding how mountain-top mining should affect streamflow. Theoretically, mountain-top mining acts as a type of land use disturbance, changing predominantly forested and sub-alpine hillslopes into exposed, porous rock. As such, we expect some hydrologic responses to be similar to that of forestry and forest fires. Newly exposed areas receive less shading, and no longer contain root strength to buffer soil from mass movement. As such, we would expect snowmelt to be enhanced, and soil, in areas not reinforced by mining operations, to be more prone to mass movement.

Conversely (and unlike post-fire watersheds), no increase in runoff values has been observed (Shatilla 2013). While post-fire surfaces are hydrophobic, mine sites contain broken, porous rock, which reduces runoff and allows water to travel into much slower groundwater pathways. Enhanced rates of groundwater flow, in turn, serve to slow the watershed's response to storm events and dampen the hydrograph peaks. This suggests, barring completely saturated soils, mine coverage has some potential to reduce the intensity and magnitude of flooding, both by attenuating the storm surge, and by potentially desynchronizing the sub-watershed relative to other watersheds in the watershed.

General effects of mountain-top mining on streamflow

Although there remain many uncertainties related to mountain-top mining's effect on streamflow, our current understanding of watershed hydrologic pathways, coupled with some *in-situ* observations yield some broad conclusions:

- Enhanced landslide/debris flow potential in non-reinforced areas;
- Potential for increased sediment supply and transport;
- Enhanced rate of snowmelt and faster spring freshet response;
- Dampened storm streamflow response (due to higher porosity); and,
- Some potential for a reduction in flood magnitude.

Mountain pine beetle

In recent years, new, extensive challenges have faced land use managers. In particular, western Canadian coniferous forests have been threatened by infestations of Mountain Pine Beetle (MPB, *Dendroctonus ponderosae Hopkins*) (Alberta Sustainable Resource Development 2007). MPB has been responsible for the destruction of a significant percentage of coniferous trees in forests across western Canada. Although small beetle populations only attack old, vulnerable trees, recent outbreaks have resulted in the killing of young, healthy pine trees over 12.5 cm in diameter (Alberta Sustainable Resource Development 2007). From a watershed hydrologic response perspective, MPB outbreaks somewhat mimic many of the hydrologic responses seen in forestry and wildfire-disturbed watersheds.

As forest stands are killed, pine needles fall off and significantly reduce the forest's ability to both provide shade, and to intercept precipitation. Furthermore, pine needles falling from the forest canopy onto snow can also serve to artificially darken the surface, allowing it to absorb more solar radiation (Winkler et al. 2010a, Burles and Boon 2011). This allows for elevated snow accumulation and significantly elevated melt rates, as well as an increase in the amount of precipitation able to reach the forest floor (Redding et al. 2008). While Mountain Pine Beetle remains a significant disturbance, and driver of hydrologic change in watersheds, MPB is but one of a series of external disturbance patterns that threaten to alter watershed hydrology.

General effects of Mountain Pine Beetle infestations on streamflow

- Enhanced streamflow response to storms,
- Increased magnitude and total streamflow within the watershed

Climate change

Climate change in the coming century is likely to result in significant changes to precipitation and temperature patterns within the valley (Intergovernmental Panel on Climate Change 2014). In particular, many of the natural disturbances discussed in this chapter are likely to see an increase with the onset of warmer, drier temperatures. A reduction in cold spells would result in more frequent, more extreme MPB outbreaks (Stahl et al. 2006), while outbreaks have also been linked to warm air temperatures (Aukema et al. 2008). Furthermore, warmer drier spring-summer weather has the potential to increase the likelihood and severity of forest fires (Westerling et al. 2006).

Among the potential land use changes, which have the potential to directly influence the hydrology of the Elk Valley, climatological changes themselves have the potential to affect streamflow, and in turn affect the ecology and water quality of the valley. The specific climate change projections, and their relationship to flooding will be further examined in Section 6.

General effects of climate change on streamflow
■ Higher proportions of rain to snow result in less winter snowpack and potentially lower spring streamflows, ■ More intense precipitation and more frequent disturbance events can result in more flooding.

3.2 *Streamflow in the Elk River Watershed*

Streamflow in the Elk Valley follows a nival (snowmelt-dominated) regime, defined by a late-spring peak discharges coinciding with peak snowmelt. High flows occur almost exclusively between May and mid-July (Figure 4), while the rest of the season is defined by steady, low flow rates. Streamflow peaks in the region between mid-May and mid-June, with peak annual flows for every year of record falling within those two months.

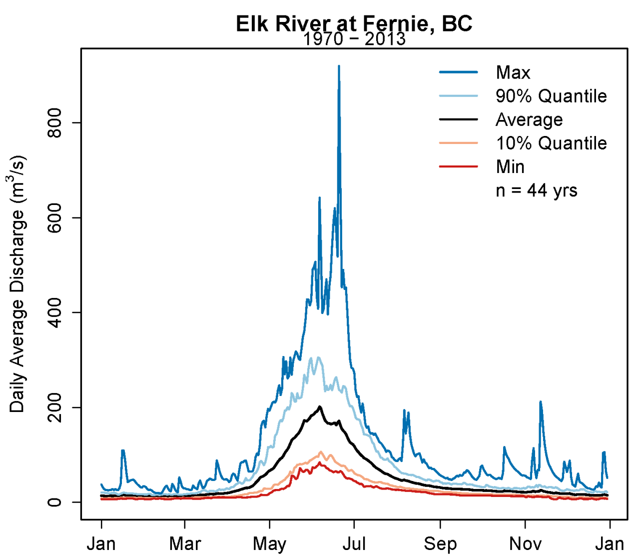


Figure 4. Elk River at Fernie flow regime (1970-2013)

The peak in spring flow coincides with peak snowmelt in the region (Figure 5). Automatic snow pillows for three sites in the Elk Valley watershed show that the snowpack gains mass until roughly May 1, when it begins to melt. The snowmelt season, particularly for further downstream sites Morrissey Ridge and Moyie Mountain, is relatively short; in an average year snow is gone at both sites by July 1. Snow persists later in the year at Floe Lake, which is located along the continental divide, and receives significantly more snowfall.

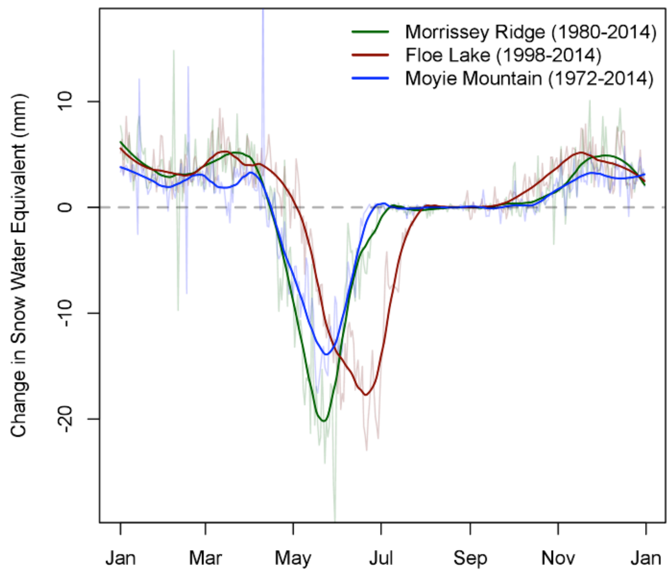


Figure 5. Average change in snow water equivalent for each day of year. Thick lines are loess smoothed (span = 0.15).

Average measured snowmelt in the region is rapid, allowing much of the stored winter snowpack to be delivered into the rivers and streams of the Elk Valley within a very short period of time. This large increase in water availability drives much of the observed spike in spring streamflow in the Elk watershed.

Another factor that plays a significant role in driving spring streamflow is large rain events. Rainfall in in the Elk Valley is highest in May and June (Figure 6), with average monthly rainfall exceeding 100 mm in June at Fernie, and 55 mm at Sparwood. This peak in precipitation also coincides with maximum snowmelt rates, further enhancing streamflow. Fernie receives roughly twice the precipitation of Sparwood, located up-valley, closer to the Elk Valley headwaters. Precipitation also peaks again in the fall (October - November), although what falls as rain in the valley at Fernie and Sparwood is most likely snow at higher elevations, and does not appear to immediately contribute to streamflow.

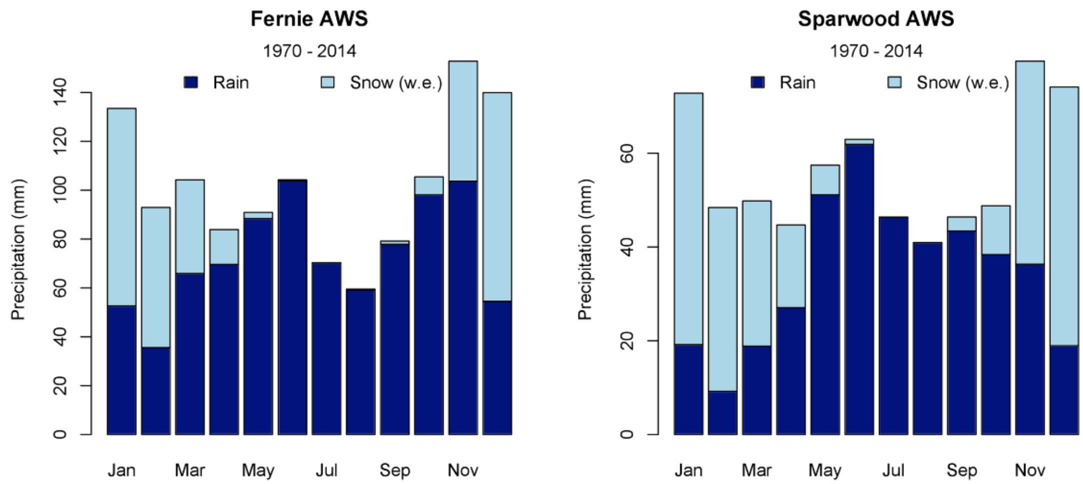


Figure 6. Precipitation for the two main Elk Valley automatic weather stations (AWS). Note that Fernie receives almost double the precipitation of Sparwood.

3.3 *What conditions drive extreme flows?*

3.3.1 June 21, 2013

The flooding observed on June 21, 2013 was the highest daily flow observed at all but one hydrometric gauge in the valley (Hosmer Creek is the exception). Flows at the Elk River below Natal and at Fernie gauges were 4.6 and 3.3 times their median annual peak flows, respectively. Peak daily flow records were also set at Fording River at the Mouth gauge, measuring 3.3 times the median peak annual flow. Many other sites in the valley do not have reliable estimates of discharge due to the flood's unprecedented level (Figure 7).

Figure 7. Extensive flooding in Hosmer during the 2013 flood event. Credit: RDEK

Leading up to the peak of the June 2013 flood event, extremely high rainfall was observed at the Sparwood and Fernie weather stations, located in the Elk Valley. On June 19, 82 mm of rain was recorded at Sparwood, representing 1.45 times the average monthly precipitation at the site. During the same time-period, the Fernie weather station recorded 52 mm of rain, half its average monthly total. The storm was the largest daily May-June rainfall on record at Sparwood from 1970 to 2014, and the second largest at Fernie (Appendix A).

During the lead-up to the flooding, snow pillows at Morrissey Ridge and Moyie Mountain showed no change in snowpack, suggesting that most snow had melted by that point. In contrast, the Floe Lake snow pillow showed between 10 and 30 mm (w.e.)/day of melt, suggesting that although air temperatures during the storm were unseasonably cool (10 ^{o}C below normals), precipitation at higher elevations was still falling as rain, and not snow. This is significant in that it suggests that rain at higher elevations was falling on an already isothermal (saturated) snowpack, allowing for high runoff rates, and limited infiltration. The majority of rainfall being transported as runoff is a critical factor to enhancing the storm spike in streamflow, as it travels quickly from hillslope to stream, rather than travelling through much slower groundwater pathways.

3.3.2 June 7, 1995

Flooding observed on June 7, 1995 was the second highest daily flow observed at most hydrometric stations in the Elk Valley (Figure 8), and was the largest annual maximum daily flow at Hosmer Creek. Hosmer Creek gauge recorded an average daily flow 5 times larger than its median peak annual flow. Gauges on the Elk River at Natal, Fernie and Phillips Bridge recorded flows 2.1, 2.3 and 2.4 times the median peak annual flow, while Fording River flows at Clode Creek and the Mouth were 4.2 and 2.8 times their median peak annual flows.

Similar to the June 2013 flood event, June 1995 was marked by extremely high rainfall in the valley. On June 6, 1995, 79 mm of rain was recorded at Fernie, representing 76% of its total average monthly rainfall. Sparwood recorded 45 mm of rain on June 6, as well as an additional 16 mm on June 5, which combined, represent 108% of its total average monthly rainfall.

Figure 8. Excavator operator pushed into Coal Creek during the 1995 flood while building a temporary dike to protect Fernie's Airport subdivision. He was rescued from equipment. Credit: unknown.

Snowpack measurements in the watershed leading up to the storm and subsequent flood are limited. Manual May 1 snow surveys from Mount Joffre, Thunder Creek and Floe Lake all showed snowpack levels 70 - 100 mm (w.e.) above normals, while a May 15 manual survey at Fernie showed the snowpack to be 12 mm below normals. Although it is difficult to discern the state of the snowpack leading up to the flooding, it is likely that snow persisted in the alpine. Air temperatures at both Fernie and Sparwood were above average leading up to the large rainfall, with maximums reaching 10 - 11 ^{o}C above normals on May

29. In general, it is likely that this flood event was driven primarily by a historically large rainfall event, but was also exacerbated by high baseflow driven by a seasonal peak in snowmelt.

3.3.3 June 17, 1974

Flooding observed on June 17, 1974 was the third largest maximum annual daily flow recorded in the Elk Valley. Gauges on the Elk River at Fernie and Natal measured peak daily flows 2.3 and 2.1 times the median peak annual daily flow. The event was also notable for the Fording River at the Mouth gauge, which recorded its second highest daily flow (2.9 times the median peak annual daily flow). Line Creek also experienced its largest recorded event (3.4 times the median), although it should be noted that no 2013 data were available at this gauge. Notably, the event was not a significant flood at gauges Elk River at Phillips Bridge, or Hosmer Creek.

Unlike the June 2013 and June 1995 floods, the June 1974 flood was not preceded by an anomalously large rainstorm. The only rainfall event within 2 weeks of the flood occurred on June 6 when 11 mm of rain was recorded at Fernie, and 2.8 mm at Sparwood. Instead, the week leading up to the peak discharge is marked by anomalously warm temperatures. Maximum temperatures for Fernie and Sparwood are 8-11^{o}C and 7-12 ^{o}C above normals, with Sparwood registering 31.4 ^{o}C on June 16. Mean daily temperatures were 4 to 8 ^{o}C above normals, while neither weather station showed any significant anomaly in minimum temperatures.

Snowpack data for Moyie Mountain show extremely high snowmelt rates in the days leading up to June 17. Between June 9 and 16, only one day recorded less than 25 mm of melt, while daily melt was between 42 and 68 mm (water equivalent) from June 10 to 13. This melt is especially noteworthy because peak melt for Moyie Mountain usually occurs in late May (April 1 manual snow survey from Moyie Mountain showed snowpack to be almost double normals). Contrary to the other two major floods in the valley, the 1974 flood was driven by high rates of snowmelt, which were exacerbated by the presence of snow at lower elevations later in the year, allowing for a much larger snowmelt input. This mechanism had a much larger effect at upstream sites, while lower elevation sites (Phillips Bridge), or sites with different snowpacks (Hosmer Creek), experienced only a damped peak from the heatwave, or did not experience one at all.

3.3.4 Historical anecdotal flood evidence

In addition to these three recorded major floods, anecdotal evidence is available for several large floods that preceded consistent WSC hydrology measurements in the Elk Valley. On June 19, 1916, flooding on the Elk River resulted in 4 bridges being swept away, as well as significant damage to infrastructure and the evacuation of 50 families (Figure 9). On May 25, 1948, flooding washed away hundreds of feet of CPR track, and several bridges collapsed or were washed away. Only 6 years later, on May 20, 1954, significant flooding once again caused significant infrastructure damage, including damage to 125 yards of a dike built by the city in 1953. Although substantial weather data are not available during these flood events, their late spring timing suggests a similar mechanism of flooding (snowmelt-elevated streamflow and heavy rains) as observed in 1974, 1995 and 2013.

Figure 9. The Elk River flowing over the main highway bridge connecting downtown to west Fernie in 1916. Credit: J.F. Spalding

3.3.5 Revisited: What causes major floods in the Elk Valley?

Floods in the Elk River drainage are driven primarily by extreme weather. Heavy, intense precipitation supplies a large input of water in a short period of time, and most likely produces significant overland flow and a fast response. However, large rain events, in and of themselves, are not enough to cause massive flooding; their timing is also critical. Extreme rain storms of similar magnitude have been recorded for both Fernie and Sparwood during the fall season (October - November), and yet these events have not led to widespread flooding, or even annual peaks in streamflow. The timing of these floods is critical, not because it is when extreme rain events are most frequent, but because it also coincides with peak streamflow brought about by snowmelt. Without an already elevated streamflow in the Elk River watershed, rainfall events can bring a spike in streamflow, but have not been able to create conditions for peak annual flows and widespread flooding.

However, as we have seen in June 1974, the converse is not necessarily true; extreme rainfall is not a prerequisite for extreme flows. The lingering availability of snowmelt, brought about by a high winter/spring snowpack or a cold early spring, can supply enough water to create flood conditions, particularly in the uppermost reaches of the watershed. Furthermore, this type of event has a distinctly longer persistence of high flows (Figure 10, Figure 11), relative to the 2-3 day spikes observed in rainfall-triggered flood events.

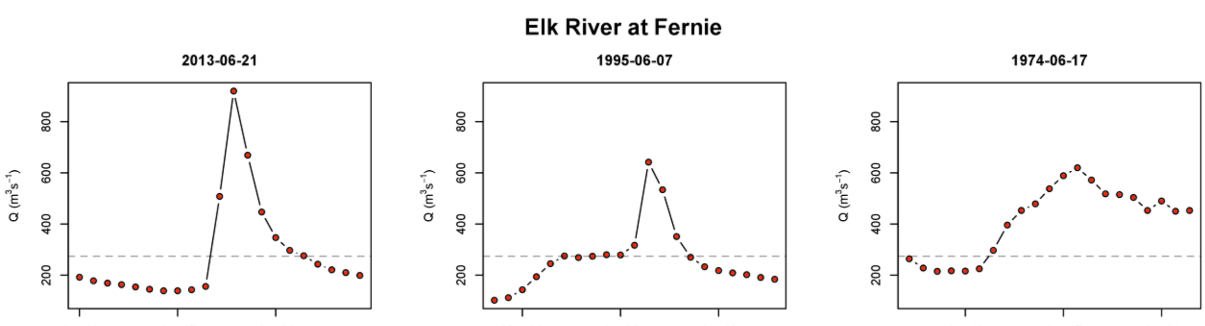


Figure 10. Flood hydrographs from Elk River at Fernie WSC station. Dashed line corresponds to median peak annual daily flow.

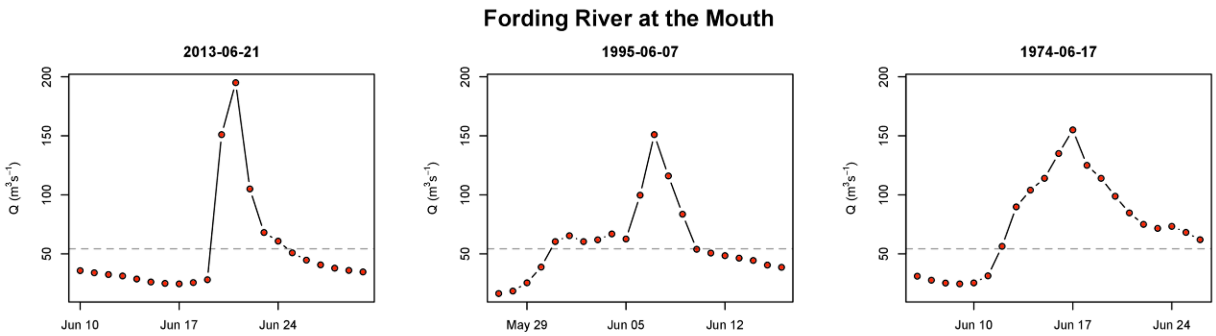


Figure 11. Flood hydrographs from Fording River at the Mouth WSC station. Dashed line corresponds to median peak annual daily flow.

3.3.6 Winter flooding

In mountain rivers following a nival (snowmelt) dominated regime, such as the Elk River, flooding typically occurs during spring snowmelt. During the spring, the snowpack melts quickly, leading to high water levels. High spring streamflow (termed *freshet*) creates conditions where the watershed is more vulnerable to flooding, and additional water input, most often due to large rainstorms, is more likely to overflow banks and trigger flooding. Although this is by far the most common mechanism to initiate flooding in snowmelt-dominated watershed, there remains the possibility for flooding to occur through other mechanisms, particularly during the winter months. Specifically, there is the possibility for ice jams and rain-on-snow events to occur within the Elk Valley, while also some evidence to suggest climate change has the potential to increase the frequency and severity of these events (Beltaos 2002).

Rain-on-snow events

Rain-on-snow events are relatively common occurrences on mountain slopes in environments with moderate winter air temperatures (Marks et al. 1998). During periods of seasonal snow-cover, mild frontal events can bring warmer air temperatures and heavy rainfall. Mild air temperatures tend to warm the winter snowpack to near or at its melting point, initiating snowmelt and runoff. This process is greatly intensified by the input of rain to the snowpack. The rain is warm enough to enhance snowmelt, as well as provide a significant input of runoff itself, allowing for a substantial amount of new water input to the river watershed. Flooding due to rain-on-snow events is relatively common in the Pacific Northwest (McCabe et al. 2007) and other regions (Sui and Koehler 2001), and can occur wherever warm air masses can bring rain over snow-covered terrain. Rain-on-snow events are more common in northwestern North America during cool-air La Niña conditions (McCabe et al. 2007); however, further inland, the more continental climate of the Elk Valley requires warmer air masses for winter rains to occur.

3.3.7 Ice jams

Ice jams, also known as ice dams, occur when river ice and frazil, a needle shaped ice crystal that resembles slush, impede the normal flow of water in a stream or river. Ice jams can result in flooding due to two main interconnected processes: 1) a large backup of ice along the river can be up to several metres thick, significantly inhibiting or damming downstream flow; and, 2) the ice mélange creates high surface roughness within the river channel, significantly increasing the frictional resistance, slowing flow, and exacerbating the backup (British Columbia Ministry of Environment 1999, and Environment Canada 2015). Typically, these events occur during the spring, but can occur during any warming that leads to river ice breakup (Prowse and Lalonde 1996). Although these events typically occur on large, low gradient rivers such as the Peace and Mackenzie (e.g., Prowse and Lalonde 1996), they are possible on any river system that accumulates a significant amount of winter ice. Most recently, a December 2014 ice jam on the Kicking Horse River (CBC News 2014), a river of similar size and character to the Elk River, threatened the town of Golden, although no major damage was recorded. Boyer (1992) reported that ice jams formed on the Elk River at Fernie in 1984, 1990, and 1991. These jams occurred during extended cold periods, and during periods of rapid snowmelt and/or rainfall (Boyer 1992; Figure 12).

Figure 12. Ice dam, south of Fernie, 1986. Credit: Dwain Boyer.

3.4 *Is the flood hazard in the Elk Valley changing?*

3.4.1 Hydrologic regime

Temporal changes in mean annual flow, annual minimum daily flow, and annual maximum daily flow, are investigated at gauge sites on the Elk River (at Fernie, below Natal), Line Creek, and Fording River (at the Mouth) from 1970 to 2013. One of the main factors contributing to flooding in the Elk Valley is elevated baseflows, where higher background flows have the potential to create more severe flooding for equal intensity storms.

Mean annual flow from all four sites show no detectable change; only Fording River at the Mouth shows an increase in mean annual flow during the study period, however it is not statistically significant. Likewise, although decreases are observed at gauges along the Elk River and at Line Creek, only Line Creek shows a discernible trend, and even then, the signal is weak and swamped with noise (Figure 13).

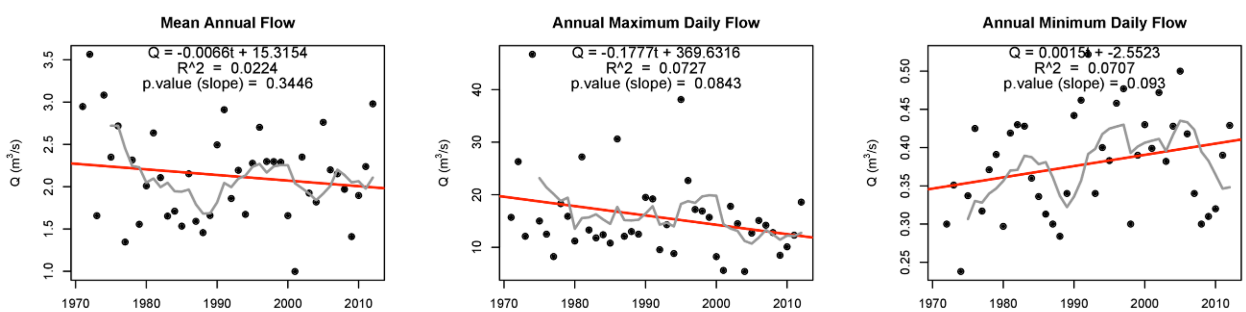


Figure 13. Change on flow characteristics for Line Creek at the Mouth. Grey line is a 5-year running mean, while the red line is a linear regression.

Maximum annual daily flows show no significant change at either Elk River station, or at Fording River at the Mouth. In particular, it is highly probable that peak flows at Elk River at Fernie have not changed since 1970 ($p = 0.999$, Figure 14). Annual maximum daily flows show a significant (42%) decrease at Line

Creek (p = 0.08) during the study period, supporting the idea that mountain top mining increases infiltration and reduces runoff.

Annual minimum daily flows show no general regional trend; individual sub-watersheds have varied, significant responses. Elk River at Natal shows large variability in minimum flows, but no discernible trend across the study period. Elk River at Fernie shows an increase in minimum flows during the study period, however it is also highly variable, and is not statistically significant (α=0.9). Both Fording River at the Mouth and Line Creek show significant increases in minimum flows during the study period, this again supports the concept that mountain top mining can increase late season streamflow. The relationship is particularly strong for Fording River, where minimum daily flows have increased 33% during the study period (p = 0.05).

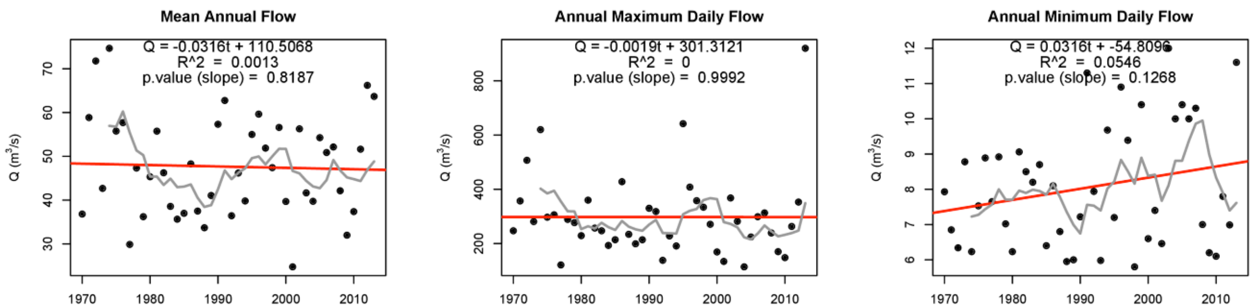


Figure 14. Change on flow characteristics for Elk River at Fernie. Grey line is a 5-year running mean, while the red line is a linear regression.

Conclusions from regional hydrology trends

- It is highly unlikely that mean annual flow is changing in the valley, although it is possible that there is a decrease at Line Creek.
- There is no change in annual maximum daily flows at Elk River at Fernie, and a change is unlikely at Elk River at Natal and Fording River at the Mouth. Peak flows are likely decreasing in Line Creek.
- Annual minimum daily flows are statistically increasing at Fording River and Line Creek, while possibly increasing at Elk River at Fernie. There is no discernible change at Elk River at Natal (near Sparwood).

3.4.2 Hydro-meteorology

Changes in May-June weather patterns were investigated at Fernie and Sparwood weather stations from 1970-2014. Large rainfall events were the primary driver of large floods in both 2013 and 1995. Precipitation data were subsetted for May and June of each year to reflect the fact that spring precipitation is of primary importance for flood potential, given that it typically coincides with snowmelt-elevated streamflow. May-June rainfall totals show a definite increase (p = 0.039, 0.006) for both Fernie and Sparwood (Figure 15).

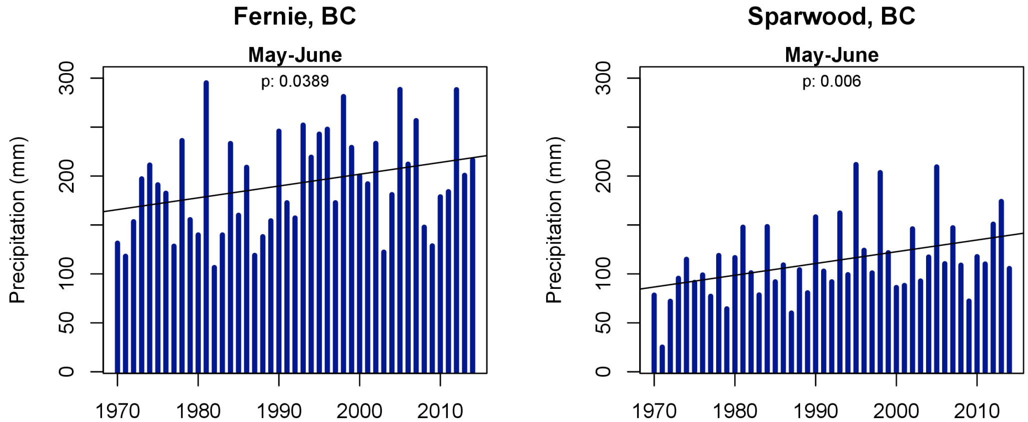


Figure 15. May-June rainfall totals for Fernie and Sparwood, BC from 1970-2014. Black line shows linear regression model, while the p value is calculated for the slope of the model.

Although an increase in spring precipitation is likely to increase flood risk in the area, it does not directly contribute to flooding, because the intensity of individual rain events is much more important than the monthly totals. A further examination of May-June rainstorm patterns shows that the number of large storms is most likely increasing at Fernie. Since 1970, there is a significant increase in the number of events where the rainfall was greater than 10 mm. Fernie weather station also shows an increase in the number of storms greater than 15, 20, and 25 mm; however, the sample sizes are not large enough to draw statistically significant conclusions. Similarly, while Sparwood has recorded an increase in the number of storms greater than 10, 15, and 20 mm, the relatively small sample size of large storms at the sites makes strong conclusions difficult. For intensity-duration frequency analyses see Appendix B.

The increase in spring rainfall appears to weakly translate into spring snowpack in the region. Both Moyie Mountain and Floe Lake snow pillows show an increase in May 1 Snow Water Equivalent (SWE; which is the amount of water in the snowpack) (from 1972 and 1998 to present, respectively); however, neither trend is statistically significant. Morrissey Ridge (1980-2014) shows a slight decrease in May 1 SWE; however, it is also not significant.

Air temperatures at both Sparwood and Fernie do not show any statistically significant change during the study period. While no relationship is particularly strong, there is some indication that average minimum May-June air temperatures may be increasing at both sites ($p = 0.21, 0.35$). Similar to precipitation patterns, average conditions are less of a concern than the likelihood of extreme conditions. There is evidence to suggest that the number of hot days in May and June is decreasing in both Fernie and Sparwood. In particular, Fernie has had a significant decrease in the number of days where daily air temperatures in May-June were greater than 28 ^{o}C ($p < 0.05$), while there is also some moderate indication that the same is true for 26 ^{o}C (Figure 16). Sparwood shows a similar trend to Fernie; however, the dataset is noisier, and no statistically significant conclusions can be drawn.

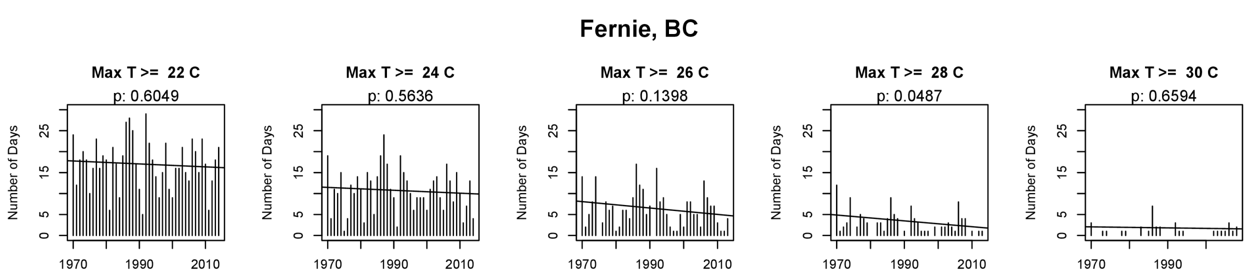


Figure 16. The number of May-June days where maximum daily temperature was greater than a given threshold, Fernie, BC 1970-2014.

There is some indication that the number of May-June days where the mean air temperature is above 18 ^{o}C is decreasing for both Fernie and Sparwood ($p = 0.23, 0.05$). Furthermore, a significant decrease was detected in the number of May-June days at Sparwood where minimum (most often overnight) air temperatures are greater than 12 ^{o}C, and there is some indication that the same is true for Fernie.

Conclusions from regional hydro-meteorological flood drivers

- There is a definite increase in the total May-June rainfall at both Fernie and Sparwood.
- There is a probable increase in the number of large storms at Fernie, and an indication that the same may be true for Sparwood.
- There is some indication that May 1 SWE is increasing in the Elk Valley headwaters.
- There does not appear to be any systematic change in average air temperatures for either Fernie or Sparwood.
- There appears to be a decrease in the number of springtime days reaching extreme air temperatures, and a decrease in the number of warm nights.

4. Effects of flooding on community

4.1 *History of flooding*

Figure 17. Elk Dam, June 2013. Credit: Dwain Boyer

Human memory is short and fuzzy at best, therefore a complete assessment of flooding in the Elk Valley was completed as part of this Strategy. Obtaining a comprehensive picture of the history of flooding in the Elk Valley required the review of issues of the Fernie Free Press 1902-present, and archival documents and photographs from the Fernie and District Historical Society and the Sparwood Public Library. More recent flood history was obtained from the Fernie Free Press, the Elk Valley Herald, E-Know, fernie.com, BC CTV, CBC, and RDEK Public Notices. As well, noted personal communications from various Elk River Flood Hazard Assessment reports from 1990s to present were used. Highlights of historic floods events in the Elk River Watershed dating back to 1903, the resulting damage, emergency action deployed, and community response are provided (Appendix C).

Since the settlement of coal mining communities of the Elk Valley there have been nine noted flood events, the first in June 1903 and the most recent occurring in June 2013. During the first half of the 1900's, floods ranged as frequent as 6 years apart (between 1948 and 1954) to 25 years apart (1948 and 1923). In the latter half of the 1900s, from 1974 to 2013, major floods happened between 18 years (1995-2013) and 21 (1995-1974) years apart.

The most noted damage from flooding in the Elk Valley has been washing out roads and railway bridges, which interrupt the transportation of people and industrial goods. The second most noted interruption was to industrial activity, resulting in suspended operations and workers being laid off. Damage to homes was also extensive, with residents temporarily evacuated. Other impacts were landslides which blocked roads, as well as damage to civic infrastructure including communications, gas lines, power services, access roads and sewer lines. There is also a history of dikes being breached. During the 1995 flood, the dikes constructed in Fernie in 1983/84 were breeched at Coal Creek, as was the dike at Boivin Creek in Elkford, and the dike in Lower Hosmer. Warnings and alerts were issued about the Elko dam. There were observations of wildlife drowned and domestic livestock were moved to higher ground. In some floods students were sent home.

Extreme events like floods require rapid and effective action. In the early years of the Elk Valley, the most common response to flooding was residents building temporary dikes, rip rapping banks with whatever material was available (e.g., coke oven bricks and stone) in an effort to protect personal property. Diversion channels were constructed, and ditches were bull dozed to drain water. Private land owners often took matters into their own hands, resulting in altercations with authorities. Starting with the 1954 flood, the community became more prepared for spring floods. They attended flood defense meetings and were better coordinated in their efforts of sandbagging, patrolling and emergency response. The most recent flood of 2013 saw highly coordinated efforts between RDEK Emergency Services, municipalities, RCMP, local fire departments and search and rescue. Starting in 1974, citizens and communities started asking for flood financial assistance, and in 1995 the province announced an $18 million flood-assistance package. Following the 2013 flood, Elkford applied for half a million dollars in recovery costs. In Sparwood, flood damage resulted in the loss of the waterline under the Elk River, damage to Corbin Road and trail damage by the pedestrian crossing, which totalled $2.3 - 3 million (personal conversation with Sparwood elected official at the Solutions Symposium).

Beginning with the 1974 flood, equipment was dispatched into the Elk River and tributary streams to dredge and channelize the river. This was noted as a high-risk activity as witnessed by a stranded operator in Coal Creek during the 1995 flood (Figure 8). After the 1986 flood, statutory decision makers noted that floodplains were for flooding and they discouraged the clearing of trees along the river and floodplains and river dredging in an effort to protect fish habitat.

4.2 *Community concern and opinion on flooding*

4.2.1 Overview

> *While the focus of flood hazard and mitigation can often be infrastructure and property, it is vital to remember that most importantly flooding impacts people.*

A central focus of the Elk River Flood Strategy has been to create opportunities for dialogue with residents, to identify and address gaps in flood literacy, and then to collect and summarize this input for community decision-makers. To achieve this, two ERA educators attended 21 community events from May to September 2015, and spoke with over 1,400 people throughout the Elk Valley. Discussions occurred with a broad representation of the community, and included: individuals aged 2 to 80, multi-generational landowners, people who had just moved to the Elk Valley that day, and residents from many different walks of life (Figure 18). Residents shared their experiences with flooding, concerns and ideas, and had the opportunity to learn more about flooding in the Elk River Watershed from educators.

Figure 18. Elk River flood education and outreach booth (left), and wetlands and rip rap hands-on flood mitigation strategy models (right).

Two hundred people completed Elk River Flood Surveys with respondents spread approximately in proportion to populations of Elk Valley communities. In additional to the on-line surveys, oral history interviews were conducted with 17 long-time residents of the Elk Valley. The interviewees' anecdotal impressions of past flooding events helped confirm the community experience with and attitude to flooding.

The diverse opportunities for community members to discuss flooding and provide input were received with enthusiasm. The results of the survey and oral histories correlated closely with anecdotal reports heard from the educator face-to-face interactions with community. Local knowledge from these long-term residents is to be respected as some regularly visit the same locations in the watershed every day, even multiple times in a day. Local knowledge could be an early warning system of 'when something's up' with regards to prospective flooding.

Feedback from key stakeholders and interested community was gathered from two events. The first was the 'Elk River Flood Strategy Technical Review Workshop' on October 14, 2015, where preliminary findings were presented and public feedback incorporated. The second was the 'Solutions Symposium for Flooding in the Elk River Watershed' on April 12, 2016, where feedback was obtained on key findings and how to best implement the recommended Elk River Flood Strategy.

4.2.2 Community input

This section summarizes responses to the Flood Survey using an on-line survey tool. Residents replied that flooding in the future is a concern (53% stating that flooding is definitely a concern and 26% flooding is somewhat of a concern) (Figure 19). Most experienced the 2013 flood (88%), many experienced the 1995 flood (35%) and only a small percentage of residents (2%) remembered the 1974 flood. Most of the oral history participants witnessed all three floods, and some also remembered earlier flood events. They expressed that flooding has been a part of Elk Valley life for a long time and will continue to be a part of its future. During the interviews, questions were often raised about the impacts of climate change on the frequency and magnitude of future flood events. There was also concern about the cumulative effect of land use changes from activities such as forest removal, particularly the current rate of logging on the east side of the Elk Valley, and related slope failures in hazard areas resulting in land/mud slides. There was a general apprehension that flooding could become more of an issue in the future.

> *Flooding is a human construct; it's only a flood when it affects people or infrastructure. We can't fight them, only adapt!*
>
> *Either we manage in a systematic fashion or nature will do it in one go.*
>
> \- Long-time resident

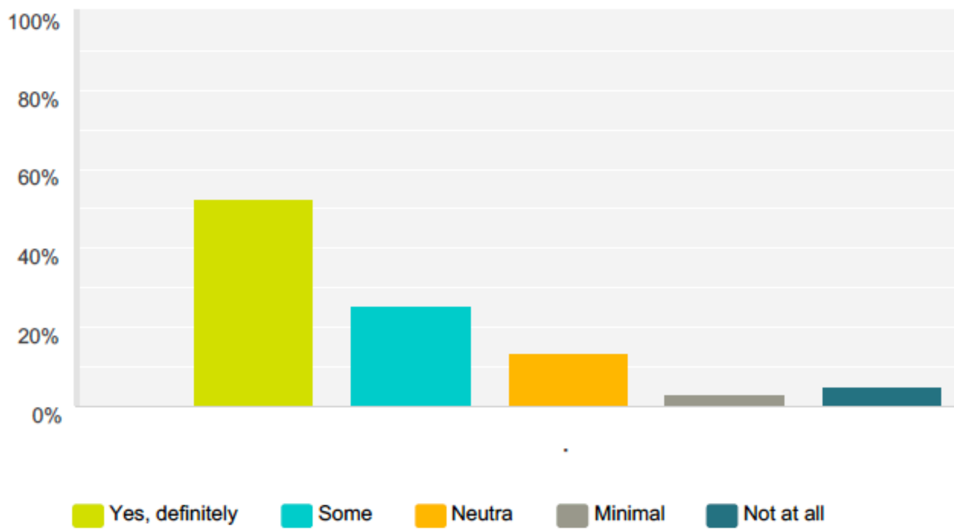


Figure 19. Survey question: Is flooding in the future a concern for you?

Oral history participants spoke of surprise at the force of flood-water and the speed of flood onset. All recalled damage to infrastructure, mainly roads, and community property. Many had clear memories of damage to their homes, water intake on creeks and personal property, and the challenges of making repairs and seeking compensation. Participants spoke proudly of community responses, with stories of strangers showing up to sandbag their house and heavy equipment operators helping wherever possible. Most felt that the emergency response made them feel safe (61%), and were both timely and effective. A few improvements were suggested, including giving emergency response teams the power to restrict access to high-risk areas such as the tops of dikes, and preparing a social response plan to support families through the time of crisis.

It was scary as hell; although frightful, these flood events united the community.

- Long-time resident

Fish know what to do in a flood; moving into floodplain areas and river channels, and then moving back to the mainstem when floodwaters subside.

- Local fisher

Survey results suggest that infrastructure damage (79%) and environmental impacts (76%) of flood mitigation are residents' main concerns (Figure 20). Survey comments from residents indicate they are concerned about industrial activity with potential for mine tailing ponds to spill over or fail in a flood, as well as the impacts of the current increase in forestry activity in the watershed. One resident expressed the sentiment of many concerned about the "knee jerk reaction to flooding with short term fixes and funding that pays for infrastructure replacement. Why fix failures; why not invest in improvements?" It is clear that residents value healthy ecosystems and questioned the effect of flooding on wildlife, fish, tourism and recreation experiences.

Community residents were also concerned about communities being isolated by damaged infrastructure like washed out bridges or roads (58%), damage to personal property (57%), the cost of flood mitigation (52%), and the general impact on daily life (52%). Surprisingly, personal safety (44%) was their lowest concern. In the oral history interviews a number of respondents noted that 'floods are a big economic issue'. Most residents felt safe (61%) with some not feeling safe (16%) during a past flood event. Residents varied in their concerns about flooding depending on their proximity to the flood plain and some expressed concern that they do not understand where they are situated in terms of the floodplain and projected 100 - 200 year flood levels.

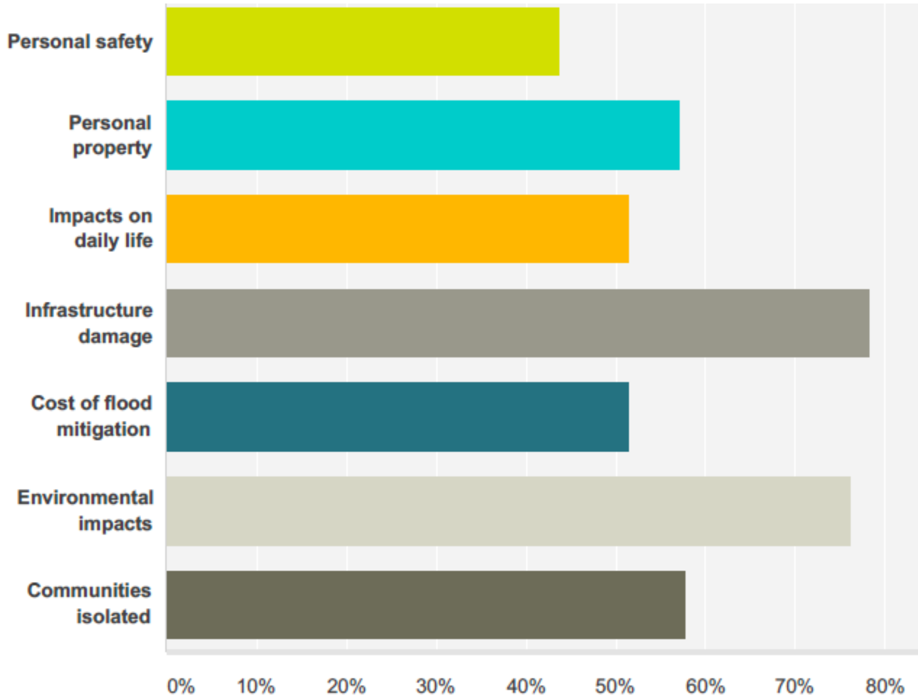


Figure 20. Survey question: What about flooding is a concern for you?

The opinions of oral history participants on historical response to flooding and effective mitigation methods were varied. Many expressed a need to study evolving flood mitigation methods that are effective while maintaining healthy riparian ecosystems. Many voiced concern about the downstream effects (e.g., increased velocity and erosion) they had witnessed from historic channelizing and recent diking. One participant urged that mitigation measures be designed "for the 99% of days without flooding," by considering public access, recreation function and aesthetics.

Residents in the survey placed an overall emphasis on prevention and non-structural flood mitigation methods, where possible. Riparian enhancement (81%) and municipal zoning (64%) were the preferred strategies (Figure 21). Oral history participants all felt a desire to "do it now and do it right," although they acknowledged that the "challenge is balancing effectiveness, impact, cost and longevity of solutions." Some felt their communities are unprepared and were unhappy with restrictions on rebuilding damaged mitigation structures beyond pre-existing levels. Many pointed to climate change and the need for the implemented flood strategy to be adaptive.

Rip-rap was a supported flood mitigation solution (41%), especially in highly vulnerable areas. Dikes (31%) and dredging (6%) were the least supported mitigation options. Several anecdotal responses encouraged municipalities to 'improve stormwater management by encouraging new developments to use rain gardens, pervious pavement, bioswales, and stormwater retention to slow down and treat water in constructed wetlands before discharge to the Elk River'.

Support for maintaining healthy ecosystems was a priority for residents, with one resident noting the value of soils and trees left undisturbed to absorb water and moderate snow melt

Another resident commented that "*perhaps rip-rapping could also include vegetating areas with shrubs, where appropriate*".

– Elk Valley Residents

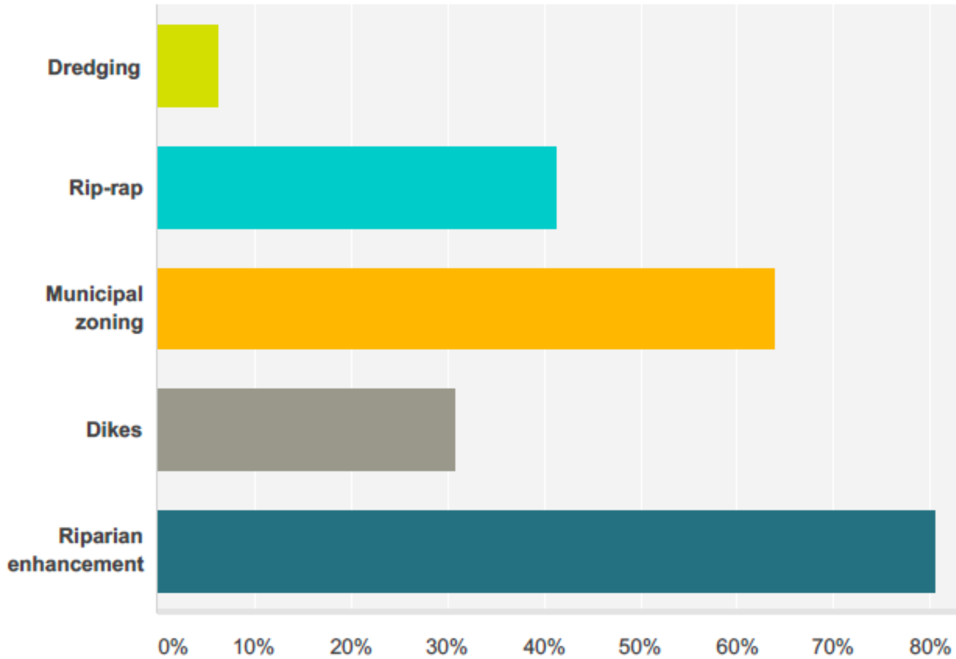


Figure 21. Survey question: What flood mitigation strategies do you support for offsetting the effects of future floods?

Residents identified specific areas of concern for flooding in the Elk River watershed. Most of the areas were in the historic floodplain along the Elk River. In Elkford, the most vulnerable areas identified are the farms north of town, Round Prairie, the Union Hall and the road to Elk Lakes, which was heavily damaged in the 2013 flood. In Sparwood, Mountain View trailer park was the area of highest concern, as well as the Lower Elk Valley Road and Matevic Road. Fernie's areas of highest concern were the Annex, West Fernie, Airport subdivision, and properties adjacent to Coal Creek, Canadian Tire/Independent Foods, the Stanford Inn, and the Fernie Golf Course. One property owner downstream of Fernie was particularly concerned about a possible increase in river velocity eroding their property. In the RDEK, the area of greatest area of concern was lower Hosmer, the area west of the Hosmer Bridge, and especially around the Hosmer Bridge. Other areas in the RDEK of concern were below Cokato Road (Hill Road and Thompson Road), and properties in the floodplain along the Elk River north and south of Fernie. There was an interesting comment from a long term Michel resident that 'Michel Creek was dredged and had been channelized and aligned along the left side of the valley, but during the 1948 flood it reverted to a meandering course."

We used to take out river gravels as a preventative mitigation effort to stop the Elk River from meandering, which increased the flow and velocity of the Elk River for a short distance, to bail out Hosmer. The old Great Northern Railway (GNR) grade acted as a dike protecting lower Hosmer; after the 1995 flood, the GNR railway grade was breeched and is now largely gone.

- Long term Hosmerite

Many oral history participants urged residents to accept a future with flooding. They emphasized the importance of public education, focusing on a range of topics from flood hazard areas to a better understanding of mitigation options, their effectiveness and environmental impacts. This would lead residents to more informed opinions on options for mitigation.

Residents were interested in learning more about flooding and mitigation solutions (Figure 22). There was widespread interest in improved flood risk mapping (65%), information on community emergency response plans (50%), flood mitigation options (47%), Elk River hydrology and behaviour of the river (44%), and the need to develop their own personal flood safety plan (32%). The predicted impact of climate change was also requested. Residents were predominantly interested in receiving further flood information online (78%), with significant interest in a printed pamphlet distributed by municipalities (33%), as well as further outreach education (24%). After speaking with the community outreach educators, 60% of respondents felt they had more knowledge about flooding. One person would like to see one-way valves installed in culverts under the dike in James White Park, to prevent flooding like what occurred in 2013 on Mount Proctor Avenue.

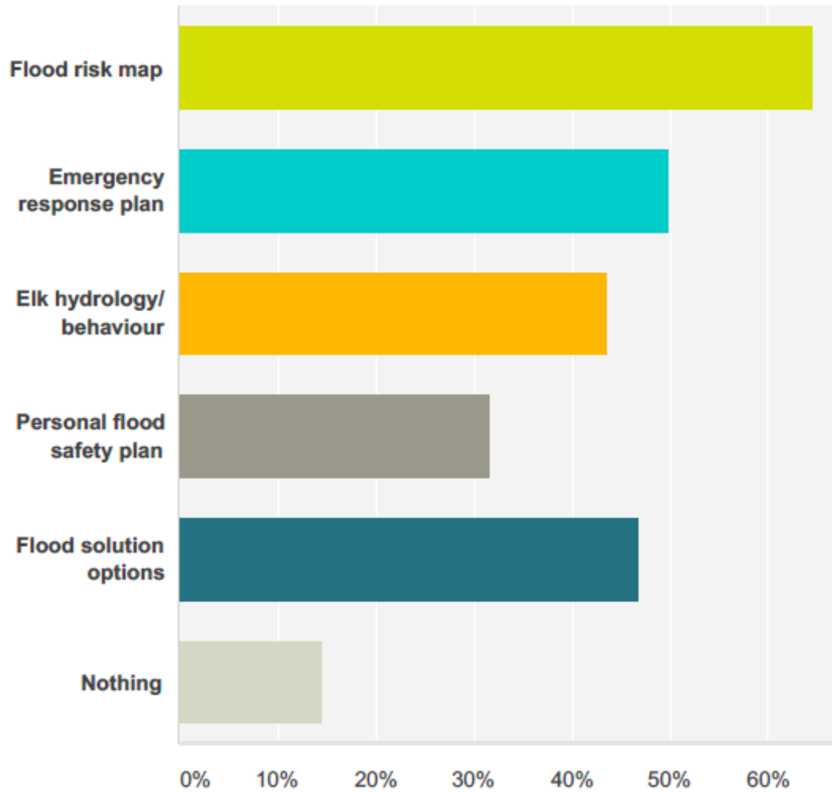


Figure 22. Survey question: What would you like to know about flooding in the Elk Valley?

The public who interacted with the ERA community educators and completed the survey were thankful for the opportunity to provide input to a watershed wide flood strategy, and they saw the need to work together on proactive strategies that increased public awareness and engagement. The Elk Valley has strong communities with residents who are concerned about flooding and who appreciate opportunities to provide input on a proactive, holistic, Elk River watershed-wide flood strategy. One long-time resident concluded their oral history interview with a statement that captures the general attitude toward the Flood Strategy community outreach program: ***"I don't know if you can do anything, but at least you listened. You're the first person who came down here and listened".***

When asked, 'Is there anything else to pass on to municipalities or the Elk River Alliance about flooding in the Elk Valley?'

1. The top response was support municipalities restricting new development in floodplains.
2. Residents also want municipalities to advocate for protection of adverse downstream effects as a result of industrial activity such as logging.
3. Mitigation of flooding is essential, but must proceed with careful consideration of the ecology of the river and watershed as a whole.
4. There was very little support for dredging, with comments suggesting it 'as a waste of effort and resources'.

4.3 *Municipal leaders, key questions about flooding*

During January and February 2015, Lee-Anne Walker, ERA Executive Director delivered an Elk River Flood Strategy 8-minute Power Point overview presentation to the following organizations:

- January 20: Elk Valley Cumulative Effects Management Framework (CEMF) Working Group members (Province of BC, Teck Coal, Ktunaxa Nation Council, Elk Valley Municipal Government Representative, Canfor, Jemi Fiber)
- January 26: City of Fernie Committee of the Whole (Mayor, All Councillors, Staff)
- February 10: District of Elkford, Regular Council Meeting (Mayor, Council and Management Staff)
- February 16: District of Sparwood, Regular Council Meeting (Mayor, Council and Key Staff)
- February 19: Elk Valley Integrated Resource Task Force (Representatives from Wildsight, Canfor, Jemi Fiber, Rod and Gun Clubs, Motorized and Non-Motorized Recreation, Back Country Guides Association)
- May 2015: RDEK Area A Flood Control Service Meeting in Hosmer

Beyond informing people about the purpose, goals and objectives of the Strategy, a secondary intention was to gather input from participants regarding: What key questions they have and would like to have answered about flooding in the Elk Valley? How could ERA's Flood Strategy support their decision making regarding future flooding?

Participant responses were collected and a summary of key questions was provided to the entire research team to guide the development of the Strategy. Below is a ranking of questions and suggestions provided during the five presentations, based on the number of times the question was raised. Every attempt was made to answer these key questions in this Strategy:

1. What is the community emergency response plan for flooding in the Elk Valley? Who monitors water levels and activates emergency response plans?
2. Why does the government provide remediation funding after a flood to pre-flooding levels when clearly it has failed for a reason (in some cases was replaced to that level three time previously)?
3. Explore the various cost/benefits of flood mitigation options, so that the best decisions can be made to protect residents and community infrastructure.
4. What is the relationship between the effects of watershed-wide forestry, mining, removal of vegetation and hardening of surfaces and flooding? How can we protect watershed function to reduce the impacts of flooding?
5. How can we protect our most critical infrastructure (e.g., Highway 3 & 43, CPR, bridges, municipal infrastructure)?
6. What is the role of course woody debris in the river and the risk it places damming up around infrastructure, bursting and flooding?
7. The Strategy must be collaborative with existing processes (CEMF, RDEK Area A Flood Control Service Area, Municipal Official Community Plans and Bylaws) and provide a holistic watershed wide perspective with pro-active solutions.
8. Is there an inventory of materials and stockpile of suitable rocks for riprap in reserve to aid in flood emergency response, and what is the cost of that material?
9. What are effective strategies to slow the flow of water, retain it in the watershed and increase resilience in the watershed to flooding?
10. Can we better understand river morphology to mode:l a) how much water there might be in future climate change scenarios, and b) where water is likely to go so that we are better prepared? Do we have up to date 200-year flood plain maps?
11. What is the effect of floods on ground water in communities like the Annex in Fernie and West Fernie?
12. Review past floods and community response to learn from our past successes and failures.

5. Effects of flooding on fish and wildlife and mitigation options that improve habitat

5.1 *Wildlife species and stream side habitats of importance*

The floodplain area from Elkford downstream to Elko extends across three biogeoclimatic (BEC) zones (Ministry of Forests, Lands and Natural Resource Operations (FLNRO) 2012, Meidinger and Pojar 1991):

- The Montane Spruce (MS) zone occurs from Elkford downstream past Sparwood 10 km, and for a 5 km section upstream of Elko. This zone has a cooler climate characterized by cold winters and moderately short, warm summers. A distinctive feature is the extensive, young and maturing seral stands of lodgepole pine that have formed following wildfire.
- The Interior Cedar-Hemlock (ICH) zone extends downstream of Sparwood, past Fernie 20 km. This zone is one of the wettest and most productive forest in the interior of BC. Riparian climax vegetation include: Engelmann spruce, white spruce, subalpine fir, black cottonwood, and Western red cedar.
- Elko is situated in the Interior Douglas Fir (IDF) zone, which has warm, dry summers, with a fairly long growing season. The dry mild subzone present around Elko is distinguished by the presence of Douglas fir and western larch.

In these three BEC zones, the riparian/wetted/moist habitats of the Rocky Mountain Forest District hosts 7 red-listed (extirpated/endangered/threatened species at risk and requiring investigation) and 17 blue-listed (special concern and sensitive to human actions and natural events) animal species in BC[1] (Table 2; BC Conservation Data Centre (BC CDC) 2015). Of these, 14 species are breeding birds and 16 are listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as endangered, threatened or special concern[2]. Preserving the riparian habitat that these species depend on is important for them, as it is for many other species with healthy populations.

Table 2. Sensitive animal species known in at least one of MS, ICH, and IDF BEC zones, in moist/riparian habitats of the Rocky Mountain Forest District (BC CDC 2015)

Scientific Name	Common Name	BC List	COSE-WIC	Breeding Bird
Aeronautes saxatalis	White-throated Swift	Blue	-	Y
Anaxyrus boreas	Western Toad	Blue	SC	N
Ardea herodias herodias	Great Blue Heron, *herodias* sub spp.	Blue	-	Y
Ascaphus montanus	Rocky Mountain Tailed Frog	Red	T	
Asio flammeus	Short-eared Owl	Blue	SC	Y
Botaurus lentiginosus	American Bittern	Blue	-	Y
Buteo platypterus	Broad-winged Hawk	Blue	-	Y
Buteo swainsoni	Swainson's Hawk	Red	-	Y
Chrysemys picta pop. 2	Painted Turtle, Rocky Mountain Pop.	Blue	SC	N
Contopus cooperi	Olive-sided Flycatcher	Blue	T	Y
Cypseloides niger	Black Swift	Blue	E	Y
Euphagus carolinus	Rusty Blackbird	Blue	SC	Y
Euphydryas gillettii	Gillette's Checkerspot	Red	-	N
Falco peregrinus anatum	Peregrine Falcon, *anatum* sub spp.	Red	SC	Y
Gulo gulo luscus	Wolverine, *luscus* subspecies	Blue	SC	N

[1] BC Listing: Red listed species are candidates for, Extirpated, Endangered, or Threatened status; and blue-listed species are Special Concern.
[2] COSEWIC listing: Endangered species face imminent extirpation or extinction, Threatened is likely to become endangered if limiting factors are not reversed, and Special Concern are particularly sensitive to human activities or natural events.

Scientific Name	Common Name	BC List	COSE-WIC	Breeding Bird
Hirundo rustica	Barn Swallow	Blue	T	Y
Lithobates pipiens	Northern Leopard Frog	Red	E	N
Megascops kennicottii macfarlanei	Western Screech-Owl, *macfarlanei* sub spp.	Red	T	Y
Melanerpes lewis	Lewis's Woodpecker	Blue	T	Y
Myotis septentrionalis	Northern Myotis	Blue	E	N
Pekania pennanti	Fisher	Blue	-	N
Rangifer tarandus pop. 1	Caribou (southern mountain pop.)	Red	E	N
Recurvirostra americana	American Avocet	Blue	-	Y
Ursus arctos	Grizzly Bear	Blue	SC	N

Western Toad

Great Blue Heron

Fisher

5.1.1 Wildlife habitats potentially influenced by floods/flood mitigation efforts

Riparian areas

Riparian areas contain some of the most biologically diverse wildlife habitats found in forests. Of the 340 vertebrate species that live in BC, over 40% utilize the unique habitats provided by the vegetation and stand structural diversity found adjacent to streams, lakes and wetlands (Koning 1999).

Figure 23. Riparian area along the Elk River, 2015. Credit: Dave Weller (http://wellerfish.me/elk-river-bc-08092015/)

The riparian area is the zone with the greatest potential to be influenced by floods and flood mitigation strategies. The riparian area is an important transition zone between aquatic and upland habitat. Frequent, seasonal surface and subsurface water inundation that occurs in the riparian zone supports plant species that are distinct from species on adjacent upland sites. Vegetative cover in the riparian area contributes directly to healthy watershed function and fish and wildlife habitats as described below (Koning 1999; Figure 23, Figure 24).

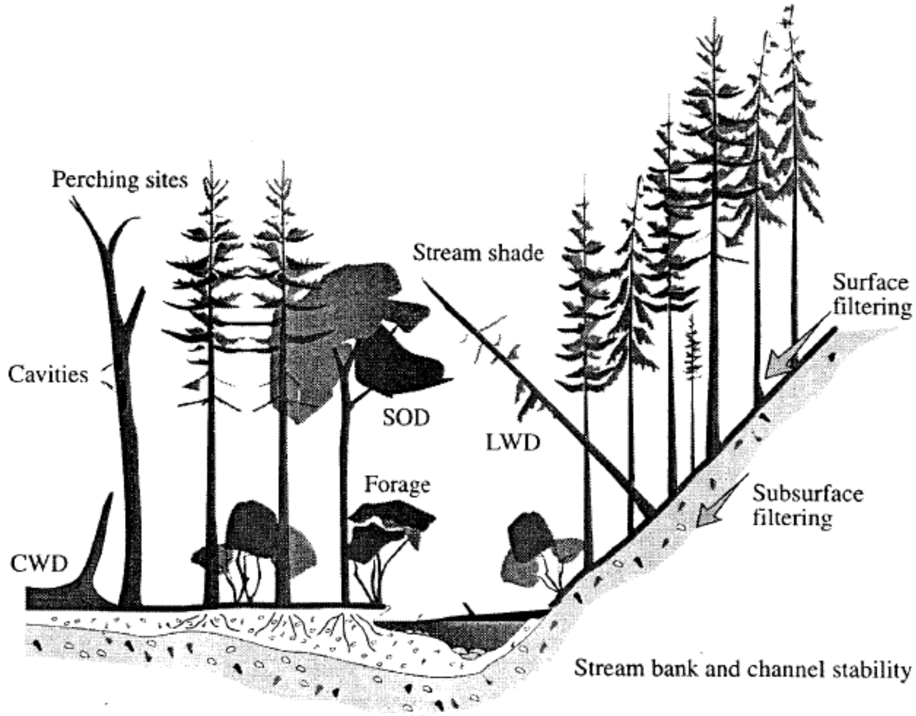


Figure 24. Ecological function of riparian vegetation. Source: Koning 1999.

General watershed function of riparian areas:

- Maintains bank and channel stability through solid root mass and ground cover. The ability to protect stream banks from erosion and maintain stream stability increases as the stands age and root systems become more extensive.
- Reduces scour/erosion in the stream channel by allowing flood energy to dissipate over a wide area.
- Filters surface and subsurface contaminants via physical, chemical and biological processes in soils.
- Filters fine sediments resulting from upland surface erosion. The filtering ability increases as the width of vegetated area increases.
- Vegetation further reduces flood damage by dissipating energy of the flow, and by stabilizing banks and steep slopes against the erosive forces of overland flow (Shroba et al. 1979 - Cited in Hickey and Salas 1995).

Aquatic life function:

- Contributes large woody debris (LWD), which has numerous benefits:
  - increases complexity of pool and riffle sequences;
  - creates escape refugia and cover important for fish for spawning and rearing juveniles;
  - alters stream gradient locally to retain gravel,
  - catches small organic debris (SOD); and,
  - In large streams, large woody debris (LWD) influences channel morphology through debris jam creation on gravel bars and armouring banks.
- Provides SOD (leaves, twigs, detritus, and terrestrial insect drop), which contributes to algae production, and in turn provides energy for aquatic insects. Deciduous litter provides the most important source of energy for stream invertebrate populations, and is generally the preferred substrate for aquatic microbes and insects.

- Regulates stream temperature by providing shade, with mature trees required in larger streams for effective shading.
- Regulates instream algal production by controlling sunlight (for photosynthesis) reaching the stream.
- Bank roughness provided by root systems reduces water velocity adjacent to the channel bank and provides complex bank geometry. This complexity provides vertebrates with shelter and resting areas away from the higher water velocities (Craig and Zale 2001 – Cited in Reid and Church 2015).

Wildlife function:

- Provides diverse stand structure. Because they are relatively dynamic, riparian areas typically have many different ages of trees which are used differently by wildlife.
- Provides coarse woody debris (CWD), wildlife trees, nest and perch sites, and summer and winter denning.
- Provides summer and winter forage.
- Provides connectivity corridors for wildlife. Maintaining unrestricted access from valley bottom to upland habitats is important for animals migrating to and from seasonal winter and summer ranges, and travelling between areas of their home range (McPherson et al. 2015). Wildlife corridors generally follow riparian areas, and extend to connect with other habitats of value (e.g., for feeding, migration or nesting) including isolated waterbodies and old growth forest units (McPherson et al. 2015). Wildlife corridors can enhance biodiversity and ecosystem connectivity, and mitigate habitat fragmentation caused by development (Corporation of the City of Fernie 2014).

In addition to the above ecosystem benefits, riparian areas provide important recreational and economic benefits to the Elk Valley. Examples of recreational uses include trails, picnic sites, birdwatching, dog walking, etc. Healthy intact riparian areas contribute to the local economics by increasing the real estate value of the area, by drawing tourists, and by providing the habitats necessary to support the recreational fishery in the watershed. Losses of riparian habitat can occur through the installation of some traditional types of flood mitigation strategies. Maintaining riparian habitat is important.

Cottonwood stands

Black cottonwood (*Populus trichocarpa*) are the foundation of the riparian forests in the Elk River watershed, both as pure stands interspersed through the landscape and as individual or small groups of trees within coniferous forests (Jamieson et al. 2001, Polzin 1998; Figure 25). Black cottonwood is a shade intolerant tree species, which relies on episodic flooding to open canopy space and clear moist areas of land to serve as seedling establishment sites. In addition to the riparian attributes listed above, cottonwood stands provide several additional benefits to fish and wildlife, including (Jamieson et al. 2001):

- Produce high biomass when young that is utilized as forage by ungulates and other browsers;
- Have a relatively short life span and thus provide vertical structure, cavity sites, snags, and down wood more quickly than conifers;
- Are more palatable than conifers and thus are used by a range of herbivorous insects and mammalian browsers;
- Support more productive shrub and herb layers than occurs under conifers, thus increasing the complexity and diversity of bird habitat provided.

Figure 25. Cottonwood stand in Morrissey (Photo: BW Bandy Everybody has to be somewhere blog)

Because of these characteristics, riparian cottonwood stands provide very high biodiversity and species abundance (Bruce et al. 1985, Achuff et al. 1984, Bunnell 2000- Cited in Jamieson et al. 2001). Many sensitive listed species are also dependent to some degree on hardwoods in riparian areas (Jamieson et al. 2001). Although cottonwoods support diverse flora from their early and mid-seral stages, the habitat complexity and richness is amplified in larger older sized stands, which provide increased vertical structure (Jamieson et al. 2001).

Black cottonwood depends on periodic flooding for successful recruitment and growth (Braatne et al. 1996 - Cited in Polzin 1998). Annual flooding recharges the water table and is important for the recruitment and maintenance of cottonwoods (Mahoney and Rood - Cited in Polzin 1998). Seed dispersal coincides with declining river flows following spring high water (Braatne et al. 1996 - Cited in Polzin 1997). Barren point bars formed by fine sediment deposition as annual floods recede, provide moist sites with full sunlight exposure creating prime sites for seedlings to establish (Bradely 1982, Scott et al. 1996 - Cited in Polzin 1998). Cottonwoods also reproduce asexually, through rooting of branch fragments and suckering from lateral roots (Peterson et al. 1995 - Cited in Polzin 1998). Reproduction is thus promoted by fluvial disturbance. This was exemplified by a study of the Elk and Kootenay rivers following the major 1995 flood event by Polzin (1998). Cottonwood recruitment was abundant one and two years following the flood in free-flowing river systems; while in contrast, no seedlings were successful downstream of the Libby Dam where flood flows were attenuated and this resulted in little change in bank configuration (Polzin 1998).

Wetlands

Wetlands are a critical component of maintaining the health of ecosystems for fish, wildlife and humans. Wetlands provide a number of important ecological functions ranging from water purifiers and fish nurseries to carbon sinks and wildlife breeding grounds. Most wildlife in the province use wetland habitat at some point in their life cycle, and many red- and blue-listed species are wetland-dependent.

-Columbia River Basin Biodiversity Atlas, 2013

Hydrologic characteristics of the Columbia River watershed have resulted in well-distributed water areas with a rich array of wetlands (Columbia River Basin Biodiversity Atlas 2013, Figure 26). Wetlands are common in all three BEC zones (Meidinger and Pojar 1991). Mineral wetlands are common in the watershed, and these are primarily classified as swamps and marshes (L. Walker pers. comm.). Swamps are dominated by tall woody vegetation, and the resulting wood-rich peat (Wetlands Research Center 1997). Marsh wetlands have shallow water, that usually fluctuates seasonally or annually due to flooding, evapotranspiration, groundwater recharge, or seepage losses (Wetlands Research Center 1997).

Figure 26. Wetland habitat. Credit: Community Mapping Network, BC Wetlands Atlas (http://www.cmnbc.ca/atlas_gallery/bc-wetlands-atlas).

Wetland areas play positive roles in response to flooding. Flooding in wetlands generally spurs an increase in biological production throughout the food chain (Bayley 1991 - Cited in Hickey and Salas 1995). Wetlands improve water quality by intercepting sediment and using nutrient rich overland runoff in vegetative growth (Gilliam 1994, Hey et al. 1994, and Haertel et al. 1995 - Cited in Hickey and Salas 1995). Wetlands also retain floodwaters, slowing flows and lowering flood peaks (Demissie and Khan 1993 - Cited in Hickey and Salas 1995). Water seepage from wetlands could also help to maintain more favorable base flow conditions later in the year. These characteristics and functions all act to benefit fish.

Draining and disconnecting wetland and floodplain areas compounds flooding impacts by speeding the conveyance of floodwaters to the main channel and increasing flood stages (Hickey and Salas 1995). Separating the channel and floodplain also destroys key aquatic habitat and reduces the productive potential of aquatic systems (Hickey and Salas 1995).

Beaver

Beavers are prevalent along the Elk River shoreline and off channel areas. As a result of their ability to dam flows, beavers are important contributors to Elk River watershed function and create high value fish and wildlife habitat, similar to wetlands. The following are some highlights from the Alberta Cows and Fish Program (Fitch 2016):

- Behind the beaver dams, water is slowed and sediment becomes trapped causing the elevation of the streambed to rise, widening the valley and increasing water storage capacity.
- The sediment and raised water table encourages the establishment of vegetation which in turns further aids in filtration, and slows velocity, reducing stream bank erosion.
- Beaver ponds provide benefits during floods, through increased storage capacity.
- Beaver activity can help mitigate the effects of drought, through surface water retention behind dams, shallow ground water storage, and slow release to enhance downstream flows.
- Beaver ponds stabilize water temperatures, cooling receiving water.
- Beaver ponds can provide important overwintering and low flow refuges for fish.

Overall, beaver workings contribute substantially to the complexity, connectivity and vegetation diversity of landscapes, creating valuable fish and wildlife habitats.

5.2 *Fish and fish habitats of importance*

5.2.1 Fish species

Fish species found in the Elk River and its tributaries upstream of the waterfall and dam barrier at Elko are:

- Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*),
- Mountain whitefish (*Prosopium williamsoni),*
- Bull trout (*Salvelinus confluentus interior lineage).*
- Longnose dace (*Rhinichthys cataractae*),
- Longnose sucker (*Catostomus catostomus*), and
- Eastern brook trout (*Salvelinus fontinalis)*, a non-native species.

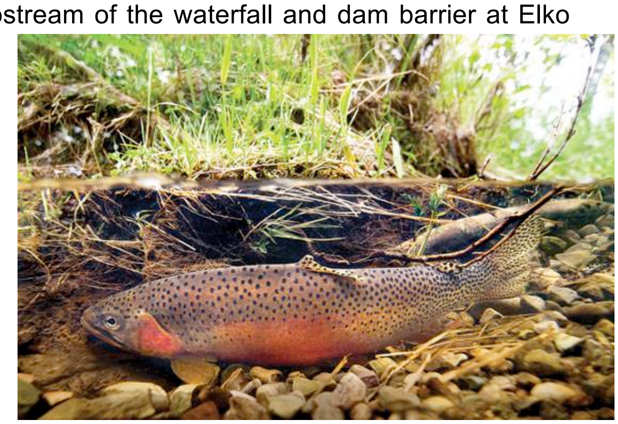


Figure 27. Westslope cutthroat trout. Credit: Montana Outdoors Magazine (http://fwp.mt.gov/mtoutdoors/)

Bull trout (interior lineage) and westslope cutthroat trout are species of Special Concern in BC and under COSEWIC (BC CDC 2015). Additionally, westslope cutthroat trout are a species of Special Concern throughout their range in British Columbia under the federal Species at Risk Act (SARA, Figure 27).

The Elk River watershed is known for its world-class fishing. In response to high fishing pressure, and in order to maintain the high quality of angling experience, the Elk River and its tributaries have been designated as Classified Waters by the BC Government, requiring special licencing provisions and angler targets. Guided and non-guided fishing throughout the watershed is important to the local economics. For these reasons, incorporating mechanisms to maintain healthy fish populations and habitats is important when designing flood mitigations.

5.2.2 Impacts of floods on fish populations

Flooding often has a positive effect on fish populations in large low-gradient rivers. For example, macroinvertebrate densities generally increase in large low-gradient rivers, due to the influx of food that occurs over the expanding water surface (Hickey and Salas 1995). The heightened invertebrate production cycles through the food chain and results in increased numbers of higher predators, including fish (Hickey and Salas 1995). Certain fish species actually depend upon, seasonal or periodic extreme flooding for spawning and migration processes. Westslope cutthroat trout are triggered to spawn by flows. The fish migrate to their natal stream during the spring peak river discharge, and spawn during the descending limb of the hydrograph (Schmetterling 2000). This allows the embryo and young fish to develop in the absence of floods, during the warm summer period.

The potential also exists for floods to impact fish populations. The most vulnerable fish life stages are the recently hatched (fry) and juveniles, since these fish are the smallest and thus have the weakest swimming abilities (Pearsons et al. 1992, Harvey et al. 1999). Fry and juveniles inhabit shallow slower stream edge and off-channel habitats, but even in these sheltered areas, small fish can be overtaken by flood flows. Bull trout spawn in the fall and hatch in the spring in higher gradient tributaries. The relevance of this for Elk River populations is that while bull trout hatch is timed to occur before spring floods, it is on the order of weeks or a few months before the spring dominated hydrograph peaks. As such, there has been strong evidence of floods impacting bull trout fry in Elk River tributaries. The significant negative relationship between June flows and bull trout fry recruitment (i.e., hatching and surviving) has been documented in Line Creek since 2006 (Allan and Stemo 2006). Annual monitoring programs continue to document this with the most recent major flood (June 2013) reported as essentially eliminating recruitment in that year (Robinson and McPherson 2014). Population level effects of these floods are not yet known for Line Creek. The degree of impact depends on a number of factors, including: flood timing & intensity, extent of intact floodplain, and stream habitat complexity.

If winter floods increase as predicted, fry, juvenile and incubating eggs of fall spawning species (bull trout and mountain whitefish) may experience added environmental stresses. In rain dominated areas such as the west coast of BC, winter floods result in high sediment transport in watersheds with steep and unstable terrain, particularly those which have been recently logged (Hartman et al. 1996). In these areas, there is evidence that associated landslides, debris torrents and bank erosion, have negatively impacted spawning and rearing habitats, influencing overwintering survival (Hartman et al. 1996). The vulnerability of the Elk River watershed to increased winter floods will depend on factors including geology, land form, hydrometeorology, and level of disturbance.

Given proper conditions, fish populations and stream habitat can quickly respond to these relatively short-lived, localized events (Roghair et al. 2002, Pearsons et al. 1992, and Abbott 2000). However, chronic disturbances (i.e., land use changes, habitat alterations, climactic changes, the introduction of exotic species, etc.), can cumulatively exacerbate the impact of such events and decrease the ability of fish and habitat to respond to them (Roghair et al. 2002). Pearsons et al. (1992) found that following floods, hydraulically complex stream reaches (see next section) lost proportionately fewer fish, had higher fish diversities, and maintained similar fish assemblages than hydraulically simple stream reaches. Abbott (2000) documented that post-flood densities of westslope cutthroat trout increased with increased large woody debris count, and decreased with increased cumulative equivalent clear-cut area. These observations point to the importance of responsible land management practices to protect fish and fish habitat values.

5.2.3 Instream fish habitat

Stream channel and riparian habitat complexity help to control the abundance and variety of organisms dwelling in river systems. In general, the greater the variety of micro-habitats available, the greater the number of species that will find suitable habitat in the ecosystem (e.g., Junk et al. 1989). Factors that characterize stream habitat complexity include variation in: water depth, temperature and velocity; nutrient input quantity and type; light availability; and, substrate texture, composition, and availability (Reid and Church 2015). These factors are controlled by natural fluvial processes and the associated riparian environment (Junk et al. 1989, Quigley and Harper 2004).

Stream morphology (general)

The morphology of the Elk River in the study area is Riffle-Pool channel type (Figure 28). Riffle-Pool channel types occur in low gradient, meandering watercourses flowing over wide floodplains (Hogan et al. 1996). The value of fish habitat for Riffle -Pool channels is determined by channel pattern, bar type, large woody debris characteristics and stability. When stable, this channel type provides **very high fish value**, through the following habitat features (Hogan et al. 1996):

- Repeating riffle-bar-pool sequence;
- Diverse pool size, shape and depth;
- One or two main channels, with off-channel/side channel habitat;
- Mainly diagonal point bars;
- Cobble and gravel sediment;
- Large proportion of undercut/overhanging banks; and
- Large woody debris.

These habitats become negatively influenced, with resulting decreased fish value, when sediment supply is limited (degradation), and when sediment supply is high and sediment transport is limited (aggradation). These instabilities result in a more uniform channel. Erosion associated with floods can lead to aggradation, while flood mitigation efforts (e.g., diking and bank armouring) can lead to channel degradation. Traditional diking and bank armouring work against the natural fluvial processes that create these features.

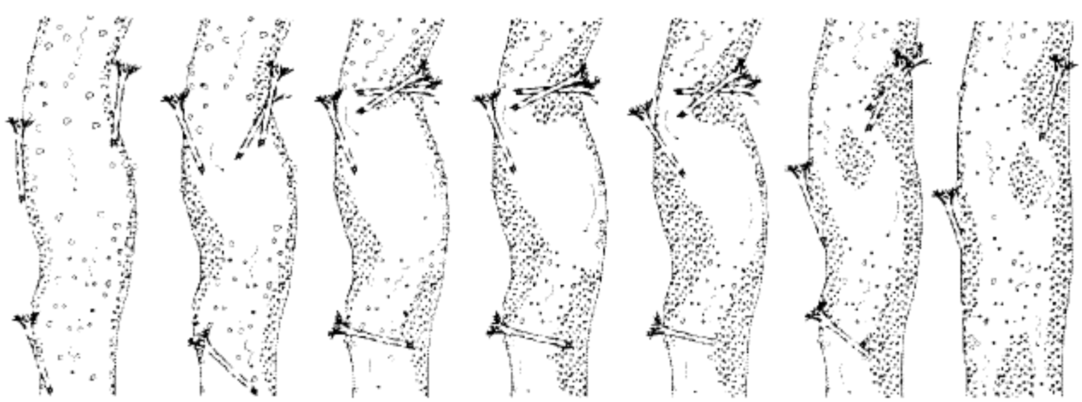


Figure 28. Riffle-Pool ($RP_{g\text{-}w}$) channel type, and respective salmonid habitat value relative to channel disturbance. Credit: Hogan et al. 1996.

Large woody debris:

Large wood debris is a piece of dead wood, having a diameter of 10 cm or larger (Johnston and Slaney 1996). Reid and Church (2015) referenced several papers (e.g., Buffington et al. 2002, Keeton et al. 2007, and Cederholm et al. 1997) documenting the values of large woody debris in low gradient laterally unstable, gravel bed channels; with a summary as follows. Large woody debris influences lateral channel migration and can deflect flow toward banks, leading to the formation of back channels, islands, and other floodplain features. Log jams strongly control pool formation, both up and downstream of the structures, and help regulate sediment transport rates by trapping and gradually releasing sediment (Figure 29). Large woody debris also acts as refugia for many species, increasing habitat complexity, and introducing and retaining organic debris within stream systems.

Figure 29. Large woody debris on Elk River provides instream structure and stabilizes this gravel bar. Credit: Elk River Guiding Co.

Pools:

As per the BC Fish and Fish Habitat Assessment Procedures (BC FHAP; Johnston and Slaney 1996), pools are areas of slower, deeper water, with finer sediments and a water surface gradient near 0%. Pools are created by scour or impoundments resulting from obstructions (e.g., large woody debris, boulders; Figure 30). As per the BC FHAP, a habitat unit is classified as a pool when the minimum surface area is >10 m^2 and the minimum residual depth[3] is to be 0.8 m (based on the Elk River mainstem, where the bankfull channel width is greater than 20 m). A higher percentage of pool habitat results in higher fisheries value. This is because pool habitat is important to fish for refuge and cover during almost all life stages. The stream hydraulics at the pool tail-out (i.e., glides), provides optimal water depth, velocity and substrate conditions for salmonid spawning. Pools provide important cover from predators. In the heat of summer and cool of winter, pools may be the only places that fish can inhabit, as a result of sufficient water quality conditions (i.e., temperature and oxygen).

[3] Residual depth approximates the pool at zero flow, and is the difference between the maximum pool depth and the depth at the pool outlet.

Figure 30. Deep pool created by large woody debris on Elk River. Credit: Hatch Magazine.

Undercut banks:

Riparian vegetation root networks allow for the development of undercut banks; as unconsolidated bank material is eroded, the roots support a layer of soil above (Figure 31). Undercuts help regulate water temperature and provide shelter for various species, particularly salmonids (Schmetterling et al. 2001; Beamer and Henderson 1998 – Cited in Reid and Church 2015).

Figure 31. Undercut banks along Michel Creek. Credit: Fernie Fly Fishing.

Off-channel habitat

Off channel habitat is important to fish for rearing areas and for refuge during high flows. This is particularly true for fry and juvenile life stages, which do not occupy much of the mainstem habitat in these systems (Robinson 2011). Increased habitat suitability in terms of water depth and velocity, as well as a reduced risk of predation from other fish drives fry and juvenile fish to these secondary habitats. Relict channels in the floodplain are important to reduce flows during high flood events (Figure 32).

Figure 32. Off channel habitat along the Elk River downstream of Fernie.

Substrate

Substrate, or the material on the bed of waterbody, is important to fish for providing spawning habitat, juvenile cover, and areas for invertebrate production (Figure 33). Most of the fish species inhabiting the Elk River watershed primarily spawn in tributaries where finer gravel substrates and appropriate stream velocities and depths are found. An exception would be mountain whitefish, which spawn in larger aggregations in deep glide and pool habitat off the mainstem. Isolated areas containing suitable conditions still do occur in/near the Elk River mainstem (at outlet of pools, side channel habitat, or confluences with tributaries). The size of the substrate used as cover from high flow velocities typically increases as the fish size increases; with juvenile and adult salmonids using large cobbles and boulders on bed surfaces (Schmetterling et al. 2001).

Figure 33. Juvenile bull trout seeking shelter amongst substrate.

Substrate is also important for benthic invertebrate production (bottom dwelling organisms without backbones), which is the food required by fish. The majority of invertebrate production in streams occurs in riffle habitats that are comprised of coarse gravel substrates (Klingeman et al. 1998). Well graded mixtures of gravel and cobble produce the highest invertebrate abundance, while silt, sand, boulders and bedrock produce lower abundances (Klingeman et al. 1998). The gravel and cobble habitats are particularly important to the main invertebrate food sources used by salmonids, which are invertebrates from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), collectively known as EPT (Klingeman et al. 1998). Both fish spawning success and insect productivity are negatively impacted by the deposition of fine particles, filling the interstitial spaces between the rocks (Klingeman et al. 1998).

5.2.4 Impacts of traditional flood mitigation efforts on fish and instream fish habitat

Floods can create large-scale changes in channel size and location through extensive bank erosion and lateral movement. When communities, land and infrastructure are built in the floodplain, these channel changes are concerning and mitigation measures are often required to decrease impacts from future similar events. While mitigation measures may decrease the likelihood of overland flows and shoreline erosion, altering fluvial processes and disconnecting the natural floodplain often leads to channel degradation and a loss of the fish and wildlife habitat values.

Flood mitigation measures utilized to date along the Elk River have included rip rap bank armouring and dike construction, or a combination of both. Rip rap armouring involves using large rock that theoretically should not be moved by the river to prevent bank erosion, while dikes increase the bank elevation to prevent flooding outside of the channel banks. These techniques are effective in locally stabilizing stream channels over the short term. However, there are numerous concerns with rip rap and dike installations.

At these structures, complex habitat features are typically removed such as undercut banks, large woody debris, overhanging riparian vegetation, and side channel habitat. These losses can impact diversity and abundance of fish assemblages.

Vegetated natural banks almost always provided superior habitat than rip rapped sites. Sites with only 14% of their site length vegetated provided higher habitat value than rip rapped sites.

- Quigley and Harper 2004

In addition to the immediate direct habitat losses at the site, rip rap armouring and dike installations impact channel morphology. These structures concentrate flows to the centre channel to improve the efficiency of water movement through an area. Local sediment deposition is inhibited and increased sheer forces occur, resulting in degraded conditions. Degradation results in an overall reduction of stream habitat diversity and fish habitat value through the following (Hogan et al. 1996, Quigley and Harper 2004, Reid and Church 2015):

- Channel bed scour;
- Restricted lateral channel migration, and thus prevention of natural meanders;
- One main channel (loss of floodplain high-water refuge habitat and access to off-channel rearing habitat);
- Extensive riffles;
- Small shallow pools (due to erosion of riffle crests);
- Simple, uniform riffle and run shapes;
- Limited large woody debris, and where present, large woody debris is oriented parallel to the banks;
- Reduced proportion of gravels, and subsequent higher content of cobbles and courser texture bed sediments; and,
- Downstream erosion;
- Loss of riparian and wetland functions which benefit the watershed, wildlife and fish, as described earlier.

In addition to localized impacts, channelization has the potential to result in watershed scale effects. A major effect of widespread installations is the reduced ability to attenuate flood peaks, which can result in downstream hydrological impacts (Quigley and Harper 2004). Bank protection can also influence the channel upstream and downstream of a site during future floods, which typically results in the installation of additional bank protection (Washington Department of Fish and Wildlife (WDFW) 2000 – Cited in Quigley and Harper 2004). Bank protection may also lead to a perception that properties adjacent to the channel are safe, and subsequently result in increased floodplain development (WDFW 2000 – Cited in Quigley and Harper 2004).

Reid and Church (2015) reviewed several studies documenting fish population changes following rip rap installation. Overall the impacts were variable, with resident trout species appearing more resilient than anadromous salmon. Coarse riprap was more beneficial than fine rip rap for providing shelter for fish. In degraded channels or stable systems with little bank complexity, riprap appeared to enhance habitat for a variety of fish and their invertebrate food sources, but successful invasive species and altered trophic relationships negated some of the benefits (Reid and Church 2015). Schmetterling et al. (2001) supported these conclusions by reporting that rip rap does not provide the habitat required to support multiple age classes of species, such as habitat provided by natural banks that include large woody debris.

As fisheries managers we need to recognize and educate others that lateral streambank erosion is a natural process that must be allowed to occur in many stream types.

- Rosgen 1994

5.3 *Ways to enhance/protect habitat when implementing traditional flood mitigation*

Under natural conditions, floods are generally beneficial to fish and wildlife habitat. The high flow events provide many important functions (e.g., recharge the water table, contribute nutrients, stimulate cottonwood regeneration, scour out pools, increase area of undercut banks, and contribute large woody debris to the instream environment). Maintaining riparian areas, wetlands and off-channel flood areas in the floodplain will minimize flood related issues by providing space for floods to dissipate across the landscape. Thus, flood control solutions should start by restricting building in the floodplain.

If infrastructure already exists in the floodplain which cannot be removed and must be maintained, then flood mitigation measures which preserve the natural floodplain are to be sought (i.e., alternatives to channelization). Examples include setback dikes at anticipated problem areas, stepped levees, greenbelts, meander zones, riparian conservation easements, subdivision regulations, building codes and zoning ordinances (Quigly and Harper 2004; see Example 1 and 2 in the next section).

If there is development in the floodplain, infrastructure and human safety need to be protected. Often installation of hard structures at the water's edge (such as dike and riprap) are the best solution. When possible, opportunities are to be sought to enhance hard engineered structures, so as to offset fish and wildlife habitat losses. This may include bioengineering techniques which use vegetation or a combination of it and construction materials to control erosion. See Examples 3-5 in the next section, which include incorporating vegetation and/or LWD in the structure. Structures appropriate to the site are to be designed by a suitably qualified professional. Costs for bioengineering are site specific and depend on the experience of the crew. Some considerations are as follows (Pierre Raymond, Terra Erosion Control, pers. comm.).

- If bioengineering can be used with a rock toe, costs can be as much as 5 times less than full rip rap applied to an area.
- Incorporating vegetation in rip rap is roughly 1.5 times the cost of installing rip rap alone.
- Vegetation incorporated into rip rap can replace the need for compensation, at a significantly reduced cost.
- Bioengineering gets stronger with time, while traditional structures weaken with time; thus maintenance costs for bioengineering works installed correctly are typically less than for traditional engineered structures.

If channelization works (rip rap or dikes) are the only viable alternatives for streambank protection, and are to be applied at a scale large enough to potentially affect river processes, a hydrological assessment should be conducted. The impact assessment should consider landscape-level ecological and hydrological processes, and downstream cumulative impacts to the watershed (Quigly and Harper 2004, Reid and Church 2015). Finally, where possible seek opportunities to restore previously disturbed areas within the floodplain, by re-establishing wetlands, and reconnecting off-channel habitats. These improvements will increase the surface area for flood flows to dissipate over the landscape, and aid in protecting downstream infrastructure and fish and wildlife habitats.

Flood mitigation planning principles

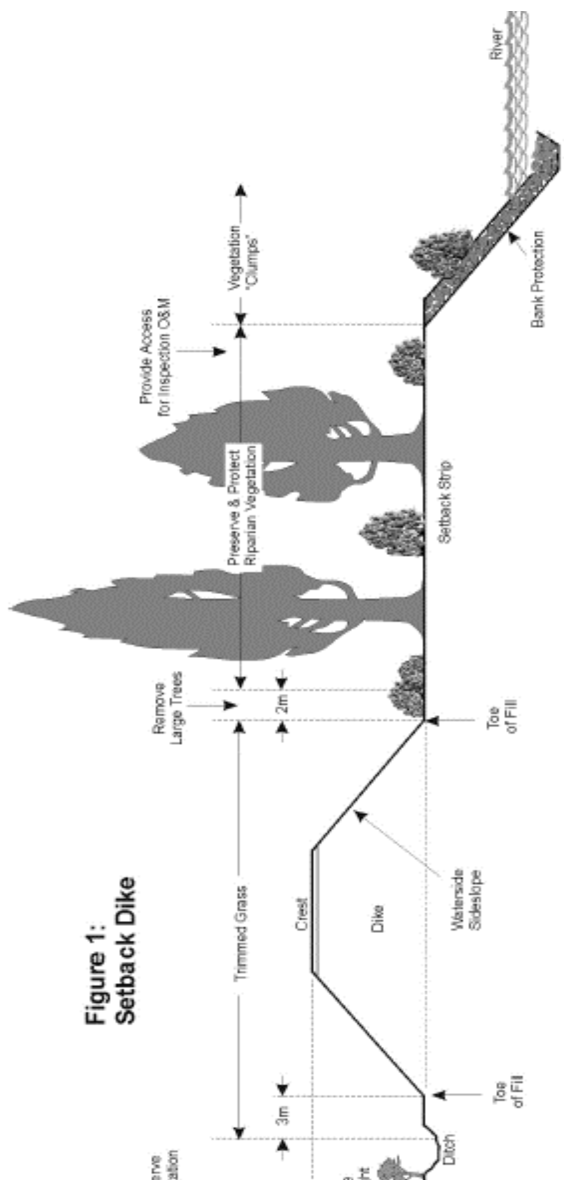
1. Build developments and infrastructure outside of the floodplain.
2. Setback installations as far as possible, to increase cross-sectional area of flood flows.
3. Only use traditional hard approaches when absolutely necessary.
    a. Limit footprint size.
    b. Limit narrowing, straightening, and cutting off floodplain.
    c. Incorporate natural habitat elements (i.e., woody debris and vegetation) to offset the fish and wildlife habitat losses (Province of BC 2003; see examples which follow).
4. Re-establish previously disturbed floodplain areas such as wetlands, off-channel habitats and riparian areas.

5.3.1 Mitigation examples

Example 1. Setback and vegetated dike

As per Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment (BC Ministry of Environment, Lands and Parks & Department of Fisheries and Oceans Canada (BC MELP & DFO 1999):

- Vegetation management should, where possible, include efforts to preserve and enhance fish and wildlife habitat in the overall stream/river corridor.
- Vegetation (including roots and canopy) can improve both dike safety and habitat through soil conservation and erosion control. For example, setback strips, overbank and vegetation between flood protection works and the watercourse are recognized for their dike safety, environmental and aesthetic values (Figure 34).
- The sideslopes of dikes built without a setback from the river are to be cleared above the toe of fill. Portions of bank protection extending below the dike height may contain vegetation clumps (Figure 35).



Example 2. Setback rip rap trench

A rip rap lined trench provides protection from stream migration towards infrastructure (Figure 36):

- Buried rip rap toe.
- Set back so as to maintain riparian vegetation along the stream edge.

Figure 36. Setback rip rap trench to protect road from a channel migrating (to right of photo).

Example 3. Vegetated rip rap

Install brush layers and/or staked live cuttings within the rip rap (Figure 37, Figure 38):

- Provides bank protection by forming a root mat and increasing deposition of sediment and debris.
- Provides fish and wildlife riparian habitat benefits.
- Installation examples for various jurisdictions (e.g., City of Nelson, City of Edmonton, Teck Cominco Trail) (Terra Erosion Control Ltd.).
- The provision for vegetation in dike rip rap has also been discussed above (See Example 1 - setback and vegetated dike).

Figure 37. Examples of live cutting pockets being installed in rip rap (Photos: Terra Erosion Control Ltd.).

Figure 38. Vegetated rip rap installation – brush layer of live cuttings protected by plywood (left), vegetation growth two years after installation (right) (Photos: Terra Erosion Control Ltd.).

Additional measures to reduce fish habitat impacts during rip rap installation include (BC MELP 2000):

- Scallop the low water shoreline by increasing and decreasing the rip rap slope. The small embayments create eddies and shear zones, providing low-velocity fish rearing habitat.
- Place large rocks (>1 m diam.) at the rip rap toe at the low water shoreline. The large rocks provide flow diversity, creating low velocities, eddies and shear zones for rearing salmonids. Riprap >300 mm diam. supports greater densities of rearing salmonids than smaller rock (Lister et al. 1995).

Example 4. Integrated LWD and vegetated system

Integrate LWD and vegetation into bank protection to provide fish habitat (Figure 39). This may be achieved by:

- Incorporating long coniferous logs with root wads attached (Douglas Fir or Western Red Cedar), with >70% of length trenched into bank.
- As necessary, incorporating rip rap at toe of bank.
- Adding boulders for fish habitat.
- Above the high water mark, wrapping fill soil in geotextile, and installing live cuttings (brush layers) across the bank.

Figure 39. Log crib wall with vegetated lift to stabilize slope along the Inonoaklin River, Edgewater BC for Ministry of Transportation and Highways (Photos: Terra Erosion Control Ltd.).

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Example 5. Integrated system – rip rap, rock groins and bioengineering

Treatment of highly erosive bank, along the outside bend of the Cowichan River involved (designed by Kerr Wood Leidel; Figure 40):

- Rip rap guidebank;
- Groins (or spurs) as a river alignment control measure, with the following benefits:
  - Deflects flows away from the bank to reduce erosion
  - Establishes the thalweg (main channel flow) nearer to the centre of the channel;
  - Encourages riparian zone re-establishment; and,
  - Embayments create areas of low velocity for fish habitat.
- Bioengineering, which included soil wraps and willow stakes. Bioengineering increases the long-term stability, reduces siltation to the stream from the bank, and improves fish habitat.

Figure 40. Stoltz bluff before and after bank stabilization project. Credit: Kerr Wood Leidel.

6. Simulating floods in the Elk Valley

6.1 *Simulating historical hydrology*

Hydrological modelling was completed to investigate the impact of land use and climate change over time in the Elk River Watershed. This type of modelling involves describing how meteorological inputs (e.g. air temperature and precipitation) interact with watershed features such as vegetation and soil, and ultimately how much water is conveyed to the stream. In order to conduct this modelling, soil types, surficial geology, topography, land use, and other supporting datasets were used to characterize the watershed. These datasets were combined to define Hydrologic Response Units (HRU's), which are regions of similar characteristics that are assumed to respond in a homogeneous way.

Hydrological modelling conducted here also required streamflow and meteorological data. Streamflow data were obtained for the period from 1970 to 2015 from the Water Survey of Canada (WSC) stream gauge located at Fernie (referred to as Hydat). The Environment Canada meteorological station located at Sparwood provided historical daily air temperature and precipitation data for the period of 1970 to 2015, and where data were missing, relationships with nearby stations were used to fill in records. The hydrologic model was calibrated to the Fernie WSC stream gauge using an iterative process. Further work will be conducted as part of a PhD thesis to determine model parameter uncertainty, and to refine this work; however, for the purposes of this report, we determined hydrologic processes were being represented reasonably well. For more information on how GENESYS hydrological processes function please refer to MacDonald et al. (2009).

In order to determine if a hydrologic model is suitable for prediction, it must first be compared with streamflow observations. This comparison typically relies on a statistic called Nash-Sutcliffe, which has been specifically developed for comparing streamflow records. Nash-Sutcliffe values are analogous to an R^2 value in linear regression, where a value of 1 indicates a perfect fit. Simulations with a Nash-Sutcliffe value above 0.5 are deemed to be suitable for prediction; however, higher values are preferred. The GENESYS model was able to recreate streamflow simulations for the Elk River at Fernie with a Nash-Sutcliffe value of 0.73 (Figure 41). The highest daily streamflow in the historical record between 1981 and 2010 were not completely captured by the model, including the large event of 1995. This is due to the fact that this is a daily model, and uses daily average conditions which are not typical of larger streamflow events. In addition, larger streamflow events in this watershed can be driven by rain on snow, where rainfall may be localized and is not captured by the model.

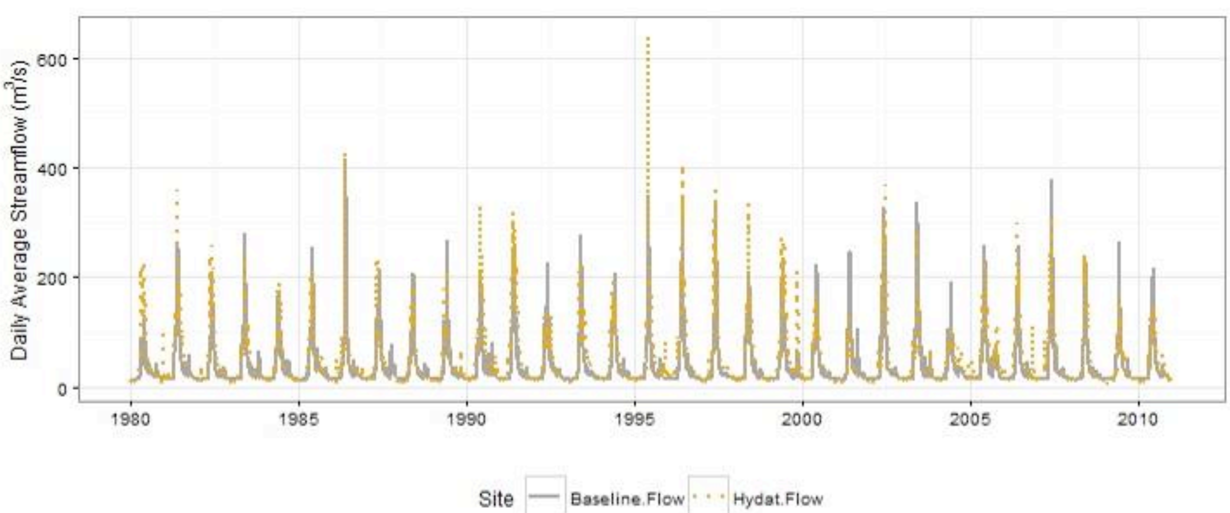

Figure 41. A daily streamflow comparison between the WSC (Hydat flow) station and GENESYS output (Baseline) for the period from 1981 to 2010.

Model under-estimate of peak streamflow is due to several factors. However, most notably, the model is operating on a daily time step; therefore, does a good job of simulating daily average conditions but does not represent complex hourly or sub-hourly meteorological conditions. It is these conditions that can dramatically affect large runoff events that result in high streamflow. Long-term hourly simulations require hourly meteorological data and a model formulation that is able to calculate hydrological processes at this small time step. GENESYS was not developed to be an hourly model and hourly meteorological data are from local stations have significant gaps. For the purposes of this work, it was determined that this model and daily time step are sufficient for simulating long-term future conditions, and can provide valuable insights into how flooding may change in the Elk Valley over time.

All future simulations are compared to the 1981 to 2010 period, as this provides a reference period for the 2011 to 2041 future climate scenarios. The time period from 2011 to 2041 is not meant as a recreation of those years, rather as a comparison relative to the 1981 to 2010 reference point. Also, when comparing future streamflow simulations, the historical simulation is referred to as the “baseline”.

6.2 *Potential future streamflow conditions*

Future streamflow was simulated for the two climate change scenarios and one land use change scenario. The scenarios were also combined to quantify the cumulative effect of climate and land use change on hydrological conditions in the Elk Valley. The Climate BC version 5.21 tool (Wang et al. 2012) was used to obtain two future climate change scenarios (RCP 4.5 and RCP 8.5) for one general circulation model (Can ESM2) for the period from 2011 to 2041. These future climate change scenarios represent greenhouse gas concentration pathways (RCP) that are focused on when greenhouse gas concentrations will stabilize. The RCP 4.5 assumes radiative forcings will stabilize at 4.5 Watts per meter squared (W m2) by the year 2100, while RCP 8.5 is comparatively higher at 8.5 W m2 by 2100.In general, air temperatures are projected to increase under these scenarios, and so is winter precipitation. Summer precipitation is projected to decrease. A simple “delta” method was used to perturb the input climate datasets for GENESYS using daily scaled data, where scaling was based on the relative differences between future climates and historical climate at the Sparwood meteorological station.

Land use change was simulated as a 3,100 hectare (ha) harvest scenario, representing approximately 5 years of timber harvest at the current annual allowable cut in the Elk Valley. It was also assumed that harvest area would not exceed 10 ha and would be distributed randomly below an elevation of 2000 meters above sea level. Please note, land use change scenarios were only evaluated for 10 years of simulation, and it was assumed that there would be negligible hydrologic recovery of the forest.

Figure 42 is a comparison of the relative differences in monthly average streamflow for the period from 2011 to 2041 for all future climate change scenarios. Climate change scenarios result in higher baseflows during the fall and winter, an earlier onset of spring snowmelt associated with higher streamflow, and a reduction in streamflow during the summer. The land use change scenario and land use plus climate change scenarios are presented in Figure 42, for the period from 2011 to 2022. Land use change results in a much smaller hydrologic response relative to climate change during all seasons, with largest changes during May, which are indicative of an earlier onset of spring snowmelt and subsequently higher early-season streamflow. June streamflow is slightly lower in the land use change scenario; this is due to the desynchronization of runoff response associated with earlier onset of spring snowmelt at lower to mid elevations that are being disturbed in this scenario. Baseflow response to the land use change scenarios is extremely small and not meaningful in this case. The combined effects of climate and land use change are similar to those in the climate change scenarios, with a slight additive effect.

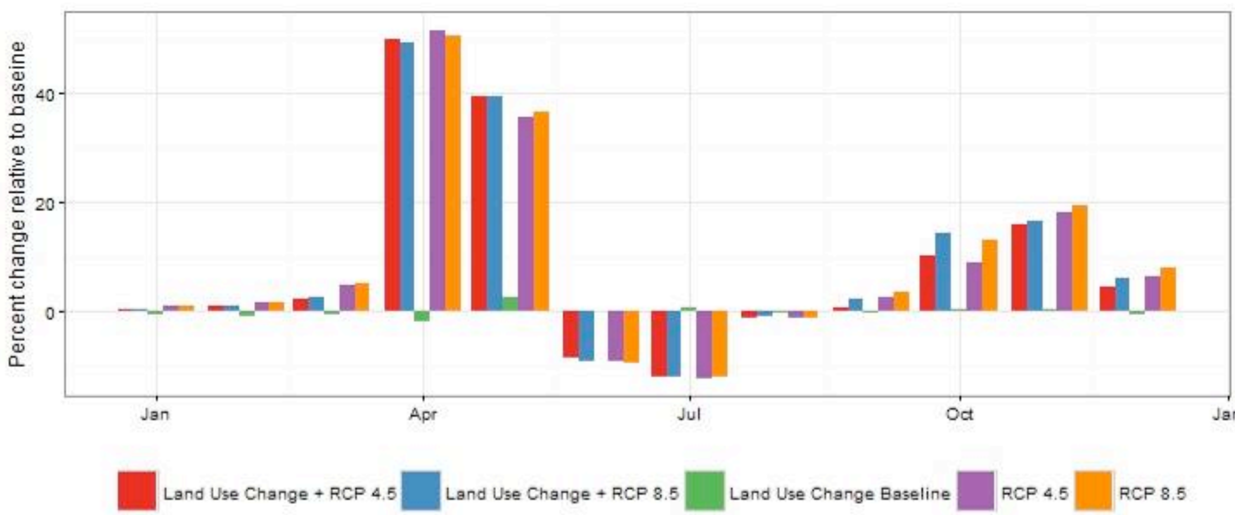

Figure 42. A comparison of monthly average streamflow changes relative to the baseline for the RCP 4.5, RCP 8.5, land use, land use + RCP 4.5, and land use + RCP 8.5 scenarios.

Overall, climate change simulations resulted in the greatest effects on daily peak streamflow, with 6.3% and 6.5% increases on average for the RCP 4.5 and 8.5 scenarios, respectively (Figure 43). However, 13 of the 30 years in the simulation for both the RCP 4.5 and 8.5 scenarios showed lower peak streamflow, this is likely due to warmer air temperatures that result in more rain than snow in these years. The RCP 4.5 and 8.5 scenarios have very similar responses, indicating that even moderate climate change expressed in the RCP 4.5 scenario could change the hydrologic regime of the Elk River, with an earlier onset of spring freshet. This is important as drier and wetter years relative to what has been experienced historically could be expected. A comprehensive flood strategy must acknowledge this change in variation and plan accordingly.

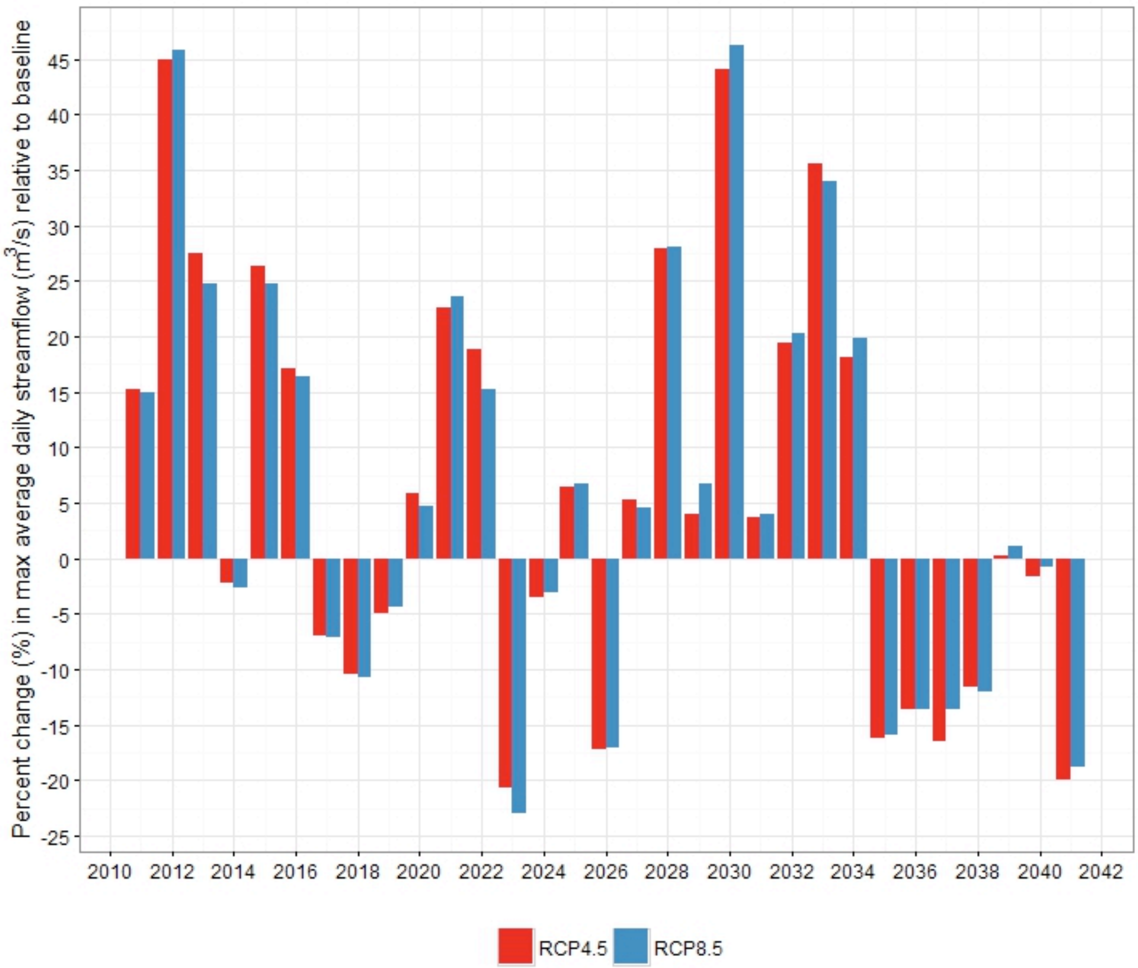

Figure 43. A comparison of maximum average daily streamflow between the baseline and RCP 4.5 and RCP 8.5 scenarios for the Elk River at Fernie.

The land use change scenario resulted in an average 0.04% decrease in peak streamflow over a 10 year period (Figure 42). This is due to an earlier onset of snowmelt at lower elevations where harvest is assumed to occur, resulting in a desynchronization of runoff generation across the watershed. This earlier onset of snowmelt results in less water reaching the stream later in the season; therefore, streamflow is reduced overall.

Figure 42 also demonstrates the effect of the land use and RCP 8.5 scenario, demonstrating that climate change has an over-arching effect on hydrology and hydrologic response at the scale of the Elk River. However, there is a slight cumulative effect of the combined land use and climate changes, with larger streamflow responses relative to simply looking at climate change. It is important to note that these simulations are conducted at the scale of the entire watershed; therefore, do not necessarily represent the response in individual smaller watersheds.

6.3 *Historic and future hydrology summary*

Historical trends suggest there hasn't been an increase in mean annual flows or peak flows has been observed in the valley and only minimum annual flows have increased. These trends point towards enhanced storage in the valley, potentially due to increased groundwater infiltration, made possible by rock exposure in the headwaters. While there is limited evidence to suggest flooding has changed in the valley, caution is advised, since many of the statistical relationships are noisy, and only weak relationships can be made with much of the meteorological and hydrometric data. Furthermore, the return periods of the rainfall rates and streamflow that produced the largest previous floods in 2013, 1995 and 1974 are much larger than the current available data in the area, suggesting that it is difficult to adequately constrain future probabilities of similar events with existing data.

Future simulations suggest the hydrologic regime of the Elk River is likely to change, with higher and lower flows, and on average higher spring freshet associated with more winter snow accumulation. Climatic conditions are the primary driver of future hydrologic change, and present a real challenge to dealing with flood (and drought) hazard. Ensuring the Elk maintains resiliency to future change and allowing the river to behave in a natural manner is critically important. Maintaining non-critical infrastructure in the floodplain will continue to present risk, and these simulations suggest future flood hazard is likely to be different from the historical hazard we have experienced.

6.4 *Floodplain mapping Elkford to Elko*

Floodplain mapping in British Columbia delineates an area that has a 1 in 200 chance of flooding. These are tools that can be used to help guide planning decisions. Floodplain maps are expensive to produce, and require specific expertise from engineering professionals. The Province of British Columbia has conducted floodplain mapping for a long period of time. However, in recent decades, the provincial government has handed the primary responsibility for flood management to local governments. Therefore, infrequent mapping updates have taken place.

In addition to floodplain mapping, high hazard flood mapping has also been conducted in areas that have characteristics like braided streams, alluvial fans, debris flow hazards, ice jams, and other potentially hazardous areas. The flood hazard mapping describes areas that have higher hazard relative to the standard floodplain mapping. Datasets for the floodplain and flood hazard mapping were provided by the RDEK, and are shown in Figure 44 for visual purposes only. There were no meta data provided to indicate the year or methods of this mapping.

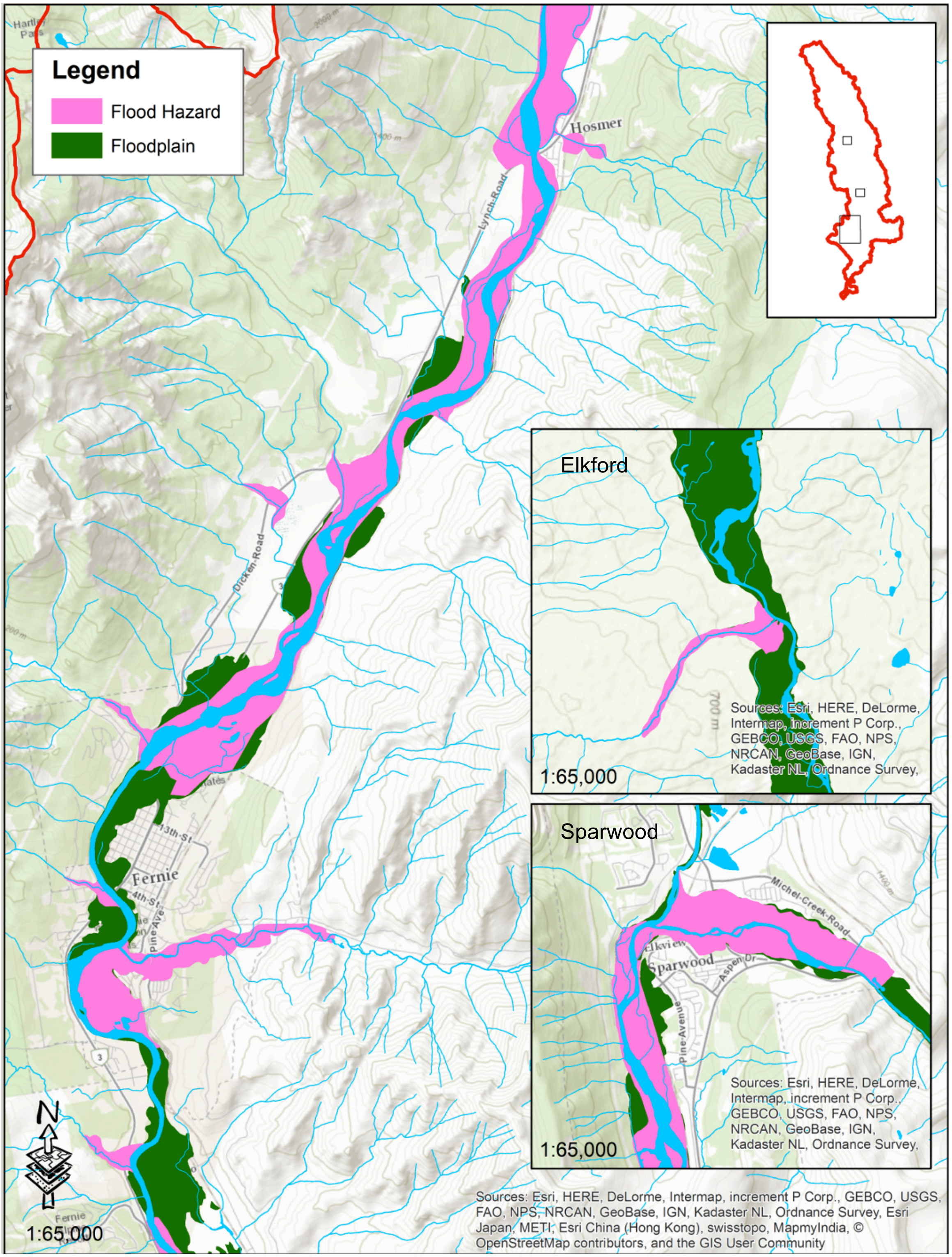

Figure 44 Floodplain and Flood Hazard mapping near Elkford, Sparwood, and between Hosmer and downstream of Fernie. The inset map on the upper right indicates the locations of Elkford, Sparwood, and Hosmer.

6.5 *Visual hydraulic model - changing hydrology on flood levels*

A 1-Dimensional HEC-RAS hydraulic model was developed for the Elk River between Hosmer and Coal Creek to enable a comparison between relative inundation levels resulting from different streamflow events and to help in developing the conceptual designs for the RDEK. This portion of the Elk River was selected primarily due to constraints in financial resources, and it encompassed areas that were affected by recent flooding. The hydraulic model used stream channel surveys and a 2012 LiDar Digital Elevation Model (DEM) provided by Teck Coal. This combination of stream channel survey data and DEM provided a means of creating a model within the budgetary constraints of this Flood Strategy.

In addition to the hydraulic model, a web-based visualization tool was created to allow individuals to readily access hydraulic model information for areas of interest. Figure 45 presents an example of the online visualization tool. This tool can be found at: http://elkriveralliance.watersimulation.ca and can be used to visualize simulated 1:200 flows in addition to the inundation of water levels during the 1995 and 2013 events.

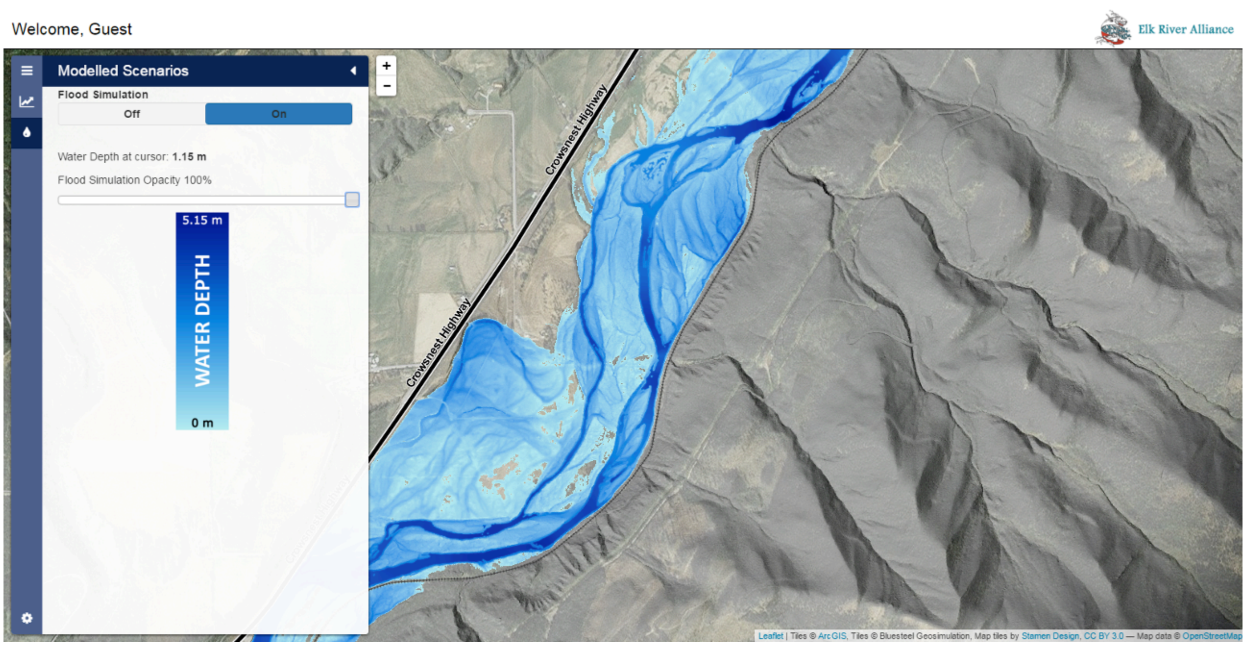

Figure 45. Example of the web-based flood inundation visualization tool developed as part of the Flood Strategy.

7. Reducing flood damage

Large flood events are a cyclic part of a watershed; however, they also have the potential to significantly harm human health, damage infrastructure, and permanently alter topography and landscapes within the valley. Reducing flood damage must use an effective watershed management strategy that considers both non-structural and structural flood management approaches.

When developing these strategies strive to "be prepared" and consider that reducing flood damage is a shared responsibility between private landowners and governments. Given the current understanding of watershed function and the interconnectedness between hydrology, ecology and water quality, it is also important that flood management measures maintain the natural integrity of the watershed and preserve watershed functions. A range of flood management strategies are available for the Elk River Watershed, each with varying costs, benefits and environmental impacts.

7.1 *Non-structural flood management strategies*

7.1.1 Emergency planning and response to keep people safe

Emergency planning and response is a key component of any flood strategy. It consists of proper flood warnings, evacuations, and general preparedness. These actions are critical in the initial moments of a flood event, and can often save lives. Emergency planning and response is handled by local government who outline the basic stages of flood hazard warnings, evacuation plans, and flood fighting measures (e.g., sandbagging or earthen levees and/or dewatering areas with mobile pump stations) (City of Fernie n.d). Furthermore, after the floodwaters have receded and the clean-up is complete, officials should evaluate the flood event and revise the emergency response plan if deemed necessary.

> *Each municipal emergency plan should identify routes to circumvent flooded areas; explain how to protect drinking water supplies and sewers; and set out instructions for sandbagging, evacuating residents, establishing reception centres, and cleaning up.*
>
> \- Environment Canada, 2013

In any emergency situation emotions can run wild and to help constituents respond in a calm manner, clear, effective actions, communicated effectively, will help people be prepared. The first priority of flooding is personal safety. All residents should have on hand a 72-hour survival kit with enough water, food, first aid, medications and necessary supplies to be self-sufficient for a few days. Residents should plan to evacuate their home in a moment's notice. To help, residents should know the exact location of their most important documents, heirlooms, and personal items, so that they can be gathered quickly and removed to safety, and ensure sufficient means of communication (i.e. battery powered radio) (Emergency Management BC 2012).

There are many stages that can lead to a flood. In the Elk Valley, the typical condition is high water coinciding with a spring rain. Municipal governments have emergency preparedness plans in place for flooding and emergency response personal that will support community during the various stages of flooding (Emergency Management BC 2012, and S. Robinson pers. comm.):

STAGE 1 – Rivers are high and it is raining – known precursors to flooding in the Elk River

1. Be Flood Smart. Elk Valley residents are advised to learn as much about flooding as possible in their community before a flood occurs. Residents should know the location of their property relative to flood prone areas. See Section 7.1.2 to find the location of floodplains susceptible to flooding.
2. Watch the Local Weather Forecast at the following Government of Canada website: https://weather.gc.ca/city/pages/bc-52_metric_e.html
3. Monitor water levels in each community at the BC River Forecast Centre which will indicate flood warnings and advisories posted at: http://bcrfc.env.gov.bc.ca/warnings/
4. Prior to a flood, review and be familiar with Emergency preparedness processes for each community:
   - In BC, local governments lead the initial response to emergencies and disasters in their communities. For more information about the BC Provincial Emergency Program call 1.800.663.3456 or see http://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery.
   - City of Fernie Flood Response Plan: http://www.fernie.ca/assets/Residents/docs/Part%20I%20Flood%20Response%20Plan.pdf
   - District of Elkford: http://www.elkford.ca/emergency_services
   - District of Sparwood: http://www.sparwood.ca/node/683
5. In the event of flooding, residents should know how to turn off the water, electricity and gas in their home. Consider posting instructions on or near these appliances.
6. Local government Emergency Program Coordinators have flood preparedness plans in place. RDEK staff, and/or your jurisdiction's Fire Chief are the key coordinators for:
   - Mitigation to prevent a disaster like flooding (where possible);
   - Preparedness so that systems are in place and the key people are trained to deal with a flood;
   - Response procedures that will be appropriate and deployed in the event of a flood; and,
   - Recovery process to resume to normal life activities for residents and businesses in a timely manner.

STAGE 2 – Elk River waters are rising to a noticeable high level

1. Continue to watch the weather (see link above), the BC River Forecast Centre reports, and the real time Elk River flow levels, using the link to the Water Survey Canada gauges on the Elk River Alliance's website (http://www.elkriveralliance.ca/real_time_river_level).
2. Authorities will patrol dikes and monitoring key infrastructure, like Fernie's Fairy Creek Dam and Highway 3 bridges.
3. Monitoring devices may be installed by local government in key local areas, particularly in unprotected areas, where flooding is permitted to occur (e.g., James White Park or Annex Park in Fernie, Beaver Pond area in Sparwood).

STAGE 3 – Limited flooding is observed

1. Daily patrols will be deployed to watch dikes, bridges and key infrastructure.
2. Emergency services will enact their communications plan via the radio and the Internet.
3. Community members and emergency services staff and volunteers may start filling sandbags.
4. Authorities and the public continue to monitor the weather, river forecast centre and water levels.

5. Flooding will be allowed on land in unprotected areas near communities (e.g., Annex Pond and James White Park in Fernie) and these levels will be monitored.
6. People may be deployed to mark road detours and restrictions, and respond to community requests.

STAGE 4 – Severe flooding occurs

1. Continuous patrol of dikes, bridges and key infrastructure will occur, on a 24-hour basis.
2. Forces will be deployed to institute road detours, closures and respond to community requests.
3. Dikes and key infrastructure may be reinforced.
4. Extra equipment will be deployed, as required, to areas requiring assistance.
5. Local governments may request a state of emergency, which is then approved by the BC Government.
6. Authorities will aid with enforcement of the ‘state of emergency’ declaration. Residents at risk of flooding will be informed to be prepared to evacuate at a moment’s notice. Removal of children will be mandatory from homes at immediate risk of flooding, which will be enforced by the RCMP.
7. **Community Emergency Operations Centres** will become the hub of overall coordination of flood response, which are located in places like the Fernie Chamber of Commerce and Hosmer Hall.
8. **Reception Centres** will be deployed and operated by Emergency Social Services, where volunteer’s will be available to aid people affected by flooding, for usually no longer than 72 hours. These Centres will provide food, water, shelter, and information to residents in need. The shared group lodging provided will keep friends and neighbours together to support each other. People are to register as evacuees of the flood, so that they can be tracked in case outside people are trying to reach them since they are not at home. Past Reception Centres for flood disasters have been Fernie Community Centre and Hosmer Community Centre.

7.1.2 Personal planning to protect property

Home is our refuge; it should be a safe place from the occasional ‘storms of life’. Here we describe how to keep citizens safe, and at the same time protect their homes and contents against flood damage.

The most likely time of flooding is in the spring, based on a chronology of flooding from the early 1900s to present. June is the most likely time for flooding to occur, coinciding with peak snowmelt and sometimes heavy spring rains. However, the risk of flooding can happen anywhere and at any time of the year in the Elk Valley. For example, as noted in the Hydrology analysis (Section 3.3) and Flood Chronology (Appendix C), floods can even occur in the winter as a result of ice dams.

Step 1: Assess your flood hazard by knowing where your house is located in the floodplain.

The BC Government defines the floodplain as a lowland area, whether diked, flood-proofed, or unprotected, which is at an elevation susceptible to flooding. To find out where personal property is in

> *Most floodplain maps in BC are out of date, putting communities and citizens at risk. Only 21% of BC communities and First Nations have access to floodplain maps that are ten years old or less, while 31% have no access to at all floodplain maps.*
>
> \- BC Real Estate Association, 2015

relationship to the floodplain, refer to floodplain maps on the BC Government, Ministry of Forest Lands and Natural Resource Operations, Water Stewardship Branch website, click on "Index of Designated Floodplain Areas by Region' (http://www.env.gov.bc.ca/wsd/data_searches/fpm/reports/region4.html). The floodplain maps of the Elk River were issued near Elkford in September 1989, Elk River near Sparwood in March 1980, Elk River and Michel Creek near Sparwood in September 1995, and Elk River near Fernie in May 1979. Although the maps are 21-37 years old, the floodplain has not changed dramatically, giving a general idea of flood hazard.

Step 2: Flood proof your home

If your home might be at risk of flooding, there are basically four choices to make: relocate, elevate, build floodwalls or flood proof your home (Figure 46).

> *Flood proofing is any measure, structural or non-structural, intended to prevent damage from flooding to a building*.
>
> -Office of Disaster Preparedness and Emergency Management (ODPEM) 2009

Flood proofing involves implementing certain household or construction measures to reduce the damage inflicted during a flood. Selecting appropriate floodproofing methods usually requires the help of experts (e.g. engineers or contractors). Although flood-proofing is not a cure for all flood problems; it is one of the important flood damage reduction tools.

Steps to decide if your home requires flood-proofing are as follows (Environment Canada 2013, and ODPEM 2009):

1. Identify if there is a risk of your house being flooded. It is best to be high to stay dry.
2. Identify the characteristics of potential flooding, including: maximum height of flood level, velocity of water flow during flood peaks, expected duration/frequency of floods, and overall susceptibility to flooding.
3. Consider structural factors. When flood waters surround a building they impose uplift (vertical) and lateral (horizontal) loads on the house. Pressures exerted must be pre-determined in order to design adequate flood-proofing. This work requires the advice of a qualified professional engineer.
4. Obtain the services of a qualified professional engineer to help you select and design the right measure tailored to your specific needs. Conduct a cost-benefit analysis of flood proofing required. This is especially important if you are located in an area susceptible to fast-moving flood waters, as the cost can be substantial.

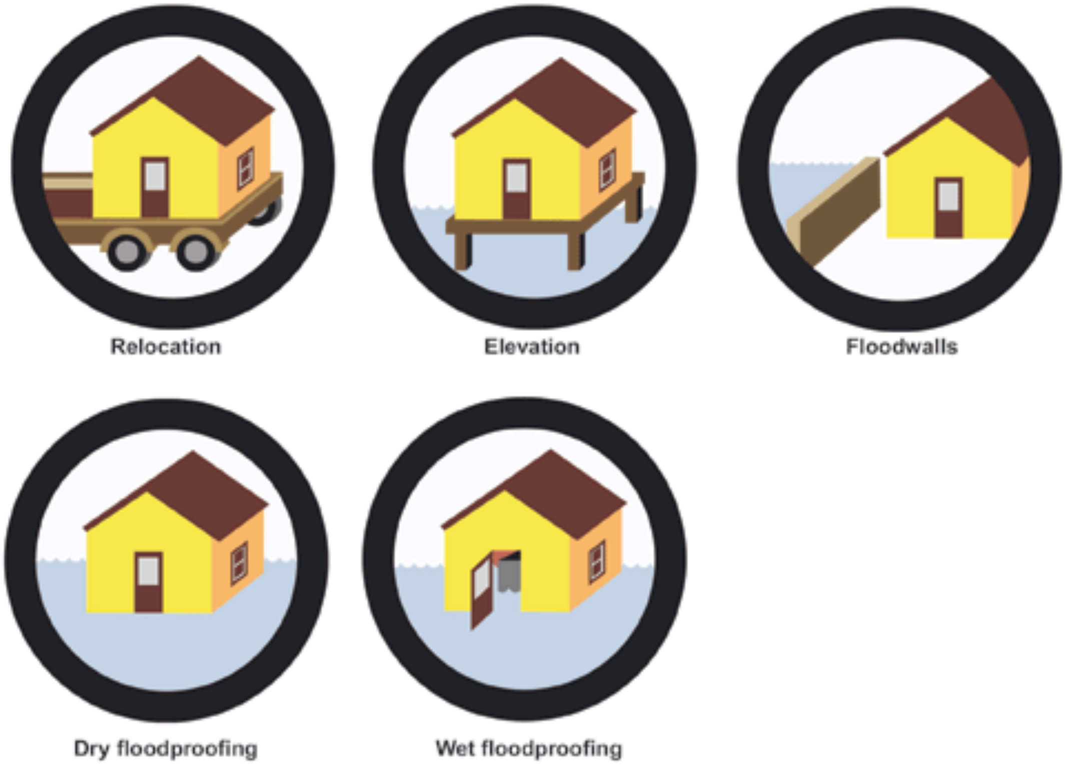

Figure 46. Basic approaches to flood proofing (Source: Government of Canada, nd).

If you decide to proceed with flood-proofing, there are two techniques to consider: dry flood proofing and wet flood proofing (Environment Canada 2013 and ODPEM 2009). Before proceeding with either dry or wet proofing your home, seek the advice of a qualified professional.

Dry Flood-Proofing refers to structural changes or measures applied to buildings located below the design flood elevation, to keep enclosed space completely dry during a flood (Figure 47). There are four types of reasonable dry flood-proofing techniques appropriate for the Elk Valley:

1. Build on fill raised above the flood-level. The best fill is sand, but clay/sand/gravely soil also works. Use heavy plastic sheeting to provide water proofing, gradually slope away from the building, and use good soil and ground cover to minimize erosion.
2. For lower level of buildings, use water-tight closure and seal-method by sealing all walls and openings (e.g., doors, windows, and drainage systems) against water penetration. To ensure they are strong enough to withstand cracking from the lateral and uplift pressure of the flood water, have a qualified professional engineer select and design the right measure tailored to the home, especially if the house is located in a flood hazard area.
3. Surround the house with flood-proof walls or berms constructed out of brick, stone, concrete or other similar material.
4. If floodwaters are rising close to the house, construct a dam of sandbags. Be prepared with burlap bags from a home improvement store and fill with 70% full of sand. Overlap bags so they hold together more easily. Consider storing a stockpile of sandbags in advance of a flood emergency.

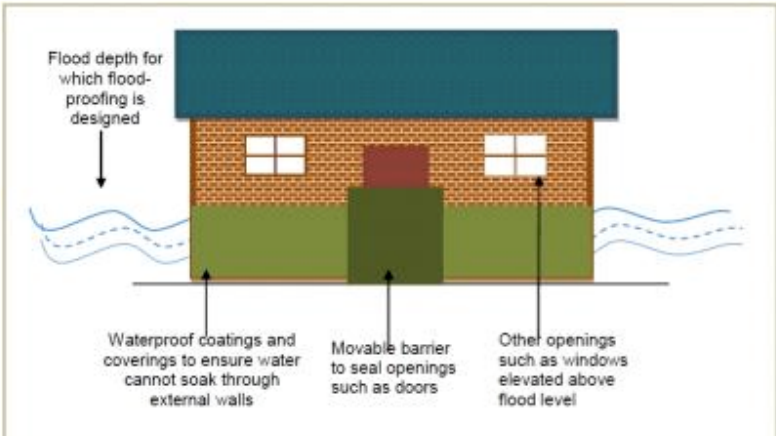

Figure 47. Basic dry flood-proofing measures for a residential structure (Source: Linham and Nicholls, 2010)

Wet Flood-Proofing means minimizing damage when floodwaters enter the house. When preparing the house for wet flood-proofing (Figure 48):

1. Remove hard to evacuate items subject to potential water damage (e.g. freezer, to higher ground).
2. Protect what cannot be removed by elevating it using blocks or raised platform of pressure-treated lumber. Consider elevating large appliances, heavy furniture, water heaters, furnaces, washer and dryer. Move valuable electronics, power tools, and important family heirlooms/documents to a second floor or attic. From a planning perspective, it might be a good idea to **not** keep these things in flood prone areas in the first place.
3. Relocate or adjust utilities such as electrical outlets, gas appliances, or solar battery storage.
4. Before a flood, unplug any electrical item that requires you to stand in or near water.
5. Varnish wooden doors and floors to keep water damages minimum after a flood. Varnishing can also prevent mold and other bacteria forming post-flood. If there is a flood, let floors dry thoroughly to help avoid buckling or mildew growth. Once dried and cleaned thoroughly, floors can be re-varnished. Better yet use stamped concrete or tile floors in basements with throw rugs for comfort. Instead of drywall, finish with varnished wood, burnished metal, or tile walls.
6. Seal off or install backflow protection systems in sewer and water systems to prevent health hazards and water damage.
7. Tape over heating and cooling ducts along the bottom to permit them to drain when flood waters recede.
8. Block openings; however, let water in through a doorway or window before it gets deep enough outside that it damages your walls.
9. Have an evacuation plan to give enough warning time to move valuable items, especially non-insurable items such as valuable papers, family mementos.
10. Turn off all utilities.

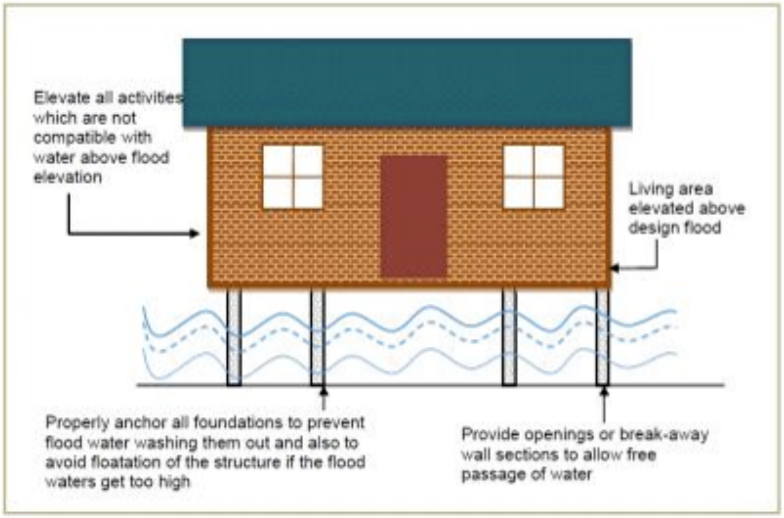

Figure 48. Basic wet flood-proofing measures for a residential structure (Source: Linham and Nicholls, 2010).

7.1.3 What homeowners need to know when a home is flooded

> *Flooding can be an expensive fix for home-owners. The cost estimate of flooding repairs from a 6 inch or 15 mm deep flood in a 2,000 square foot home is $39,150 USD or $50,895 CDN* (based on Canadian dollar to US dollar at $1.30)
>
> -National US Flood Insurance Program, nd

Overland flood insurance

Overland flooding occurs when bodies of water such as rivers and other watercourses overflow onto dry land and cause damage. According to the Insurance Brokers Association of BC (IBABC 2012), until recently coverage for overland flooding, resulting in water entering a home via doors and windows was not available for residential buildings. Some insurance companies now offer it, but conditions may apply. Most homes in the Elk Valley do not have overland flooding insurance (Deb Warner, pers. comm.). Check with the Insurance Agent to see if there is appropriate coverage for overland flooding, and be aware that homes on or near floodplains may not be eligible for overland flood coverage and farm outbuildings are not generally covered by flood insurance (IBABC 2012). Cars and trucks are covered for losses resulting from rising water under ICBC's Comprehensive and Specified Perils policies. In all cases, it is the responsibility of the insured to take reasonable action to minimize damage to insured property (IBABC 2012). Mitigation measures may include: moving vehicles, contents, vulnerable people and animals, securing premises by sandbagging and installing sump pumps (see section above).

Sewer backup coverage may be purchased as an add-on to your homeowner's policy (IBABC 2012). This covers damage caused by the overloaded sewer or septic system sending dirty water back into the home through a sewer, storm drain, sump or septic tank. Registering a claim against a policy may result in a loss of your "claims-free discount" and/or increase insurance premiums (IBABC 2012).

BC's Disaster Financial Assistance Program

BC Disaster Financial Assistance (DFA) helps those impacted by a disaster cope with the cost of repairs and recovery from uninsurable disaster-related property damage. To be eligible for assistance, the damage must result from an event for which insurance is not readily available. To assess if you qualify for assistance under the DFA after a flood, go to their website - http://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/emergency-response-and-recovery/disaster-financial-assistance, and click on 'list of events currently eligible for Disaster Financial Assistance' and contact your local authority stated. DFA may compensate individuals for essential uninsured losses and/or reimburse local governments for damaged infrastructure. Forms and additional information are available on the website.

7.1.4 Community plans and bylaws

Official community plans (OCPs) provide high level strategic planning and policy direction, while zoning bylaws contains specific regulatory requirements. Relevant sections of OCPs and bylaws that are in place to protect riparian and stream habitats, have been summarized below. Overall, there is a recognition of maintaining valuable floodplain habitats, with consistent approaches evident among jurisdictions.

RDEK area

1. As per the Elk Valley OCP (RDEK 2014), and the Elk Valley Zoning Bylaw (RDEK 2015):
    a. In general, the Elk Valley OCP encourages development to avoid streams, wetlands and riparian areas and to provide appropriate development setbacks and buffer areas.
    b. The Elk Valley OCP has mapped Watershed Protection Zones (WP-1), to protect community water supplies. These areas are to be protected by implementing the Elk Valley Zoning Bylaw, which requires that live tree cover be maintained within 60 m of the high water mark of a lake, and within 25 m of a stream or watercourse. WP-1 areas are located in tributary watersheds of the Elk River, with none on the Elk River mainstem.
    c. The Elk Valley OCP discourages development in flood prone areas unless flood protection works are in place. The Elk Valley Zoning Bylaw identifies the following minimum setbacks from the ordinary high water mark:
        - Specified rivers and creeks, including the Elk River = 30 m
        - Lake, swamp or pond = 7.5 m
        - Other watercourses = 15 m.
        - The OCP discourages development of land in the 200-year flood level and active floodplain, which are mapped for select areas in the Elk Valley.
    d. Environmentally sensitive areas (ESAs) and ungulate winter range are mapped in the Elk Valley OCP. The ESAs include habitat of red and blue listed species, wetlands, riparian areas, grassland ecosystems, old growth forests and wildlife habitat areas. In these areas, developers are encouraged to conduct inventories, assess potential impacts, and identify mitigation measures prior to development.
    e. Wildlife corridors should be considered when developing transportation networks under the OCP.
    f. The Elk Valley OCP outlines that preservation of open spaces and recreational opportunities is important to the area. As such open space, recreation and trail (OSRT) areas are designated along significant sections of the Elk River, including Morrissey, and the section from Hosmer upstream to Sparwood. In these areas, the protection of existing green space is encouraged, and access improvement to the Elk River should minimize impacts on riparian areas and consider cumulative effects on the Elk River.
2. In 2014, the RDEK established the Area A Flood Control Service Area. This program helps pay for maintenance and installation of flood mitigation works and is funded through property taxes.

3. In 2013, the RDEK commissioned the completion of a Regional Flood Hazard Study: Phase 1. The report provides a regional flood hazard assessment and flood management plan; the ultimate goal of which is to reduce flood-related damage and cost of mitigation through residual risk reduction planning (BCG Engineering Inc. 2013). The flood hazard study prioritizes previously identified flood hazard areas, describes potential effects of projected climate change on flood hazards, and outlines a framework to implement a regional flood management plan.
4. The RDEK completed the following flood mitigation projects in recent years: Hill Road earthen berm (2014 and 2015), set back erosion protection/riprap revetment at the airport (2015), and West Fernie Dyke (2013).
5. The RDEK commissioned several flood/erosion and infrastructure maintenance assessments in recent years. These have included:
    a. Elk River 2013 flood recovery Sparwood airport erosion preliminary hydrotechnical assessment (Northwest Hydraulic Consultants (NHC) 2015).
    b. Hill Road dyke assessment (Kerr Wood Leidal (KWL) 2014)
    c. Thompson Road log jam assessment (Vast Resource Solutions 2013); and,
    d. West Fernie dike improvements – Phase 3 and 4, assessment of design post 2013 flood event (NHC 2013).

Elkford

1. As per the Elkford OCP (District of Elkford 2010), and the Elkford Zoning Bylaw (District of Elkford 2014):
    a. Elkford's OCP protects the riparian area through development permit areas; whereby, generally no development is to take place within a 30 m area from a stream or wetland. Where a development requires a subdivision or building permit a Qualified Environmental Professional is to confirm these and other provincial and federal guidelines are followed as a minimum. Also native vegetation is to be retained to protect banks and fish and wildlife.
    b. Floodplain Development Permit Areas are addressed in the Elkford OCP to protect development from hazardous conditions. In 1989 floodplain mapping was completed for the 200-year floodline. Guidelines here include that new residential development shall be mitigated for the risks of flooding prior to development taking place, along with several development limitations to minimize risk to people and property.
    c. The Elkford land use map depicts the Elk River corridor/floodplain to be primarily zoned as Agricultural Land (A-1). As per the District of Elkford Zoning Bylaw, development on this land is limited (i.e., agricultural use, single-unit dwelling and kennels).
2. A Climate Change Adaptation Strategy was completed for the District of Elkford (Gorecki et al. 2010). Public input and best available science was used to review three priority areas: Wildfire, Flooding and Water Supply. These priorities were determined to be most vulnerable to future climatic changes, and were of most concern to the community in terms of impacts on safety and wellness. The Strategy was integrated into an OCP revision.
3. The District of Elkford completed the Boivin Creek Dike improvement project in (2016). The objective was to protect Elkford residents and infrastructure from flooding.

Sparwood

As per the Sparwood OCP (District of Sparwood 2015), and the Zoning Bylaw (District of Sparwood 2014):

1. Relevant policies to protect the natural environment, ecosystems and biological diversity include: developing guidelines to mitigate the loss of wetlands, wildlife habitat and indigenous vegetation areas; and working with relevant environmental organizations, and government to establish a Wildlife Corridor Identification and Protection Strategy for the area.

2. Relevant policies aimed at protecting environmentally sensitive riparian areas include conserving areas through the creation of parks, land trusts of covenants.
3. To maintain and enhance surface and groundwater quality in area, relevant polices include: supporting/ ecosystem assessments to update protection, restoration and land use strategies; and encourage the use of wetlands for storm water detention/retention;
4. Riparian Protection Development Permits are required if development is planned in designated Riparian Protection Areas (e.g., within 30 m of the Elk River and other larger tributaries, and 10-15 m of smaller waterbodies). In these areas an assessment is to be conducted by a Qualified Professional, to ensure that riparian habitat form and function are protected during development.
5. Lands within the 1:200-year floodplain have been mapped, and development within these areas requires a Floodplain Hazard Lands Development Permit.
6. The Elk River corridor is primarily mapped as Parks and Natural Areas and Agricultural Lands. In these areas, the lower density development as outlined in the Zoning Bylaw may facilitate protection of natural habitats.

Fernie

1. As per the Fernie OCP (Corporation of the City of Fernie 2014):
    a. Fernie supports the protection of its environmentally sensitive areas, which include: sensitive watersheds, riparian areas, aquatic habitats, mature and old growth forests, wildlife corridors, and habitats supporting red and blue listed species. Associated policies are to a) Endeavour to identify and protect ESAs in all relevant City plans and zoning bylaws, and b) consider establishing a Protection of the Natural Environment Development Permit Area to protect these features.
    b. Fernie supports the protection of wildlife corridors and migration paths. Examples of policies to protect these areas include: developing guidelines to mitigate the loss of wetlands, wildlife habitat and indigenous vegetation; work with environmental groups and government to establish a Wildlife Corridor Identification and Protection Strategy for the area; where feasible, connect environmentally sensitive areas through parks and greenways; and work with the RDEK to implement a 30 m protected buffer along riparian areas, and park or greenway connectors.
    c. Fernie supports the protection of aquatic systems and fish habitat. Examples of policies relevant to the Elk River include: update flood hazard mapping and Floodplain Management Bylaw; and require all new development bordering riparian zones to comply with Ministry of Environment regulations.
    d. Fernie aims to minimize the environmental impacts of storm water discharge into the Elk River and other local creeks, streams and water bodies. A relevant policy to support maintaining fish and wildlife is the City's support of retention or enhancement of existing natural wetlands.
    e. The Land Use maps reveal the prevalence of Parks and Open Space along the Elk River. These areas offer opportunities to protect riparian and aquatic habitats. The policy for new park establishment favours areas with mature tree stands, and preservation of areas adjacent to the watercourse. In natural open spaces, development is not to result in degradation of the natural environment.
    f. Watercourse Protection Development Permits are required prior to developing lands along watercourses. The Watercourse Protection Development Permit Area is located within 30 m of the natural stream boundary of the Elk River, and as listed, as either 15 or 30 m for other watercourses. To obtain a development permit, a qualified environmental professional is to complete an environmental impact study, which identifies potential impacts on the watercourse and associated mitigation measures.
    g. A Hazard Lands Development Permit is required when developing in mapped Flood Hazard Areas, to minimize risk to people and property. Here, applicants may be required to provide an assessment report prepared by a qualified professional that provides

information about the anticipated on-site and off-site environmental and geotechnical impacts associated with the development, and recommendations for mitigation of any impacts.

2. Fernie Floodplain Management Bylaw #2289 (City of Fernie 2016). The purpose of the bylaw is to reduce the risk of injury, loss of life, and damage to buildings and structures as a result of flooding. Floodplain land along the Elk River at Fernie and Coal Creek are mapped. Associated flood construction levels and floodplain setbacks are designated.
   a. The flood construction levels are mapped for the Elk River and Coal Creek and are designated at 1.5 m elevation above natural boundary of any other watercourse, lake, marsh or pond.
   b. The setbacks are 30 m linear distance from the natural boundary of the Elk river or Coal Creek, 15 m from other watercourses, and 7.5 m from standing water areas (lake, marsh or pond), and dike right-of-way.
3. An Emergency Program Review and Plan Update was completed for the City of Fernie (Disaster and Emergency Preparedness Consulting 2015). The objectives of the review were to
   a. Review the existing emergency management function, associated plans and bylaws and recommend changes to increase program efficiency and effectiveness to ensure it meets or exceeds the requirements of the British Columbia Emergency Response Management System;
   b. Develop or update the Emergency Management Plan, hazard specific plans (i.e. flood, fire, etc.), and function specific plans (i.e. emergency operations centre procedure guide, emergency social services plan, etc.); and
   c. Complete a Hazard Risk and Vulnerability Analysis (HRVA)
4. Coal Creek Floodplain Mapping (NHC 2014). Flood construction levels (FCLs) were mapped along with the 200-year floodplain boundary for Coal and Brewery creeks. Three flood hazard management zones were mapped, with recommendations for future development provided. Flood hazard Zone A was the 200-year floodway and setback area, with no further development recommended. Zone B was outside the 30 m setback area, but within the active fan, where overland flow and potential avulsions could occur. In Zone B development was thus recommended to be limited to park, open-space recreation and agricultural uses. Any buildings or structures constructed in this area should apply the BC MWLAP Flood Hazard Area Land Use Management Guidelines. Zone C identified areas within the 200-year floodplain that have largely been developed. New construction in Zone C should be such that the floor system of any habitable building, business, or building for the storage of commercial goods be constructed to a level at or above the FCL, or have another means of flood proofing.
5. Elk River Flood Hazard Assessment (NHC 2006). The state of dikes and Elk River flood hydraulics at Fernie was assessed. This involved updating flood profiles, providing comments on existing dikes/bank protection, and recommending upgrades to protect existing and potential developments.
6. Fernie Subdivision and Development Servicing Bylaw #1727 (City of Fernie 1998). This bylaw provides the regulations, standards, and specifications for the design and construction of subdivisions and developments. Schedules are provided for items such as water systems, sanitary sewers, and drainage systems.

Other Regional Initiatives

1. Cumulative Effects Management Framework (CEMF). The CEMF is being led by the provincial government. The objective of the initiative is to review the cumulative effects of development in the Elk Valley (including urban, logging, mining, recreational etc), and use this information to guide decisions around future development that may be permitted. CEMF is guided by 5 valued ecosystem components: 1) Riparian Areas (wetland occur largely in these areas); 2) Mature and Old Growth Forests; 3) Grizzly Bears; 4) Westslope Cutthroat Trout; and 5) Bighorn Sheep

(the high elevation population in the Upper Elk Valley). The information obtained from this initiative would be valuable to further extending our understanding of current and future environmental sensitivities and associated flood management priorities.

Forest management

Forest management in the Elk Valley was identified as an important issue for local citizens. In total, 68% of the land base in the Elk River Watershed is publicly managed, while 32% of this land base is privately owned. Currently, forestry on public land is managed by Canfor and BC Timber Sales (BCTS), and forestry activities on private land are managed by Canfor and Jemi Fiber. There are different regulations governing private relative to public forest lands.

- Forestry activities are governed by some key legislation that affects how forestry activities ultimately affect streamflow. Provincial legislation that applies are the *Forest Act*, the *Water Act*, and the *Wildlife Act*; while, federal legislation are the *Fisheries Act*, and the *Species At Risk Act* (SARA). These are all applicable when we look at how forest development can affect waterways. The FRPA applies to crown land and private land that is covered under a licence under the Forest Act (tree farms, woodlots, and community forests).
- On private land, the Private Managed Forest Land Act applies and Jemi Fiber is using FRPA voluntarily in S1-S4 streams to buffer streams and riparian areas, even though it is not required (A. McCuaig, Pers Comm).

> *We are using best management practices in our forestry efforts to reduce impacts of erosion into streams*
> - McCuaig, Pers Comm

- In addition to these regulations, the Forest Stewardship Council (FSC) sets out guidelines in order to maintain their certification. In order to receive FSC certification a wide range of standards must be met by forestry companies. For example, FSC certified companies like Canfor must apply riparian management strategies that are over and above what is required through FRPA in order to maintain their certification.

7.2 *Environmental non-structural measures*

The erodible corridor is an important concept to consider when discussing how to maintain a river's health and function (Robinson et al. 2016). The erodible corridor is the concept that natural rivers are not stationary in time or space, and often change course. While more commonly used in restoration, it is possible that the erodible corridor concept could be used proactively in development planning and policy (Robinson et al. 2016). To plan with the concept in mind would be to leave a wide belt which within the river channel can freely move and flood, for ecological conservation and to minimize future conflicts between human settlement and bank erosion processes (Piégay et al. 2005). The erodible corridor is thus defined as the active portion of a river valley or floodplain (Piégay et al. 2005). In the context of the Elk River Watershed Flood Strategy, the erodible corridor likely extends from valley wall to valley wall (the valley bottom). Note that the functional definition of the floodplain is not analogous with the 1:200 floodplain used for floodplain mapping described by the Ministry of Forests Lands and Natural Resource Operations (FLNRO). Previous work mapped land use within the Elk River valley bottom, and demonstrated that areas of dense development exist; however, these areas are localized and much of the Elk River valley bottom is considered to be in good condition (McPherson et al. 2013). Maintaining this into the future should be an overriding goal.

Non-structural measures for flood management often involve utilizing the watersheds natural functions for floodwater conveyance. By allowing room for the river to expand into the floodplains and by enhancing natural retention of flood waters in wetlands and riparian areas, flood amplitudes can be attenuated and flood damage can be significantly decreased. Government buyouts of already-developed properties and new zoning laws for future developments are ways in which infrastructure can be removed or minimized within the floodplains (RRBC 2011). Other non-structural methods include investing in better flood forecasting and warning systems, developing subsidized or incentivized flood insurance policies in order to minimize economic damage, and pursuing best management practices for land use activities (i.e. offsetting impervious surfaces, maintaining riparian buffers strips, practicing sustainable forestry, etc.) (RRBC 2011).

7.2.1 Riparian vegetation retention and regeneration

Riparian vegetation is an important component of riverine systems, and has many significant ecological and intrinsic benefits. Well-developed riverbank vegetation provides critical organism habitat, reduces bank erosion and channel widths, and regulates stream temperatures through additional shading (Belsky 1999, Swanson 1998, Moore 2005; see also Section 5). As well, well-vegetated riparian zones are able to store additional water, locally maintaining a heightened water table during drought conditions, trapping additional, potentially nutrient-rich sediment, and providing aesthetic appeal (Belsky 1999).

Among the many benefits of conserving and restoring riparian areas, the importance of riparian vegetation in mitigating downstream flooding is often an overlooked benefit of holistic watershed management. Well-developed riverbank vegetation has been shown to substantially increase bank roughness, in turn reducing river flow velocities (Belsky 1999). Hydraulic modelling experiments using study sites in the U.K and Italy found that the presence of tall flexible vegetation, such as grass or shrubs significantly decreased local flood risk (Darby 2006). This mechanism allows for additional storage of water upstream, delaying the timing of peak flows, and allowing for evaporation and infiltration to ultimately reduce the total volume of water transported downstream.

Similar watershed-scale hydrological modelling using the Grant River watershed in Wisconsin suggests that increased hydraulic roughness, which can be strongly controlled by riparian vegetation, can limit peak discharges by as much as 26% (Woltemade 1994). Since riparian vegetation primarily affects hydraulic roughness in over-bank flows, its effect on peak discharge attenuation is greatest for larger flood events.

As identified in the Elk River Watershed Valley Bottom Assessment, which analysed 2011/2012 orthophotos (McPherson et al. 2014), the riparian area (within 30 m of each bank of the watercourse) was largely intact between Elkford and Elko, and was mainly (74 %) natural forested area (**Table 3**). Extent of development varied by jurisdiction, with the City of Fernie having the highest percentage of infrastructure in the riparian area (15% built up, road, rail, and industrial). In comparison, areas with infrastructure were less than 5 % for other jurisdictions.

Table 3. Cover within the 30 m riparian zone (McPherson et al. 2014).

Jurisdiction	Total Area (ha)	% Natural			% Developed					
		Wat-er	Forest	Unforest Natural	Unforest Disturb	Veg. Recreat'n	Built up	Road	Rail	Indus-trial
Elkford	190	<1	61	32	4	2	1	1	0	0
Sparwood	178	<1	69	15	13	0	<1	1	1	<1
Fernie	70	1	77	1	6.5	<1	10	5	<1	0
RDEK	975	<1	77	8	12	<1	<1	2	1	<1
Total area	1413	<1	74	12	10	<1	1	1	1	<1

A report card summarizing land cover results was also prepared as part of the Elk River Watershed Valley Bottom Assessment. Overall, land coverage in the valley bottom (generally meaning the floodplain) was determined to be **Good** overall, and for most jurisdictions reviewed individually (Table 4; McPherson et al. 2014). However, Fernie rated **Fair** for 'total disturbance', 'vegetated cover' and 'forest cover'. The 'fair' category was broad ranging, with Fernie's values being nearer to the 'good' than 'poor' category. It was concluded that to maintain environmental health and function of the floodplain, it is important to continue to limit development in the valley bottom, and retain natural vegetation cover.

Table 4. Elk River Valley Bottom Assessment Report Card (Source: McPherson et al. 2014)

Indicators	Thresholds (%)*			Valley Bottom Results				
	Good	Fair	Poor	Overall	RDEK	Elkford	Sparwood	Fernie
Total Disturbance	<50	50-90	>90	36%	35%	19%	40%	64%
Total Vegetated Cover	>50	25-50	<25	77%	81%	79%	66%	39%
Total Forest Cover	>35	15-25	5-15	45%	47%	48%	37%	22%
Forested Riparian (30 m)	>50	25-50	<25	74%	77%	61%	69%	77%
Total Water				14%	13%	17%	8%	14%

*The indicators and thresholds were obtained from watershed level studies in other jurisdictions; these may be refined to best fit with objectives as more information becomes available.

7.2.2 Wetlands and beaver dams

As an extension of riparian vegetation, the presence of wetlands can substantially reduce the flood potential of a watershed (Figure 49). Wetlands are a product of either local channel gradients, or external damming due to beaver dams or large woody debris (LWD), and can create localized areas of flooding, low flow speed, and high vegetation density (Belsky 1999;). These factors, in turn dampen the effect of flooding downstream by increased water storage, higher evapotranspiration rates, and slower flow speeds (Hey 1995). Beyond the functional benefits of wetlands for flood mitigation, wetlands also provide critical habitat, improve water quality, and improve soil quality and moisture (Hey 1995; see also Section 5).

Figure 49. On larger streams and rivers where dams are not feasible, adjacent beaver ponds collect and store flood water for later release (Fitch 2016)

Research on recently re-introduced beavers in small mountain streams in Belgium found that beaver dams can significantly reduce downstream discharge peaks (Nyssen 2011). As well as reducing the magnitude of downstream floods, beaver dams were also found to slowly release water, allowing for increased flows during the driest periods of the year, providing an important buffer for both flood and drought conditions.

Further research on the hydrologic impacts of beaver dams in the Rocky Mountains of Colorado found that beavers can “create and maintain hydrologic regimes suitable for the formation and persistence of wetlands", with the majority of the hydrologic effects occurring downstream of the dams (Westbrook 2006). The presence of beaver dams during high flow periods forced excess water to travel overland, allowing for enhanced flow resistance from riparian vegetation, additional groundwater seepage and surface water storage. These factors, while confined to a relatively localized area, have a strong effect on downstream hydrology, damping streamflow peaks during floods and troughs during droughts. Beaver dams provide an important buffer in mountain and foothill river systems.

In the case of both wetland/beaver dams and riparian vegetation regeneration, a solid theoretical understanding underlies the potential benefits for flood mitigation as well as environmental benefits related to watershed function, resilience, and connectivity. However, there remains few quantitative studies examining the total flood reduction due to these measures, and an insufficient geographical range of case-studies to draw broad conclusions related to their efficacy. While these measures come with well-accepted intrinsic and environmental benefits, caution is required in solely relying on these measures to protect critical infrastructure from extreme flooding.

7.2.3 Non-structural strategies used elsewhere

Over the years we have seen an increasing trend in the frequency and severity of flood events (Simonovic 2001); however, we have also witnessed our approach to flood mitigation evolve as well. Historically, emergency response and structural measures were more frequently used to protect against flooding. For example, in the 1930's and 40's a series of small-capacity dams were constructed along many tributaries of the Red River in the United States, as well as levees and dikes to protect the municipalities in the floodplain (RRBC 2011). However, these measures are not always effective and large flood events, even in the face of immense flood-fighting efforts, can still induce catastrophic impacts. Such impacts have occurred in the Red River watershed in 1997, 2006, 2009, 2010 and 2011 from major flood events (RRBC 2011). After these damaging floods, the Red River Watershed Commission recommended complementing structural flood mitigation strategies with more non-structural solutions. Wetland conservation through "no net-loss" legislation was enacted, as well as subsidized flood insurance plans and technical innovations for improved flood forecasting and mapping (RRBC 2011). Non-structural strategies focussing on land use practices were also encouraged, such as minimizing infrastructure footprint in floodplains, offsetting impervious surfaces, buyouts of existing structures located in the floodplains, and maintaining riparian areas to improve natural floodwater retention (RRBC 2011).

Likewise, a project in the Netherlands, called *Room for the River*, is also encouraging alternative solutions to flood management on the Rhine River. The over-arching goal of this project is to "give the river more room to be able to manage higher water levels" (Room for the River n.d). This would involve taking out man-made dikes (also known as depoldering) and relocating dikes further inland (Figure 50); diverting floodwaters through high-water channels (Figure 55); excavating the floodplains and dredging the riverbed to increase storage capacity and conveyance (Figure 51, Figure 52); removing obstacles and lowering groynes (Figure 53); and improving natural storage retention through conservation of wetlands and riparian areas, and allowing light infrastructure spaces (i.e. golf courses, campgrounds, etc.) to temporarily flood (Alberta WaterSMART 2014). When all the above measures fail to provide the river enough room for safe floodwater conveyance, dike reinforcement may be considered as a final option (Figure 54) (Alberta WaterSMART 2014). The Netherlands have learned from experience, that in order to achieve successful flood solutions, clear objectives are necessary, assessments should rely on hydraulic modelling and cost-benefit analysis, resulting strategies should rely as little as possible on infrastructure, and proper engagement of local citizens is imperative (Alberta WaterSMART 2014).

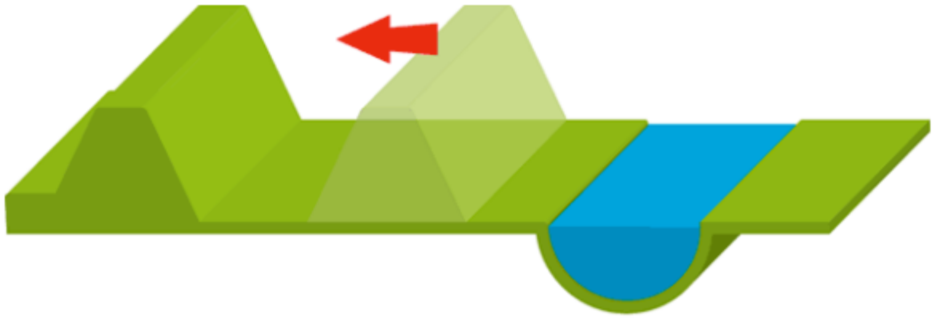

Figure 50. Relocating dikes further inland. Source: http://www.ruimtevoorderivier.nl/kennisbank/

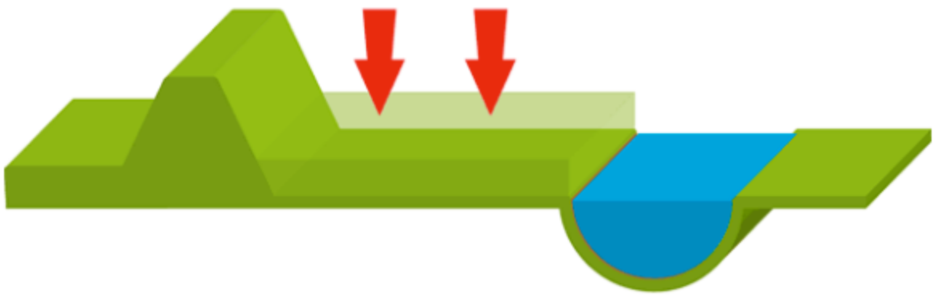

Figure 51. Excavating the floodplain. Source: http://www.ruimtevoorderivier.nl/kennisbank/

Figure 52. Dredging the riverbed. Source: http://www.ruimtevoorderivier.nl/kennisbank/

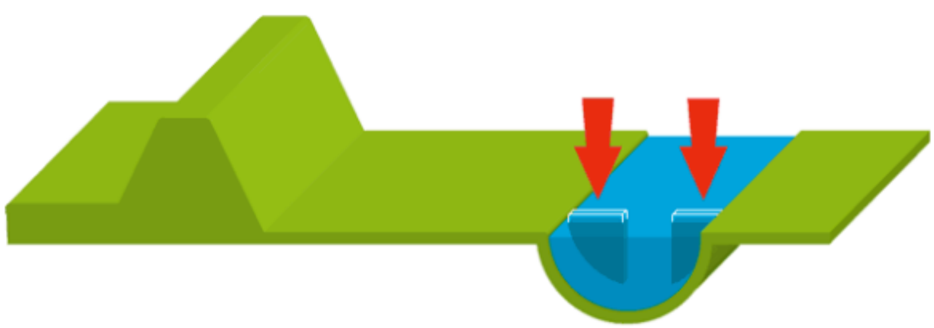

Figure 53. Lowering groynes. Source: http://www.ruimtevoorderivier.nl/kennisbank/

Figure 54. Reinforcing dikes. Source: http://www.ruimtevoorderivier.nl/kennisbank/

An approach to evaluate measures and apply similar logic has been evaluated in the Bow and Red Deer basins of Alberta. These projects focused on stakeholder engagement with an aim to "reduce vulnerability of people and infrastructure and improve the overall environmental quality" of the watersheds (Alberta WaterSMART 2014). The mainstem rivers were divided into eight segments and scanned for opportunities to implement Room for the River mitigation measures, similar to what was done in the Netherlands. Flood solution measures such as minimizing development in the flood plains, as-needed flooding of light infrastructure, and wetland restoration were identified along with other "no regret" options like mapping flood hazard areas across the whole basin, strengthening and enforcing land use best management practices, and securing long-term watershed agreements with resource companies (Alberta WaterSMART 2014). This pilot project demonstrated the value of applying Room for the River concepts to flood mitigation in Alberta. Examples of other non-structural flood mitigation options that have been used elsewhere include the Mission Creek Restoration Dike Setback Project and the Mill Creek Tree Management Plan, being carried out in the Okanagan Basin. The Mission Creek project aims to setback portions of the dike on both sides of the creek, primarily to restore the fish and wildlife stocks and habitat (Okanagan Basin Water Board 2015). Secondary objectives of this project include conserving biodiversity and species at risk, improving flood protection, and educating and engaging the community. The Mill Creek project, run by the City of Kelowna, aims to help retain, maintain and increase tree cover along the riparian areas of Mill Creek (Okanagan Basin Water Board 2015). Restoration of the natural floodplains, including conservation of wetlands and riparian areas, is a noteworthy non-structural flood mitigation solution. Offsetting or reducing impervious surfaces is another way in which floodwaters can be managed through non-structural means. Costs for the Mission Creek and Mill Creek projects were approximately $70,000 and $95,000, respectively (Okanagan Basin Water Board 2015).

In a 2006 City of Fernie Flood Hazard Study, certain flood solution options were outlined, one of which agrees with the Room for the River concepts while simultaneously improving watershed function and wildlife habitat. This option consists of abandoning an existing berm and re-grading a 50 to 75 meter buffer along the Elk River at the north end of the Fernie Golf and Country Club (NHC 2006). The area was recommended to then be re-vegetated with riparian forest (NHC 2006). Furthermore existing ponds would be connected in the Fernie golf course and low areas would be "swaled-out" to allow further floodplain drainage (NHC 2006). When first proposed in 2006, it was estimated to cost approximately $260,000, including annual maintenance costs. Other structural options outlined in the report include upgrading the existing dikes to current flood control levels, stabilizing banks with the use of riprap, and/or constructing a new dike that is set back from the existing one (NHC 2006). Further potential actions include updating flood hazard mapping and flood response plans, encouraging flood proofing of property in the floodplains, and minimizing infrastructure footprint in the natural floodplain.

7.3 *Structural flood management strategies*

Structural measures for flood management are commonly used and often consist of diversion, storage, conveyance, or protection methods (see Section 5.3 for approaches to enhance/protect fish and wildlife habitats when implementing traditional measures).

7.3.1 Diversion

Diversion measures are defined as measures that channel high flows around infrastructures, like the diversion channel in the city of Winnipeg (Alberta WaterSMART 2014, RRBC 2011; Figure 55). Diversion channels, high water channels, or floodways are man-made channels that allow excess flood waters to flow outside the river channel, by-passing critical infrastrucure, and serving to decrease flood damage by reducing the river flood level (Alberta Water Portal 2013). Construction costs are generally high (e.g. the Portage Diversion in Manitoba cost $20.5 million in 1970); however, these structures are semi-permanent and provide long-term flood protection (Alberta Water Portal 2013). While diversion structures are efficient at protecting vital infrastructure from flood damage, they also come with a high environmental cost; including the disruption to natural flows, riparian sedimentation, and serve to partially isolate the river, reducing their connectivity with the floodplain (Alberta Water Portal 2013).

Figure 55. Diversion channel during flooding transporting excess water. Source: http://www.ruimtevoorderivier.nl/kennisbank/

7.3.2 Storage

Storage measures are effective options that temporarily detain high flows, and often consist of dry dams or detention ponds, and permanent dam construction (Alberta WaterSMART, 2014). Dry dams, where excess water can be stored, allow for a regulated temporal distribution of streamflow, damping flood surges (Simonovic, 2001). Dry dams are more useful for frequent, small-scale floods that have the potential to erode river banks, while larger reservoirs can mitigate larger floods (Alberta Water Portal, 2013). It is difficult to estimate specific costs as they depend on size and required maintenance. As a long-term flood mitigation strategy, storage structures like dry dams and reservoirs have environmental impacts similar to diversion projects such as disruption of floodplain ecosystem connectivity, the river's natural flow and sediment transport processes (Alberta Water Portal 2013).

7.3.3 Conveyance

Conveyance measures improve channel conveyance capacity and often consist of widening, deepening, realigning, and protecting river channels and banks (Simonovic 2001; Figure 56). Ways to improve conveyance include channelization or bank stabilization projects, and dredging. Channelization is the process of straightening a river, thus reducing bank erosion and accommodating higher velocity floodwaters (and therefore quicker evacuation of floodwaters from the area of interest). Bank stabilization projects also protect the bank against erosion but don't always result in higher flow velocities; specifically the use of riprap stabilizes banks while also increasing bank roughness, leading to a decrease in flow velocity (Reid and Church 2015). Although these mitigation options have proven useful in specific areas of a river, concerns exist over flooding downstream where such conveyance measures were not undertaken (Alberta Water Portal 2013). Bank stabilization projects can have many impacts on river ecosystems as they result in lower woody debris recruitment and they can increase flow rates which negatively effects natural pooling and sedimentation processes.

Figure 56. Examples of riprap application on lower Fraser River. Source: Reid and Church 2015

Dredging, the means of artificially widening and deepening a river channel to allow for additional water conveyance has been proposed in many instances as a method of flood mitigation. In particular, periodic flooding of the Fraser River near Chilliwack, BC, has yielded contracts for the removal of gravel in the river, through bar-top mining. While the removal of sediment theoretically allows for additional space within the channel for water passage, in effect lowering the water level, the efficacy of this measure, and the amount of excavation needed, varies by location (Church 2012). In the case of the Fraser River, sediment accumulation was found to be relatively slow, and did not measurably affect water levels. Conversely, bar-top mining threatens “extraordinarily rich aquatic ecosystem, a source of commercial, recreational and cultural value to the population of the Fraser Valley” (Church 2012, see also Kondolf 1994). In order to fully address the potential efficacy of dredging as a flood mitigation measure, a detailed study of the sedimentation rates and channel morphology is needed, although it remains likely that further setbacks of dikes, where space permits, can yield similar or greater results (i.e. greater flood-water conveyance) through considerably less intrusive, and potentially environmentally degrading, means.

7.3.4 Protection

Finally, protection measures consist of flood barriers and dikes, have been shown to offer an effective, potentially low-cost defence against floodwaters (Alberta WaterSMART 2014). Barriers such as berms, levees, and floodwalls act to hold back floodwaters in flood-prone areas and protect infrastructure against damage. They typically consist of dense sediment materials that can decrease water velocity and absorb excess water (Alberta Water Portal 2013; Figure 57). Flood barriers are usually an effective mitigation measure as long as they are built large enough to protect against large scale flood events. However, in the case of a levee failure damage may be intensified due to the sudden burst of elevated floodwaters. The cost of such a mitigation measure depends on size, use, materials, and frequency of upgrades. Environmental impacts include an increase in river flow velocity and disconnection of the floodplain, and potential modification of aquatic habitat (Alberta Water Portal 2013).

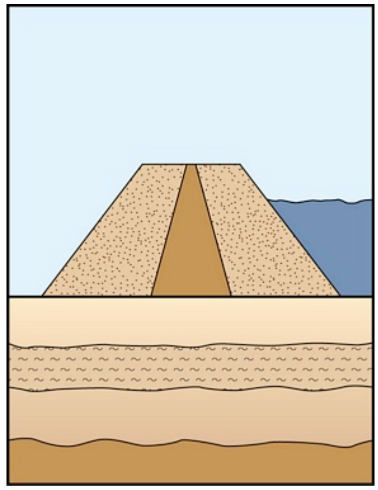

Figure 57. Schematic of a flood barrier, such as a berm or levee

7.4 *Flood hazard reduction assessment tools*

Flood management and mitigation will never reduce the flood risk in the Elk Valley to zero. The descending step change chart depicts Risk for various Elk River Flood Reduction Management Tools (Figure 58). Although flood risk is reduced, there is always a residual flood risk present. The cost of reducing risk may exceed the benefits of doing so and the funds may not be available to invest in the tools.

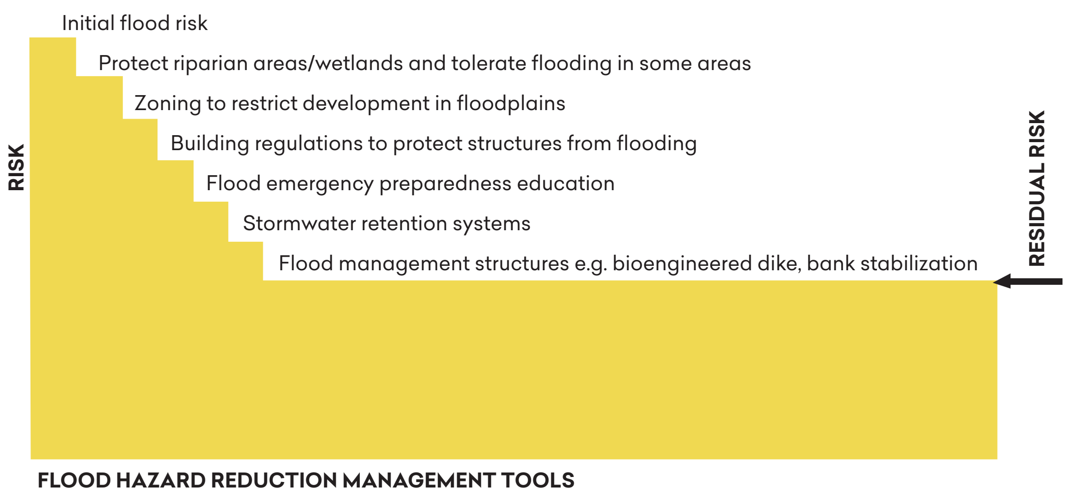

Figure 58. Flood hazard reduction assessment tool (Adapted from Jha et al. 2012 p. 444)

The Elk River Flood Strategy team developed a floodplain management matrix (Table 5). This evaluation tool is intended to help assess flood management and mitigation options. Options range from doing nothing, through buying out properties and applying traditional and bioengineering structural mitigation measures. Various risks for each option are identified, with assumptions noted. This is a preliminary tool which may be expanded as necessary.

Table 5. Floodplain management matrix for the Elk River mainstem (preliminary). Risks are identified as High (H-red), Medium (M-yellow) or Low (L-green).

	Environmental Risk	Downstream property risks	Risk of failure	Cost to implement	Economic implications
Do nothing (personal responsibility)	**L**	**L**	**L**	**L**	**M** -Neutral benefit -Landowner to properly plan (e.g. set-backs, raise infrastructure)
Zoning to exclude building in floodplain	**L**	**L**	**L**	**L**	**H** Loss of tax revenue due to no build zone
Restore wetlands	**L**	**L**	**L**	**M** Purchase property, design, materials & construction	**H** Loss of tax revenue due to no build zones
Buyout program for properties in floodplain	**L**	**L**	**L**	**H** High cost to purchase and decommission properties	**H** Loss of tax revenue due to no build zones
Setback structures (e.g. dikes)	**L** Potential risk increases with smaller set-back distance	**L** -Potential risk increases with smaller set-back distance	**L** -Potential risk building in floodplain -Risk increases with smaller set-back distance	**H** -Design, materials (rip rap rock), construction	**M** -Potential for loss of tax revenue due to no build zones - Maintenance in perpetuity
Bioengineering mitigation (non set-back)	**L** Assumes maintenance of ecological function	**L**	**H** Elk R forces likely too high for bioengineering alone but good for tributaries	**M** Design, materials, construction	**L** Maximize taxable property
Bioengineering with traditional engineering mitigation	**L** Risk increases if there is a loss of habitat	**M** May direct force of flow downstream	**M** Risk of failure to any structure in high power stream	**H** Design, materials, construction	**L** Maximize taxable property
Traditional engineering mitigation (e.g. dykes, rip rap)	**H** If loss of habitat & floodplain isolation	**M** May direct force of flow downstream	**M** Risk of failure in high power stream	**H** Design, materials, construction	**L** Maximize taxable property

7.5 *RDEK Area A priority flood mitigation concepts*

There are several flood management installations in the RDEK, situated in the Elk River floodplain with potential flood and/or streambank erosion issues (e.g., West Fernie dike, Hill Road earthen berm). The RDEK consulted with the Elk River Flood Strategy team to develop potential flood mitigation options for areas of mutual concern. The Elk River Flood Strategy provided options at a conceptual level. Concept designs and associated cost-estimates were developed to further prioritize the sites, identify additional study requirements, in order to seek additional funding for development and implementation.

The conceptual design process drew on the larger body of information provided in this Strategy document, and incorporated design elements to maintain and promote ecosystem values and function where possible (Robinson et al. 2016). However, it was identified, that it is important to recognize that structural flood and erosion management techniques inherently interfere with natural channel process and have the ability to impair the river ecosystem (riparian values included). Thus, the only true flood management strategy that can be employed without impairing the river ecosystem is avoiding development in the floodplain (Robinson et al. 2016).

8. Recommendations

8.1 *Summary of the Elk River Flood Strategy report*

Figure 59. Elk River near Hosmer. Credit: Steve Short.

The Elk River Flood Strategy began with an analysis of flooding in the Elk Valley (Section Analysis of Flooding in the Elk Valley3). The Strategy team's professional hydrologist described: the natural history of the watershed; characteristics of the Elk River as a 'freestone' gravel bed river in an erodible corridor; the human disturbances that affect streamflow (i.e. mining, forestry); the potential effects of climate change; and, the effect of streamflow on extreme flood events. His background knowledge answered the question - is flood hazard changing in the Elk Valley?

Flooding is only a problem when it affects citizens; nature is designed to deal with periodic flooding, in fact depends on it. **Section 4** explored the effects of flooding on Elk Valley communities. This involved presenting a chronology of flooding history from 1900 to 2013, including the community response and the effectiveness of their flood response. An extensive community outreach program by the Elk River Alliance resulted in 200 completed surveys summarizing community concern and opinion about flooding. Fifty-three percent of citizens were 'definitely concerned' about flooding. Of greatest concern was damage to 'critical infrastructure and the environmental impacts of flooding'. The top two flood mitigation options community supported were 'riparian enhancement and enforcement of municipal zoning'. What citizens would like to know most about flooding is 'flood hazard mapping, emergency flood response plan, and the range of structural and non-structural flood mitigation options available'. Municipal governments were also consulted about their key questions regarding flooding and flood management.

The Elk River Flood Strategy also investigated flood management strategies that protect citizens and key infrastructure, and which also protect the resilience of the watershed and wildlife habitat. **Section 5** reviewed the effects of flooding on fish and wildlife and management options that protect their habitat. Wildlife species and streamside habitats were identified as habitats of importance. Being a 'fish centric' valley, fish and fish habitats influenced by flooding and traditional flood mitigation were identified and explicit solutions were recommended to protect their habitat.

Predicting the future of flooding is a challenge. **Section 6** simulated floods in the Elk Valley by looking at historic hydrology and the potential of future streamflow conditions on flooding. Historic and future hydrology information is the base for the visual hydraulic model, one of the innovative tools of this Strategy. This web-based visualization tool, unlike one dimensional floodplain maps, will help people from Hosmer to Coal Creek see extents and depths of flood inundation under various flood scenarios (based on the 1995 and 2013 floods, as well as the projected 1:200 year flood). Limited budget restricted the Strategy to select this section as a first priority due to previous issues with flooding.

Floods will be part of the Elk Valley's future. Reducing flood damage will be a joint effort of citizens working with governments**.** **Section 7** discussed mechanisms to reduce flood damage using non-structural and structural flood management strategies. In addition to this report, the Strategy team worked closely with the RDEK Area A to examine specific sites of mutual community and local government interest and developed concept designs in preparation for recommended flood management structures.

To conclude, **Section 8** makes recommendations on what needs to be done collectively using a holistic, watershed wide approach to implement ideas to increase the safety of citizens, ensure floods result in minor disruption of life and economic activity. Flood management decision-making must consider the cost and benefit of various flood strategies, in particular prioritizing options that protect citizens, critical infrastructure, all while protecting the resilience of the watershed and wildlife habitat.

8.2 *Implementing the Strategy*

8.2.1 Assessing the cost and benefit of flood management

The Elk River Flood Strategy provides community and decision makers with comprehensive background of flooding impacts and flood management response in the Elk Valley. The Strategy is intended to help decision-makers select appropriate non-structural and structural flood management approaches. Deciding on the most effective approaches and how to integrate these with a focus on watershed and habitat protection will require evaluation of the risks and costs. Table 5 is a tool to assess the social and economic costs of flood decision making.

Table 5. Social and economic costs of flood management approaches (adapted from Jha et al. 2012)

COSTS	METRICS
SOCIAL COST	
Risk to personal safety	# of people at risk of loss of life or serious harm
Disruption of life	Level of inconvenience and stress due to evacuation, and time to cleanup/rebuild and return to normal life
ECONOMIC COST	
Damage to property	Assessed value of damaged property
Damage to critical infrastructure e.g. highway bridges, railway	Cost of capital to build infrastructure and budget to rebuild
Loss of wages from interrupted work	Length of time industry disrupted
Loss of earnings from interruption in business	Projected cost of sales for retail, tourism, etc.
Cost of clean up	Estimated cost of municipal services provided
Cost of emergency services	Cost to run emergency response centers, etc. Provision of equipment, supplies, incidental costs
BC Provincial Disaster Financial Assistance	Cost to compensate eligible residents and does not cover 100% of cost
Eligible insurance claims	Increase insurance premiums for the general population. Few if any Elk Valley residents have
Flood management design and construction	Cost of research, concept design, and construction
Flood management maintenance	Longevity of approach and annual maintenance cost

Environmental analysis can be more challenging, as it is hard to place a dollar value on the value and services provided by nature (Figure 60). The World Bank states that environmental analysis can be based on use and non-use values to people (Jha et al. 2012). The environment has intrinsic values or non-use values, for example: beauty of landscapes; habitat of rare species; sites of historical importance to First Nations, and community areas. We also value the services provided by nature: wetlands soak up and store flood water; riparian forests strengthen streambanks from erosion; and large woody debris in the Elk River creates complexity for fish habitat (Jha et al. 2012).

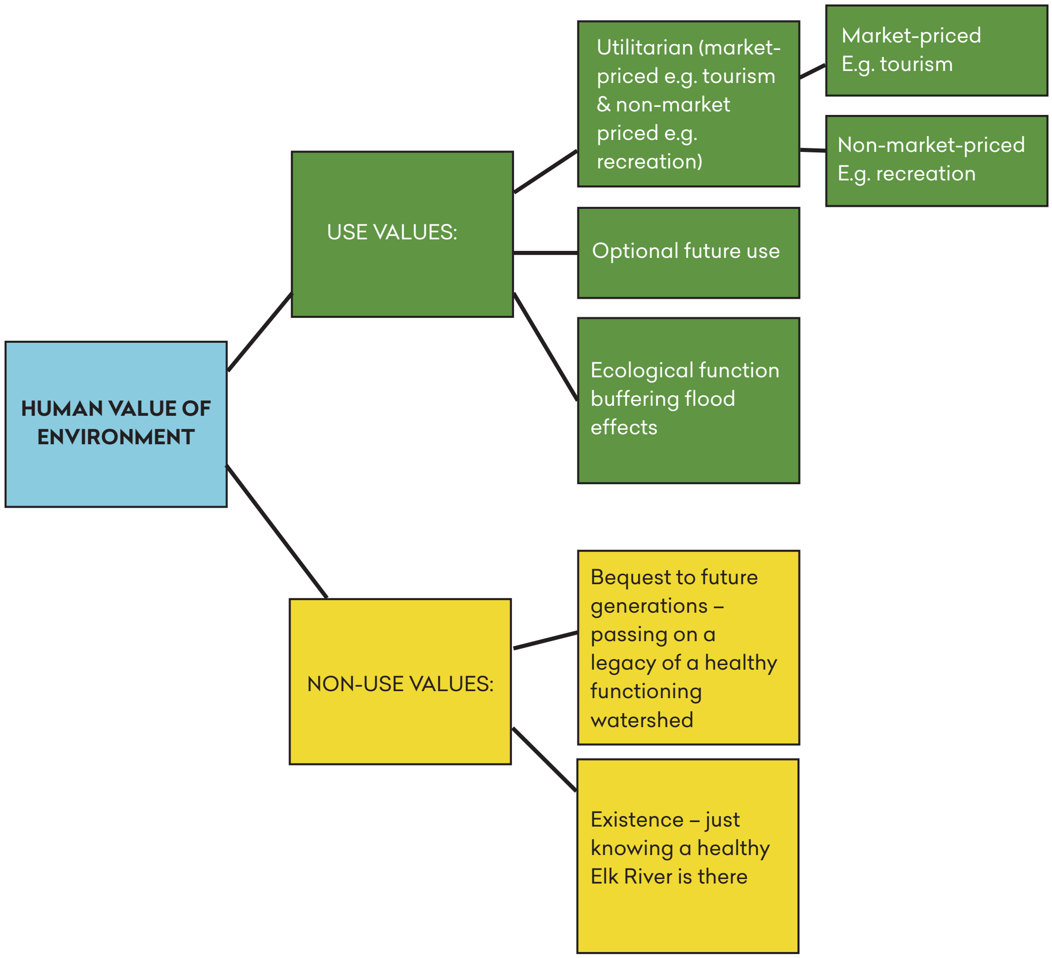

Figure 60. Environmental Values of Environment (i.e. Elk River) (adapted from Jha et al. 2012)

8.2.2 Implementing the Elk River Flood Strategy

Decision making is complex and requires support tools like the Elk River Flood Strategy, but will always require professional expertise from technical specialists, as well as input and buy-in from the community. This is especially notable as there is a level of uncertainty associated with the future predictions of flood patterns (Jha et al 2012). Still there is an urgency to make high quality and robust decisions as development proceeds. Infrastructure needs to be planned and populations protected; therefore, decision making must be flexible, and consider 'just in case' approaches (Jha et al. 2012). If we fail to plan; then plan for status quo flood approaches to fail. Flood solutions should be avoided which make the negative effects of floods worse than the natural event (e.g., trapping flood water in communities behind plugged or dysfunctional culverts, inoperable gates or breeched dikes) (Jha et al. 2012). Elk Valley decision makers are dealing with three choices with regards to dealing with flooding in the watershed (Figure 61). It is recommended that decisions are made strategically, keeping in mind the long-term benefits.

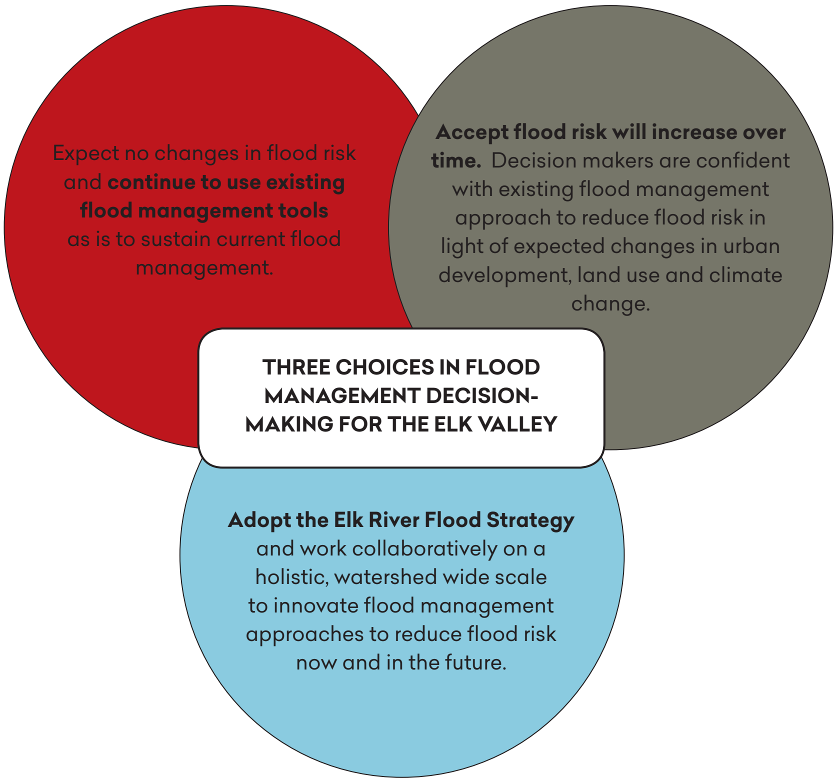

Figure 61. Three Choices in Flood Management Decision-Making Needed in the Elk Valley.

8.2.3 Elk River Flood Management Committee

It is recommended that an Elk Valley Flood Management Committee (Flood Committee) be formed, which would be tasked with reaching agreement on the community values to be protected from flooding, using a transparent, consensus-based approach to reaching agreement from stakeholders and community. To accomplish this, stakeholders would participate in a workshop to identify goals, objectives, and values; and review flood risk, and associated flood management tools. With consensus reached of stakeholder and community values, the Flood Committee would agree on assigned weighting of these values to assess the benefits of flood management approaches to the watershed. Since there is a need for community buy-in to the weighting analysis, public involvement early in the process and clear explanation of how the scoring would influence policy and decision making would occur. This is a variation on Multi-Criteria Analysis (MCA), which is a decision making matrix, described in Jha et al. (2012).

MCA aims first to establish the goals and objectives of the Flood Committee for flood mitigation measures, by examining flood risk and associated reduction measures (Table 6). Utilizing a pre-determined consensual weighting, the Flood Committee members would individually score the effectiveness of any given approach out of 100 (1 being ineffective and 100 being very effective). Using a hypothetical example of a bioengineered dike at the end of Jane Road, this measure may get a total score of 13 from Flood Committee members. This would be a relatively low score when multiplied by pre-determined assigned weighting, therefore it might not register on the priority list as a flood mitigation project for the RDEK Flood Service Area fund partner dollars.

Table 6. Proposed Elk Valley Flood Management Decision-Making Matrix (adapted from Jha et al. 2012)

ELK VALLEY FLOOD MANAGEMENT DECISION-MAKING MATRIX			
Category*	Weighting**	Score/100 1–ineffective 100-very effective	Subtotal (weighting X score)
1. Risk to life/serious injury reduction	20%	0	0
2. Social impact reduction	15%	10	1.5
3. Residential property damage reduction	15%	15	2.25
4. Business damage reduction	10%	0	0
5. Flood defense improvement	15%	30	4.5
6. Critical infrastructure disruption reduction	15%	5	.75
7. Environmental impact reduction	10%	40	4
*Cost analysis requires separate evaluation **Weighting is based on consultation and consensus derived by stakeholders, therefore are subjective and would only form the basis for discussion	100%		13

8.2.4 Implementing the Elk River Flood Strategy

An analysis of flood planning and management from the 1990s, throughout the Elk River watershed revealed that communities have and are actively studying the issue of flood hazard and mitigation, have raised money for flood protection, and have modified planning to keep in step with changing land use and climatic conditions (Appendix D). This Elk River Flood Strategy recognizes the value of this past work and integrates and builds on these previous efforts.

Living with flood risk is a devastating reality. Flood management if ignored will have financial, practical and psychological consequences. It will happen again so the Elk Valley needs champions in positions of influence for the Flood Strategy to be successful. The Elk River Flood Strategy lays out a variety of non-structural and structural approaches to flooding. The time to plan to protect citizens, critical infrastructure and the watershed function is now. Due to the lengthy process of consultation required to complete the Elk River Flood Strategy with stakeholders and community, it will take time. Following are some specific tasks that are recommended from the consultation and analysis of this Strategy.

1. **Continue to build on this flood strategy, using an integrated, collaborative and coordinated approach to flood management and mitigation (See Table 7 for actions).**
   - Encourage all levels of government, industry and community to continue to collaborate on holistic, watershed wide flood strategies.
   - Adopt the Elk River Flood Strategy as a first step toward an integrated *Elk River Watershed Flood Management Plan.*
   - Form an *Elk River Flood Management Committee,* empowering local watershed governance as stated in the new BC *Water Sustainability Act*.

- Exercise existing regulations, policy and political will to limit, where possible, development in the floodplain.
- Work with private land owners in the Elk Valley to address community concerns about flood impacts from private land.
- Continue with hydraulic modeling in high priority areas in the Elk River Watershed, similar to that which the Flood Strategy produced between the townsite of Hosmer and Coal Creek mouth. This product provides a tool to aid decision makers and residents in visualizing various flood inundation scenarios.

Table 7. Actions required to build on the Elk River Flood Strategy

Action	Who	Timing
Encourage all levels of government, industry and community to continue to collaborate on a holistic, watershed wide Elk River Flood Strategy, mirroring similar efforts with Elk Valley Cumulative Effects Management Framework (CEMF), Elk Valley/Crowsnest Pass Community of Interest Advisory Initiative, and the Elk Valley Integrated Resource Task Force.	All	Immediately
Use the research and findings from this Elk River Flood Strategy as first steps toward an integrated *Elk River Flood Management Plan* with an effective decision making framework to deal with flood mitigation requests.	RDEK, Districts of Sparwood & Elkford, City of Fernie	October 2016
Learn from other jurisdictions (e.g. Ontario) how to regulate private land, to decrease potential flood effects and work with private land conservancies. This is important given that 32% of the Elk Valley is privately owned, compared to 7% being privately owned throughout the province.		
Update floodplain maps and keep them current. Ensure there is a funding strategy to cover this technical work. The National Disaster Mitigation Program (NDMP) may be applicable, and has four funding streams: 1) risk assessments; 2) flood mapping, 3) mitigation planning, and 4) investments in non-structural and small scale structural mitigation projects (i.e., storm culvert replacement, projects that improve flood resilience). Develop guidelines and specifications for the development of floodplain maps so that they are consistent through the watershed.	Local governments working with Provincial Government NDMP program	2016-2019
Harness the Elk Valley residents “get ‘er done” common sense attitude, which recognizes that approaches are not perfect but there is a willingness to engage in iterative, adaptive strategies for proactive flood solutions.	Elk River Flood Committee	July 2016
Continue with hydraulic modeling in high priority areas in the Elk River Watershed, similar to that which the Flood Strategy produced between the townsite of Hosmer and Coal Creek mouth. This product provides a tool to aid decision makers and residents in visualizing various flood inundation scenarios.	RDEK, Districts of Sparwood & Elkford, City of Fernie	By 2018
Support local government authorities to restrict development in floodplains using zoning as well as develop flood hazard area bylaws, land development exemptions and requirements/best management practices for development in flood prone areas	Local Government	2016
Better understand the NEW BC *Water Sustainability Act (WSA)* which came into force in January 2016. The Act	ERA, District of Sparwood staff	October 2016

Action	Who	Timing
contains new policy direction related to flood management and mitigation; specifically to protect stream health and aquatic environments, consider water in land use decisions, and enable a range of governance options.	and City of Fernie Council all attended workshops with the POLIS Institute on this new policy direction	
Encourage municipalities to consider specific flood bylaws or flood risk management provisions in zoning bylaws.	Municipal Governments	November 2016
Modeled on the Fraser Basin Council, Okanagan Water Board and Cowichan Watershed Board, form an *Elk River Flood Management Committee* empowering local watershed governance as stated in the new BC *Water Sustainability Act*. Strong leadership and committed individuals that are transparent and accountable will be key to this group.	ERA as the initial sponsor	July 2016 for the first meeting
Municipalities share information about effective flood protective works, policies and best management practices, reassuring neighbors downstream they are passing on water quantity and quality in the state they would like to receive it.	Municipalities ongoing	August 2016 host first watershed tour with a focus on floods
Encourage innovation in flood solutions and discourage municipalities, industry, transportation to retreat to planning and mitigation efforts considered in a silo/status quo/business as usual approach to flood management and mitigation.		

2. Keep people safe from flood risks (See Table 8 for actions).

- Recognize the impacts of flooding on individual homeowners and educate watershed residents with practical solutions that they can take to be prepared for future flood impacts.
- Talk with residents about their local knowledge and experience with flooding and consider this input throughout the decision-making process.
- Continue to increase our collective watershed literacy about flooding.

Table 8. Actions required to keep people safe from flood risks

Action	Who	Timing
Publish the Elk River Flood Strategy on the ERA website and in printed form as a 4 page report card available to residents at local government offices and libraries.	ERA	July 2016
Around flood season, remind people of flood emergency preparedness planning, and how to keep informed about early warning signs.	Local Governments Local media	Immediately and annually
Work with realtors and developers around a code of practice to protect homeowners, prospective buyers, home builders, and renovators in flood prone areas.	Realtors, Developers, Construction Contractors	2017
Prepare to deliver "watershed tours" annually that are fun field trips with food and up-to-date, relevant flood facts. These field trips will promote thinking like a watershed and passing on	ERA to coordinate in conjunction with	2016 and annually

Action	Who	Timing
water downstream in the quality/quantity we would like to receive it.	municipal governments and staff	
Connect 'wily watershed veterans' and 'wondering watershed youth' during the watershed tours to learn cross generationally about watershed values, issues of concern and innovative solutions to flooding.	ERA to facilitate	August 2016 and ongoing
Create and make accessible flood interactive tools for emergency preparedness, improved land-use planning and public awareness.	ERA	June 2016
Continue to facilitate conversation with community about flood issues of concern using feedback tools like Survey Monkey.	ERA	Ongoing
Communicate on a regular basis the flood emergency response plan with citizens, in particular school age children as family messengers.	Municipalities could contract ERA	Every spring

3. **Protect critical infrastructure (See Table 9 for actions).**
    - Employ proactive flood management and mitigation approaches that are effective, use tax resources wisely, increase watershed resilience, and protect habitat. Avoid reactive 'quick fix/non-strategic' actions.
    - Monitor and maintain existing flood infrastructure (e.g., dikes, and streambank erosion protection) in good working condition to protect citizens.
    - Restrict dredging, as the cost to the river ecology outweighs the perceived short-term benefits.
    - Where diking and riprap are required to protect key infrastructure, incorporate natural habitat elements to offset impacts to fish and wildlife habitat.
    - Where possible, protect and re-establish riparian areas, wetlands and off-channel habitats.

Table 9. Actions required to protect critical infrastructure

Action	Who	Timing
During a flood event, support authorities to protect key infrastructure like highway bridges and roads, CPR railway and bridges, etc. to protect the economy of the Elk Valley.	All	Immediately
Where feasible, protect, restore, enhance and construct wetlands as infiltration/retention systems for floodwaters.	ERA, Fish and Wildlife groups, Nature Conservancy of Canada, The Nature Trust, Industry, Developers	Ongoing
Identify vulnerabilities across the watershed and prioritize appropriate and effective flood mitigation solutions.	Elk River Flood Committee and Local Governments	2016-2017
Track the effectiveness of the RDEK Area A Concept Designs through this Strategy, learning how to improve the process.	RDEK and ERA	2017
Identify areas vulnerable to floods, understand the specific hazards and proposed effective solutions for flood mitigation.	Districts of Elkford and Sparwood, City of Fernie, RDEK	2017

Action	Who	Timing
Monitoring the Elk River Flood Strategy implementation to ensure flood protective structures and erosion control methods are effectively implemented and the information is being used in an adaptive flood management context to guide future decision-making.	ERA and Elk River Flood Committee	Ongoing

4. **Respect the natural function of the watershed to provide a buffer of resilience to climate change (See Table 10 for actions).**
   - Use the understanding of Elk River hydrology, geomorphology, and effects of flooding on fish and wildlife to guide flood management and mitigation decisions.
   - Recognize that natural and human activity in the Elk Valley affects watershed function, and can cause fragmentation and a loss of diversity. Therefore, limit development in the erodible corridor (along valley bottom) to the furthest extent possible, to maintain ecological function.
   - When implementing structural flood mitigation, limit narrowing, straightening and cutting off the floodplain from the Elk River and tributaries.
   - Promote best flood management practices for developers and private landowners in flood prone areas.
   - Promote best management practices with municipalities regarding storm-water management, riparian protection, and erosion protection to reduce sediment in the Elk River and its tributaries, in order to protect aquatic habitat.
   - Acknowledge that crisis in the watershed can oscillate between floods and droughts; therefore, plan for mitigation measures to address both extremes.

Table 10. Actions required to protect watershed function and buffer climate change

Action	Who	Timing
Protect and enhance riparian areas and aquatic ecosystems.	All statutory decision makers, industry, private landowners, and community groups.	Immediately
Host a bioengineering workshop for municipal staff, elected officials, industry, environmental consultants and community interested in enhancing structural and non-structural flood mitigation.	ERA	May 5-6, 2016
Set specific watershed targets for flood resilience (e.g. % of riparian areas protected, % of river bank rip rapped through communities).	Elk River Flood Committee	October 2016
Sustain the natural state of undeveloped floodplains.	All statutory decision makers and private landowners.	Immediately
Target future development in areas with low flood hazard and low habitat sensitivity.	Municipal planners	Immediately

8.3 *Final Remarks*

Floods have been a part of the Elk Valley's past, and living with flood risk in the future is a reality we must face together. Although local, regional and provincial governments have taken important steps to manage flood risks in the past, holistic, integrated watershed-wide flood management plan has been largely ignored. This is likely due to lack of financial resources, leadership, practicality, as well as community short memories and general denial that the next flood will be as big as the past one.

For a holistic, watershed wide, integrated flood management plan to be successful requires champions in positions of influence. These champions need a vision of the best non-structural and structural flood measures that will persist over time. These champions, local decision makers and the community will benefit from the increased understanding of the science of flooding contained in this Strategy and the flood solutions recommended that are unique to a 'made in the Elk Valley' approach. The time scale to plan and implement and change flood risk assessment, planning and implementation is short. We need action now. This Strategy contributes to our current knowledge, provides recommended solutions, and has started the consultative process with stakeholders and community, required for the implementation of an effective, transparent and accountable Elk River Flood Strategy.

We get smarter after every flood event
- Elk Valley resident during oral history interview

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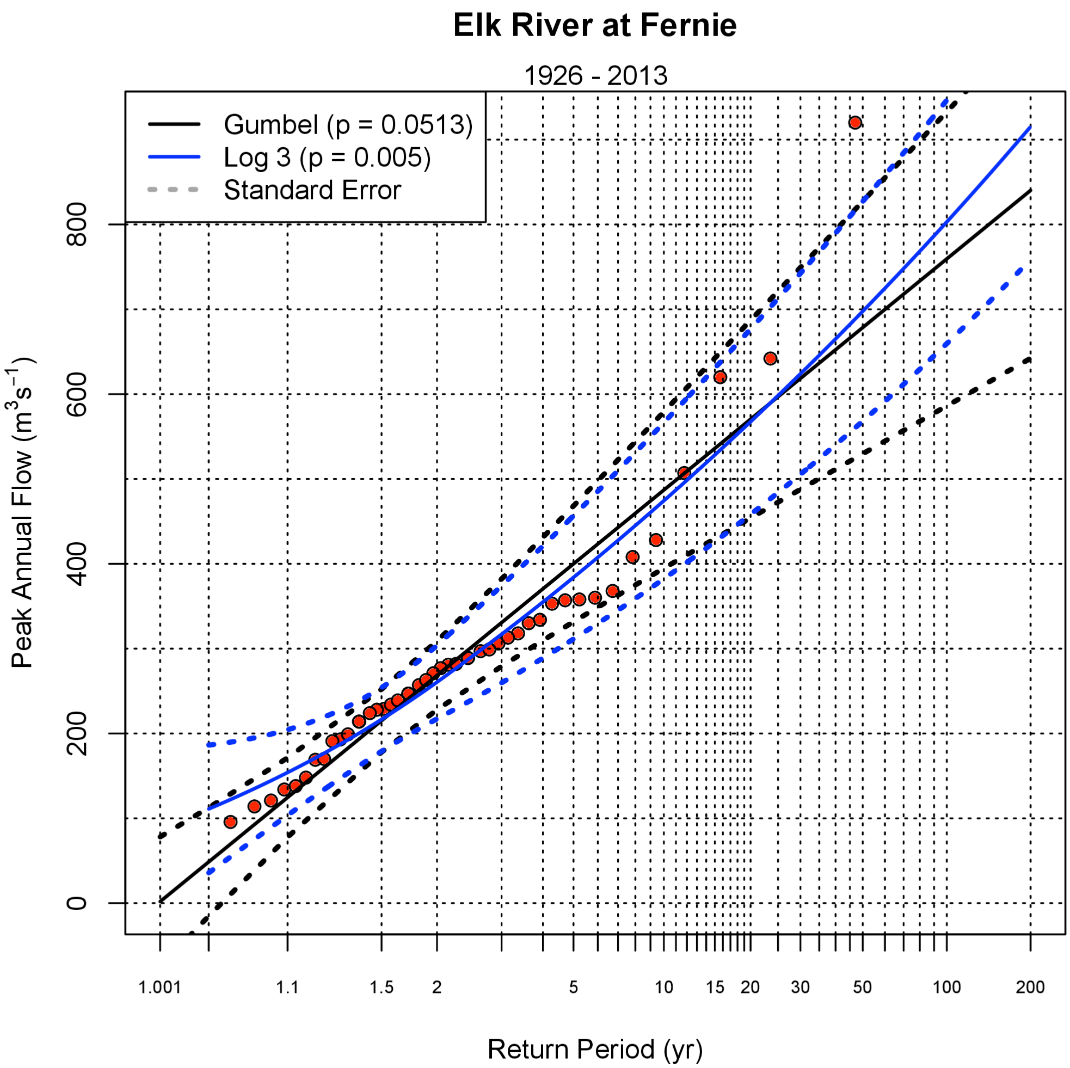
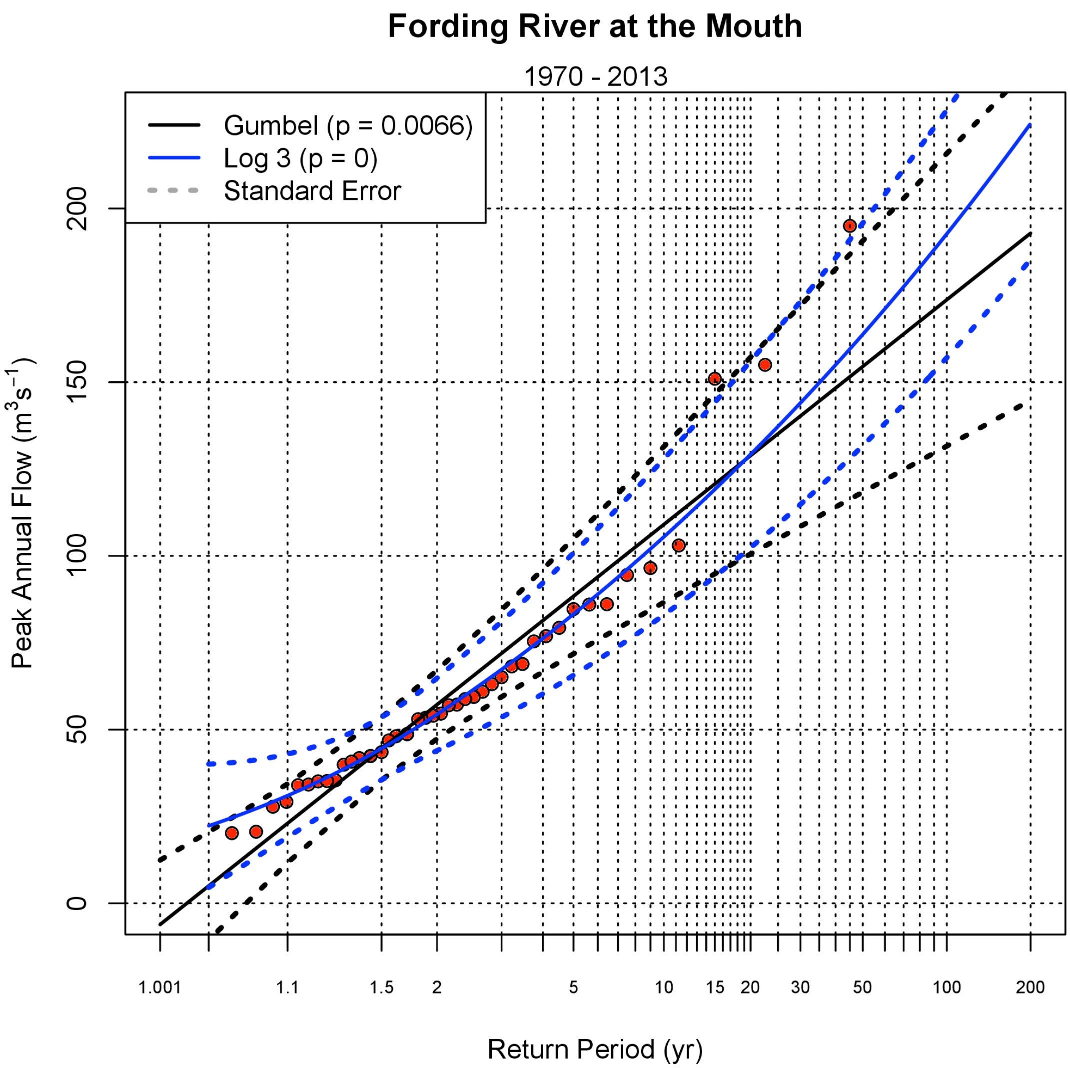
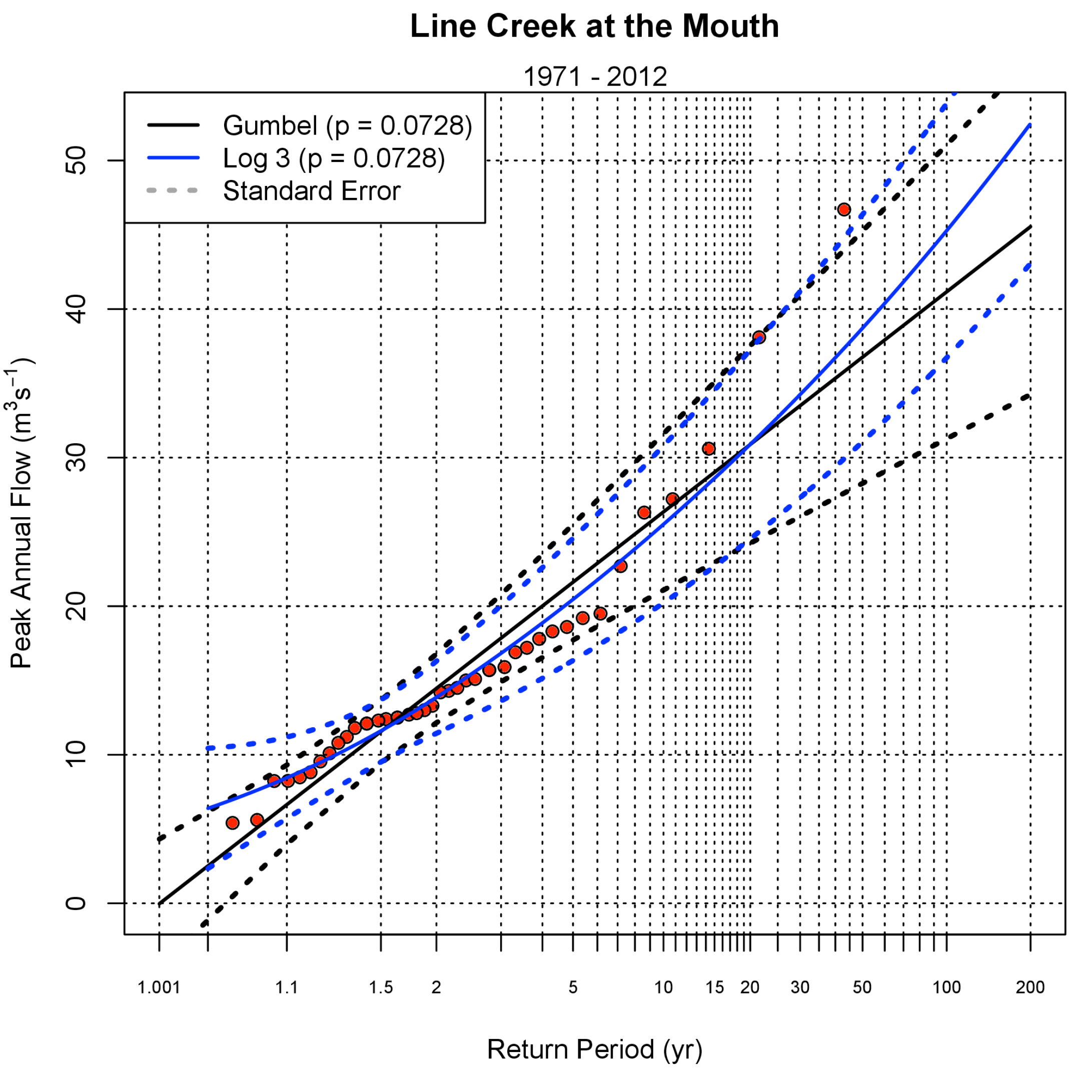
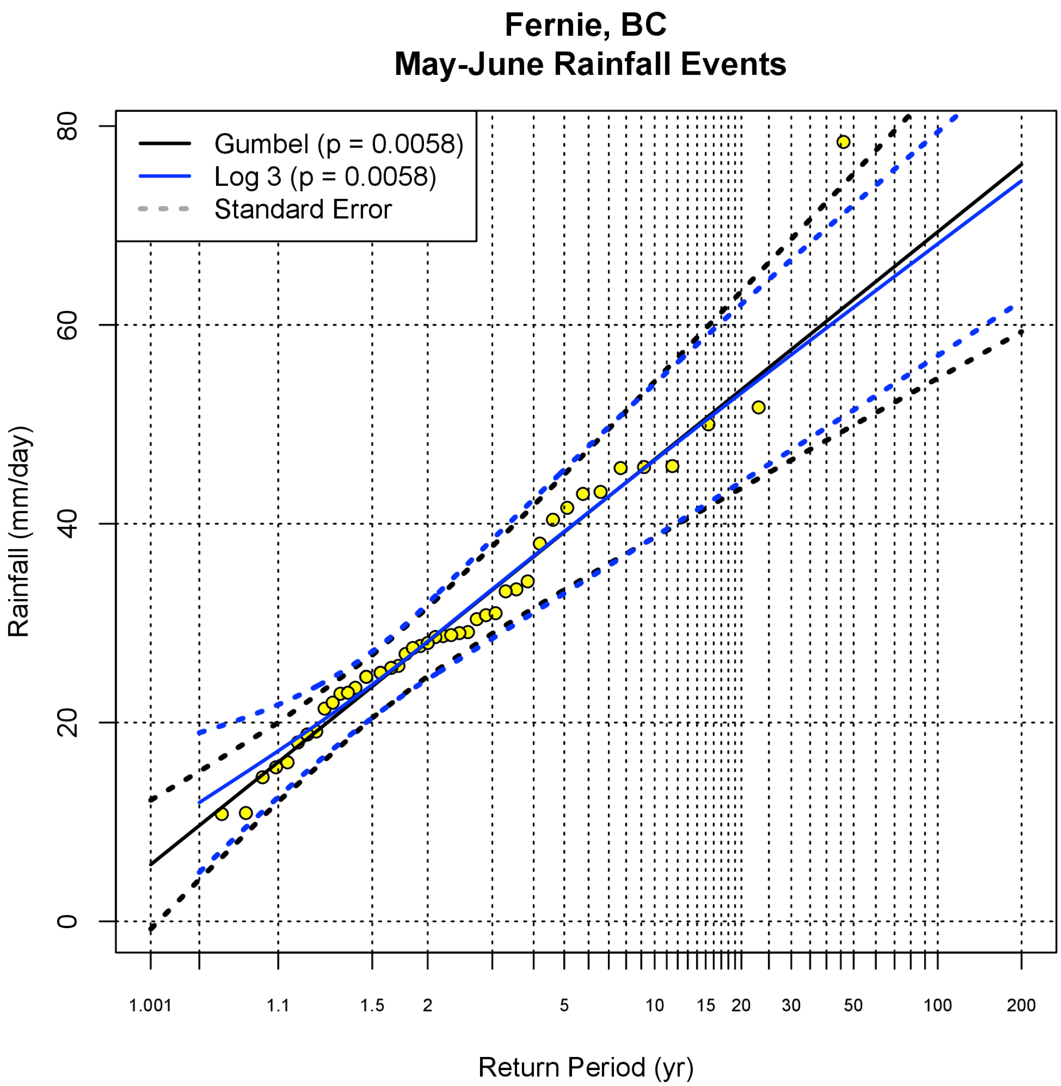
Appendix A. Selected Flood Frequency Analyses

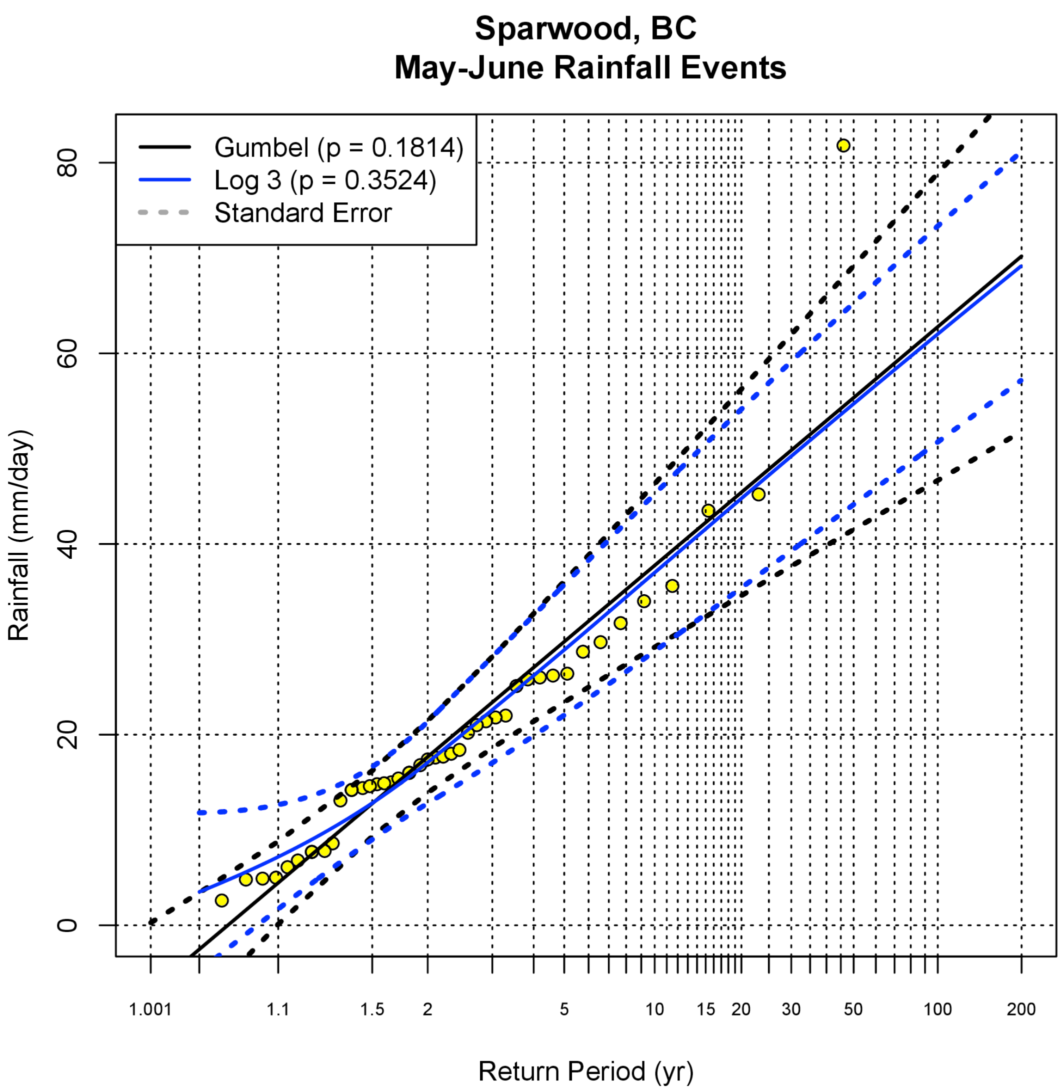



Fording River at the Mouth
1970 - 2013
Gumbel (p = 0.0066)
Log 3 (p = 0)
Standard Error
Peak Annual Flow (m3s-1)
0
50
100
150
200
1.001
1.1
1.5
2
5
10
15
20
30
50
100
200
Return Period (yr)


Line Creek at the Mouth
1971 - 2012
Gumbel (p = 0.0728)
Log 3 (p = 0.0728)
Standard Error
Peak Annual Flow (m^3s^{-1})
0
10
20
30
40
50
1.001
1.1
1.5
2
5
10
15
20
30
50
100
200
Return Period (yr)

Appendix B. Selected Intensity-Duration-Frequency Analyses




Sparwood, BC
May-June Rainfall Events
Gumbel (p = 0.1814)
Log 3 (p = 0.3524)
Standard Error
Rainfall (mm/day)
0
20
40
60
80
1.001
1.1
1.5
2
5
10
15
20
30
50
100
200
Return Period (yr)

Appendix C. Chronology of flooding in the Elk Valley

Information sources: Fernie Free Press newspaper archives, or Fernie Public Library microfiche archives, unless otherwise cited.

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
1903	June	6	Fernie Lumber Co. bridge swept away, impaired traffic along Crow Line; Mott, Son & Co. mill operation suspended; bridge foundation damage; communications with west cut off at Moyie.	-	"Serious losses"
1916	June	19	Four bridges swept away; Natal electric light plant, Riverside Lumber Co. & Ross-Saskatoon Lumber Co. mill out of commission; telegraphic & telephone communication cut off; 50 families evacuated; heavy damage to civic and private property.	Elk Lumber Co. dynamited their mill pond dam to release water and create larger channel; resulted in little difference.	"Devastation in its wake"; Request gov't compensation; build dike from Fairy Cr. bridge along city to bend at W. Fernie; build dike along Riverside Rd. to Elk Lumber Co. mill.
1923	June	3	Elk Valley Lumber yard flooded; slide at Sparwood; road washed out between Fernie and Natal; slide blocked road from Fernie to Coal Creek; light property damage in Fernie; Fairy Creek homes damaged; Crow's Nest Pass line of CPR damaged.	-	-

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
1948	May	25	Hundreds of feet of CPR track washed out; W. Fernie park flooded; tremendous residential damages; Crow's Nest Pass Coal Co. property flooded; Mannix bridge collapsed; 2 Hosmer bridges washed away; telegraph and long distance communication suspended; booms gave way at Elko and Bull river dams; Elko CPR bridge buckled.	Stone and brick from disused coke ovens placed along weakened approaches to the railway bridge at Elko; bulldozed at ditch across Hwy. 3 in attempt to save W. Fernie from flood damage (unsuccessful); traffic bridge over Mill stream blasted to loosen driftwood; boulders and gravel used in attempt to divert the Elk River away from Hwy. 3; residents illegally cut a dich to allow backed up water to flow into Fairy Cr.; stock moved to higher ground; blasted log jam west of Elko bridge; water diverted at Elko to lessen flow at bridge piers; mines shut down and miners laid off.	Police involved in altercation between residents near Fairy Creek and Provincial Works Dept.; residents protested against gov't works dept. claiming damage was their responsibility; Dept. said "we can accept no responsibility for the safety and protection of private property; old timers said worst flood since 1916; may raise W. Fernie bridge 4 ft.; local committee set up for provincial flood emergency fund; requests in paper for emergency relief money.
1954	May	20	W. Fernie park flooded; 100 ft. of Brewery Rd. flooded by Coal Cr.; 125 yards of 3,500 ft. dike built by city (1953) washed out; approach of airport road bridge washed out; 60 ft. of Airport Rd. and considerable pipeline washed out.	Meetings arranged by the local Civil Defense Corps; committees formed to mitigate flood damage; all-night patrol; sandbagging; Annex divided into sections to be watched by volunteers.	50+ residents attend flood defense meetings; support from Prov. Dept. of Public Works, City of Fernie, East Kootenay Power Co., East Kootenay Lumber Co., Coal Co.; equipment offers: Caterpillar tractors and trucks, 2-way radios; emergency plan with siren blasts to notify residents and volunteers; local Miners' Union praised for volunteer work; support from Kinsmen Club.
1974	Jan.	16	Residential damage at Ridgemont, Elkview, W. Fernie, Annex and city centre; Kings Hotel, Northern Hotel, Fernie Hotel and Free Press flooded; landslide blocked	5 pumps in basement of Tom Uphill Memorial Home; furnaces, gas and electricity shut off in W. Fernie; W. Fernie evacuated; Gov't Dept. of highway crews divert	Water diversion plan discussed by council; new storm drain to bleed drainage away from Tom Uphill Memorial Home.

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
			Belle Cr. causing flood conditions.	and pump water from residences; bulldozer used to re-channel Belle Cr.	
1974	June	18	Fairy Cr. water intake system plugged; water pressure drop; sewage treatment backed up; Rainbow Cr. washed out access road and destroyed 2 bridges; work suspended at mills; cattle trapped. ELKFORD - erosion at Wilson Cr. bridge; Bovin Cr. bridge washed out; thoroughfare on Fording Dr. ripped out; students sent home.	Men working to unplug screen filters at Fairy Cr. water intake; pumped excess water from sewage treatment; constructed and maintained dikes in Annex and Airport; Hydro issues warning; cattle evacuation. ELKFORD - rip-rapping done in to divert river; cats working to keep channels clear near Fording Dr.; bypass cut through city street and stream bottom dredged to allow Boivin Cr. through; volunteers patrolled creek banks; temporary bridge built; diverted Brule Cr.	City asks for aid for elevating dikes and rip-rapping; city hired Nohels Logging Ltd. to dredge and dike Coal Cr., but were stopped by fish and game ELKFORD - asked for flood damage aid; Rip-rapping below water intake recommended to prevent future water line damage, possible bridge over Fording Dr.
1986	June	1	Four acres of land washed out.	-	Engineer for Dept. of Environment's Water Management encourages use of flood plains for flooding and discourages the clearing of trees along the river bank flood plains.
1995	June	6	Coal Cr. dike gave way; Airport dike washed away; part of Park Avenue bridge collapsed; Coal Creek railway bridge heavily damaged; 25 locations on CPR rail line affected (including damage to 3 bridges); damage to BC gas line following Michel Cr. flood; 125 mine workers temporarily laid off; excavator turned on side in the middle of Coal Creek; estimated 10's of	Pre-flood: Constant monitoring of river, stockpiled sandbags and riprap, closed trails in Mountainview Park During the flood: 750 Airport subdivision residents evacuated; 90 families evacuated from Mountainview trailer park; Michel Hotel residents evacuated; Sparwood mayor declared a state of local emergency; attempt to build dike along Coal	Motels and residents volunteered beds, residents helped fill sandbags, "tears running down my face" – Maureen Aikman; fear of losing Fording River Road; one incident of looting; Elkford area landowners and farmers frustrated with Ministry of Environment because they won't let landowners do work along riverbanks;

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
			millions of dollars in damage; animals, bridges, roads and power lines washed away; 4km of Hwy. 3 washed out; Corbin road closed; gas leak at Michel Hotel; flooding in West Fernie; Fording River Mine damage (power lines, roads, train tracks, ponds and dikes); Crestbrook Forest Industries damage (15-20 bridges damaged, 100-200 culverts plugged or damaged, roads washed out); 375,000 cubic metres of road washed away.	Creek. After the flood: Workers from Revelstoke and engineers from Montreal and Toronto came to help; gas services shut down to test gas pipeline integrity; disaster funds approved by Ministry of Attorney General and Emergency Preparedness Canada; 80 highway workers and 60 pieces of heavy equipment working on repairs; catch and release fishing only for 3 years on Elk River and tributaries; province announces $18 million flood-assistance package.	planning a new dikes; rural residents critical of province's river policy; landowners along river ask for permission to divert the river from its original channel; "We are not anticipating doing any dredging" – Dwain Boyer, head of engineering for water management in Kootenay region; city council says its essential to dredge; Bill Westover, fisheries biologist for East Kootenays says "Almost zero survival rate" about cutthroat spawning during spring flood event.
2013	June	18	-	Local firemen evacuated citizens of Mountain View Trailer park in Sparwood (Elk Valley Herald, 2013)	-
2013	June	20	Many highways damaged by floods and mudslides; residential flooding; storm sewers backed up; James White, Annex and Dogwood Parks closed.	Hundreds of people evacuated; sandbagging stations developed; Red Cross opened a Resiliency Centre in Hosmer; financial assistance for flood damage; state of local emergency declared for Electoral Area A; flooding in lower Hosmer and Cokato Road prompted an evacuation alert in those areas (RDEK 2013).	Residents wrote letters to editor promoting dredging; various representatives discussed flood mitigation at meeting, ERA delivers educational camp with focus on Elk River watershed.
2013	June	21	High water levels breached part of the dike at Hosmer and water flowed through properties; floodwaters on the highway at Hosmer; turbid water bubbled up on upland side of the dike at Hosmer (RDEK 2013).	Evacuation order issued for properties west of the Hosmer bridge and 4 homes on Thompson Road; Elko dam alert notice by BC Hydro; BC Hydro conducted 24 hour surveillance with the BC Safety Authority	Local RCMP, Search and Rescue and Hosmer Volunteer Fire Department conducted the evacuation and Reception Centre set up at the Fernie Curling Centre; estimated 300 volunteers filled and

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
				and Emergency Management BC; Highway 3 reduced to single lane alternating at Hosmer and Ministry of Transportation and Infrastructure worked on the dike through the night (RDEK 2013).	transported sandbags at Hosmer; equipment operators, truck drivers and management personnel supported communities during flood event; Water Stewardship Branch monitored the dike and river banks in Hosmer Commerce; 88 families out of their homes (RDEK 2013)
2013	June	22	-	Evacuation order for homes on Thompson Road and Cokato Road lifted; BC Hydro crews worked through the night to divert water to minimize damage to the dam (RDEK 2013).	Fernie transfer station closed and temporary waste bins set up at Fernie Chamber of Commerce (RDEK 2013).
2013	June	23	-	Evacuation order lifted in Hosmer; Elko dam alert cancelled and BC Hydro personnel remained on site for 24 hour surveillance (RDEK 2013)	-
2013	June	24	-	-	120 clean up kits from Red Cross delivered to the Hosmer Community Centre for use throughout the valley (Duczek 2013)
2013	June	30	Road and/or bridge closures due to washouts (RDEK 2013): ▪ Meachen Creek FSR at 10.5 km; ▪ Cross River FSR (third bridge washed out); ▪ Buhl Creek FSR (bridges washed out); ▪ Albert River FSR (bridges washed out); ▪ Toby Creek Road at Panorama Ski Resort; ▪ Perry Creek bridge at 2 km (July 2 to 6 deck replacement)		Red Cross opened a Resiliency Centre at the Hosmer Community Centre to assist residents with unmet needs and began a needs analysis for resident recovery (RDEK 2013).

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
			■ Flathead FSR from Corbin south to Flathead town site (multiple washouts including all bridges and culverts); ■ McClatchie FSR at the Squaw Creek Bridge; ■ River Road FSR at 3 km, near Elko, (bridge approach damaged); ■ Wildhorse FSR at 15.5 km (large rocks on road); ■ Mause Creek FSR at 4 km (land slide); ■ Summer Lake FSR at 50 km; ■ Mitchell Creek FSR at 32 km (bridge washout); ■ Whiteriver (Whiteswan) FSR at 32.5 km (bridge approach washout), 37 km (washout), and 44 km (bridge washout); ■ Bull River FSR at 32 km (water on road), 52 km and 54 km (half of road gone and not passable), 63 km and 68 km (washouts), 71 km (land slide), 92 km (river on road), and 94 km (washout); ■ Elk River FSR at 2 km (water on road), 104 km, 118 km and 123 km (washouts), 125 km (bridge approach washout), 138 km (debris slide), 140 km (bridge approach washout), 145 km/ Weary Creek bridge (washed out); ■ Skookumchuk FSR at 35 km		

Year	Month	Day	Resulting Damages	Emergency Actions	Noted Community Response
			(washout); ■ St. Marys West Fork at 10 km (bridge washout); ■ Findlay FSR at 20km (high water and high potential for bridge damage); ■ Lavington FSR at 18 km (bridge washout); ■ St. Mary's Lake outlet bridge (high water and instability, and is to be replaced between July 15 to August 31, 2013); ■ Jumbo Pass Road closed at 5 km and 9 km (avalanche); ■ Gray Creek Pass at 3 km (washout).		
2013	July	25	-	-	District of Elkford applied for half a million in recovery costs (Hynd 2013)
2013	August	15	-	-	RDEK completing a four-phase project to upgrade the West Fernie Dike to protect property and infrastructure (Hynd 2013b)

Appendix D. Elk Valley Flood Planning 1995-2016

Elkford		
Project	**Purpose**	**Action Taken**
Boivin Creek Dike and Bank Improvements In Elkford, 2013 flood resulted in expenditures of $500,000 in emergency response and over $3 million in disaster recovery with the majority of repair work done in 2014. (2014 Annual Report District of Elkford). TOTAL COST: $2,381,000 (Federal and Provincial Share $1,587,332 Local Government Share $793,668)	Alleviate flood concerns from Boivin Creek and take proactive steps toward preventing future flooding emergencies. Strategy seen as proactive rather than reactive. Protects the safety of the public and help protect businesses and industries that provide jobs for BC. Planned to withstand a 200-year flood, plus a 20% factor for climate change.	Strengthen flood protection with higher dikes along Boivin Creek in Elkford from Peace Park to where Boivin Creek meets the Elk River, including reinforcement on both sides of the Creek and the elimination of a pinch point, formerly at the old Boivin Creek pedestrian bridge. The old bridge was replaced with a new alpine-style bridge for pedestrians. Project completed for about $1 million under budget due to obtaining economically priced rip rap. (Elk Valley Herald, 18 November 2015). Elkford has applied to use remaining $1.6 million on dike enforcing of the Elk River south of the Fording Highway Bridge. Work would fortify the bottom of the river at the bank to avoid streambank erosion.
Elkford's Climate Change Adaptation Strategy (2010) was incorporated into the Official Community Plan (adopted May 25, 2010).	The three planning areas of greatest concern to the community of District of Elkford are: 1) wildfire, 2) flooding/stormwater management and 3) water supply. Guiding principle noted in Plan is 'climate change is considered in all decision-making' and preserve open spaces, parks and trails, natural beauty and environmentally sensitive areas'.	In the Elkford Climate Change Adaptation Strategy (2010) action planning recommendations pertaining to the goal indicating: Elkford prepares for and mitigates flood risk. **Objective 1: Reduce the vulnerability of infrastructure to flooding** Specific actions identified: • Protect key infrastructure located within or near the floodplain from flooding e.g. Elkford Sewage lagoons • Update the Elk River and Boivin Creek DPA bylaws • Update Development Cost Charges for trail, park development along the river • Extend diking north and south of the District • Redesignate the floodplain and identify appropriate 'flood zones' along the Elk River • New developments to have flood-protection design

		Objective 2: Manage the land to enhance water retention Specific actions identified: • Update Road Design Standards: require water retention or on-site stormwater management techniques e.g. French Drains • Maximize bugger zones and allocate flood areas along streams and rivers • Adapt Development Cost Charges for development of greenspace in flood prone zones e.g. maintain riparian zones • Work with regional stakeholders to identify watershed-level management and storage capacity opportunities e.g. guidelines for limited development and buffer zones in proximity to streams and rivers • Identify wetland for floodland expansion upstream of town
Sparwood		
Project	**Purpose**	**Actions Taken**
BC Environment Water Division. (1995). Elk River, Michel Creek and Cummings Creek Floodplain Mapping: Design Brief. Prepared by SRK-Robinson Inc., Vancouver, BC.	Design brief resulted in floodplain maps (Map Sheers 91-2-1 through 91-2-5) at the scale of 1:5000 with 2 m contour intervals were prepared to show the outline of the 200-year floodplain.	These maps show the extant of the floodplain and flood levels used to determine the minimum floodproofing elevation requirements. It was recommended by the consultants that the maps should be reviewed to maintain the adequacy, accuracy and usefulness of the information when significant flood events, erosion and floodplain development and other changes occur within the study area.
Sparwood Official Community Plan (2015) www.sparwood.ca The OCP is a municipal bylaw that sets out the longterm vision for a community. Under the Section 875 of the *Local Government Act*, an OCP is	Sparwood's plan is a 2035 vision of 'a sustainable community with pride in our natural environment'. Goals of the Sparwood OCP that support the Elk River Flood Strategy include: 8. Provide and manage infrastructure and services, including potable water, sewage, stormwater and roads in a cost effective and sustainable matter. 11. Promote environmental conservation best	Specific related Sparwood OCP Objectives: 8.1.3 Resilience to climate change, stormwater management. 8.1.4 Integrated stormwater management using detention ponds, wetlands, and mitigate negative impacts on downstream areas and water courses. 8.7 To prevent adverse effects to the water quality of creeks, streams, rivers and other bodies of water that may receive stormwater discharge. 11.1 To protect the natural environment,

a statement of objectives and policies to guide decisions on planning and land use management within the areas covered by the plan. Development Permit Areas (DPA) are a set of development regulations permitted by the Local Government Act that affect a specific area, as shown in OCP maps.	practices. extraction areas in the community. Direction is given in the OCP to 'identify Sparwood's key natural areas, including the riparian areas around the Elk River and local creeks, and protect them through policy, regulation and enforcement.	ecosystems and biological diversity. 11.2 To identify and protect wildlife corridors and wildlife habitat areas from potentially negative impacts of land development. 11.3 To protect fish-bearing watercourses from negative impacts. 11.4 To maintain and enhance surface and groundwater quality in area watercourses. 11.5 To identify and protect areas subject to hazardous conditions. Related DPA's to Flood Management: 1. Riparian protection development permit area. 1.4 Maintain normal riparian processes such as flooding … as may be authorized by the Province of BC for flood protection. 1.6 Reduce impervious surfaces 1.9 Use constructed wetlands and detention ponds to slow the rate of runoff and improve the quality of rainwater through biofiltration 1.12 Riparian protection areas setback widths Elk River/Michel Creek/Alexander Creek/Summit Lake 30m. 2. Hazard land development permit area. 2.12 Development of lands within the 1:200 year floodplain require a Hazard Lands Development Permit. 2.13 Refer to Water Stewardship Branch those applications for development on properties within the Branch's required floodplain management setback from a watercourse. 2.14 River modification approvals for diking, rechanneling, etc. Schedule L: Floodplain hazard development permit area
Fernie		
Project	**Purpose**	**Actions Taken**
RFP City of Fernie (2016) Comprehensive Flood Hazard and Geomorphic Assessment of the Elk	This comprehensive flood hazard and geomorphic assessment would result in the development of floodplain mapping for each watercourse as well as flood mitigation	RFP tender to Professional Hydrotechnical Consulting Services closed May 20, 2016. Requests consideration of the Elk River Flood Strategy in the RFP.

River and Fairy Creek	options for Maiden Lake	
City of Fernie OCP (2014)	See purpose of BC Local Government OCP stated above in Sparwood Official Community Plan (2015) noted above.	Schedule B: Land use designations (most of the floodplain is in Natural Open Space or Parks) Schedule L: 200 Year flood hazard DPA Flood Hazard Areas is identified
City of Fernie, Bylaws	Floodplain Management Bylaw (1998): Reduce the risk of injury, loss of like and damage to buildings and structures due to flooding. Contains floodplain designation, floodplain specifications a) flood construction levels and b) floodplain setback, application for floodplain specifications.	FCL=a designated flood level plus an allowance for freeboard, or where a designated flood level cannot be determined, a specified height above a natural boundary, natural ground elevation, or any obstruction that could cause ponding. Floodplain= an area which is susceptible to flooding from a watercourse.
	Official Community Plan Bylaw (updated and adopted June 23, 2014) Schedule L: 200 Year Flood Hazard DPA (May 6, 2014)	
	Subdivision and Development Servicing Bylaw (April 11, 2009)	Geotechnical reports may be required e.g. slope stability Implications for improving permeability of surfacing and retention of storm runoff in drainage plans, erosion control guidelines to stabilize soils and reduce any erosion or sedimentation
	Zoning Bylaw (Updated July 6, 2015): Zoning is concerned with the use of land, density of use, signs, siting, size and dimensions of buildings and structures and area, shape and dimensions of parcels of land.	
City of Fernie Hazard, Risk and Vulnerability Analysis (2015)	Intended to provide a basis from which Fernie can make risk-based decisions to address vulnerabilities, mitigate hazards, prepare for, respond to and recovery from disasters, and emergencies and maintain continuity of municipal operations.	Noted risk events posing the greatest threats to flooding in Fernie: freshet flooding by melting snow, exacerbated by heavy precipitation events and ice jams in a river channel. The risk is to residential, commercial and industrial buildings and community infrastructure, access roads on Highway 3 and breech of the diking system.
City of Fernie Elk River Flood Hazard Assessment (2006)	Review the current state of dikes and Elk River flood hydraulics at Fernie by completing a flood hazard assessment including updating flood profiles, providing comments	Fernie's dikes were constructed in 1983. Historic flooding in the city occurred in 1948, 1956, 1972, and 1974. 1975 provincial Ministry of Environment prepared floodplain mapping to delineate limits of

	on existing dikes/bank protection and recommending upgrades to protect existing and potential development within the city. The report proposed potential Flood Hazard Mitigation options with a total cost estimates at $4,443,600	200-year floodplain and display Flood Construction Levels (FCL). This report has 5 components: 1) Elk River hydrology reviewed and analyzed to confirm design flows for the Elk River at Fernie; 2) Reach and local-level geomorphic conditions analyzed to determine long term fluvial changes that could affect flood and erosion hazard; 3) HEC-RAS hydraulic model to simulate flood profiles based on survey data collected by the City of Fernie in 2005; 4) Inspect river banks and dikes to provide information for hydraulic modeling and to determine potential sites of bank erosion and localized flood hazards; 5) Prepare a detailed flood hazard assessment that examines risks of flooding/erosion and outlines viable mitigation options and approximate associated costs. Update provided from City of Fernie staff (March 21, 2016) to the Elk River Flood Strategy team of recommendations/options the City has completed or is presently working on: 1. Added riprap and erosion protection (not engineered dike) upstream of golf course. 2. Drainage and monitoring of rip rap on the east bank upstream of North Fernie Bridge at the south end of golf course and rv park will be addressed in the 2016 Flood Study RFP. 3. Ongoing work has been completed on the Ghostrider utility crossing inclusive of capping and rip rap bank enforcement. 4. City of Fernie rents pumps as needed for emergency pumping for residential areas to deal with storm sewer backflow. 5. Created a survey poste in the Annex Park to monitor flood water levels. 6. Improved bank protection of Dogwood Park. 7. Ongoing maintenance of existing dikes and flood mitigation works.
Coal Creek Floodplain Mapping Final Report.	To provide guidelines for development the City is interested in identifying flood hazards	Floodplain mapping was completed accounting for 10% increase for climate change providing 200 year

(Reissued February 25, 2016)	and and developing floodplain mapping within its boundaries. Flood hazards include flooding, bank erosion and channel migration, bed lowering or degradation, and avulsion or high velocity overbank flows that could lead to damage to buildings, bridges, pipes or infrastructure.	estimated inundation extents and depths for Coal and Brewery Creek, with a 0.6 m freeboard allowance for Coal Creek and 0.3 m freeboard for Brewery Creek. Flood construction levels (FCL) are based on waterlevels determined by a 200-year flood event, potential for blockage scenarios at the five bridge crossings along Coal Creek and 0.5 m sediment deposition allowance in the channel and a 0.6 m freeboard allowance for recognized uncertainties. Three flood hazard management zones are identified on the floodplain map and recommendations for future development in these areas are provided. Zones determine development from areas that have high hydrotechnical hazards and to avoid restricting flow capacity of the channel and floodway. Zone A – Floodway and setback area (no development permits or building permits for the construction of dwellings or structures for use or occupation be permitted in this zone). Also maintains diversity of the channel and riparian habitat. Zone B – Overflow and potential avulsion area (includes Zone A, but is still at risk to flood hazard). Recommended use of land limited to non-intensive uses such as parks, trails, open-space recreation and agriculture. Any buildings or structure should apply the BCMWLAP Flood Hazard Area Land Use Management Guidelines (2004). Zone C – Overflow area. Includes the largely developed Mountainview neighbourhood downstream of the Railway Bridge and Brewery Creek south of Whitetail Drive. Mountainview is protected by standard dikes maintained by the City of Fernie. The site south of Whitetail Drive is within the projected current 200-year floodplain and is not protected by dikes, but it is substantially set back from Coal Creek. All new construction of buildings for habitation, business or storage of goods should

		be constructed such that the underside of the floor system is at or above FCL.
Fernie Whitewater Park	Develop a permanent surf wave and whitewater park features at the Dogwood Park area. Discussion with the Dan Savage and the Fernie Whitewater Society, "this project is currently on hold and no further development is occurring at the moment".	This site was chosen due to existing recreational infrastructure – fishing boat launch, road access, restroom facilities are currently available. Random berm type bolder clusters would form eddies and small waves through the reach. A river-wide drop feature would be designed to create a park-and-play wave with eddy access on both sides. River left eddy would be extended for fishing access and river right would improve a swimming area.
	RDEK Area A	
Project	**Purpose**	**Actions Taken**
RDEK Area A Flood Control Service Fund (2014)	No overall tax increase in Area A was required due to this service as it will be achieved by reducing the taxes collected for the Solid Waste service to offset the taxation, keeping it taxation neutral. Revenue for this Fund will come from fee-for-service facilities in the Solid Waste Service i.e. Exfiltration Pond disposal of septic waste north of Hosmer.	Operation and maintenance of flood-related works (such as dikes and berms), including inspecting and reporting on the status of improvements. Inspections will occur 2-4 times a year depending on climate and condition of the improvement. All mechanical improvements e.g. culverts, flap gates, slide gates are operated annually to ensure they will work during freshet and flood events.
Glawdel, Joanna. (Northwest Hydraulic Consultants). Memorandum to Jim Maletta, RDEK re: West Fernie Dike Improvements – Phase 3 and 4 Assessment of Design Post 2013 Flood Event	The West Fernie Dike and Bank Protection program is intended to protect property, residences and infrastructure in West Fernie. It was determined that the original design flood, the design elevation and riprap protection for the proposed dike improvements are appropriately designed to withstand reoccurrence of a flood similar to the 2013 event. This report reviewed the hydrology and hydraulic modeling (originally done in 2006) following the June 2013 event to assess if any alterations to the FCLs are required for the construction of Phase 3 and 4 of the dike upgrade program was to begin in July 2013.	The West Fernie Dike and Bank Protection work consisted of shaping and sloping the river bank, constructing or increasing the height of the dike, placing rip rap bank protection along 900 m of Elk River shoreline and installing flood flap gates. The project occurred between 2008-2013. For Phase 1 of the project $500,000 was provided through the Flood Protection Program and shared between the Government of Canada's Building Canada Fund and the Province of BC. The final three phases were funded one-third sharing of $2.7 million with the Building Canada Fund, Province of BC and RDEK Area A Mine Tax Sharing Fund. This flood protection structure was seen by the local Area A Representative to "safeguard water quality

		and support the local economy by protecting the Elk River sport fishery".
Miller, Jason (P.Eng. Kerr Wood Leidal). Technical Memorandum to Jim Maletta, RDEK re: RDEK Hill Road Dike Assessment, May 30, 2014	**Hill Road: Earthen berm.** An assessment served as support to a Disaster Financial Assistance (DFA) application to repair the protective structure. It was intended to provide some protection to properties in the Hill Road area. The dike was constructed in 1997 to the 1:200 year water level following the 1995 flood. Overbank flow was starting to occur during the 1995 flood and emergency sandbag placement was undertaken.	Construct an earthern berm set back on the top of the bank to provide flood protection to the properties south of the dike. (Dike geometry: 4 m wide crest, 2H:1V side slope over dike height of 1.5 m, dike fill 15-30% fines as per Provincial guidelines, 130 m long, erosion protection by vegetative cover). 220 m earth berm, one metre high set back 15 metres from the Elk River. Estimated cost of construction: $360,900. Estimated cost of Elk River rip rap protection (armoured length 270 m, slope length 15 m, rock thickness 2 m, 8,100 cubic meters of rip rap at a rate of $150 per cubic meter, the cost of supply and installation: $1.2 million – does not include engineering or a contingency)
Vokey, Shawn (PEng, VAST Resource Solutions). Letter to Brian De Paoli, Project Supervisor RDEK, December 17, 2013	**Thompson Road Log Jam**: Brief visual assessment was completed to determine options for removal of a logjam near Thompson Road.	Visual assessment determined that the removal of sediment would open up the side channel for high water river flow, but could potentially destroy valuable fish habitat. The main river channel would remain in the same location. "The decision to remove the sediment wedge or the log jam must not be decided based on a brief visual overview. It is recommended that a detail assessment of the Elk River be completed prior to the completion of any works at the log jam…from at least a river engineering, hydrological and aquatic habitat perspective".
Northwest Hydraulic Consultants report to Jim Penson, AScT, Solid Waste Superintendent, RDEK, Re: Elk River 2013 Flood Recovery, Sparwood Airport Erosion, Preliminary Technical Assessment, November	**Sparwood Airport:** To describe, assess and make recommendations regarding the bank failed and pre-existing riprap eroded east of the Sparwood Airport.	On June 21, roughly 50 m of riprap armored bank failed along with 150 m of unarmored ban, upstream of the portion of rip rap. The bank retreated 40 m towards the airport. Failure appeared to be a result of erosional loss of materials supplemented by redirected flow at the upstream end of the armoring. Assessment prescription: armor 95 m of bank, construct small rock rip rap spurs at the upstream and downstream end of the bank armoring and

25, 2013		three additional rock spurts upstream of the proposed bank armoring to keep the river off the right bank, on bank above plat live stakes from natural local species to promote stability and establishment of riparian vegetation. Cost range: $378,800 - $244,088
Regional Flood Hazard Study: Phase 1 FINAL (2013) At the RDEK Board Meeting Minutes of January 8, 2016: Moved by Director Sosnowski, Seconded by Director Booth "*That the Phase 1 Regional Flood Hazard Study be accepted and referred to Engineering Services to identify options and funding sources for Phase 2*". CARRIED	Phase 1 of the Regional Flood Hazard Study report is a regional flood hazard assessment and flood management plan with the goal to reduce flood-related damage and cost of mitigation through residual risk reduction planning.	Identified flood hazard areas, describe potential effects of climate change on flood hazards and outline a framework to implement a Flood Management Plan and recommended the formation of a Flood Hazard Management Committee to coordinate this effort of flood hazard and flood protection works in the Elk River watershed with representation from each local jurisdiction.
Province of BC		
Project	**Purpose**	**Actions Taken**
Herbery, Y., Picketts, I., Lyle, T. (April 2014). Floodplain Mapping Backgrounder to the BC Real Estate Association "Floodplain Mapping Funding Guidebook for BC Local Governments. Prepared to the BC Real Estate Association. www.bcrea.bc.ca/docs/government-relations/2014-FM-backgrounder.pdf	A key tool to preparing and planning for disasters in the floodplain map. Floodplain maps and other technical studies form a foundation to inform decisions about how and where communities grow and mitigate the risk of flood events. This document aims to discuss the variety and type of floodplain maps. Floodplain maps can serve as regulatory and administrative tools providing flood extent or depth maps that depict minimum elevations for flood-proofing, which can then be incorporated in building bylaws, subdivision approvals, and local government planning and regulations. Floodplain maps are foundational pieces of	Floodplain maps provide information on where flood waters are expected to go; that is, visualize flood hazard. To calculate flood hazard involves 3 steps: 1. Estimate the amount of water accumulated and discharged during a rain or other water inflow event. 2. A hydraulic model is then used to determine where the water might go. 3. Potential flood areas are mapped by combining water levels with a digital elevation model (virtual interpretation of topography) or base maps and surveys. Floodplain maps in the Elk Valley are largely Flood Extent Maps, which are relatively common, simple with minimal inputs of 1D hydraulic model and basic topography but have limited use and are especially

	information for landuse planning. Table 1: Contribution of Floodplain maps to adaptation and disaster risk management	outdated. The Elk River Flood Solutions Strategy produced a Flood Depth Map, relatively common and simple with inputs being 1D Hydraulic Model and Digital Elevation Model, and can be useful for basic land use planning. The Elk River Flood Solutions Strategy also created an interactive flood tool to be used with various land use and climate change scenarios, useful for flood planning.
Elk Valley Cumulative Effects Management Framework (CEMF) Many of the same players working together on CEMF are also collaborating on this Elk River Flood Solution Strategy by sharing GIS data, reports, expertise and resources to protect identified valued components. The Flood Strategy is a practical example of CEMF's proactive commitment to ongoing collaboration. In turn, the Flood Strategy will model assessment of human actions on indicators like land use, climate change, flood water inundation animation on valued components downstream.	CEMF is a decision support tool that will provide a practical, workable framework that supports decisions related to assessment, mitigation and management of cumulative effects in the Elk Valley. The central purpose of CEMF is to support decision-makers make decisions that lead to management actions. CEMF is respectful of public input and will adapt to new information. Since the fall of 2014 the Province of BC has taken the leadership role in coordinating CEMF through the Cumulative Effects Coordinator for the Kootenay-Boundary region of Forest, Lands, Natural Resources Operations. CEMF is working more broadly than the Elk Valley Water Quality Plan (aka Area Based Management Plan) towards managing cumulative effects from multiple sources in the Elk Valley that may influence valued components in both aquatic and terrestrial environments. The Water Quality Plan will provide valuable information to CEMF, particularly with respect to Westslope cutthroat trout.	Flooding is the 'poster child' of the cumulative effects of the positive or negative changes to the valued components of the Elk Valley caused by the evolving effects of past, present and reasonably foreseeable activities, events and conditions. Five valued components, which are things in an ecosystem people value as a expression of social, economic, cultural and environmental values, have been selected: 1) grizzly bear; 2) riparian habitat; 3) Westslope cutthroat trout; 4) bighorn sheep and 5) old growth/mature forest. Four of the valued components are effected by flooding. Riparian areas tend to have mature and old growth forests and are utilized by grizzly bears at certain times of the year and for connectivity corridors. Riparian areas have a direct influence over fish habitat and water quality. Elk Valley CEMF has determined specific 'high level' metrics used to measure and report on the condition and trend of a valued component. CEMF is a 'collaborative, consensus-based, transparent, integrated' decision making tool. 32% of the Elk Valley is private land, compared to 7% provincially. This challenge must promote best management practices, value-based, peer driven, accountable actions from private land owners. Alces Landscape and Land-Use Ltd. is developing a tool that makes decision making more accountable to the community. This tool models land use and

		changes to various valued components.
NEW Water Sustainability Act WSA (enacted May 2014) replaces the old Water Act.	Core Regulation Areas in the WSA: 1. Groundwater: Protecting BC's buried treasure 2. Environment flows: ensuring aquatic ecosystems thrive 3. Monitoring and reporting: building a foundation for better decision-making 4. Water objectives: integrating water issues into land and resource use decisions 5. Planning and governance: preparing BC for a sustainable future POLIS Project on Ecological Governance. (2015). Awash with opportunity: ensuring the sustainability of British Columbia's new water law. University of Victoria, Victoria, BC. www.poliswaterproject.org/awashwithopportunity	WSA has the potential to better integrate water issues into land-use decisions through the new authority it creates to set water objectives through regulations. Water and watershed planning is critically important for long-term water stewardship and to articulate a sustainable vision for the watershed and future uses. Enforceable plans can provide an opportunity for preventing and mediating conflicts, protecting ecosystems, and responding to future water uncertainties e.g. flooding. The comprehensive water sustainability plans have the ability to provide tailor-made solutions to regional issues. But critical to their success is the implementation of such plans. Governance-the processes of decision-making and provisions for holding those decision-makers accountable, links plans from paper to action in the watershed. Possibility exists for shared and delegated decision-making that offers potential for improved partnerships, co-governance with First Nations, and innovative decision-making going forward.