A Cumulative Watershed Effects Assessment Template for the Eastern Slopes:

The Geomorphic and Riparian Components with a Case Study of Todd Creek Watershed

VERSION # 4: May 22, 2013

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Acknowledgements

Funding for the project was provided by Alberta Environment and Sustainable Resource Development (AESRD). Funding contracts were arranged by Axel Anderson of the Foothills Research Institute and Deanne Newkirk and Brian Hills of AESRD Science and Technology Support. The terms of reference for the case study was established with input from Connie Simmons and Shannon Frank of the Oldman Watershed Council, Paul Harper of Fisheries and Oceans Canada, Marina Irwin of AESRD Lands, Matthew Coombs of AESRD Fish and Wildlife, Tim Juhlin of AESRD Lands, Kevin France of AESRD Rangelands, and Robert Boyce of Devon Canada Corporation. Data used in the case study was obtained with the assistance of Debbie Mucha of the Foothills Research Institute, Brad Hurkett of the Alberta Conservation Association, Brad Tyssen and Jonathan Dewalt of AESRD Forest Planning Section, and Norine Ambrose of Cows and Fish.

Part 2 of this document outlines a procedure to guide a cumulative watershed effects assessment for Alberta Eastern Slopes with a focus on geomorphic and riparian processes. A parallel procedure entailing a separate assessment of cumulative impacts to hydrological processes is described elsewhere. Given the inherent linkages between geomorphic, riparian and hydrologic processes, the risks identified in the two separate assessments should be compiled and then revisited to ensure linkages between the process groups are adequately developed; thus, a revision of the assessment is anticipated following compilation of impacts to geomorphic, riparian, and hydrologic processes.

Part 3 of this document contains a case study of the cumulative watershed effects to geomorphic and riparian processes. It was specifically written to illustrate a range of analyses that can be completed with a focus on watershed processes and use of the ArcGIS based NetMap tools. The first step in such a process would be to consult watershed stakeholders. This step was not undertaken for the entire Todd Creek watershed, specifically for the public lands within the White Zone and private rangelands. Another important step is to obtain input on the findings by the stakeholder team. This consultation process is not planned for this exercise. Thus, while the study area and methods are detailed, the results are preliminary and not put into context.

Cover photo: Todd Creek watershed looking southwest towards Livingston Range.

Executive Summary

This three-part document provides a template to guide cumulative watershed effects assessments (CWEA) within Alberta's Eastern Slopes.

Part 1, Introduction, establishes that a CWEA is intended to provide stakeholders and resource managers with information on risks and impacts to recognized water values; thus, a CWEA is nested within an overarching resource management framework. An effective CWEA must: (1) be tailored to values, pressures, and legislative frameworks; (2) be organized around three categories of watershed processes including erosion, riparian function, and hydrology; and (3) include both a rapid desktop analysis (Level 1 to identify sensitive landforms, data quality and gaps, and risks) and specific field assessments to measure impacts (Level 2). In recognition of the need for a flexible CWEA that is tailored to specific values and pressures within each study area, the Level 1 analysis is completed using a computer model of the earth's surface that simulates the inherent ecosystem connectivity including downstream and upstream movement of any watershed component of interest (e.g., fish, sediment, and pathogens). The flexibility within this approach differentiates the methodology described herein from the assessment protocols that have been adopted by other jurisdictions in North America.

Part 2, CWEA Template for Eastern Slopes, outlines the four parts of a CWEA including: (1) setting the terms of reference; (2) describing the study area to specifically identify sensitive landforms and to identify data sources and gaps; (3) completing the risk assessment; and (4) summarizing the findings.

Part 3, Todd Creek Case Study, provides an example of a Level 1 CWEA consistent with the approach outlined in Part 2. This case study shows that a desktop analysis can be used to identify risks, but field assessments are required to identify where risks have translated into real impacts. It also highlights that an investment in base data (e.g., ATV trail locations) is a pre-requisite for any desktop analysis. It also illustrates how the results from desktop analysis can focus subsequent field assessments within specific locations. This case study also recognizes that the next step is to communicate the findings to managers and stakeholders so that the linkages with the overarching resource management framework are maintained. With the information, the managers and stakeholders can set priorities and allocate resources for the Level 2 assessment. The findings also highlight that the CWEA is a living process because although management of the various values will ideally be coordinated, the management of the various values will proceed at different rates. For example, a field assessment of road-related impacts could proceed; however, due to a data gap in ATV trail locations, that field assessment will be delayed until such time as suitable base maps are available.

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Part 1. Introduction

1.1 Purpose of Assessment

Cumulative watershed effects assessments (CWEAs) can take many forms (Scherer 2011). When the analyses are nested within an overarching adaptive resource management framework, they can serve to inform decision makers about options to improve stewardship of a wide range of resources that are inextricably linked by their geography (MacDonald 2000). To make decisions, resource managers require information on current impacts so they can be remediated and on potential future impacts so they can be avoided (Reid 2010).

All jurisdictions are faced with limited resources to complete such assessments. As such, existing information must be fully exploited before embarking on highly specialized or field investigations. In Alberta, the widespread availability of digital elevation models (DEMs) derived from Laser Imaging, Detection and Ranging (LIDAR) allows the desktop CWEA to be completed at a resolution that exceeds what has been considered by other jurisdictions. Thus, the methodology described in Part 2 and demonstrated in the case study in Part 3, is unique given its emphasis on computer-driven analytical procedures that exploit a high resolution DEM.

In Alberta, funding for any subsequent management actions will be limited in any given year and also according to the sector responsible for the impact. Inevitably, the recommendations from a CWEA will be screened through a ruthless prioritization exercise before implementation. These realities should be considered at all stages of the CWEA. For example, in Alberta, the extensive resource road network developed over multiple decades presents well recognized risks to aquatic values and infrastructure (e.g., Scrimgeour et al. 2003). Realistically, such issues that have taken decades to develop may take decades to address. In recognition of this challenge, a number of private agencies in Alberta have formed a partnership that utilizes a rigorous risk identification process that considers both environmental protection and infrastructure management to determine remediation priorities for the extensive resource road network (Foothills Research Institute 2013). This CWEA is intended to feed directly into such management systems.

Given these objectives and limitations, the Washington Department of Natural Resources (2011) identified three components of an effective CWEA that are also suitable for an Alberta CWEA:

1. the assessment should be tailored to social values, pressures, and legislative frameworks;
2. the analysis should be organized around the region-specific watershed processes that generally fall within three categories – erosion, riparian functions, and hydrology; and
3. the assessment should include a rapid overview phase (Level 1) to identify sensitive landforms, data sources, and risks to values of interest, followed by detailed field-based investigations (Level 2) to identify where risks have translated into measureable impacts and identify appropriate remediation measures.

These three components are reviewed in the following subsections.

1.1.1 Setting the Terms of Reference for a CWEA

Typically, watershed analyses are initiated where cause-and-effect relationships are suspected between management activities and impacts to values but the specific mechanisms haven't been proven. For example, in 1908, the United States Geological Survey (USGS) was tasked with determining what specific measures could be applied to minimize the downstream impacts from debris generated by hydraulic mining in the headwaters of the Sacramento River (Gilbert 1917). In Alberta, researchers investigated potential connections between abnormally high cancer rates in Fort Chipewyan and concentrations of toxic elements in an upstream area heavily developed for bitumen production (Kelly et al. 2010). Both of these examples are noteworthy because they examined the processes by which the materials of interest were generated and then conveyed to the locations where other values were compromised. By using this process-based approach, Gilbert (1917) found that depending on the watershed, mining debris contributed between 60 and 70 percent of the total debris generated, with debris from hydraulic mining the dominant of four mining related sources. The sources of the remaining 30 – 40 % of the debris included agriculture, roads, trails, and grazing. In fact, most studies initiated to determine the cause of an impact to a specific water-related value identify that a number of management activities have altered watershed processes thereby causing the undesired effect (Reid 2001). Thus, the emphasis on physical and ecological processes throughout all stages of CWEA is important, starting with setting the project terms of reference. For both the Sacramento and Athabasca River examples, the state of watershed process knowledge was also advanced, much to the benefit of subsequent works. Such advances in knowledge are difficult to achieve with correlative approaches (e.g., correlating increasing road densities with decreasing native fish populations) where the cause-and-effect relationships are not specifically linked.

When a change to a watershed value is measured or predicted, stakeholders have several options for their response – they can choose to apply mitigation measures, curtail specific activities, or alternately determine that when placed in context, the impact is irrelevant. A response that requires change within unorganized sectors where habitual human behavior is widely dispersed across a region can be much more challenging to implement in comparison to a response intended to modify institutionally accepted best management practices that are regularly reviewed. For example, random camping and un-restricted off-highway-vehicle (OHV) use that has been allowed for decades in various regions of Alberta's east slope and foothills regions (e.g., Paul and Boag 2003) will likely be more difficult to change in comparison to industry-specific best management practices on road maintenance that are updated on a regular basis. Because this pilot project focuses on physical processes, including those that are altered by habitual human behavior, the conclusions may assist the social scientists and managers who are in the business of modifying human behavior. Engaging both unorganized and institutional sectors is important at all stages of the larger adaptive management process and within the CWEA.

CWEAs for existing and proposed developments require robust frameworks because they encompass impacts to a variety of water-related values over a range of scales through space and time. Fortunately, modern legislation-driven frameworks are typically designed to highlight relevant economic, ecological, and social concerns; hence, CWEAs are typically completed with the purpose of informing decision makers about existing and future risks to the resources of interest. The methods described in Part 2 and demonstrated in the case study within Part 3 emphasize the need to tailor the CWEA to relevant values, pressures and legislative frameworks.

1.1.2 Erosion, Riparian, and Hydrologic processes

Conceptually, the CWEA has three elements including (1) watershed processes that determine (2) input rates of watershed elements that ultimately impact (3) the public resources (Figure 1) (Washington Department of Natural Resources 2011). Watershed processes are divided into three groups – erosion, riparian, and hydrology – each with specific types according to the geography and land-use. The types of processes within each group do not operate independently. Vegetation modifications by grazing, linear disturbances (i.e., pipelines, power lines, and seismic lines), and forestry have potential to affect specific erosion processes including mass wasting (i.e., landslides), surface erosion, and streambank erosion. With the overlap between erosion and riparian processes, the analyses are presented in a single section. Hydrologic processes include changes to peak flows, low flows, and water yield. Changes in peak flows have potential to induce erosion processes, specifically channel scour.

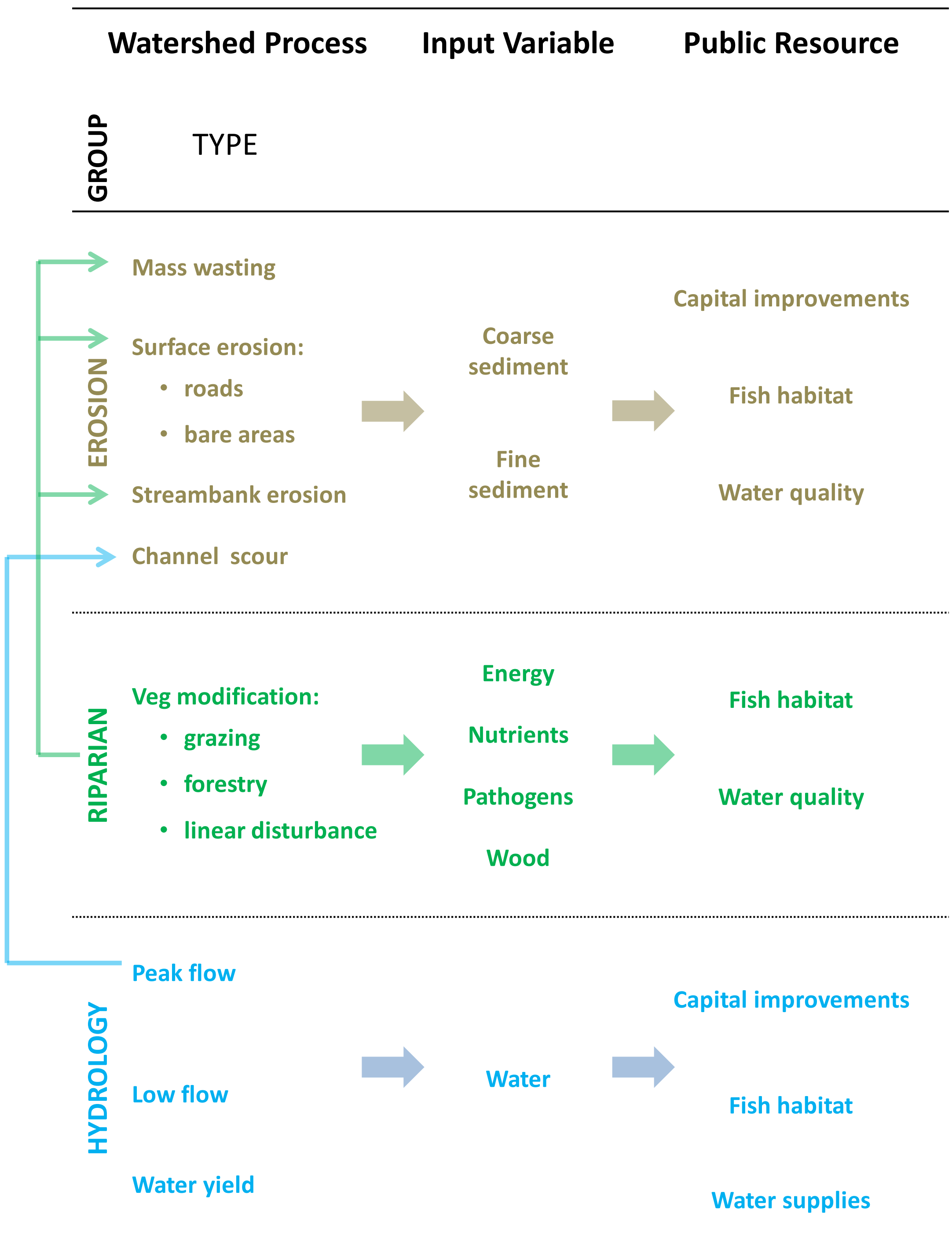


Figure 1. Connections between watershed processes, watershed input variables, and public resources in East Slope watersheds with land-use activities that include forestry, grazing, petroleum development, motorized recreation, and random camping (adapted from Washington Department of Natural Resources 2011).

1.1.3 Level 1 Assessment to Identify Data Availability, Sensitive Locations, Risks and Threats

The abundance of information for Alberta's Eastern Slopes including detailed geologic mapping, fish inventories, LIDAR data, and stream crossing inspections is very uncommon in comparison to other jurisdictions. Therefore, the initial desktop assessment can be completed at a much greater level of detail than that used by other agencies. Washington Department of Natural Resources (2011) has set the appropriate watershed size for assessment as between 40 and 200 km^2. The upper size limit of 200 km^2 could be considered for the Eastern Slopes region, especially considering that the 1 m Alberta LIDAR DEM contains 100 times the data of the 10 m DEM typically used for watershed analyses in Washington. Ultimately, the challenge is to have a sufficient level of detail to guide future site specific assessments while aligning the report recommendations with boundaries used for resource management planning.

1.2 Conceptual Model of Earth Surface Processes and GIS Framework

This CWEA uses a GIS-based platform designed to simulate natural earth surface processes. This section includes a description of how water-driven erosion - a dominant earth surface process - is distributed across the landscape. Then we describe how a digital landscape and stream layer have been designed to emulate these natural processes. Finally, we describe how a community of watershed stakeholders, managers, and researchers are working together to constantly improve the virtual model of the earth and the tools used to simulate processes and identify sensitive locations and risks to watershed values.

A watershed can be viewed as a series of connected processes that transfer products including water, sediment, organic matter, nutrients and pathogens along a chain. In most cases, the product originates in the upland region and is then transferred along the chain through a specific process to the next downslope region (Figure 2). The four regions, in sequential order along the chain, are uplands, swales, colluvial channels, and fluvial channels (Montgomery and Foufoula-Georgiou 1993). Over time, the dominant processes acting within each region create a unique signature on the landscape that can be detected based on the local slope and drainage area (Gilbert 1917; Hack 1957; Horton 1945; Leopold et al. 1964).

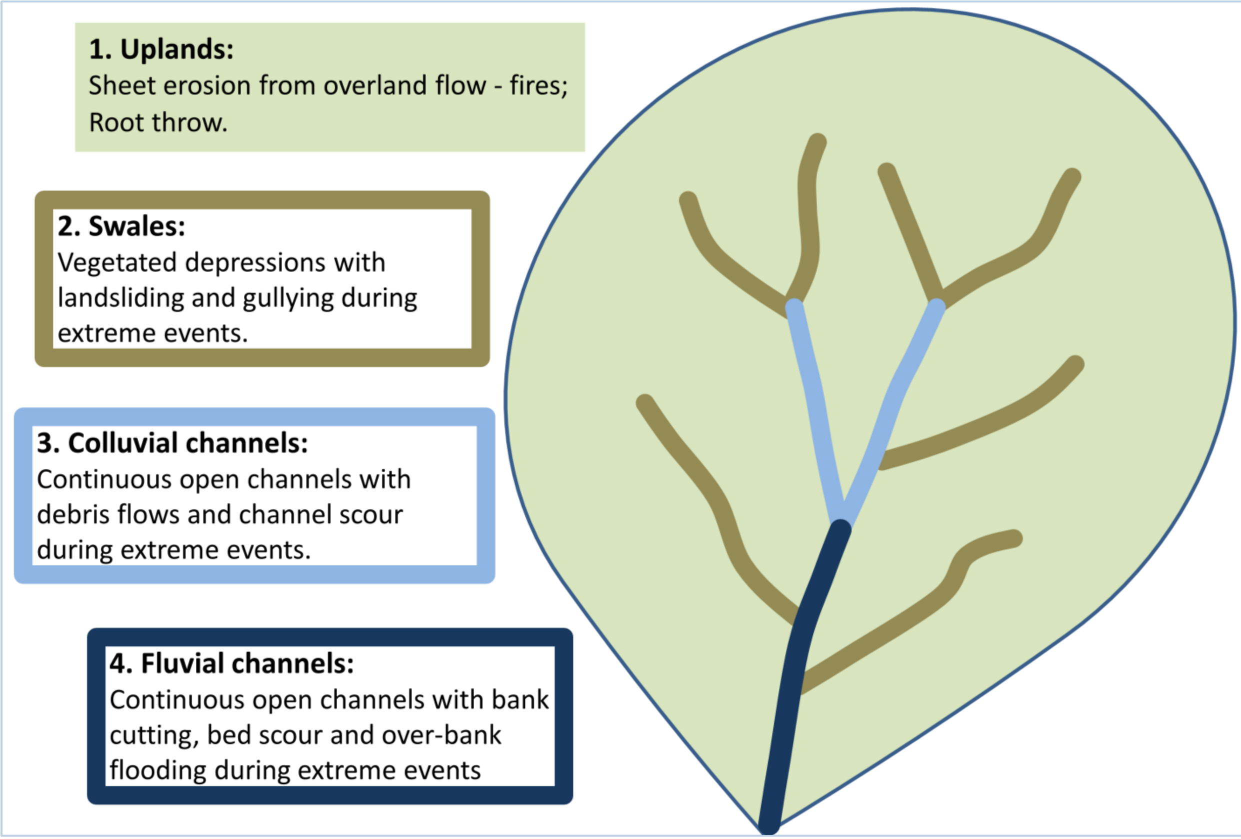


Figure 2. Diagram of the four watershed regions that are characterized by a common set of erosion processes.

The proposed CWEA for Alberta's Eastern Slopes uses the NetMap digital landscape and stream layer, both of which have been developed to emulate the accepted conceptual model of erosion processes and form of the earth's surface (Benda et al. 2007). The digital landscape includes the four process regions and the processes that connect them (Figure 3). Consistent with Montgomery and Foufoula-Georgiou (1993), measures of slope and drainage area from digital elevation models (DEMs) are used to divide the landscape into regions that share a dominant erosion process. A key component of the stream layer is its division into segments, or stream reaches, each one attributed with a set of geographic features to support analysis (Table 1). Each reach is numerically linked to every grid cell in its adjacent uplands, and also to upstream and downstream reaches, a property that emulates natural connections that enables the user to simulate a range of natural watershed processes.

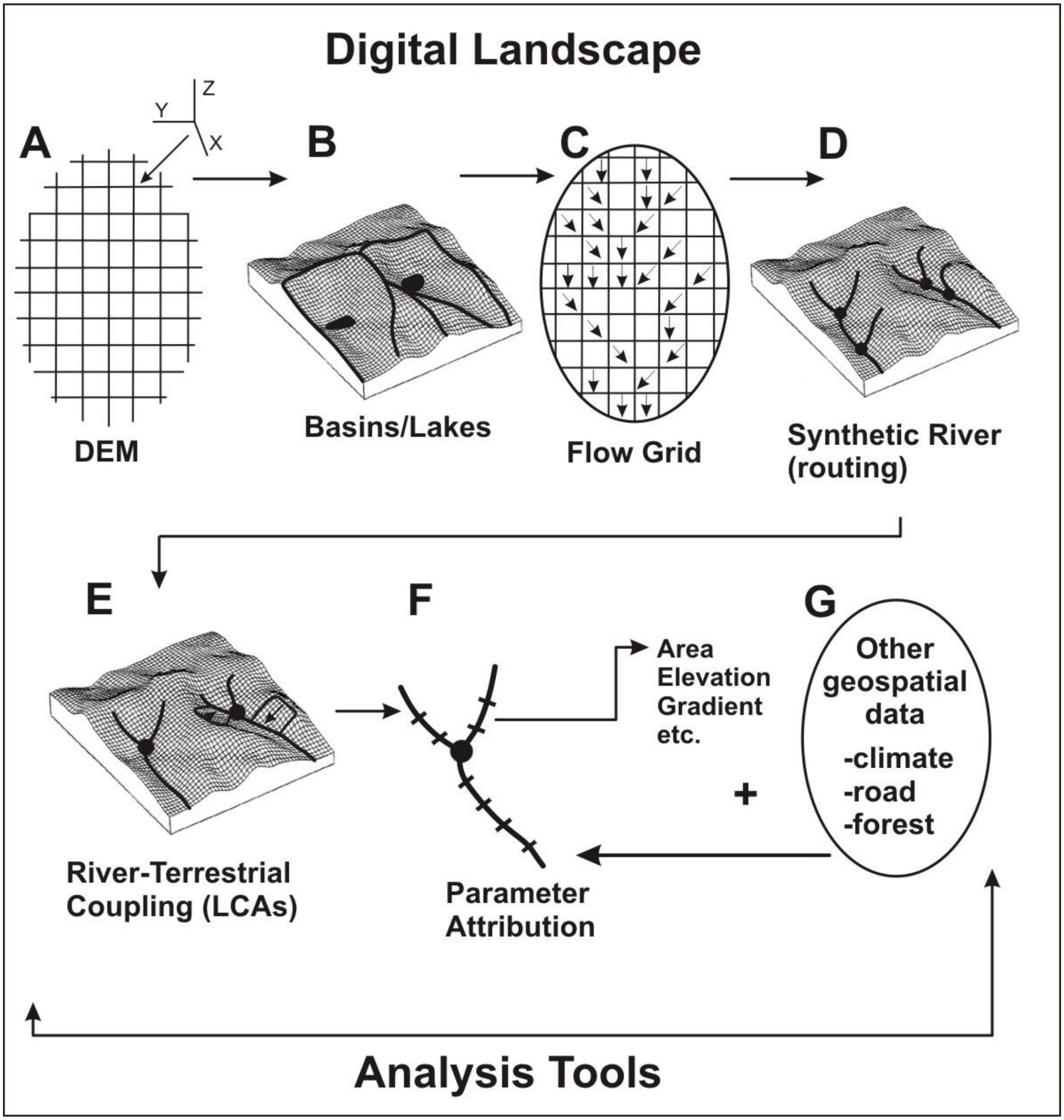


Figure 3. The digital landscape is comprised of a series of elements including (A) DEM, (B) basin and sub-basin boundaries and lakes, (C) flow direction grid, (D) a synthetic river with segments set by the spatial grain of the DEM, (E) information connections including drainage wings that allow for the upstream, downstream, down-slope and up-slope transfer of information, and (F) parameter attribution of each stream segment (Table 1). Additional geospatial information can be integrated into the digital landscape to support various types of environmental assessments (G). The digital landscape can stand alone or be coupled to a suite of watershed analysis tools (Table 1) (Figure from (Benda et al. DRAFT 2013).

Table 1. A partial list of attributes contained within the synthetic river and potential applications when used with analysis tools (Table adapted from Benda (DRAFT 2013).

Synthetic River Attributes	Example Application
(1) Segment Length	• Add up length of reaches of certain type
(2) Channel gradient	• Evaluate fish habitat suitability • Used as one predictor of stream power.
(3) Maximum downstream gradient	• Determine if natural fish migration barriers exist downstream.
(4) Cumulative drainage area	• Required in statistical regression to predict channel width, channel depth, mean flow and stream power. • Used to determine channel type.
(5) Local drainage area	• Determine extent of terrain adjacent to reach.
(6) Elevation	• Estimate reach climate
(7) Distance to outlet	• Determine distance to downstream reservoir or waterbody.
(8) Floodplain width	• Assessing risk to infrastructure
(9) Bankfull width[1]	• Used with other information to engineer stream crossings.
(10) Wetted width[1]	• Used to evaluate fish habitat potential during based flow conditions.
(11) Bankfull depth[1]	• Used for calculating floodplain extent.
(12) Mean flow[1]	• Used for estimating habitat suitability for fish.
(13) SLk index	• A measure of the degree to which the channel gradient of a reach deviates from what would be expected in an idealized long profile. Used to identify knickpoints, a common feature in Alberta's Eastern Slope streams.

[1] Requires statistical regression with drainage area.

Although we have both a widely accepted conceptual model of how watersheds function (Figure 2) and advanced computer models that mimic idealized landscapes (Figure 3), special considerations are required when these tools are applied over terrain with complex geological structures and a history of multiple glacial ice sheet advances (McCleary et al. 2011). These considerations include integrating spatial information from other sources (e.g., geology maps), calibrating reach descriptors (e.g., reach slope), and validating model predictions (e.g., watershed region). Such procedures, required to ensure that issues identified through a desktop CWEA analysis will align with actual issues on the ground, are detailed in Part 2.

To date, all of NetMap tools have been designed by a team of geomorphologists, geologists, biologists, and computer programmers at Earth Systems Institute in response to specific watershed management issues that one of the client user groups is addressing. For example, the United States Forest Service (USFS) required tools to identify priorities for road erosion mitigation and fish passage remediation (Benda et al. 2007). In Spain, floodplain tools were required to set priorities for floodplain restoration along major rivers (Benda et al. 2011). The tools developed for each of these projects were added to the set for use by all members of the community of NetMap users. Users receive regular updates as new tools are added.

Part 2. A Cumulative Watershed Effects Assessment Template for the Eastern Slopes: The Geomorphic and Riparian Components

This part of the document is a guide for the resource manager with a background in watershed science who will be completing a desktop CWEA using the NetMap digital landscape and toolset. The specific scope of a CWEA within Alberta's Eastern Slopes will vary across individual catchments according to values, land-use history, and ongoing pressures. However, the conservation of native fish species and managing road (and ATV) impacts are universal challenges in this region. Thus, this guide has an emphasis on tools and techniques to advance these issues.

2.1 Setting the Terms of Reference

The importance of this part of the assessment cannot be understated. Ideally, this component of the project will be completed by the agency funding the CWEA and you will focus on the technical aspects. Regardless, the project outcomes will reflect the level of stakeholder engagement in the CWEA. For example, relevant data sets for the desktop analysis are held by a variety of corporations, provincial and federal governments, and NGOs. The depth of the analysis will be limited by the types and qualities of data that the various stakeholders provide you to work with. Proceed as follows.

Obtain and review relevant documents that identify values, pressures, and stakeholders. Focus on recent synthesis documents such as State of the Basin reports, long-term forest management plans, and provincial/federal listings of aquatic species. Form an advisory team comprised of stakeholders and managers. Consider representatives from the watershed council, Alberta Environment and Sustainable Resource Development (AESRD), Fisheries and Oceans Canada (DFO), forest industry, energy industry, agricultural industry, livestock industry, Cows and Fish, and the Alberta Conservation Association (ACA). The size of the team should reflect the resources that you have available to finalize the terms of reference. Consult with your advisory team members and:

1. Identify their water-related values;
2. Identify known pressures on their water values;
3. Identify time period for the review by specifying which historical and potential future activities will be considered;
4. Identify relevant data sets with information on values and pressures; and
5. Confirm project area boundaries.

Individual meetings rather than a meeting of the entire team at once can be a means to develop a comprehensive terms of reference. Compile the information into a document for review by the advisory team. Name all relevant data sets and identify the steps required to obtain them (e.g., complete data sharing agreements). Get approval from your team, and then initiate all required data requests.

2.2 The Study Area

This part of the CWEA is divided into three sections. The first part, Watershed Characteristics, provides relevant information on the physical setting and processes. The second part, Spatial Distribution of

Values and Pressures, details the information that will be available for the analysis. The third section, a summary table, recognizes that the quality of the spatial information that is available will limit types of analysis that can be completed. For example, water-related impacts from ATV trails are a concern in the Eastern Slopes; however, an assessment of the effects can only be completed where the trail locations are known. Within the summary table, you will identify each required data layer, evaluate the quality and determine if it is suitable for use in the assessment.

2.2.1 Watershed Characteristics

Start this section with an overview of the study area including a map with names of streams, major peaks and ridges. Look for sub-basin boundaries that will divide the area into manageable sizes for the watershed analysis.

2.2.1.1 Geology

The bedrock geology for much of Alberta's Eastern Slopes has been extensively studied largely to support development of the coal and petroleum resources. Maps are available to the public in digital format through the websites of the Alberta Geological Survey (www.ags.gov.ab.ca) and the Geologic Survey of Canada (http://www.nrcan.gc.ca/earth-sciences/about/organization/organization-structure/geological-survey-of-canada/9590). In this section, use this information to highlight important bedrock features, specifically those that: (a) exert strong control on watershed form and channel gradients, (b) have potential influence on groundwater downwelling or upwelling locations; or (c) impose topographic constraints on resource road development. This section is developed iteratively. Start with a general search, but if you discover potential geological anomalies while researching subsequent sections of the CWEA, refer back to detailed geological maps to find more information about the relevant feature that is appropriate to include.

2.2.1.2 Geomorphology

Surficial materials for much of the Eastern Slopes have been mapped for two purposes. First, Bayrock and Reimchen (1975) mapped surficial materials and their erosion potential for the Rocky Mountain Foothills at 1:50,000 scale. Second, as part of the physical land classification initiative (e.g., Karpuk and Levingsohn 1980), surficial materials were described at various levels within a hierarchical land classification. Use these information sources to identify land units where erosion may be influenced by land use activities including timber harvest, roads, or land clearing. Also identify soil texture for use in road surface erosion modelling.

2.2.1.3 Streams

The digital stream layer must have an acceptable accuracy for stream locations and physical attributes. Review the digital stream layer to determine if natural flow path locations are sufficiently represented. Diversions at road crossings are the main problem. Follow the QA/QC procedures (McCleary 2012) to identify any locations that require correction. Although this step is a requirement during the production of any NetMap stream layer, if you encounter an outstanding problem you have two choices open to you. First, you can fix it yourself. One of the NetMap tools under development in spring of 2013 for ArcGIS 10 will allow the user to edit and correct channel locations. If this tool is available, then use it.

Second, if the tool is not yet available and the location must be fixed to proceed with the CWEA, contact Lee Benda to request that Earth Systems Institute make the required correction.

Three reach attributes required for the CWEA assessment are channel type (e.g., upland, swale, colluvial channel, and fluvial channel), bankfull width, and wetted width. Unlike channel gradient and floodplain width (calculated at an elevation above the stream equivalent to two times the bankfull depth), neither channel type, bankfull width or wetted width is measured directly from the DEM – all are calculated using statistical relations that are typically region specific. As a result, they require validation using field inventory data.

To validate channel type, bankfull width, and wetted width, prepare maps that show predicted values and the best comparable information from existing field inventory information. For most study watersheds in Alberta, there will be little available data on the location of swales and colluvial channels as most work has focused on channels that have expected high value fish habitat. Consider using fish presence sites as an indicator of fluvial channels as these two characteristics have been found to be related in the foothills watersheds near Hinton (McCleary et al. submitted). Bankfull width and wetted width are required measurements for fish and fish habitat surveys completed in Alberta. This information can be found in the records of the AESRD Fish and Wildlife Management Information System (FWMIS). For wetted width, limit records used to those collected during the baseflow season (e.g., August). Where required, calibrate the statistical relations used for channel type, bankfull width and wetted width using available data and update the fields in the reach table.

Note that bankfull depth is the reach table attribute used to set the scaled elevation value that is used within the NetMap Floodplain Tool. Floodplains are an important component of the CWEA you will complete. Unfortunately, this channel characteristic is not required during fish and fish habitat inventories in Alberta; thus, field data from other channel reference site surveys in the province should be considered (Figure 4).

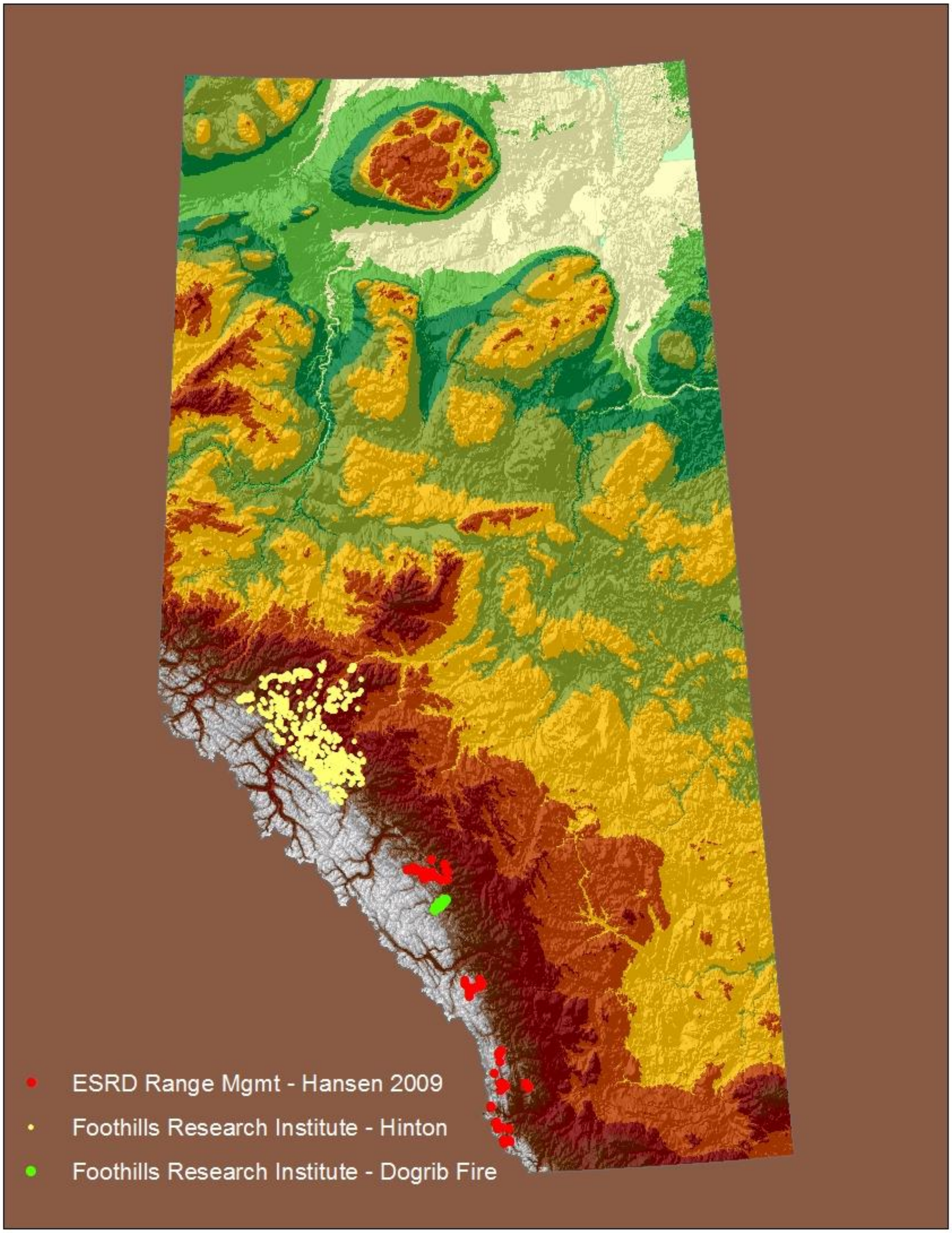


Figure 4. Alberta Eastern Slopes and Foothills reference site locations including ESRD Rangeland Management sites (Hansen et al. 2009), Foothills Research Institute sites within the Hinton Wood Products FMA (McCleary and Bambrick 2003) and Foothills Research Institute sites within the Dogrib Fire area (McCleary 2005)

2.2.1.4 Floodplains

Floodplains are a landform of specific interest in CWEAs. Multiple geomorphic processes are active on floodplains including inundation, sediment deposition, erosion from bank migration and channel relocation. These landforms also provide habitat for numerous species and can be convenient areas for a variety of land uses due to their flat topography. However, floodplains are sensitive to a variety of impacts. Until recently, floodplains were only mapped along major rivers; however, floodplains associated with all watercourses, including small streams, can now be delineated from LIDAR DEMs. This section details the methods to produce a calibrated floodplain model for your area of interest.

Field measures of floodplain width from within the study area are required to calibrate all DEM-derived floodplain models. Fortunately, a commonly accepted field technique for determining floodplain width described by Rosgen and Silvey (1998) has been used in a number of reference site projects completed in Alberta (Figure 4). Of specific interest for Eastern Slopes watershed assessments are the roughly 100 reference reaches established in the Clearwater, Elbow, and Oldman River watersheds (Hansen et al. 2009). Also of interest are reference sites established in the Dogrib Fire research area (McCleary 2005), and in the foothills near Hinton (McCleary and Bambrick 2003). The Cows and Fish Program also use the same methods (Fitch et al. 2001). Given the widespread use of this field methodology in Alberta, field measures of floodplain width within any given watershed assessment area may be available to calibrate floodplain maps produced from LIDAR DEMs. The Grassland Vegetation Inventory also includes data that may be relevant for calibrating a floodplain model. The following section reviews the approach for such a calibration exercise.

Terminology used herein is consistent with published field manuals for floodplain delineation, including those by Rosgen and Silvey (1998). Important terms include bankfull depth, 50-year floodplain, and entrenchment ratio. The bankfull depth (d_{bkfl}) represents the maximum water depth in a channel cross section during the dominant discharge or mean annual flood (i.e., flood recurrence interval of 2.33) – the flow level sufficient to mobilize the streambed and shape the channel. Field methods for measuring bankfull depth (D_{bkfl}) are detailed by Rosgen and Silvey (1998) and Anonymous (1996 - available online). As a guideline, the 50-year floodplain corresponds to the area inundated during a flood at an elevation of twice the bankfull depth (Rosgen 1994). This definition of floodplain and floodprone area is used within this CWEA. The floodprone width is measured laterally from the left edge of the floodplain, across the channel to the right edge (Figure 5). The entrenchment ratio is the width of the floodprone area divided by the bankfull width. Channels with well-established floodplains would typically have an entrenchment ratio greater than 2.2 (Rosgen 1994).

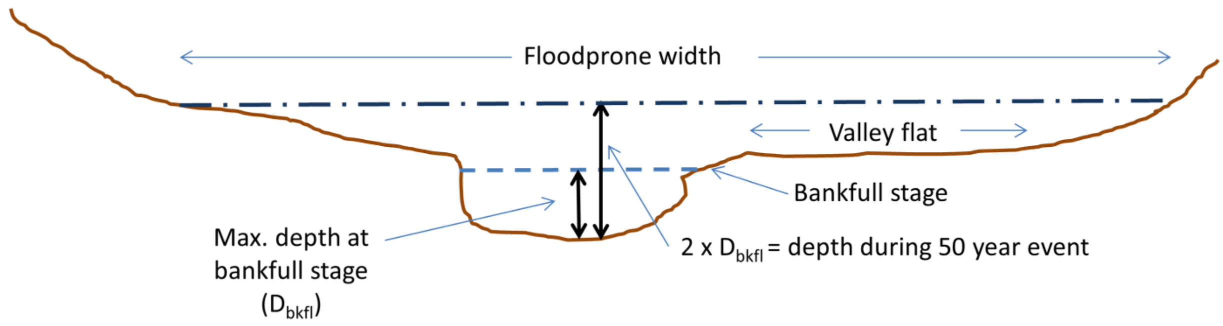


Figure 5. Diagram showing relationship between bankfull depth and floodprone width.

Identify the best source of information for true measures of floodplain width. If required, convert the information into digital format. Compare the true measures of floodplain width to a range of predicted inundation levels based on bankfull depth multipliers (e.g., 1, 2, 3, 4 and 5 times the depth at bankfull stage). There are three options. First, you can select the best bankfull depth indicator to represent the floodplain. Second, if none of the inundation levels are satisfactory, you can use the NetMap Floodplain Mapping tool to create a floodplain at a specified elevation or a new bankfull depth multiplier (e.g., 2.5). Third, if the predicted inundation levels do not represent true floodplain width across a range of stream sizes, you can evaluate the accuracy of the bankfull depth model. If required, you can change the bankfull depth – drainage area relation, and then use the NetMap Floodplain Mapping tool to recreate floodplains.

2.2.1.5 The longitudinal profile

Use the NetMap profile graphs tool to generate a longitudinal profile for the length of each watershed included in the CWEA. Identify knickpoints and sections with lower gradient than expected. Identify the location of any such anomalies and examine geology layers, including strata and faults, for a possible explanation.

2.2.1.6 Summary of Sensitive Landforms

Complete a summary table describing any landforms or features that are inherently sensitive to disturbance. Include a name, description of sensitivity and a cross-reference to the best map.

2.2.2 Spatial Distribution of Values and Pressures

The purpose of this section is to review the spatial information that will be used in the CWEA to represent important water values and capital improvements. Identify where there is with sufficient data and where data gaps should be filled.

2.2.2.1 Native Fish and Fish Habitat

Prepare a request for fish and fish habitat inventory data from the ESRD Fish and Wildlife Management Information System (FWMIS). This request must be approved by an ESRD representative, so submit it to the person on your advisory team representing ESRD, Fish and Wildlife. Also contact the ACA and DFO to determine if they have any additional datasets. For habitat data, be sure that your request includes the habitat features that will be important for the CWEA. Such features may include bankfull width, wetted width, and substrate characteristics.

Natural and anthropogenic fish migration barriers have two important considerations in native fish conservation that should be addressed in the CWEA. First, such migration barriers can lead to habitat fragmentation that can cause local extirpations of some species in headwater streams. Secondly, migration barriers can also block the upstream migration of non-native fish into headwater streams that support resident native fish populations. Thus, all available information on migration barriers should be compiled.

When the stream layer is created, the user must specify the target reach length. If detecting local bedrock features such as falls and chutes is important, use a very short target reach length. For example, in the Upper Oldman project, a 10 m target was used. Although this results in very large datasets (e.g., close to 500,000 reaches for a 500 km^2 catchment), the resulting stream layer contains the best available information that can be derived from a LIDAR DEM for the purposes of detecting natural migration barriers such as falls and chutes in headwater streams. If the reach length in the stream layer is either too long or short, NetMap tools that are under development will allow you to adjust the target reach length and re-create the network.

The next step is to create the best available map of fish distribution by species. If the detailed inventories are available in the study area, information on habitat can be specified based on inventory data and expert opinion – an approach used by Montana Fish Wildlife and Parks in a project to support regional road management (Benda 2012). Otherwise, use the variety of NetMap aquatic habitat tools to model potential fish distribution. Three habitat elements important for consideration when modelling fish habitat include energy, climate and size (e.g., Bozek and Hubert 1992; McCleary and Hassan 2008; Paul and Post 2001). Peterson et al. (2008) applied this approach to predict spawning and rearing habitat for westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) in northwest Montana (Figure 6). If westslope cutthroat trout inhabit the basin, apply the Peterson et al. (2008) intrinsic westslope cutthroat habitat potential model using the NetMap Aquatic Habitat Tools. Compare the results from the NetMap output with field data. Work closely with the AESRD Area Fish Biologist and other biologists on your advisory team to produce a map that will assist the road management agencies to set priority sites for remediation. It will be important to have consensus from the appropriate biologists on your team before such maps can be used within the CWEA or distributed to other stakeholders.

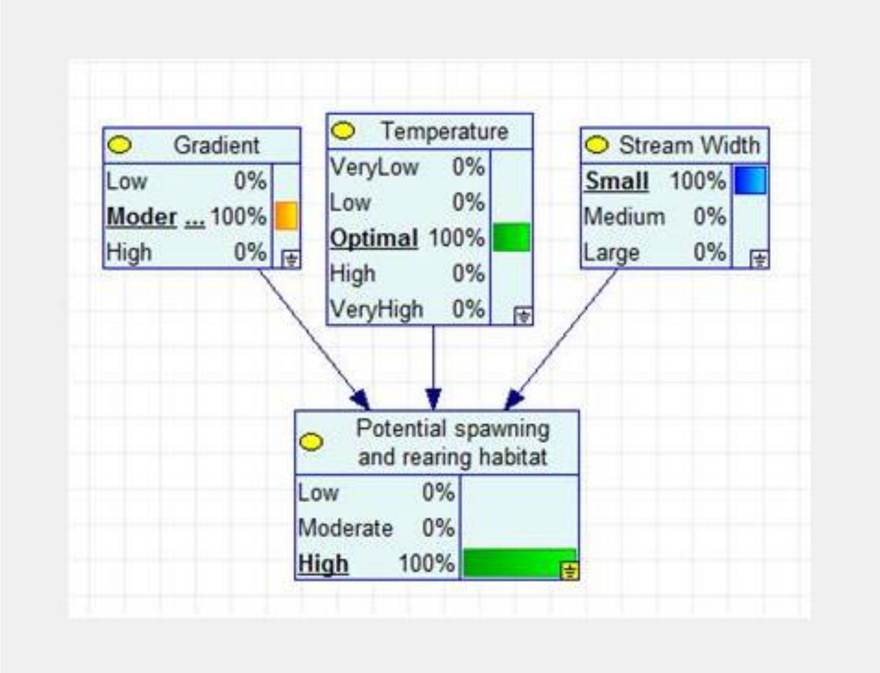


Figure 6. Diagram showing how Peterson et al. (2008) combine gradient, temperature, and stream width to predict potential westslope cutthroat trout spawning and rearing habitat.

In summary, the fish habitat maps that you generate are important because they will be used to identify locations of valuable habitat that will be considered when evaluating impacts and screening remediation opportunities.

2.2.2.2 Water Quality - Suspended Sediment

Within the Eastern Slopes, suspended sediment that alters water quality can impact specific values including water used for domestic purposes, water used for municipal purposes, water used for industrial purposes, and water that maintains productive habitat for fish, especially habitat for native salmonids. Consult the advisory team to determine which of these water quality values are important and at what locations.

For more than five decades, sediment from surface erosion has been recognized as the greatest single pollutant of streams in the North America, with roads in forested regions and livestock grazing in riparian zones two of the greatest contributors (Waters 1995). In a review of the effects of forestry on water quality based on research projects completed in the 1960's and 1970's in Canada, Krause (1982) found that the potential for sedimentation from forestry-related soil disturbances, especially roads, is high in the Alberta Foothills and intermediate in the Rocky Mountains. Thus, sediment from roads has long been recognized as a major pollutant that can be best managed through regular inspections and best practices. Reducing sediment generation from rangeland riparian areas has also been one of the goals of Alberta's Cows and Fish Program (Fitch et al. 2001).

The success of the CWEA for roads and trails will reflect the quality of the data that you have to work with. To determine how complete the roads layer is, overlay it on the orthophoto and LIDAR bare earth hillshade. Most roads are easy to recognize using the orthophoto. Check the roads layer to ensure that are all roads evident on the images are included. While reviewing the roads layer, collect the information for each road type that will be required to run the Roads WEPP tool including road design, road width, traffic level, soil texture, and road surface type. Repeat the same steps using ATV trail maps.

You will be completing similar analyses for both roads and trails; so when the roads and trails layers are finalized, append the trails layers to the roads layer. Ensure that you maintain the appropriate Feature Type descriptor for the ATV trails in the attribute table. Use standard ArcGIS tools to clip the road segments at the boundaries of your floodplain layer. This will allow you to isolate road segments at risk during the floodplain assessment (see section 2.3.1 – Roads and Capital Improvements on Floodplains).

Other sediment sources may also generate suspended sediment that can affect water quality. Study the orthophotos to identify other bare areas. They may include hillslopes with minimum vegetation cover and livestock feeding areas. Digitize a polygon representing the boundary of each bare area and measure the distance from the polygon to the nearest watercourse (Figure 7). Also identify entire stream reaches where riparian areas have low vigour (Figure 8).

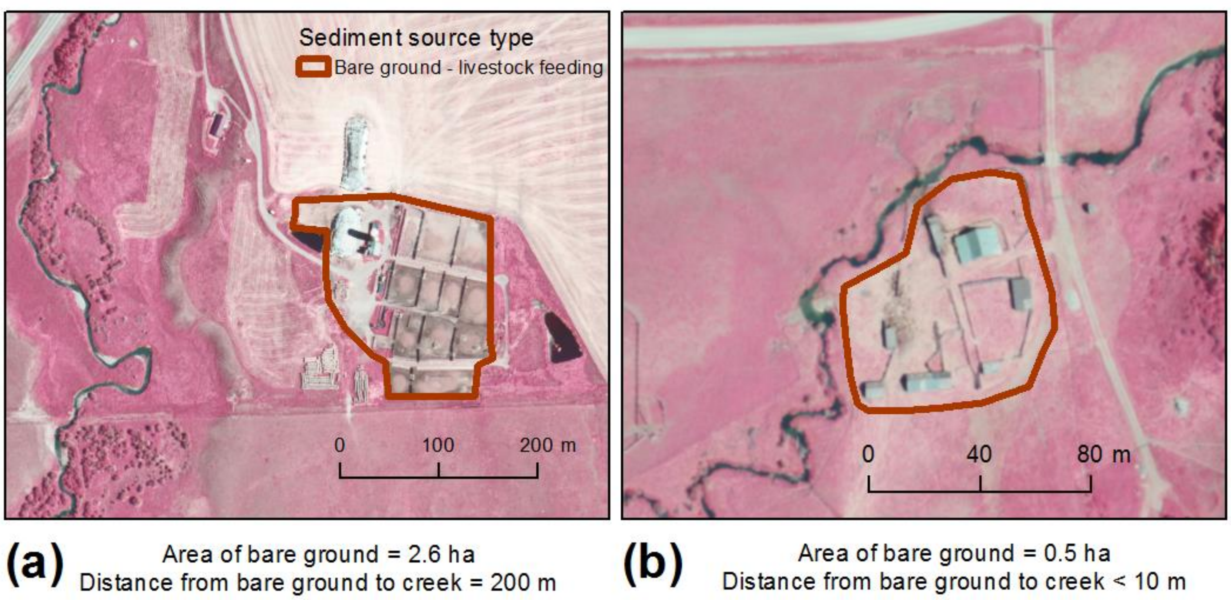


Figure 7. Infrared orthophotographs showing the digitized bare ground polygons for (a) a feedlot operation with water treatment ponds (dark triangles) and (b) a livestock feeding area and barns adjacent to a stream.

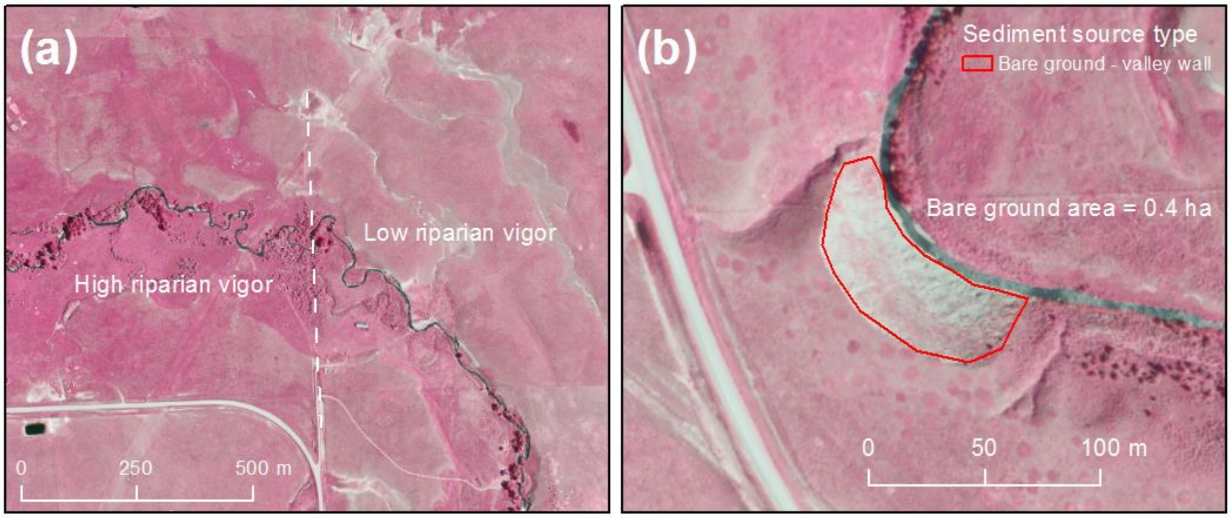


Figure 8. Infrared orthophotographs showing potential sediment sources on rangelands including (a) contrasting riparian vigor associated with property line and (b) a section of bare ground on a valley wall along the outside of a meander bend in Todd Creek.

2.2.2.3 Water Quality - Pathogens

Surface runoff from bare ground in areas heavily used for livestock feeding can convey pathogens into streams (see example in Figure 7). Where these streams also have elevated levels of suspended sediment, cohesive flocs that incorporate pathogens can form; thus, streams with both elevated sediment levels and pathogens sources may present a cumulative impact. Identify the subset of bare area polygons that may present a pathogen source during surface runoff events.

2.2.2.4 Recreational Use - Random Camping

Random camping is a popular recreational activity in designated zones within Alberta's Eastern Slopes. Within streams that support westslope cutthroat trout, there is some evidence that direct and indirect mortality from angling is greater within reaches that are in close proximity to random campsites (Paul and Boag 2003). Providing camping opportunities and sustaining native fish populations is a difficult management challenge to resolve. An important step in advancing this issue is to create an overlay of random camping locations and fish populations that are susceptible to angling related impacts.

Compile data on random camping locations. Consider remotely-sensed information and also expert knowledge of forest officers. A person familiar with the area may be able to identify the campsites that are popular with anglers.

2.2.2.5 Recreational Use – ATVs

ATV use is an important recreational value for many Canadians with sales in Alberta the highest in Canada and increasing at a rate of 12% annually (Gunther 2006). In addition to providing angler access to remote locations, ATVs can impact fish habitat in two ways. Like roads, erosion from ATV trails and subsequent sedimentation can reduce the productive capacity of fish bearing waters. Secondly, mobilization of channel substrate at ATV fords (instream crossings) has potential to affect habitat structure, including reducing pool depths, in downstream areas (Paul and Boag 2003).

Accurate maps of ATV trail locations are required for the CWEA. If erosion risk modelling from ATV trails is one of the desired outcomes from the CWEA, the standard WEPP descriptors for each trail segment are also required (see 2.2.2.2 Water Quality - Suspended Sediment).

2.2.2.6 Capital Improvements – Buildings and Other Facilities

Identify all private and public capital improvements, including buildings and facilities, located in close proximity to watercourses, especially those thought to be within the floodplain. The extent of the road network, an important infrastructure component, was previously described in 2.2.2.2 Water Quality - Suspended Sediment.

2.2.2.7 Evaluation of Data Layers required to complete the CWEA

Summarize the terms of reference and the data (Table 2). Note that fish habitat is a good umbrella indicator for other watershed values because it can be impacted by a diverse set of watershed processes.

Table 2. Summary of the three elements of the cumulative watershed effects assessment (values, watershed inputs, watershed process group) and data required to complete the analysis.

Watershed value	Relevant watershed input variable	Relevant watershed process group and type	Data source	Data quality	Suitability of data for use in the CWEA	Required action
Fish habitat	Coarse and fine sediment	Erosion: Mass wasting Streambank erosion Channel scour Surface erosion				
	Energy Nutrients Wood	Riparian: Vegetation modification from grazing, forestry, and linear disturbance				
Water quality	Fine sediment Pathogens	See fish habitat Riparian: see fish habitat				
Capital improvements	Coarse and fine sediment	See fish habitat				

2.3 Risks to Watershed Values from Erosion and Altered Riparian Processes

2.3.1 Roads and Capital Improvements on Floodplains

Using the calibrated floodplain layer (see section 2.2.1.4 Floodplains), you will complete simple spatial queries. There are two options for these queries. First, you can use the ArcGIS Select by Location tool. Second, you can use the NetMap Roads in Floodplains tool. In either case, ensure the roads layer is split at floodplain boundaries. Use the ARCGIS intersect tool if required. Also ensure that the roads layer has a length field for each segment. Summarize the query results by road type. For infrastructure, summarize the results based on consequences. Is the infrastructure at risk from flood damage? Are ecological impacts the main concern?

2.3.2 Streambed Alterations at Culverts and Motorized Vehicle Fords

The impact from a crossing depends upon the crossing type (e.g., culvert, bridge, and ford). Proceed with this analysis once you have this information. Prepare a summary table of crossing type by stream type to highlight the extent of problems in the watershed. A detailed table with information by crossing is also helpful. For culverts, include the extent of fish habitat upstream from each crossing. For vehicle fords where impacts can include mobilization of the stream bed, include the type of habitat found in the vicinity of the crossing (e.g., spawning, overwintering). This information is required for remediation planning systems that use a priority system to identify which sites are fixed first (e.g., McCleary et al. 2007).

2.3.3 Road Erosion

The Level 1 road erosion assessment can be completed using the NetMap Road Tools. The tools use two steps to assess erosion from road surfaces. In the first step, the road layer is broken into segments at topographic high and low points. In the second step, the tool applies the U.S. Forest Service (USFS) Water Erosion Prediction Project (WEPP) technology to predict total sediment yield from the low point of each road segment and sediment delivery from each road segment to the nearest watercourse. The WEPP technology predicts annual sediment production using precipitation patterns from the nearest USFS weather station. It is possible to prepare a climate file that accurately represents precipitation patterns for individual watersheds in Canada; however, for the purposes of a desktop CWEA, it may be sufficient to use the closest USFS weather station with a similar climate to that of the study area. For example for Crowsnest Pass watersheds, consider the station at Seeley Lake, Montana. Soil texture can be determined from the maps of surficial geology by Bayrock and Reimchen (1975). Complete a separate assessment for each class of roads within the study area using appropriate values for each of the input parameters (Table 3). For each road type, prepare a map that shows sediment production for individual road segments. Compile the findings across all the road categories within a single table.

Table 3. Example road erosion input parameters by road type based on assessment of road features taken from digital orthophotos for the Todd Creek watershed.

Road type	Road design	Road width	Traffic level	Road surface
Paved, undivided, 2 lane	Insloped, vegetated or rocked ditch	12 m	High	Paved
Road, gravel, 2 lane	Insloped, vegetated or rocked ditch	10 m	High	Gravel
Road, gravel, 1 lane	Insloped, vegetated or rocked ditch	6 m	Low	Gravel
Road, unimproved	Insloped, vegetated or rocked ditch	4 m	Low	Gravel
Truck trail	Outsloped, rutted	3 m	Low	Native

2.3.4 Sediment and Pathogen Source Survey

Using the data from the orthophoto review of potential sediment sources (see section 2.2.2.2 Water Quality - Suspended Sediment), arrange the findings into categories based on the type of follow-up assessment required. Example assessment categories include (a) Cows and Fish riparian assessment for rangeland issues such as reaches with low riparian area vigour and bare areas within pastures; and (b) detailed runoff assessments from development lands including livestock feeding areas.

2.3.5 Summary of Risks

Create a summary table with the results from each type of risk assessment that was completed. Include the risk, a description of the spatial extent of the risk, and the next steps to be considered by the advisory team.

2.4 Summary of Overview Assessment Results

Within this summary section, insert duplicate copies of the three tables including summary of sensitive landforms, evaluation of data, and summary of risks.

Part 3. The Todd Creek Case Study

3.1 Terms of Reference

In 2012, funding for this project was provided by two separate sources including Alberta Environment (AENV) and Alberta Sustainable Resource Development (ASRD). Later in 2012, these government agencies were combined into Alberta Environment and Sustainable Resource Development (AESRD). The first step identified in the process was to consult with Oldman Watershed Council (OWC) and ESRD staff to identify:

1. Water-related values
2. Known pressures on water-related values
3. A data set with information on values and pressures.

The initial consultations were expanded and included OWC, DFO, ESRD Lands, ESRD Forestry, ESRD Rangelands, and Devon Energy Corporation. All individuals who were consulted were engaged in specific watershed management challenges (Table 4). Advisory team members had different preferences for a pilot area based upon their priority issues, but were, overall, in support of including Dutch and Racehorse Creeks.

Table 4. Summary table by organization of values, pressures and data sources.

Organization	Water-related values	Known pressures	Available datasets
OWC	Riparian zones Water quality Fish habitat Native fish populations	Grazing Erosion and pathogens Stream crossings Invasive aquatic species	
DFO	Fish habitat Native fish populations	Direct impacts from instream operation of ATVs. Stream crossings. Fishing pressure from widespread random camping. Unregulated and unenforced recreational users.	Devon has stream crossing inspection program.
ESRD – Fisheries	Fish habitat Native fish populations	Erosion and sedimentation at road, ATV trail, and single track trail crossings. See DFO	FWMIS data
ESRD – Lands and Forestry	Fish habitat	Need to understand erosion and sedimentation impacts relative to the different types of crossings to guide management. Need to evaluate effectiveness of ongoing remediation programs.	Road and ATV trail locations.
Devon Energy Corp	Native fish populations Fish habitat	See DFO Stream crossings	 Data from Devon stream crossing inspection program.
ESRD – Rangelands	Riparian zones	Grazing impacts within sensitive sites.	AESRD riparian health assessments and Grassland Vegetation Inventory maps. Cows and Fish surveys. Recent stream channel reference project by Thompson and Hansen.

3.2 The Study Area

3.2.1 Watershed Characteristics

The study area includes the Oldman River watershed upstream from Highway #22 and Todd Creek – an adjacent basin that empties into the Crowsnest River near its mouth at the Oldman Reservoir (Figure 9). Tributaries that are suitably sized for watershed analysis are also shown. Three main ridges create the north-south boundaries between these basins. The Whaleback Ridge forms the easterly divide between Bob Creek and Callum Creek – a stream that lies immediately east of study area. The Livingston Range creates the westerly divide between Camp Creek and tributaries to the Upper Oldman and Livingston Rivers. The Livingston Range also divides Todd and Daisy Creeks. Plateau Mountain is the source of the Livingston River. The High Rock Range forms the continental divide along the western study area boundary. Tornado Pass lies along the western boundary of Dutch Creek which forms the lowest point along High Rock Range within the study area. Tornado Mountain is the obvious high point directly north of the source of Dutch Creek.

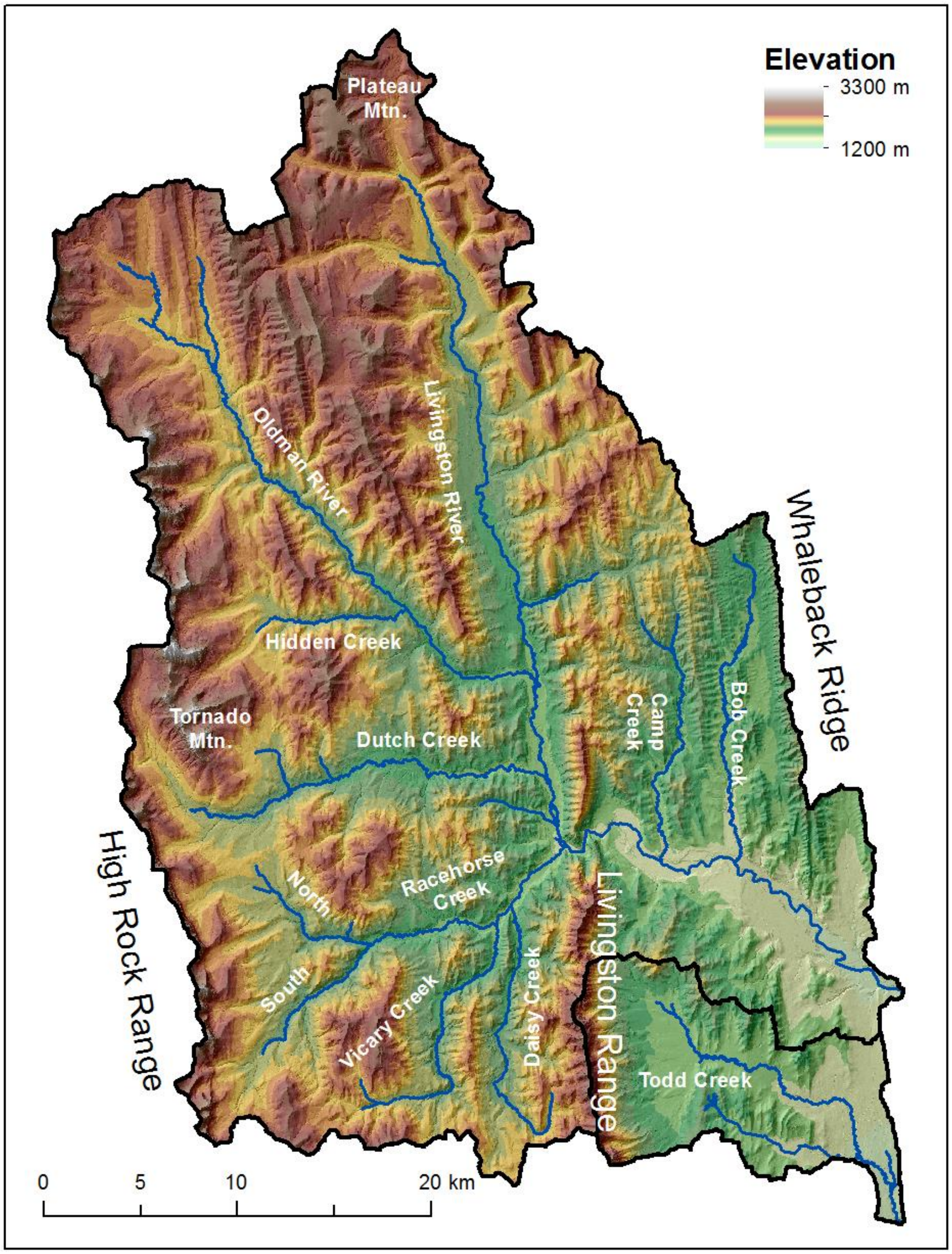


Figure 9. Map of study area including terrain and main tributary streams to the Oldman River.

A number of options exist for sub-dividing the larger study area into basins for individual assessments (Table 5). Boundaries for watershed assessments in Racehorse Creek, Livingston River, and the Oldman River, upstream from the Livingston River confluence should be made in consultation with the parties requesting the assessment. Todd Creek is the main catchment that is examined in this project and its size falls within the size limits of those recommended in other jurisdictions.

Table 5. Basin and sub-basin names and their drainage areas.

Basin/Sub-basins	Drainage area
Todd Creek	117 km^2
Oldman River upstream from Hwy 22	932 km^2
Tribs to Oldman River east of Livingston Range	
Bob Creek	68 km^2
Camp Creek	52 km^2
Racehorse Creek	285 km^2
North Racehorse Creek	43 km^2
South Racehorse Creek	66 km^2
Daisy Creek	59 km^2
Vicary Creek	62 km^2
Dutch Creek	142 km^2
Livingston River	330 km^2
Oldman u/s from Livingston	320 km^2
Hidden Creek	64 km^2

3.2.1.1 Geology

The bedrock geology in the Crowsnest Pass region has been extensively studied largely to support development of the large coal deposits initially reported more than a century ago. The following description will highlight important bedrock features, specifically those that: (a) exert strong control on watershed form and channel gradients, (b) have potential influence on groundwater upwelling locations; or (c) impose topographic constraints on resource road development.

In the Rocky Mountain portion of the study area, four major faults run parallel in a north-south direction, each with a westerly dip (Figure 10). At the Lewis Thrust, limestone and dolomite from Upper Paleozoic formations were thrust over the younger sandstone and shale of the Belly River Formation. Limestone and dolomite form the steep cliffs and cirque walls along the continental divide, while the Belly River formation extends as lower relief terrain lying eastward from the base of the cliffs. The Coleman Thrust, the next major fault to the east, is of significant economic importance due to valuable coal seams in the Mist Mountain Formation found along the thrust's hanging wall. One seam, that lies in parallel to the fault, has been exploited almost continuously along its length between South Racehorse Creek and a Vicary Creek Tributary (Bustin 1996). These coal formations are overlain by the highly erosion resistant conglomerates of the Cadomin Formation (Bustin 1996). The Cadomin Formation, which extends as far north as Grande Cache, Alberta, is remarkable as a cap atop many front range/foothills ridges and also as a knickpoint with ledges or waterfalls at valley bottom exposures at well-known locations such as Elbow Falls west of Calgary, and also at unnamed falls that are successfully passed by bull trout (*Salvelinus confluentus*) on their upstream migration in MacKenzie Creek near Hinton (Figure 11). Furthermore, the Cadomin Formation does have potential to host an aquifer (Riddell 2012), and as such valley bottom exposures may contribute towards the specific conditions required for bull trout spawning. The McConnell Thrust, approximately five kilometers east of the Coleman Fault, corresponds to rugged terrain in the lower ¼ of Dutch and Racehorse watersheds. At the Livingston Thrust, limestone and dolomite from upper Paleozoic formations was thrust over the much younger sandstone and shale formations that are typical of the Alberta foothills. The Oldman River has cut a notch through the Livingston Range at a feature called the Gap. East of the Livingston Thrust, another series of closely spaced north-south running faults are responsible for the foothills topography, with resistant formations exposed along the crests of the parallel series of foothills ridges and more erodible layers forming the corresponding valley troughs. These include the Todd Creek, Mill Creek, Tetley and Watson Faults.

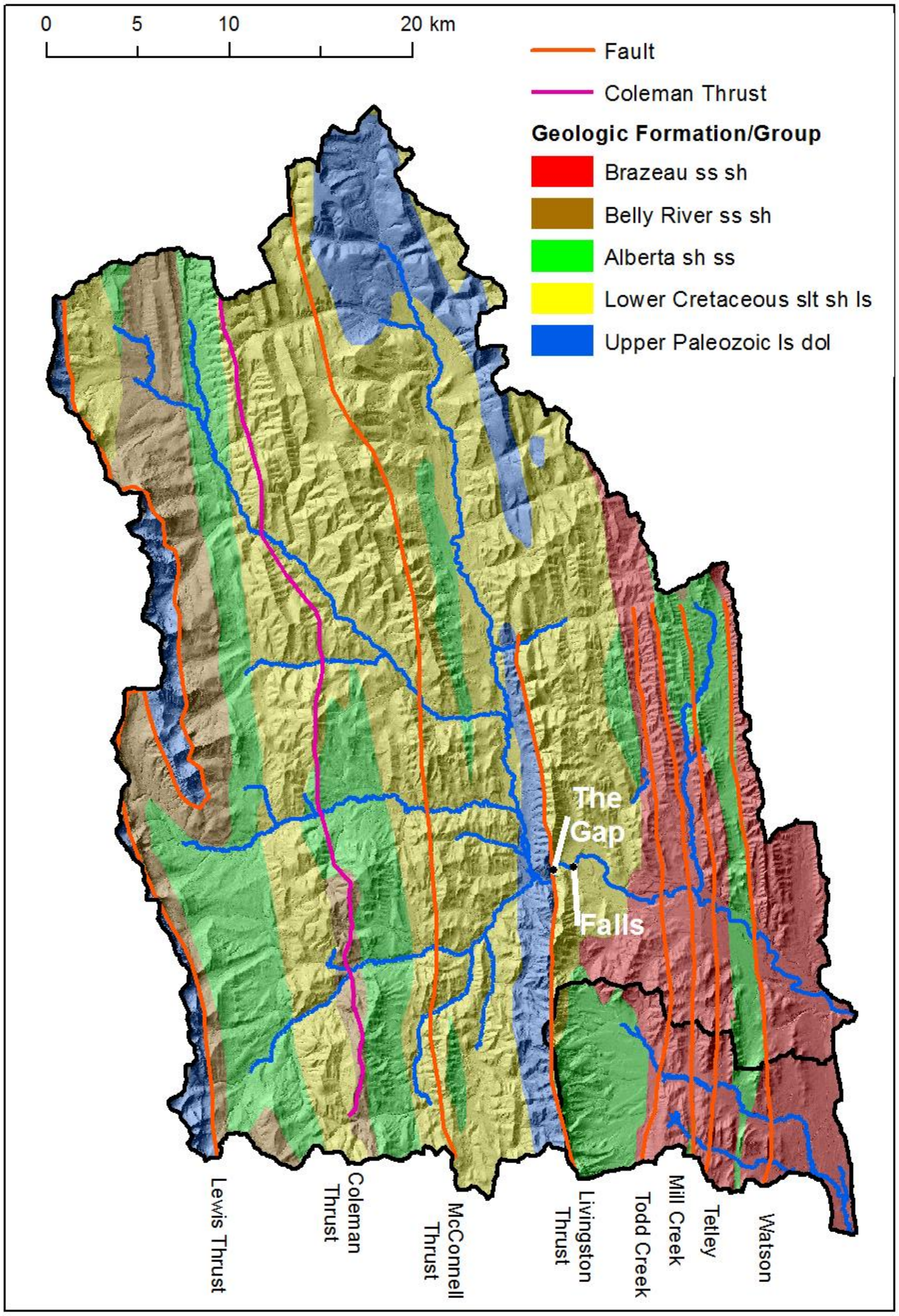


Figure 10. Geological map with formations and faults for the Upper Oldman and Todd Creek watersheds (based on Bustin 1996; Hamilton et al. 1999; Norris 1989; Price et al. 1992).

Figure 11. Falls created by Cadomin Formation knickpoint in Mackenzie Creek near Hinton.

The drainage network, especially on the west side of the Livingston Fault, displays a trellis pattern with streams either following the north-south running valleys that have formed in more erodible formations or alternately cutting deep clefts perpendicular to the fault lines through the resistant layers.

3.2.1.2 Geomorphology

Surficial materials for the study area were mapped by Karpuk and Levingsohn (1980). The following description is based on information contained within various levels of the hierarchical classification that they applied. In subsequent sections, selected drainage basins, including those of Todd, Racehorse and Dutch Creeks, are described in detail using maps and figures based on a digital landscape and drainage network derived from high-resolution LIDAR DEMs (digital elevation models).

The four north-south faults exert strong control on the local relief and distribution of erosion processes within the study area. Bedrock exposures are largely limited to limestone and dolomite within both the High Rock Range along the continental divide and the Livingston Range along the Todd Creek–Racehorse Creek divide. Rock-fall and related processes have deposited colluvium along cliff bases of these ranges where slopes typically exceed 45 percent. Although glaciation may have left blankets of till across much of the area between the Lewis and Livingston Thrusts, these deposits have been subsequently eroded from all areas except those with less than 15 percent slope where morainal deposits remain. In areas with slopes between 15 and 45 percent, saprolite, or weathered bedrock, is the dominant surficial material. Surprisingly, the expected bedrock–colluvium–saprolite–moraine sequence is not followed in the headwaters of Racehorse, Dutch, and Hidden Creeks; rather, a band of low relief moraine abuts against the colluvial deposits from the Highrock Range. The band of terrain was extensively developed with roads for logging and other forest management activities. In Racehorse Creek, roads were not constructed along the typical downstream route which would have required crossing the rugged terrain associated with the Coleman and McConnell Thrusts; rather, the main gravel road follows an easier route over low gradient morainal surficial materials (Figure 12) that lead across the Allison Creek - Racehorse Creek divide to the south.

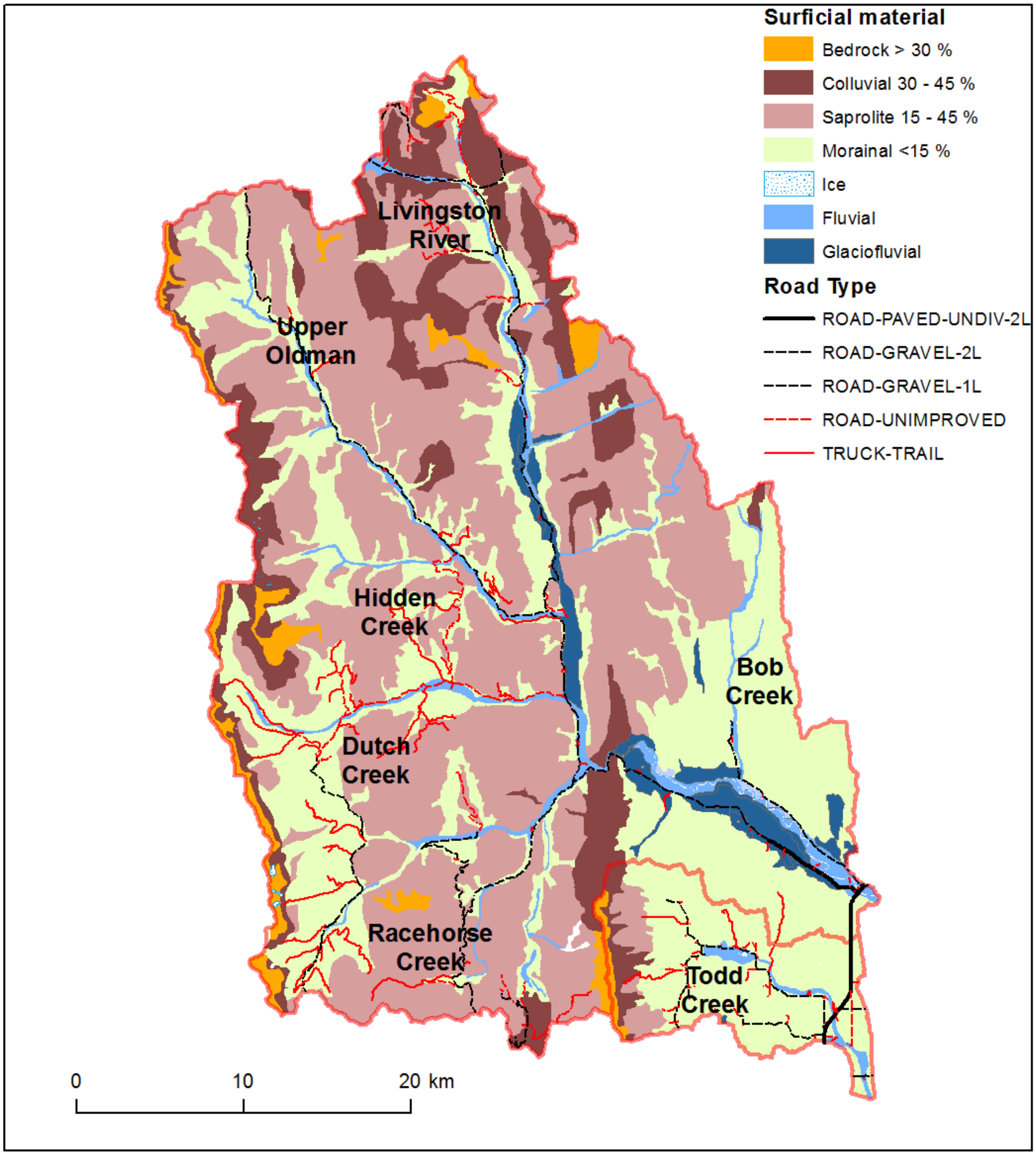


Figure 12. Map of surficial materials for the study area based on Karpuk and Levingsohn (1980).

In Todd Creek basin, surficial materials in the upper 2/3 of the basin are very patchy and include tills of Cordilleran origin, whereas the materials in the lower 1/3 are a more uniform cover of tills from Continental origin (Figure 13). Till depth in the Alberta foothills decreases as a function of slope, thus supply of continental till for erosion in the lower 1/3 of the basin is expected to be greater than that of cordilleran tills in the upper basin.

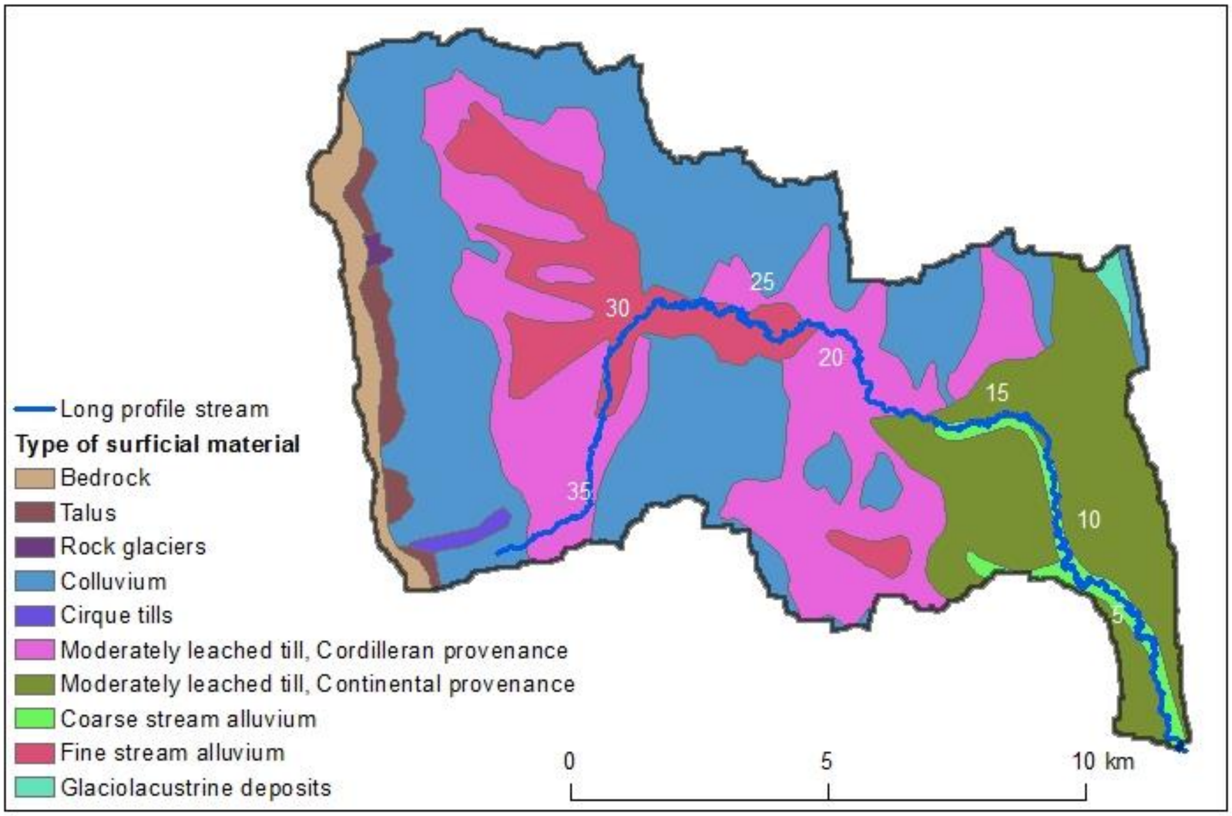


Figure 13. Type of surficial material for Todd Creek based on Bayrock and Reimchen (1975).

3.2.1.3 Streams

Two important steps were taken to produce the final stream layer. First, the entire network was examined for diversions away from expected natural flowpaths. Second, the reach length was adjusted to detect waterfalls, chutes and other knickpoints along small streams that may control upstream fish migration. Once the final streams layer was produced, important reach attributes including channel type, bankfull width and wetted width were assigned. Each of these steps is reviewed in the following paragraphs.

As expected, when producing the stream layer from the LIDAR-derived DEM, road beds caused diversions away from the natural flowpath in numerous locations. Using the hillshade model and orthophotos, such locations were visual identified and digitized (Figure 14A). Next, the DEM was modified using an excavate function at these locations. Then the stream layer was regenerated (Figure 14B). For Todd Creek, approximately 80 corrections were made.

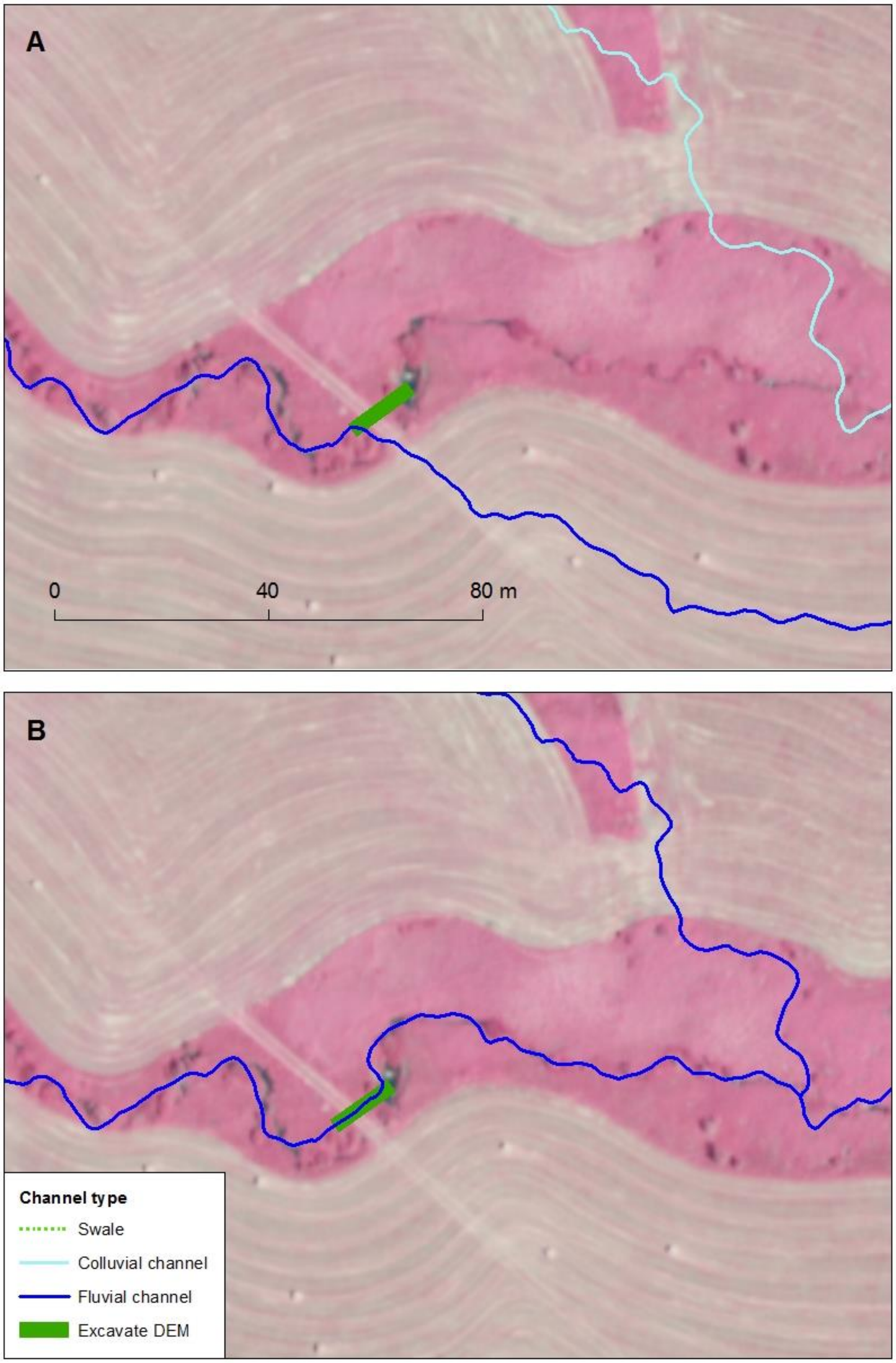


Figure 14. Digital infrared orthophotos for a location in Todd Creek watershed showing (A) the raw LIDAR-derived network with a digitized line segment indicating flowpath correction location and (B) the corrected network.

Adjusting reach length to suit specific assessment objectives was an important part of this project. During the consultation phase, AESRD and DFO fisheries biologists emphasized that information on the location of natural fish migration barriers within small streams can help to identify isolated populations of westslope cutthroat trout and also help to predict where upstream migration of non-native fish may be controlled two important aspects of developing regional scale native fish conservation plans. To meet this goal, an iterative approach was used during the creation of the stream network to determine a suitable minimum reach length for detecting waterfalls and chutes in headwater streams. Decreasing the minimum reach length does come at a cost because as the dataset size and number of reaches increases, the speed at which the layer can be displayed and analyses can be completed will decrease. Using Wintering Creek as a test area (Figure 15A), after several iterations using different reach lengths, a 10 m minimum reach length provided the best differentiation of known habitat features including a potential fish migration barrier at a bedrock outcropping (Figure 15B) and reach lacking any such features (Figure 15B).

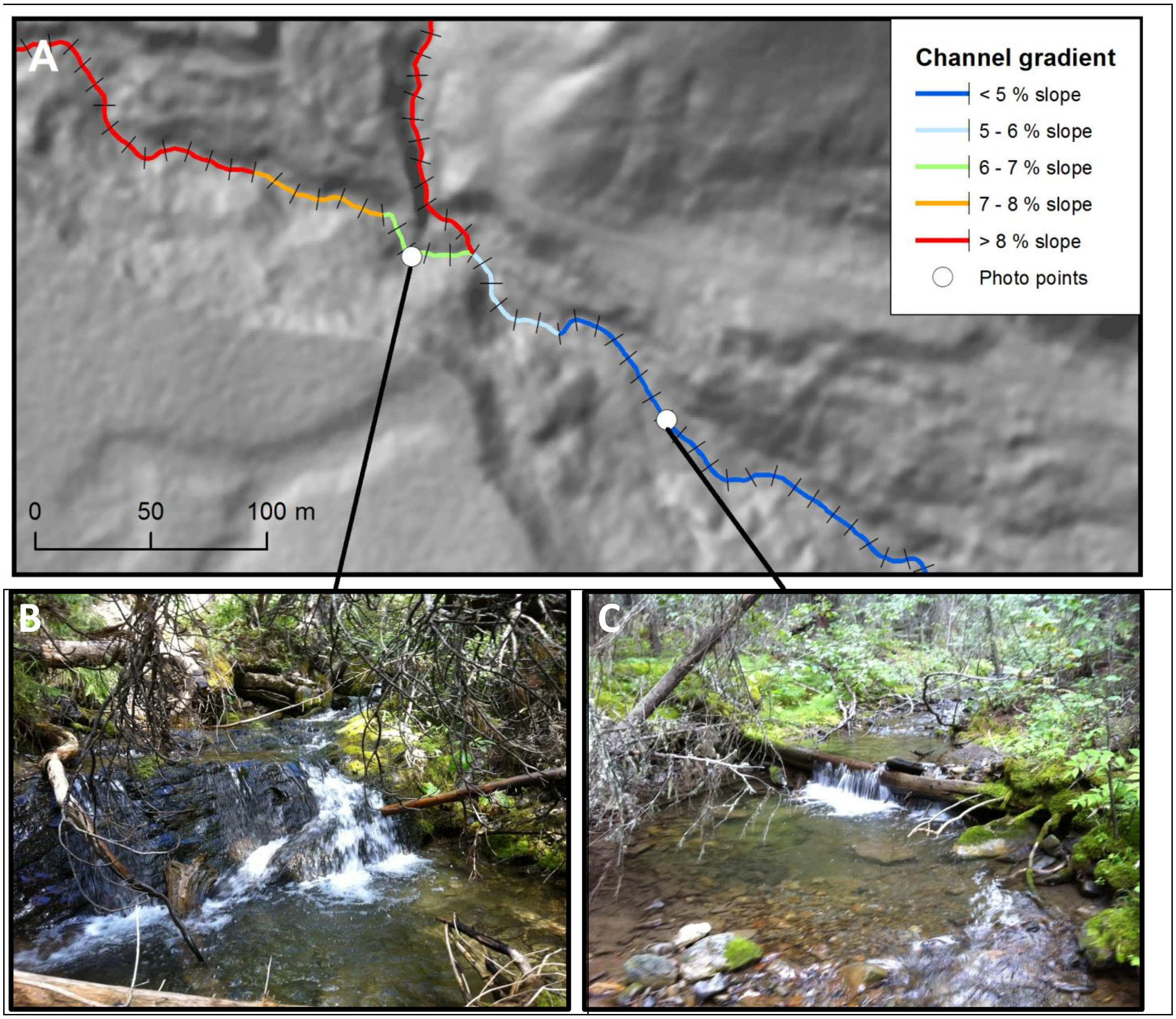


Figure 15. (A). Map of a section of Wintering Creek using 10 m minimum reach length with channel slope by reach and photo points including (B) a bedrock outcropping that poses a potential fish migration barrier, and (C) a log step in medium gradient reach that provides known juvenile rearing habitat for westslope cutthroat trout.

Using a 10 m minimum reach length also proved effective for detecting important stream gradient features at the watersheds, including hanging valleys with over-steepened outlets and migration barriers (Figure 16). Such maps have important application in regional scale conservation strategies as they show potential refuge habitats where westslope cutthroat trout may be protected from the impacts of invasive non-native fish species. Furthermore, fluctuations in reach steepness and valley confinement can promote local changes in groundwater flux that create productive bull trout spawning sites (Baxter and Hauer 2000); such patterns are evident along both South and North Racehorse Creek (Figure 16).

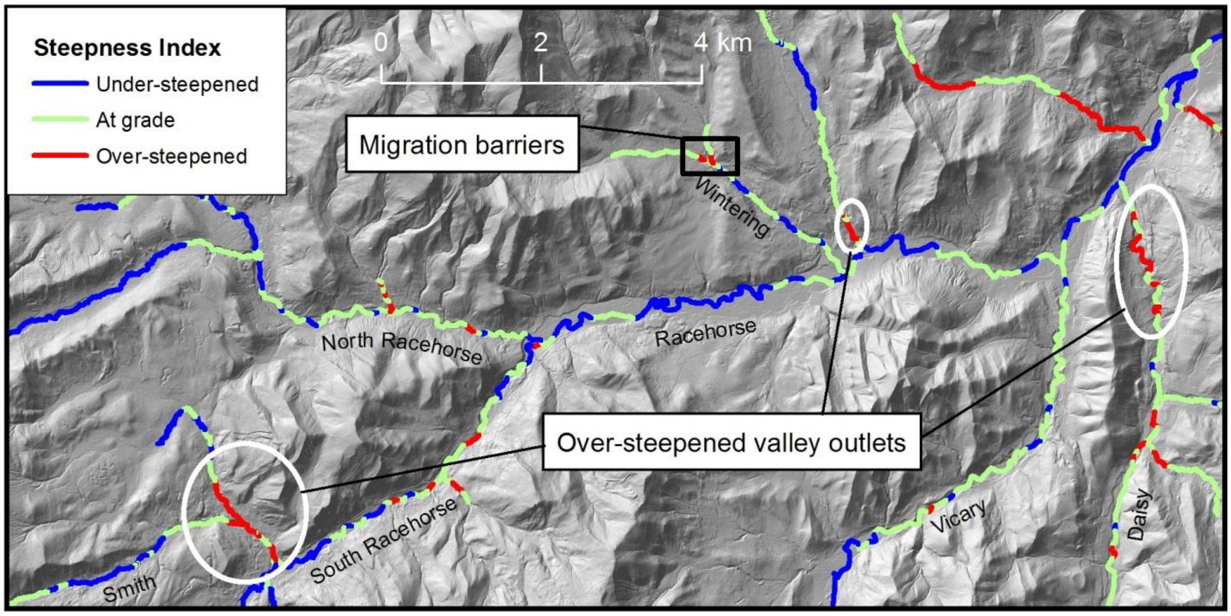
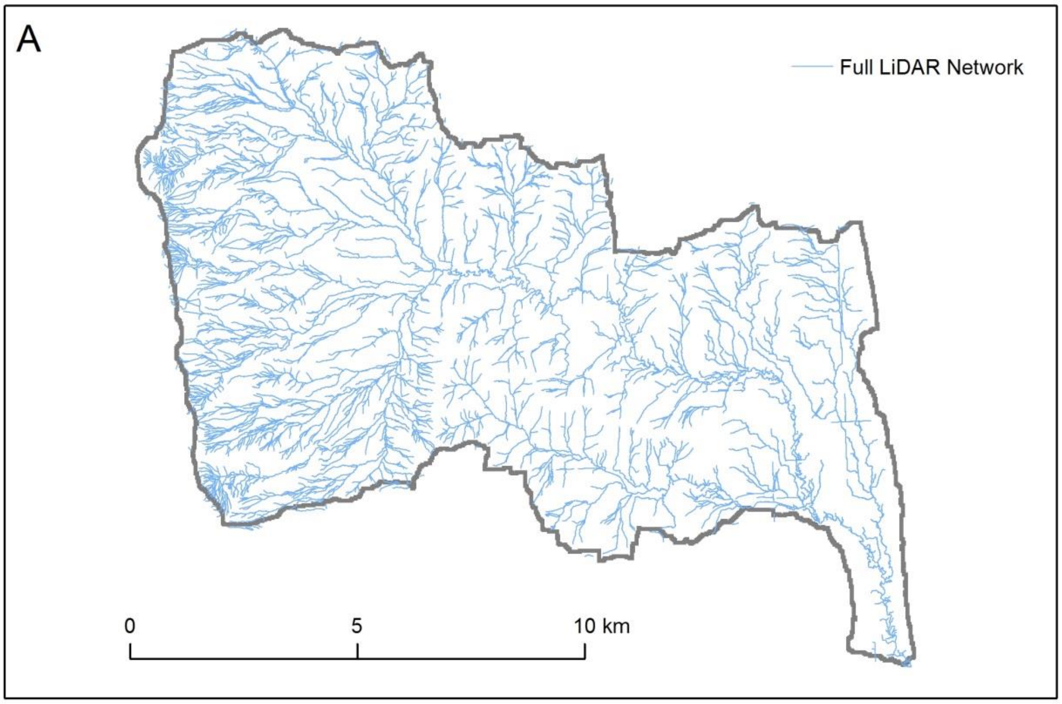


Figure 16. Map of Racehorse Creek and tributaries with reach steepness index showing over-steepened valley outlets and Wintering Creek migration barriers.

After the stream layer was produced, three reach attributes were assigned including channel type, bankfull width and wetted width. Channel type information was not available for the study area, so the model developed from field surveys (see Figure 4) in steep foothills watersheds near Hinton (McCleary et al. 2012) was applied. This reduced the drainage density from 7.5 km/km^2 in the full LIDAR network (Figure 17A) to 1.7 km^2 for open channels (e.g., colluvial channels and fluvial channels) in the attributed network (Figure 17B).



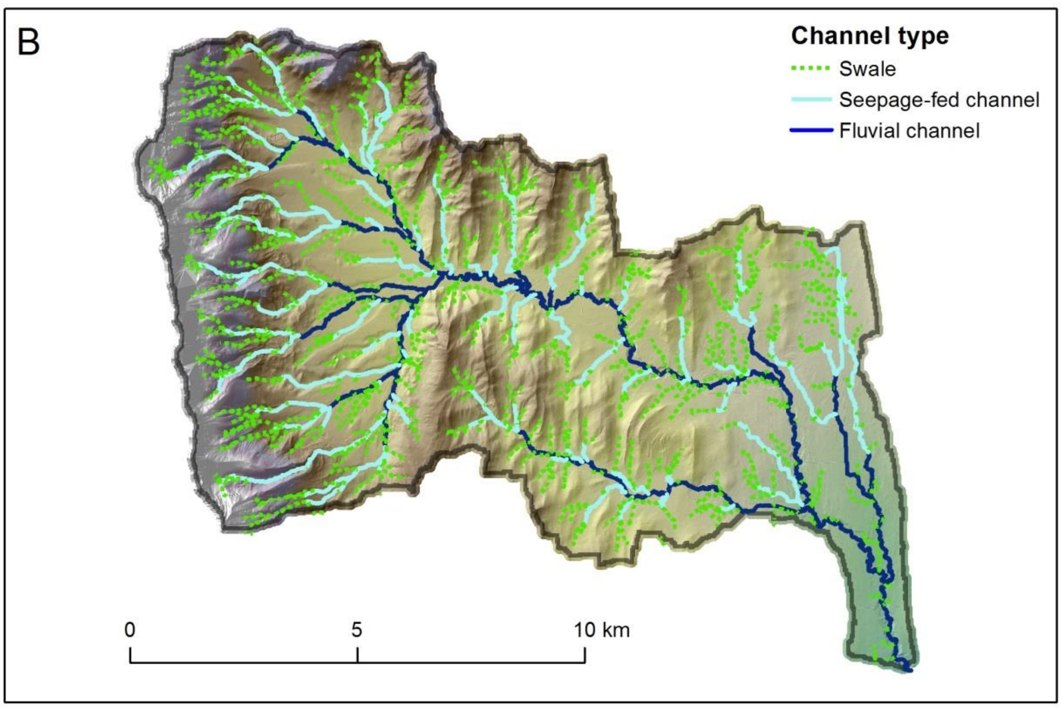


Figure 17(A). Map of the full LIDAR network for Todd Creek. Total drainage area = 117 km^2, drainage density = 7.5 km/km^2, mean reach length = 10.4 m, total number of reaches = 84,013. (B) Map of drainage network with classification applied. Drainage density including swales = 3.9 km/km^2. Drainage density of colluvial and fluvial channels = 1.7 km/km^2.

Fortunately, the Alberta Fish and Wildlife Management Information System (FWMIS) included bankfull and wetted width measures from a number of sites within Racehorse and Dutch Creek watersheds.

These sites were mapped using location data within the FWMIS records. Then, each site was snapped to the nearest reach within the new digital stream layer. Drainage area from the attributed reach table was used to predict both bankfull width and wetted width (Figure 18). These models were then applied to all reaches within the study area watershed.

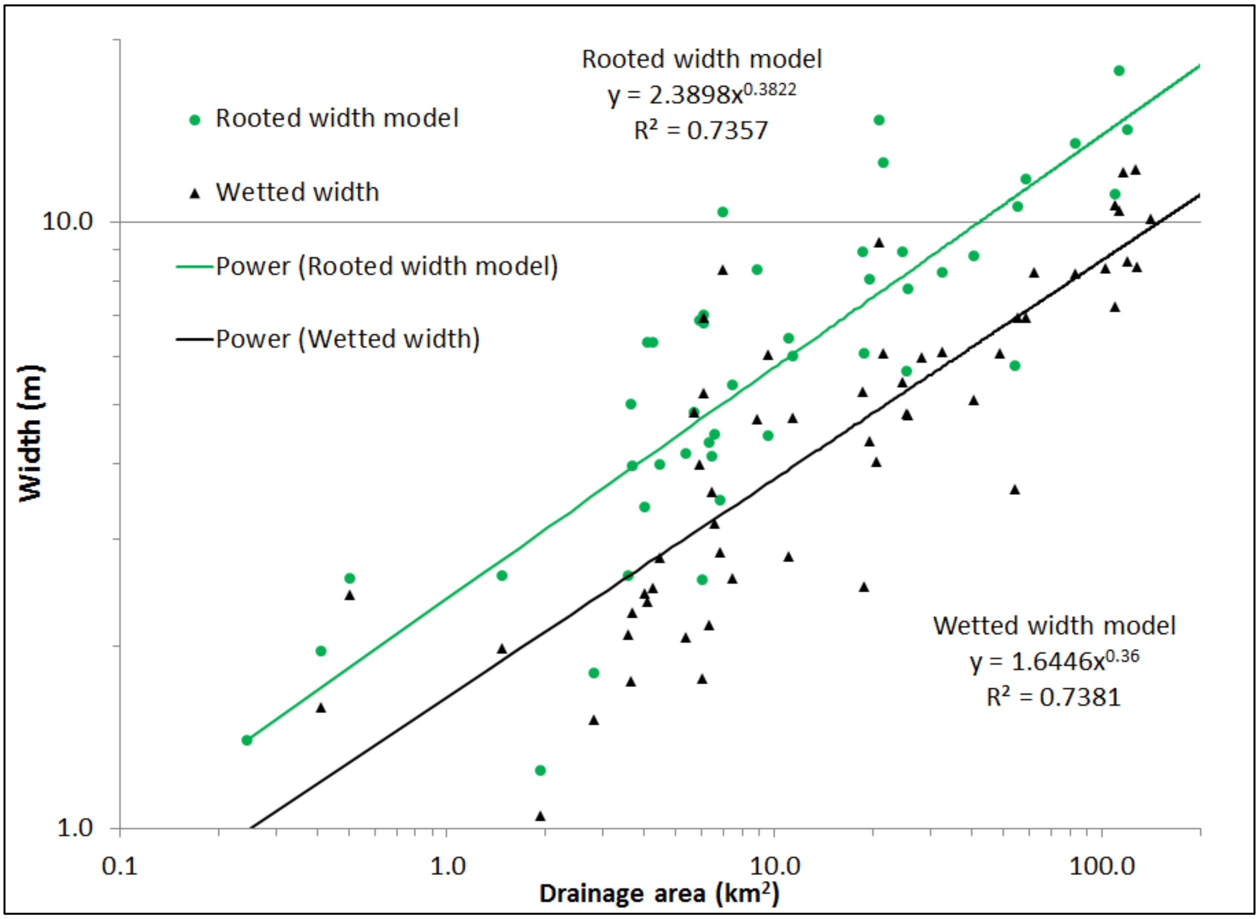


Figure 18. Rooted width and wetted width models using FWMIS data from Racehorse and Dutch Creeks. Note: only wetted widths measured during the August and September baseflow season were used.

Wetted width was especially relevant in this assessment because it was one of three required attributes in the westslope cutthroat model developed by Peterson et al. (2008) that was for Todd Creek (see Section 3.2.2.1. Native Fish and Fish Habitat in Todd Creek). Given the different precipitation patterns between Dutch / Racehorse Creeks and Todd Creek, the width predictions may be larger than expected (Figure 19); none-the-less, these models were based on the best information that was available.

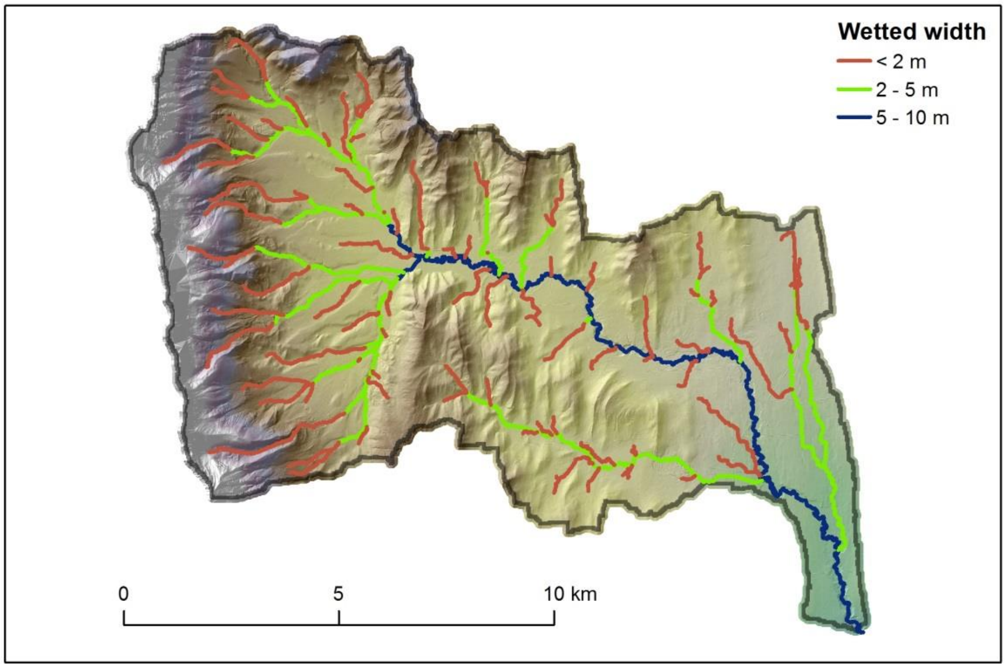


Figure 19. Map of Todd Creek with predicted wetted width from the model developed with data from Dutch and Racehorse Creeks.

3.2.1.4 Floodplains

In this section we present the results from two different exercises used to calibrate the floodplain maps in the study area. The first used data from the Cows and Fish field assessments; the second used data from Grassland Vegetation Inventory (GVI) polygons. The following technical comparisons were warranted because field-calibrated floodplain maps were required to assess impacts within the watershed analysis.

In 2012, as part of a riparian assessment completed by the Cows and Fish Program, floodprone width was measured, using the previously described methods, at two locations in Todd Creek and one location in Dutch Creek. With the Cows and Fish field procedure, the riparian zone boundaries align with the floodprone area (Fitch et al. 2001). The field measures of floodprone width at these three locations were compared to maps of wetness index from the ESRD Wet Areas Mapping Program, and also to floodprone width calculated at three different stages (i.e., elevation at the stream channel plus 1 x D_{bkfl}, 2 x D_{bkfl}, and 3 x D_{bkfl}). We used the NetMap Floodplain Mapping Tool within the Fluvial Morphology Tools to map the floodprone area for the Todd Creek, Racehorse Creek and Dutch Creek watersheds. One run of the tool was completed for each of the three flood stages.

For Reach A in Todd Creek, the Cows and Fish riparian area was captured well within Zone 1 of the WAM wetness index (Figure 20A and C), and aligned closely with the NetMap 1 x D_{bkfl} floodplain polygons (Figure 20A and C). For Reach B in Todd Creek, the Cows and Fish floodprone area aligned closely with Zone 1 of the WAM wetness index (Figure 20B and D), and fell within the NetMap 2 x D_{bkfl} floodplain polygons (Figure 20B and F). For Reach C in Dutch Creek, the Cows and Fish floodprone area aligned closely with Zone 1 of the WAM wetness index (Figure 21A and B), and fell within the NetMap 2 x D_{bkfl} floodplain polygons (Figure 21A and C).

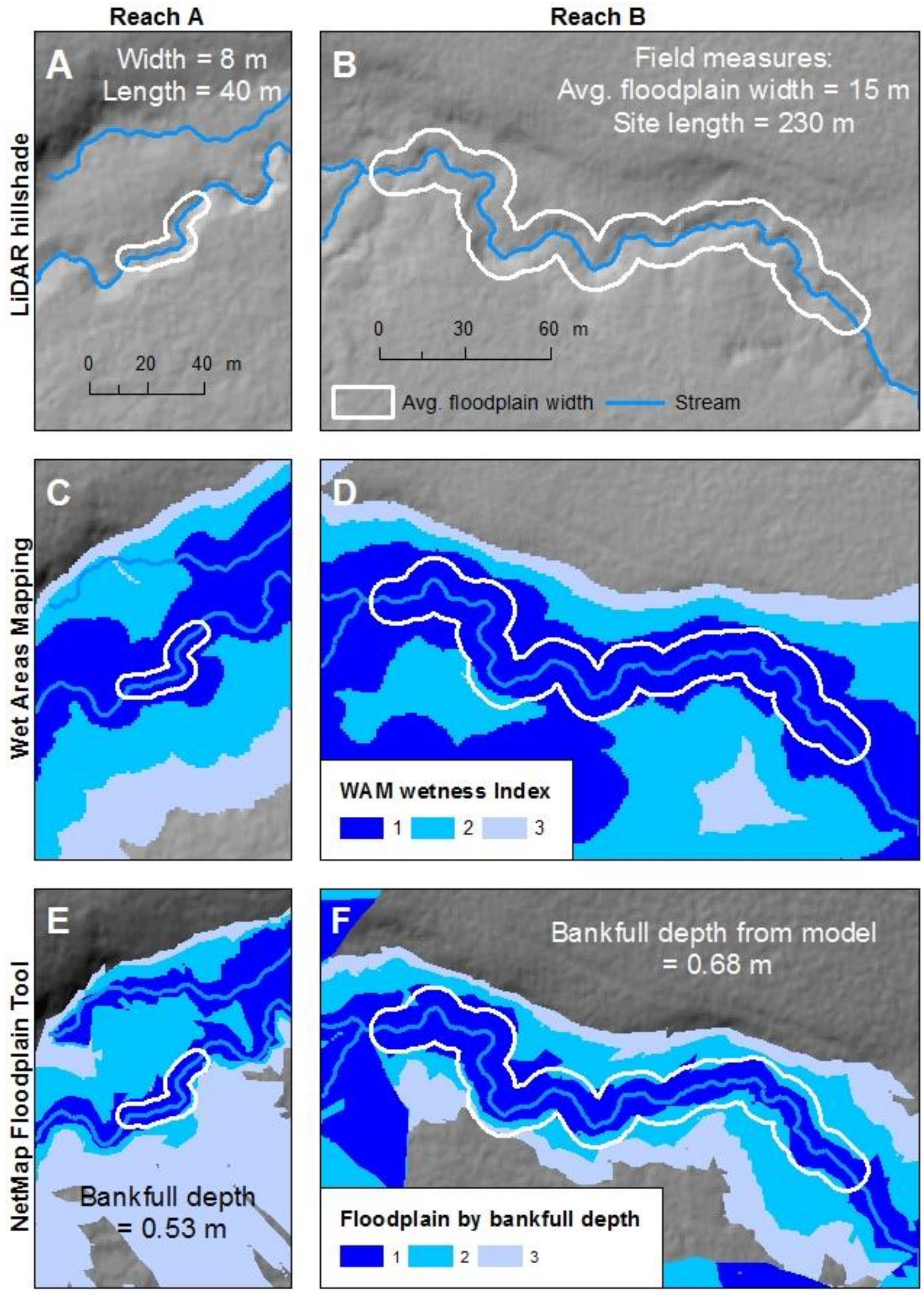


Figure 20. Comparison of field measures of riparian zone width in Todd Creek from the Cows and Fish Program at: (A) Reach A and (B) Reach B, with Wet Areas Mapping wetness index for (C) Reach A and (D) Reach B, with NetMap floodplain polygons from five different bankfull depth multipliers for(E) Reach A and (F) Reach B.

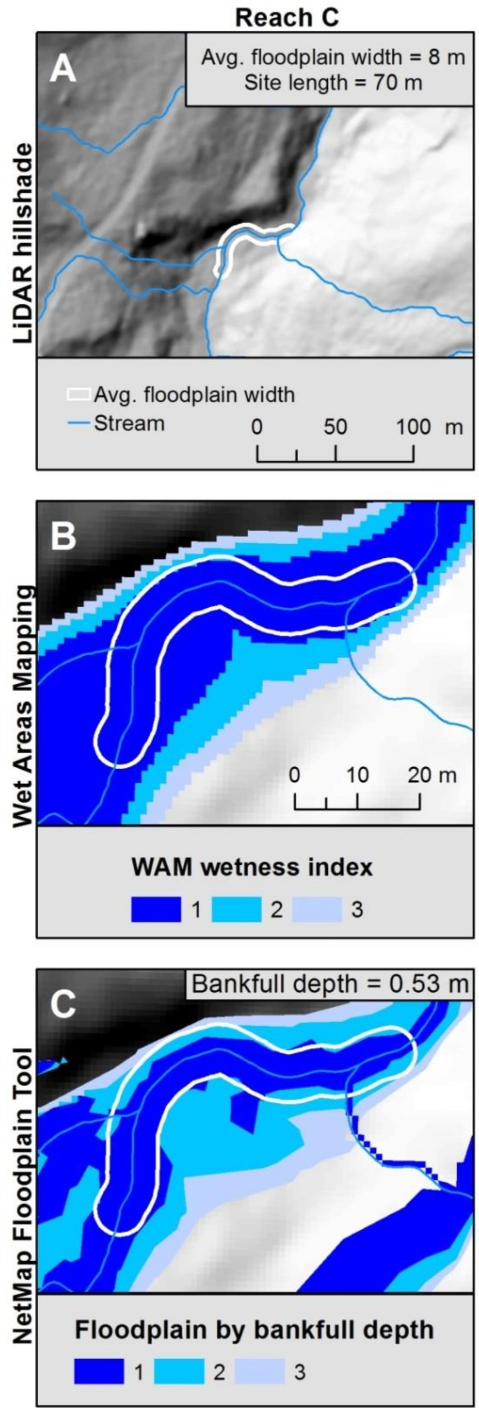


Figure 21. Comparison of field measures of riparian zone width in Dutch Creek from the Cows and Fish Program at (A) Reach C with (B) Wet Areas Mapping wetness index and (C) NetMap floodplain polygons from five different bankfull depth multipliers.

The Grassland Vegetation Inventory was only available for portions of the Todd Creek watersheds. The inventory was done at a scale where riparian areas along large rivers may have been mapped, with most of the narrow riparian zones along the small watercourses in Todd Creek excluded. The inventory did identify portions of the apron of alluvial fans as a site type called Overflow, which has a hygric soil moisture rating. These Overflow polygons were effectively captured within the NetMap 2 x D_{bkfl} floodplain polygons (Figure 22A) and within Zones 1 and 2 of the WAM wetness index (Figure 22B).

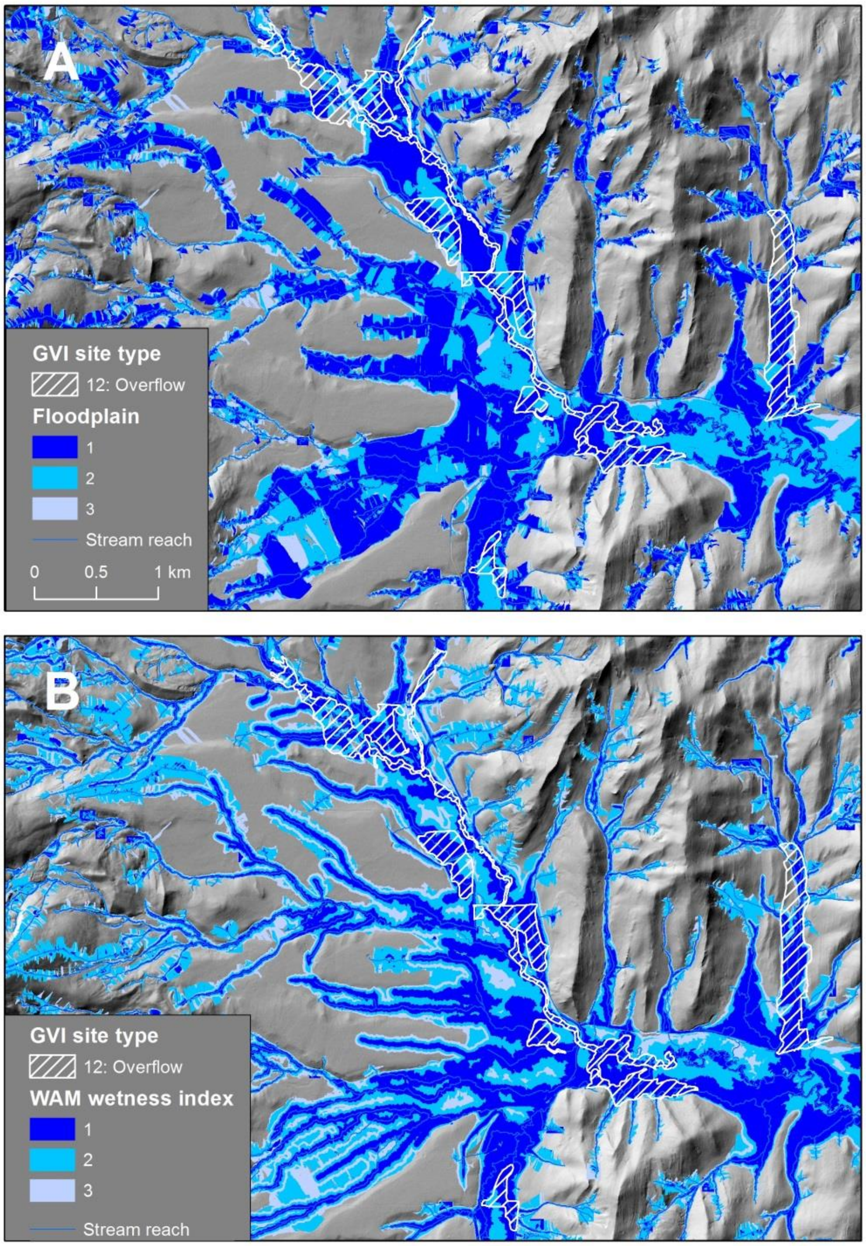


Figure 22. Maps showing comparisons between Grassland Vegetation Inventory (GVI) polygons with an "overflow" site type with (b) NetMap floodplain polygons from five different bankfull depth multipliers and with (c) Wet Areas Mapping wetness index.

These two comparisons support the use of the WAM index values of two and the NetMap 2 x D_{bkfl} polygons to represent the floodprone area; however, because the NetMap 2 x D_{bkfl} floodplain polygons are linked to the channel network, they were easily filtered to display only for predicted streams (colluvial and fluvial channels) within the watershed of interest (Figure 23).

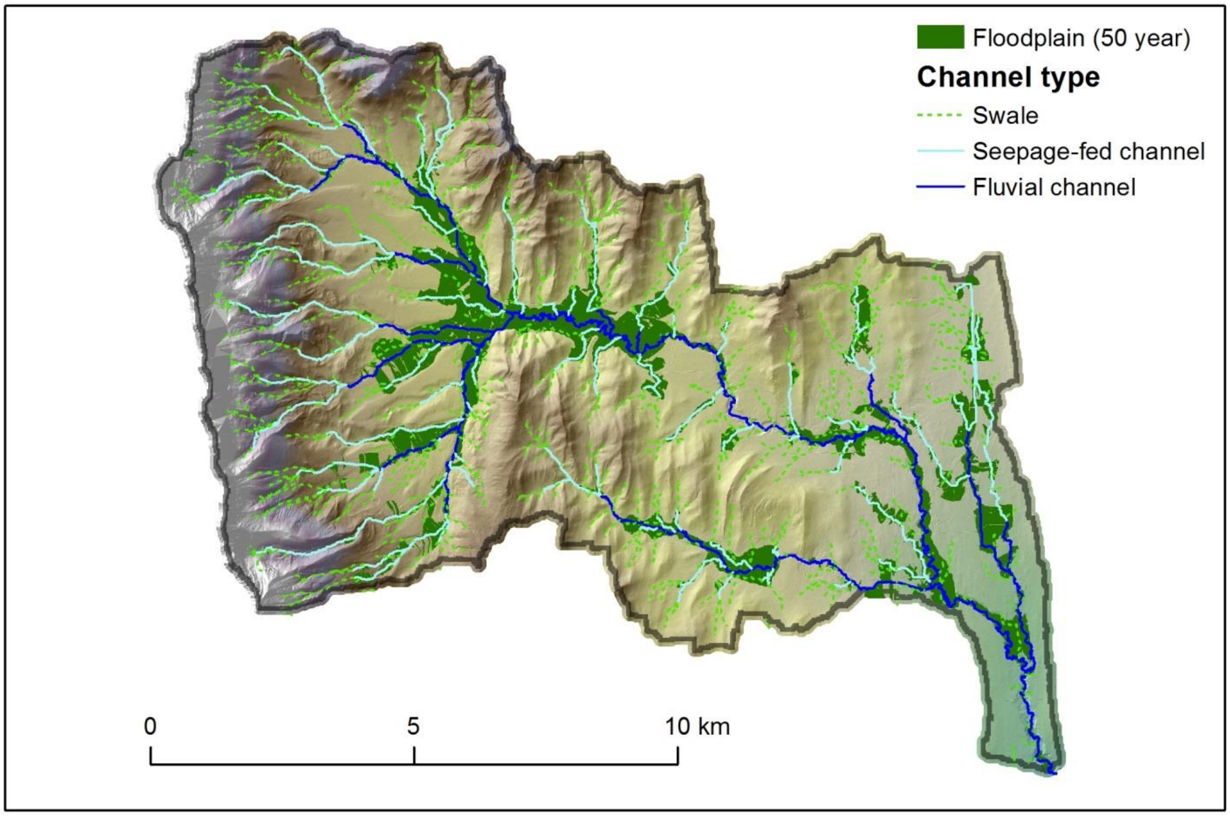


Figure 23. Map of predicted floodprone area and drainage features for Todd Creek.

3.2.1.5 Todd Creek longitudinal profile

The following description highlights the main geomorphic features along the 40 km stretch of Todd Creek, from its source downstream to its mouth (Figure 24 and Figure 25). Important features include those that influence erosion and riparian processes.

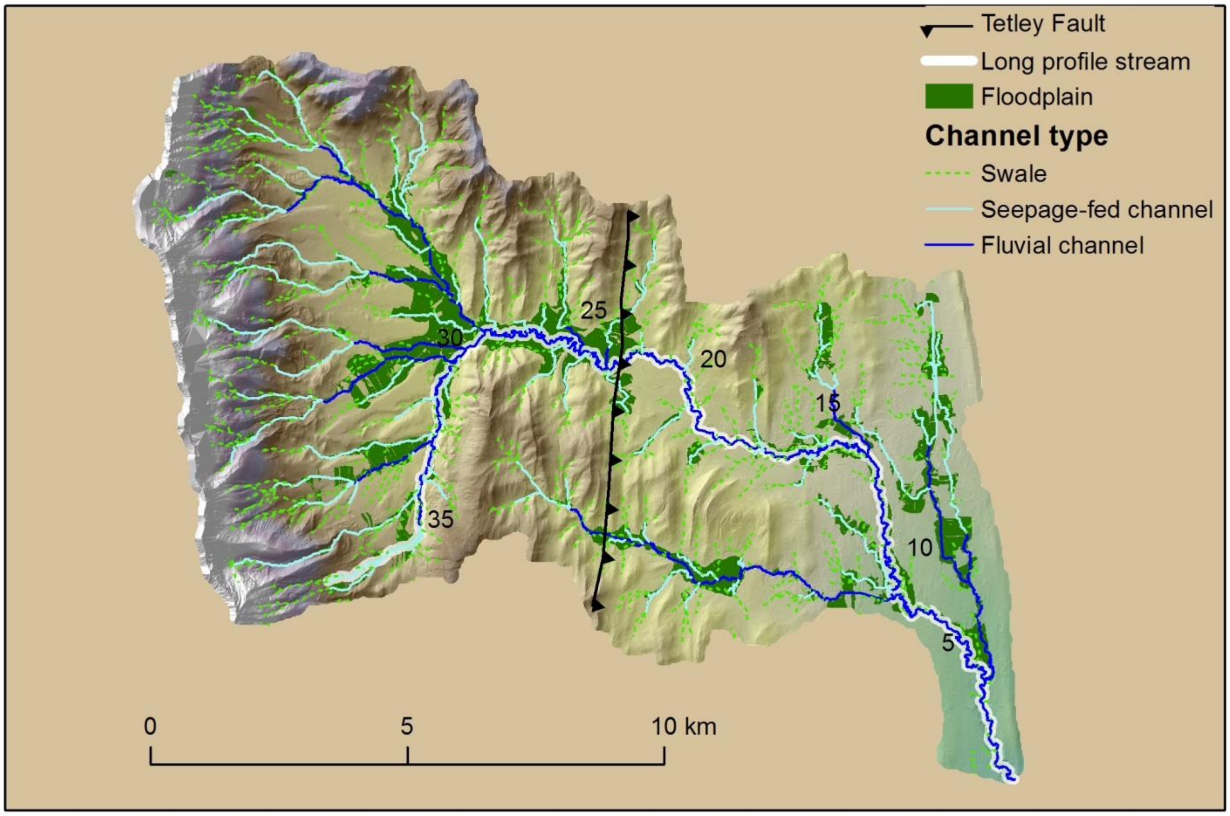


Figure 24. Topography of Todd Creek including streams shown by width class, the predicted 50 year floodplain (twice the bankfull depth), and the long profile stream with distance upstream from mouth (km).

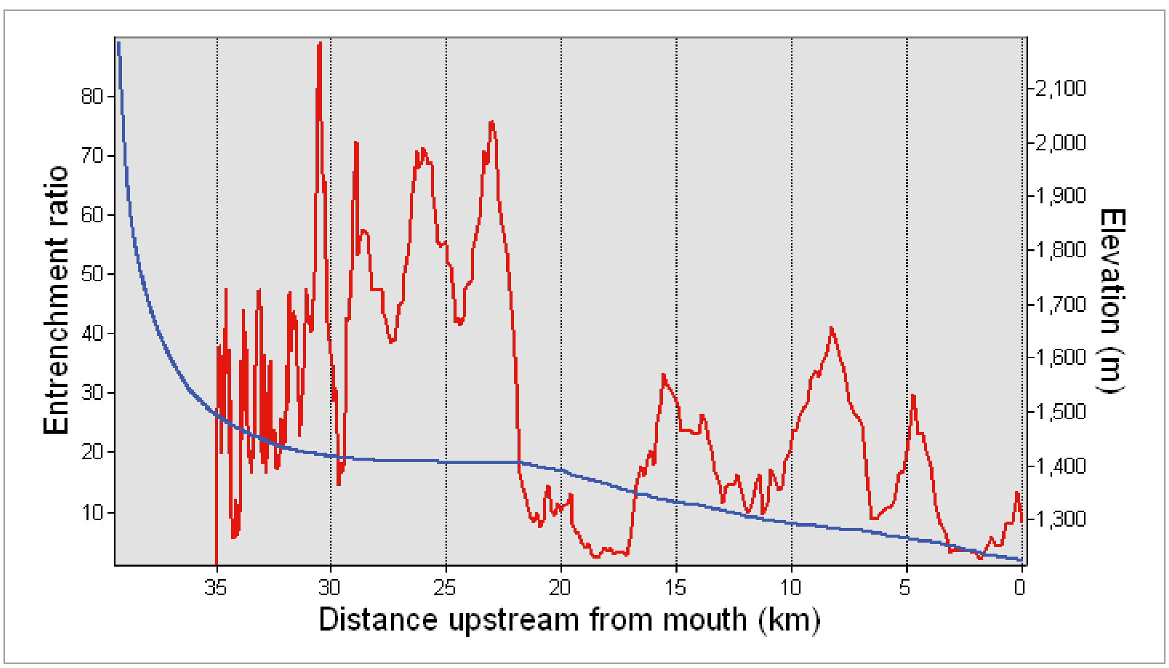


Figure 25. Longitudinal profile of Todd Creek (blue line) with entrenchment ratio (red line). Entrenchment ratios are not presented upstream of the 35 km mark due to the steep channel gradients that limit floodplain development.

Streamflow originates in steep rubble-covered alpine areas on the lee slope of the Livingston Range. Channels converge below treeline across an apron of alluvial fans. In the glaciated terrain of western Canada, alluvial fans typically grew rapidly in the immediate post-glacial period as debris flows transported unstable glacial deposits from steep areas to lower relief positions; then as the landscape stabilized and sediment supplies became limited, many streams started to incise into their fans (Ryder 1971). Such a pattern is evident from the long profile where although the channel enters an alluvial fan, the active floodplain remains narrow between the 35 km and 31 km mark (Figure 24 and Figure 25). During major storms, sediment deposited where the channel is no longer incised and interacts with its floodplain, may cause the channel to change course; thus, due to its sensitivity, this dynamic section of stream should be considered for a detailed assessment using existing procedures from other jurisdictions (e.g., Wilford et al. 2009). On lower positions of the fan, between the 30 and 22 km points, the channel has a wide floodplain and low gradient. The gradient of this wetland reach is geologically controlled by an erosion resistant strata, which according to Price (1962) is associated with the Tetley Fault line near the 22 km mark (Figure 24). This low-energy wetland reach (Figure 26) functions as a sediment sink for all transported bed material and a portion of the suspended matter.

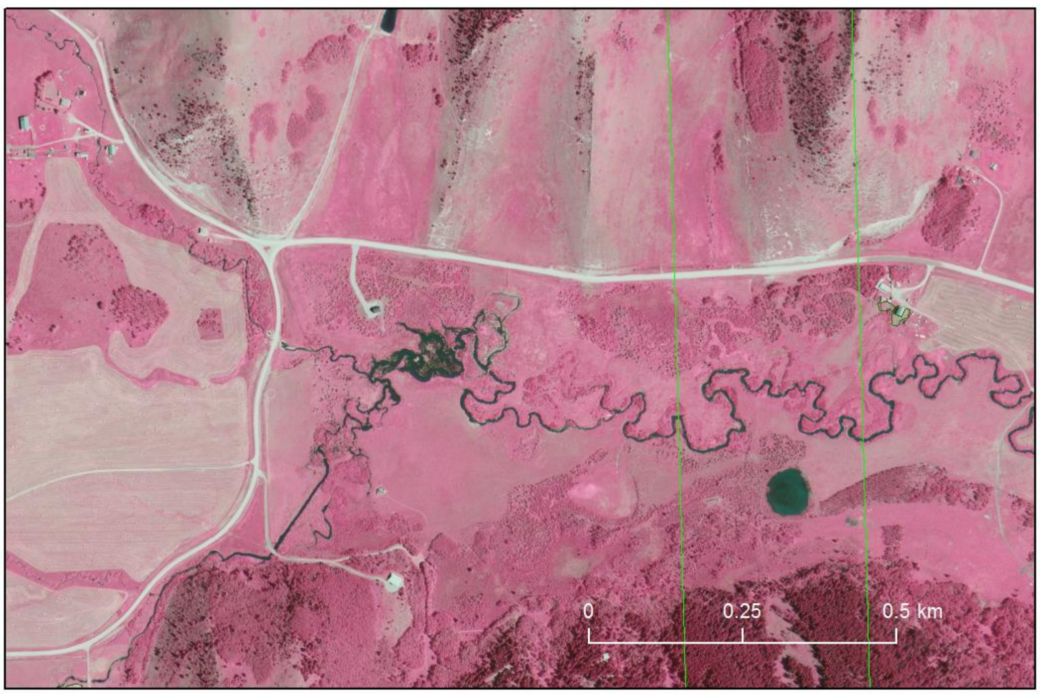


Figure 26. Wetland complex at confluence of north and south forks of Todd Creek approximately 30 km upstream from the mouth (source is 2006 Government of Alberta orthophotos).

Complex groundwater flowpaths are expected to originate at the apex of each paraglacial fan in Todd Creek. Coarse alluvial material and lack of bedrock control are expected to promote downwelling while local over-steepening of toe slopes in lower positions on the fan may create regions of upwelling. The effect of forest removal on streamflow is influenced by the degree of hydrologic connection between the harvested site and the stream of interest (see review in Smith 2011). Thus, the hydrologic assessment of the potential impacts of logging on streamflow within the Todd Creek tributaries should consider the distribution of gaining and loosing reaches within the area of interest.

Immediately downstream of the knickpoint near the Tetley Fault, Todd Creek will start anew in terms of sediment load, which should recover quickly as the channel recruits material from the erodible valley side walls through the lower watershed – a zone according to Bayrock and Reimchen (1975), that is covered in thick till of continental origin. Between the 17 and 4 km marks, the floodplain typically widens along one bank with a confining feature along the other. Below the 4 km mark, the channel gradient remains consistent and the floodplain narrows.

In summary, a rapid analysis of the digital landscape (including hillslope, floodplains and stream channels) highlights the sequence of different natural erosion processes operating along the course of Todd Creek. Gullies in the upper reaches are steep enough to generate landslides. Debris from such events has accumulated to form an apron of coalescing alluvial fans. Channels appear to be incising into the upper fan while continuing to develop the lower fan. Channel gradient increases downstream of a knickpoint near the midpoint of the watershed. Erosion processes including slumping and undercutting of toe slopes are expected downstream of the knickpoint, where in channel is confined. Downstream from the 11 km mark, the Todd Creek valley gradually increases in depth in relation to the adjacent uplands. At the stream mouth the valley is 30 m deep, typical of other coulees in the region.

3.2.1.6 Summary of Sensitive Landforms in Todd Creek watershed

The review of watershed characteristics for Todd Creek revealed three specific regions in the watershed are inherently sensitive to impacts (Figure 8). These locations could be flagged for a field review to determine present status or closely considered when assessing potential impacts of any proposed developments.

Table 6. Sensitive landforms in Todd Creek watershed.

Location	Description of sensitivity	Reference map
1. Active alluvial fans	This is a very dynamic part of the watershed. The channel is expected to migrate laterally across the fan in response to deposition of debris from upstream or on-site erosion.	See the western extent of fine stream alluvium in Figure 13.
2. Wetlands	Typical of all wetlands, the low gradient reaches of Todd Creek and its tributaries located upstream from the Tetley Fault are sensitive to a wide range of impacts.	In Figure 24 see the floodplain upstream from the Tetley Fault. Also see Figure 26.
3. Confined mainstem channel	Downstream from the Tetley fault, Todd Creek is contrained on either one bank or both banks. Todd Creek will continue to erode it banks in such locations. Loss of vigorous riparian vegetation will likely increase erosion rates in these areas.	See Figure 24.

3.2.2 Spatial Distribution of Values and Pressures

3.2.2.1 Native Fish and Fish Habitat in Todd Creek

Although a number of fish species inhabit the study area, this assessment focuses on two native salmonids of management concern – westslope cutthroat trout, and bull trout. Westslope cutthroat trout are listed both federally and provincially as threatened (Alberta Sustainable Resource Development and Alberta Conservation Association 2006; Committee on the Status of Endangered Wildlife in Canada 2006). Bull trout are listed provincially as a species of concern (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). Status of westslope cutthroat trout distribution and population levels has been studied extensively in Alberta (Cleator et al. 2009).

The spatial fish habitat model developed by Peterson et al. (2008) for predicting spawning and rearing habitat for westslope cutthroat trout was applied to the Todd Creek watershed. Temperature was based on recorded values from summer baseflow fish inventories from FWMIS sites for Todd Creek (rated as optimal), and habitat size was characterized using the wetted width model (Figure 18). In the remainder of this section, fish inventory records and model outputs are compared.

Westslope cutthroat trout are widely distributed in the headwater streams within the western portion of the Todd Creek watershed, but have also been captured downstream near a road crossing close to the mouth (Figure 27). Westslope cutthroat trout from within one of the tributary streams in the western half of the study area are a genetically pure strain (pers. comm. M. Coombs, Alberta Environment and Sustainable Resource Development 2013). None of the westslope cutthroat trout locations from FMWIS were located on colluvial channels – all were on fluvial channels that are shown with spawning and rearing habitat value assigned (Figure 27). Although some high value habitat is predicted within tributaries that enter Todd Creek in the eastern half of the watershed, the lower elevation and reduced shading from rangeland vegetation may create a temperature regime above optimal for westslope cutthroat. These maps highlight the locations of valuable habitat for a threatened species for specific consideration when evaluating channel sensitivity to disturbance arising from land-use.

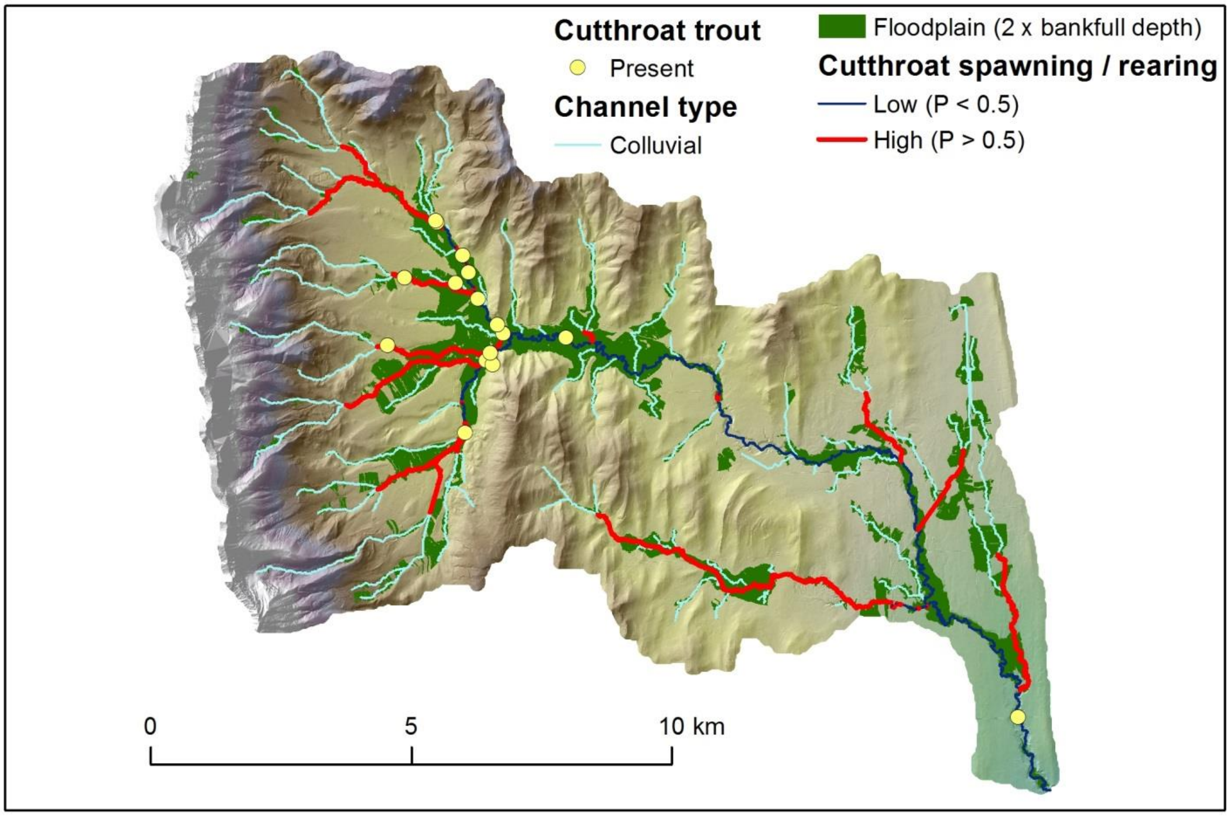


Figure 27. Map of westslope cutthroat locations within Todd Creek from FWMIS database, predicted spawning and rearing habitat value for fluvial channels based on Peterson et al. (2008), and predicted extent of 50 year floodplain.

3.2.2.2 Water Quality – Suspended Sediment

This section reviews that data on areas of bare ground that will be available for the surface erosion analysis. The three sources of interest are roads, trails, and other areas of bare ground.

The roads layers for Todd Creek was found to be complete when compared to the bare earth DEM and orthophotos; however, although ATV trails are known to follow cutlines, there was no way to discern the location of any ATV trails that presented an erosion risk.

To identify other locations with active erosion in Todd Creek, a sediment source/sink survey was conducted based on features that were readily discernible on orthophotos. Infrared orthophotos proved very helpful for identifying specific locations with bare ground and riparian areas with low vigor. The upper watershed contains two types of naturally occurring bare ground rock fall and gullies (Figure 28). The middle and lower basin contains at least 18 bared areas where land-use has either created or accelerated surface erosion (Table 7 and Figure 28).

Table 7. Description of bare ground polygons along the long profile channel in Todd Creek including type, distance to stream, and area.

Number	Type of bare ground	Distance to stream (m)	Area (ha)
1	non-vegetated livestock feeding area	10	0.10
2	non-vegetated livestock feeding area	5	0.67
3	non-vegetated area near settlement	20	0.65
4	non-vegetated livestock feeding area	200	2.95
5	non-vegetated livestock feeding area	5	0.20
6	non-vegetated area near settlement	0	0.01
7	non-vegetated valley wall, no slumping	0	0.06
8	non-vegetated valley wall, no slumping	0	0.07
9	non-vegetated valley wall, no slumping	0	0.16
10	non-vegetated valley wall, no slumping	0	0.12
11	non-vegetated valley wall, no slumping	0	0.04
12	non-vegetated valley wall, no slumping	0	0.35
13	non-vegetated valley wall, no slumping	0	0.17
14	non-vegetated livestock feeding area	20	0.02
15	non-vegetated livestock feeding area	10	0.05
16	non-vegetated livestock feeding area	60	0.08
17	non-vegetated livestock feeding area	5	0.48
18	non-vegetated livestock feeding area	0	0.12

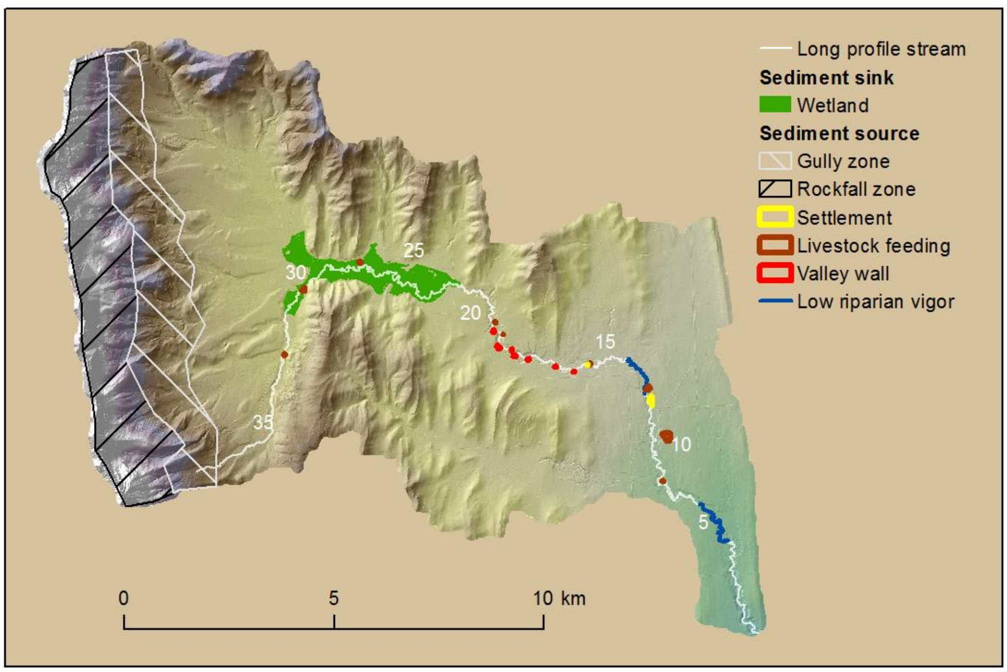


Figure 28. Map of sediment sources and sediment sinks based on analysis of Government of Alberta 2006 digital colour infrared orthophotographs. Note, the sediment source survey focused on the main long profile stream and did not cover the other tributaries.

3.2.2.3 Water Quality - Pathogens
Livestock feeding areas in close proximity to a stream present potential pathogen sources. A total of nine such feeding areas of varying size and distance from the stream were noted along the long profile channel (Table 7).

3.2.2.4 Recreational Use – Random Camping
No information on random camping locations was available for Todd Creek.

3.2.2.5 Recreational Use – ATVs
No information on ATV trails was available for Todd Creek.

3.2.2.6 Capital Improvements – Buildings and Other Facilities
In Todd Creek, all private and public capital improvements on the floodplain, especially those located on the active alluvial fan may be at risk from watershed processes. Information on type and location was not obtained for this assessment.

3.2.2.7 Evaluation of Data Layers required to complete the CWEA
The data layers sufficient to proceed with a Level 1 CWEA include roads, fish habitat, and areas of bare ground (Table 8). In order of importance for the Level 1 CWEA, the data gaps include riparian health assessments, capital improvements crossings and buildings, and ATV trails.

Table 8. Summary of the three elements of the cumulative watershed effects assessment (values, watershed inputs, watershed process group) and data required to complete the analysis.

Watershed value	Relevant watershed process group and type	Data source	Data quality	Data suitable for use in the CWEA?	Action to acquire suitable data
Capital improvements: roads	Erosion – surface erosion	AESRD	Good	yes	
Capital improvements: crossings	Upstream fish migration	None	NA	No	Acquire crossing type data
Capital improvements: building	Inundation	None	NA	No	Acquire data
Native fish and fish habitat	All	AESRD and Peterson et al. 2008	Good	Yes	
Water quality	Erosion – surface erosion of roads and bare areas. Riparian veg modification	AESRD road layer. Sediment source survey. Riparian health – no data. Trails no data.	Roads – good. Bare areas good.	Yes for roads and bare areas. No for riparian health and ATV trails.	Consult advisory team to determine status of ongoing riparian health assessment program on public and private lands. Consult advisory team to determine if ATV trails are known risk in Todd Creek.
Recreational use random camping					Todd Creek is not designated for random camping.

3.3 Risks to Watershed Values from Erosion and Altered Riparian Processes

3.3.1 Roads on Floodplains

In Todd Creek, most of the roads located within floodplains occur in the large wetland in the western half of the study area (Figure 29). Of the road types, the unimproved class has the greatest length in floodplains (Table 9). These roads typically provide access to residences and ranch facilities that tend to lie within sheltered areas along valley bottoms. Field visits are required to confirm impacts and to identify remediation opportunities.

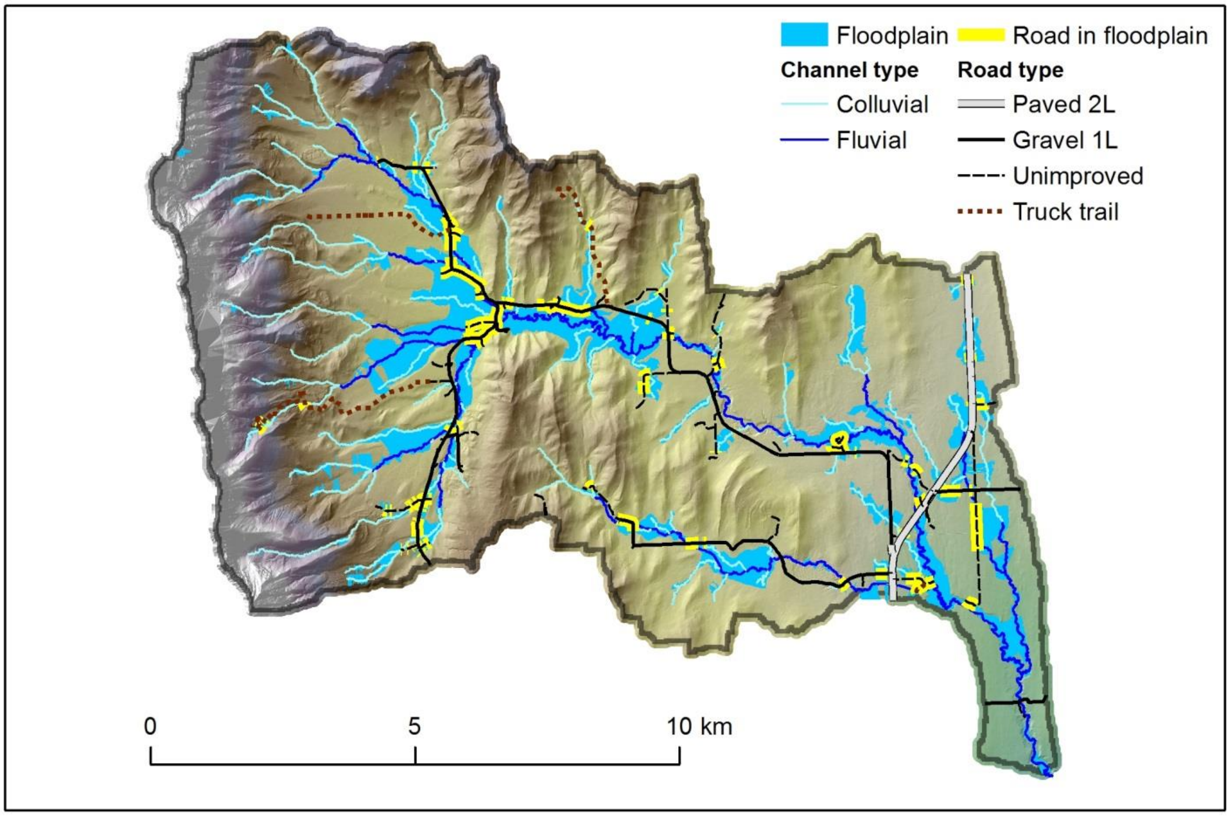


Figure 29. Map of Todd Creek watershed showing roads, by type, located within a floodplain.

Table 9. Summary of road by type including total length and length in floodplains.

Road type	Total length (km)	Length in floodplain (km)	Length in floodplain (%)
Paved - two lane	6.8	0.7	10.5
Gravel - one lane	31.1	6.5	20.8
Unimproved	25.5	7.2	28.2
Truck trail	11.3	0.6	5.6
Total	74.6	15.0	20.1

3.3.1.1 Sources of Error – Floodplains

There are two potential sources of error in the floodplain map for Todd Creek. First, in several instances, the true floodplain is excluded from the map where major road fill slopes are located. For example, although a one-lane gravel road does cross Todd Creek near the mouth, and the large road fill extends across the floodplain, this site was not identified as a location where a road is located within a floodplain. In this case, the road prism itself is built up much higher than the stream and was excluded from the floodplain map. If identification of large fill slopes within floodplains is important, the floodplain map should be modified to include such areas. Second, in the open rangelands of the eastern half of the study area, roads are shown within the active floodplain where there may be no open channel or true floodplain. This source of error can be addressed by calibrating the channel type map using information on channel head locations specific to the study area.

3.3.2 Streambed Alterations at Culverts and Motorized Vehicle Fords

As an overview, there are 72 crossings in Todd Creek (Figure 30). Three categories were set, including crossings in colluvial channels, crossings in fluvial channels with a low rating (e.g., P < 0.5) for westslope cutthroat trout spawning and rearing, and crossings in fluvial channels with a high habitat rating (e.g., P > 0.5). The respective count within these categories was 41, 18 and 13. Information specific to the type of crossing (e.g., culvert, bridge, and ford) at each road-stream intersection is required to proceed with a more detailed risk analysis.

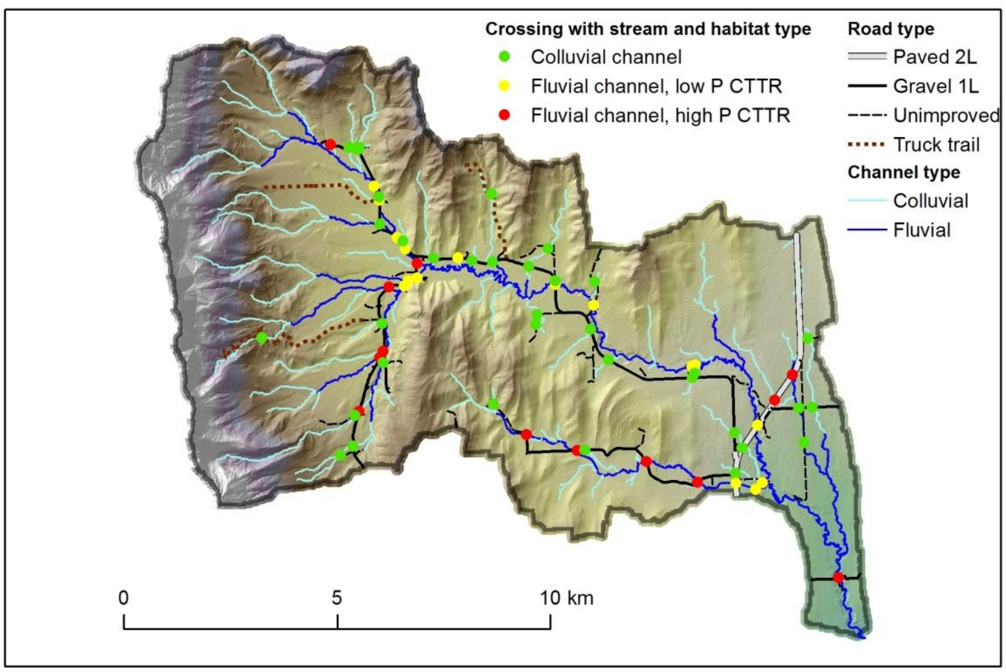


Figure 30. Map of Todd Creek with stream crossings by channel and fish habitat type, road types and channel types.

3.3.3 Todd Creek Road Erosion

Using NetMap Road Tools including, Road Drainage Diversion and Road Surface Erosion (WEPP), we developed models to predict sediment production to streams from all roads in the Todd Creek watershed (Figure 31A). This analysis is presented in three sections including sources of error, detailed review of one location, and a basin-scale overview. A detailed error assessment was warranted because this project is the first test of NetMap tools using a high-resolution DEM (e.g., 1 m) while many of the tools were developed and previously tested within areas that use low-resolution DEMs (e.g., 10 m).

3.3.3.1 Sources of Error – Road Erosion

The first step in the erosion analysis entailed using the Road Drainage Diversion tool to convert the Todd Creek roads layer into a format suitable for erosion modelling. This tool splits the road layer at all drainage points, including all intersection points, with the raw LIDAR network and any other topographic lows (Earth Systems Institute 2013). Roads are also split at topographic high points. Then the Road Surface Erosion tool was used to estimate sediment yield from individual road segments and to route the sediment into the nearest connected reach. The output layers were examined for three potential sources of error including inaccurate slope values, artificially shortened road segments, and artificially shortened reach lengths.

First, the main source of error in GIS-based road surface erosion is misalignment between the road and the DEM – a problem potentially amplified by the use of low resolution DEMs (Benda 2012). In Todd Creek, only 1 % of all roads had a slope greater than 12 %, and of these many were plausible based on road type and location. In comparison, in the Clearwater River watershed, where a 10 m DEM was used, approximately 10 % of all roads had gradients greater than 12 % that were considered spurious. These improved results in the Todd Creek project can be attributed to the high resolution DEM with close road alignment. In addition to a statistical comparison of road segment slope, a location of high erosion risk (gravel road with high traffic, steep road segments, in vicinity of highly sensitive habitats) within Todd Creek covering about 0.5 km2 was examined (Figure 31B). This section of road was identified as a potential high sedimentation risk during a field reconaissnace. The slope values for this vicinty that were generated from the Road Drainage Diversion tool all seemed plausible. In addition, a map of road segment slope that includes informatino on sensitive aquatic habitats, in and of itself, can provide a preliminary means to identify those road segments with a potential high sedimentation risk.

Inaccurate road segment length is a second potential source of error in GIS-based road surface erosion modelling. In the Clearwater River roads analysis project, with an average road segment length of 133 m, road erosion predictions were reasonably close to field measures (Benda 2012). For the Todd Creek analysis, average road length was almost half as long at 77 m (e.g., Figure 31B). The shorter length may be an artifact of using the extremely dense full LIDAR network (Figure 17) to split the roads, or it could accurately reflect improved detection of drainage points at topographic lows. Because segment length is one of the driving factors in road erosion modelling (Flanagan and Livingston 1995), and this project represents the first application of the NetMap road erosion tools using a high-resolution 1 m DEM, a review of the road segment length outputs from the Road Drainage Diversion tool was warranted. When we compared predicted sediment yield and slope by road segment, we noted that total yield for short steep segments was lower than expected and typically were not flagged during mapping exercises; however, when we standardized total yield by road length (Figure 31C), the effect of any potential artificial shortening of road length was diminished. Thus, when the purpose of the road erosion modelling is to flag high risk road segments rather than to accurately predict sediment input, and until such outputs can be field validated, the use of a standardized total yield (e.g., yield/segment length) for the Level 1 analysis is supported.

Artificially shortened reaches present a third potential source of error when conducting road surface erosion modelling. This is only a concern when the analyst selects the option in the Road Surface Erosion tool that predicts the quantity of sediment that will be routed from an individual road segment to the nearest stream. When average reach length is several hundred metres, a resultant map over large areas can allow the user to visually identify sections of stream with high predicted sediment inputs; however, for Todd Creek, where reach lengths averaged 10.4 m, the user must zoom into the area of interest in order to see any potential "hot spots" (Figure 31C). This problem can be countered by first selecting all reaches with high aquatic habitat value, then sub-selecting only those high habitat value reaches that also have high sediment input values. This process has been automated within the NetMap Spatial Overlaps tool.

In summary, of the three potential sources of error within the NetMap roads tools, two are a concern, and within the Level 1 analysis, both can be addressed so that useful information is developed. Inaccurate road segment slope values were not flagged as an obvious concern with the 1 m DEM. This result can also be attributed to the close alignment of the roads layer and the DEM. The second issue, artificially shortened road segments can be partially addressed by standardizing sediment yield predictions by road segment length. The third issue, artificially shortened reach segments, can also be mitigated by reviewing high resolution local-scale maps rather than regional-scale maps, and also by using overlap techniques to mathematically identify stream reaches with high aquatic habitat values that also have high predicted sediment input values.

3.3.3.2 Example One Lane Gravel Road near Westslope Cutthroat Trout habitat

The output from the Road Drainage Diversion tool includes a measurement of road slope by segment. Because segment slope and segment length are main drivers in erosion modelling, this information provides a preliminary indication of portions of the road network that present sedimentation risk to sensitive aquatic habitats (Figure 31B).

For the Road Surface Erosion Required model variables include road (or trail) hydrologic connected length (flow along the road to drain points or stream channels), road gradient, width, surface type, traffic level (high to low), design (inslope, outslope), soil type, and hillslope distance and gradient to the nearest stream (Flannigan and Livingston 1995). Due to its multiple crossings over high value westslope cutthroat trout habitat (Figure 31A), relatively high traffic levels, and regular road maintenance, the main one-lane gravel road is of specific concern. The road branches off the paved highway and follows the Todd Creek mainstem until the fork, at which point the road continues southward off the bottom of the map (Figure 31A). Although the road surface erosion model has been applied and validated in watersheds with a 10 m DEM (e.g., Benda 2012), the Oldman project represents the first application of the models with a 1 m high-resolution LIDAR-derived DEM. Average road segments lengths and stream reach lengths within the Todd Creek watershed were 77 and 10 m respectively ¬ values much shorter than those from 10 m DEM projects. The short road segment lengths allowed close examination of road slope values and a preliminary assessment of erosion risk for a location know to support genetically pure westslope cutthroat (Figure 31B). Predicted road erosion was rated as low, medium, or high for individual segments and then conveyed to the nearest reach for a similar sediment input rating (Figure 31C). The highly localized sediment input reaches (Figure 31C) are an artifact of the short reach lengths. These maps highlight the specific segments of the busiest gravel road that present a sedimentation risk to high value habitat. The next step is to complete the field validation of the model predictions, including a model sensitivity analysis to evaluate different road segment and reach lengths. Overlaying the predicted road surface erosion with westslope cutthroat spawning and rearing habitat was used to identify provisional hotspots where the sediment stressor intersects quality fish habitat (Figure 31). If validated, the predictions could be used to design and implement sediment reduction activities at specific locations, those areas that would yield the greatest benefit to fisheries.

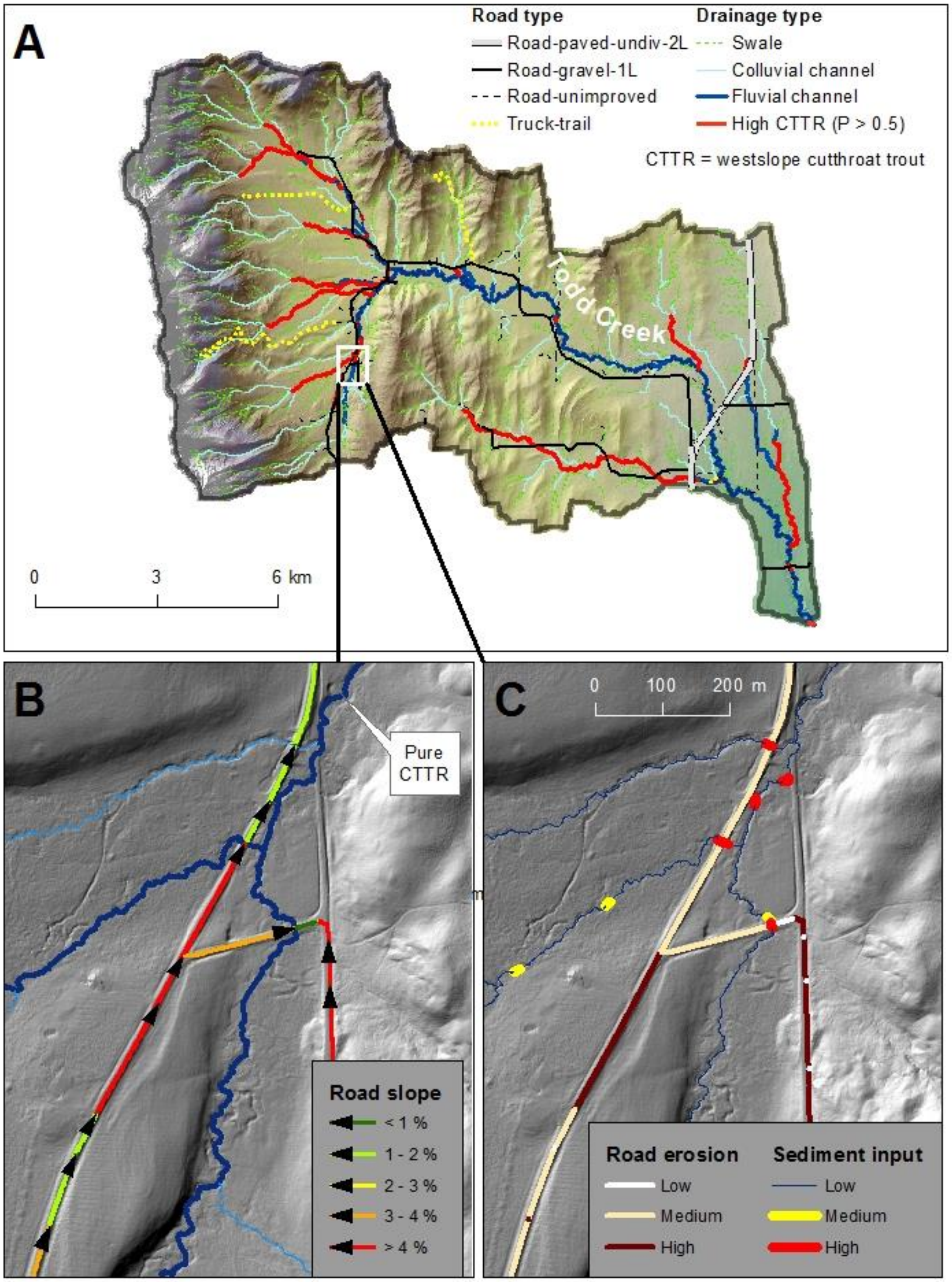


Figure 31. Map of the road and stream networks in Todd Creek with: (A) all roads by type and streams with drainage type including fluvial channels with a high probability of westslope cutthroat trout (CTTR) spawning and rearing habitat (extent window shows location of Maps B and C); (B) streams by drainage type and outputs from the Road Drainage Diversion tool including slope class for individual road segments within a location known to support a pure strain of CTTR; and (C) outputs from the Road Surface Erosion (WEPP) tool including predicted road erosion by road segment (standardized by segment length) and predicted sediment input from road segments to individual stream reaches.

3.3.3.3 Basin-Scale Overview by Road Type

Numerous assumptions complicated the interpretations of WEPP road surface erosion models across entire watersheds with various road types (see Section 3.3.3.1 Sources of Error – Road Erosion). Therefore, this overview of erosion risk relies entirely upon maps of road slope – a dominant factor determining annual sediment production.

When the slopes of the three different types of roads in the western half of Todd Creek are compared, it is apparent that each type has specific areas of high risk (Figure 32). Average road slope increases across the three types, highlighting the need for proper road design and drainage in any logging roads planned for the western portion of the basin (Table 10).

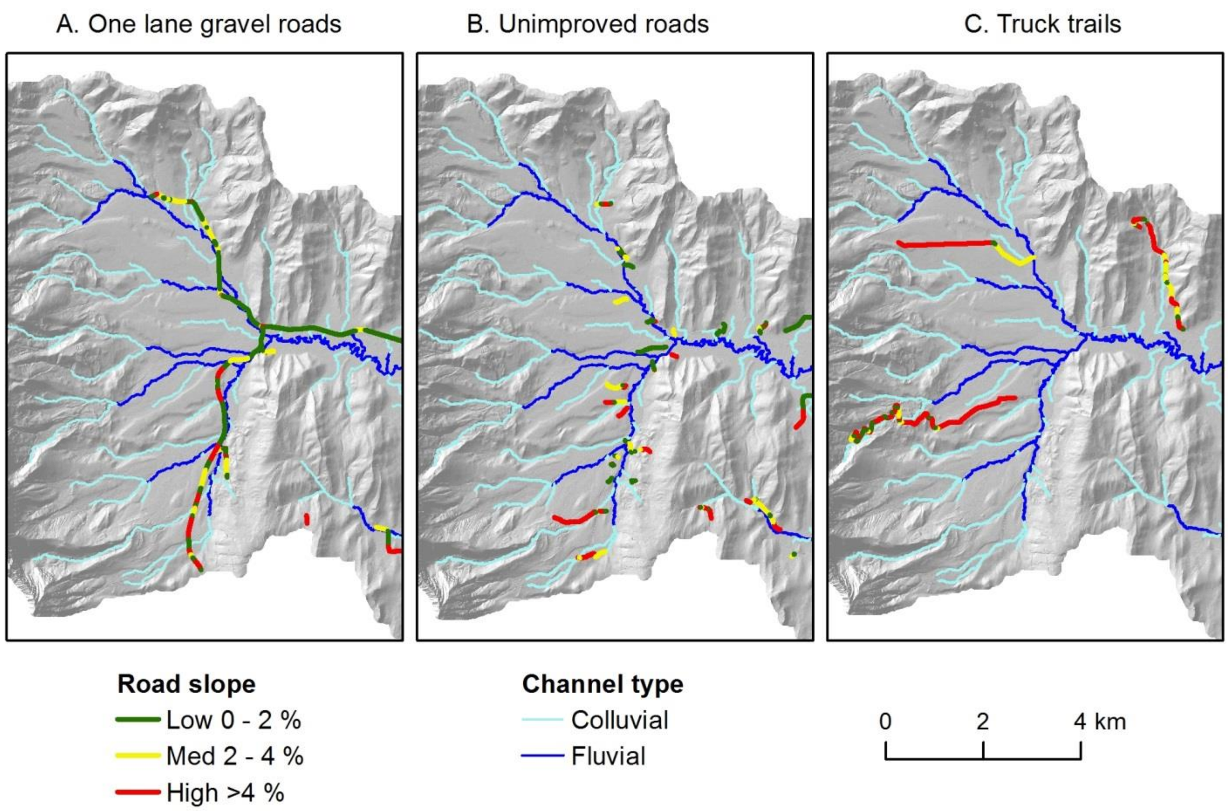


Figure 32. Maps of road slope categories and channel types for (A) one-lane gravel roads, (B) unimproved roads, and (C) truck trails.

Table 10. Summary of road type by road slope class for Todd Creek watershed.

Road type	Slope Class						Avg. slope	Total (km)
	Low slope (<2 %)		Medium (2-4 %)		High (> 4%)			
	km	%	km	%	km	%		
One-lane gravel	17.6	56.6	8.2	26.3	5.3	17.1	1.5	31.1
Unimproved	11.2	44.1	7.4	28.8	6.9	27.1	2.9	25.5
Truck trail	0.5	4.0	3.2	28.3	7.6	67.7	4	11.3
Total	29.3	43	18.8	28	19.8	29		67.9

3.3.4 Todd Creek Erosion on Bare Ground

A simple risk assessment was completed based on the type of bare ground and its location in terms of the floodplain. The three categories includied (1) areas of bare ground above the floodplain, (2) bare areas due to settlement located on the floodplain, and (3) areas of bare ground for livestock feeding (Figure 33). The latter present an obvious source of both sediment and pathogens that could impact water quality. Of the eight areas of bare ground, two were settlement areas and six were for livestock feeding.

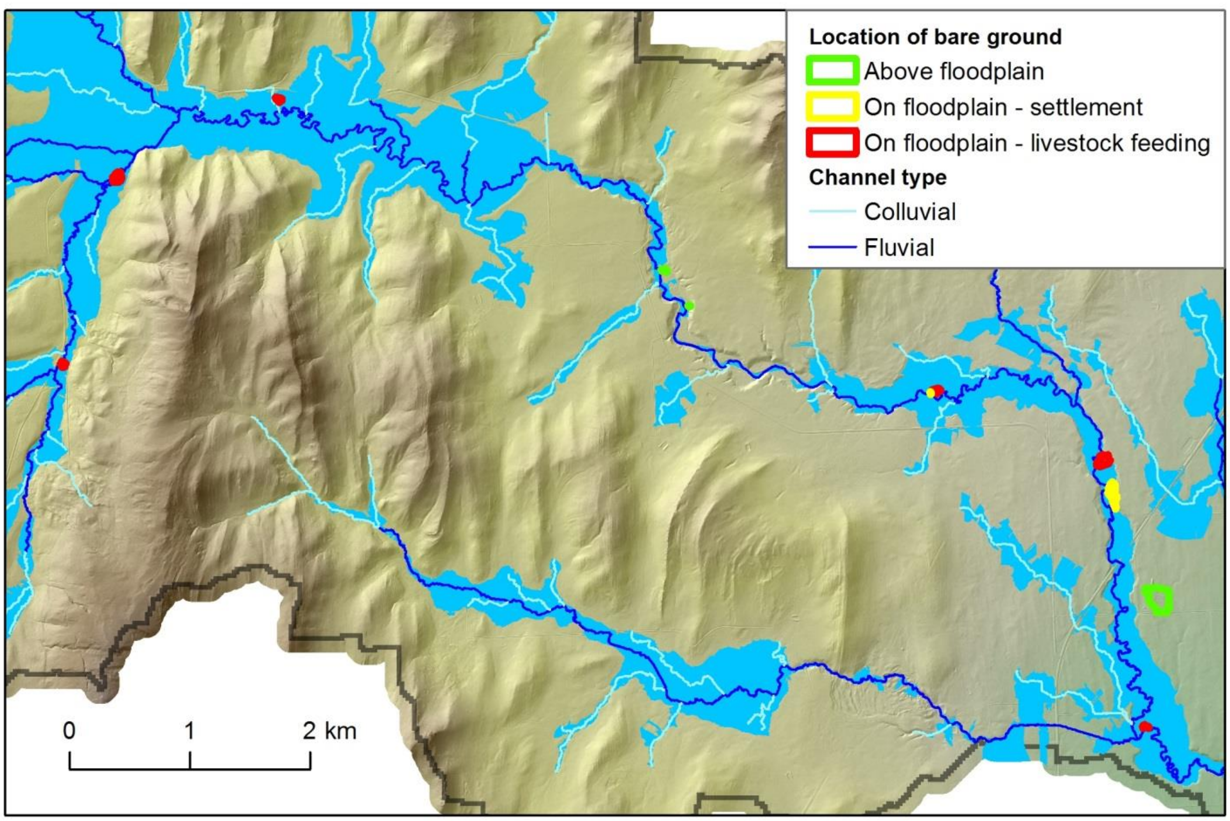


Figure 33. Map of location and type of bare ground on floodplains for Todd Creek watershed.

3.3.5 Summary of Risks

This desktop analysis identified a number of potential risks to watershed values. The next steps include communicating results to stakeholders and if supported, complete field work to identify locations where these risks have translated into actual impacts (Table 11).

Table 11. Summary of risks to watershed values from erosion and altered riparian processes.

Risk	Extent	Next steps
Roads within floodplains	20.1 percent of all roads in the watershed lie within floodplain.	Communicate to stakeholders and determine interest in follow-up.
Streambed alterations at culverts and motorized vehicle fords	72 crossings in total with 13 in high value fish habitat.	Communicate to stakeholders and determine interest in follow-up. Complete stream crossing inspections.
Sedimentation from roads	67.9 km of road in the watershed. 29% of all roads have high slope class and present sedimentation risk.	Communicate to stakeholders and determine interest in follow-up. Inspect road segments with high slope to identify ongoing erosion and impacts.
Erosion of bare ground	8 sites with bare ground within the floodplain, including 6 livestock feeding areas that present potential sediment and pathogen sources.	Communicate to stakeholders and determine interest in follow-up. Complete site visits to identify potential for runoff and delivery of sediment and pathogens to stream channel.

3.4 Summary of Overview Assessment Results

The three summary tables from previous sections are replicated below. They include a summary of sensitive landforms (Table 12), values, pressures, data quality and gaps (Table 13), and a summary of risks (Table 14). These tables are intended to help guide the next steps that watershed stakeholders will take to achieve their specific management goals.

It is important to note that not all of the potential pressures on watershed values in Todd Creek are at the same stage in terms of risk analysis and management (Table 13). Such a pattern will continue into the future for any study area. Therefore, a CWEA should be considered as a work in progress, with datasets, analysis tools, and risk analysis maps available to interested stakeholders and managers for the purpose of achieving watershed management goals.

Table 12. Sensitive landforms in Todd Creek watershed.

Location	Description of sensitivity	Reference map
1. Active alluvial fans	This is a very dynamic part of the watershed. The channel is expected to migrate laterally across the fan in response to deposition of debris from upstream or on-site erosion.	See the western extent of fine stream alluvium in Figure 13.
2. Wetlands	Typical of all wetlands, the low gradient reaches of Todd Creek and its tributaries located upstream from the Tetley Fault are sensitive to a wide range of impacts.	In Figure 24 see the floodplain upstream from the Tetley Fault. Also see Figure 26.
3. Confined mainstem channel	Downstream from the Tetley fault, Todd Creek is contrained on either one bank or both banks. Todd Creek will continue to erode it banks in such locations. Loss of vigorous riparian vegetation will likely increase erosion rates in these areas.	See Figure 24.

Table 13. Summary of the three elements of the cumulative watershed effects assessment (values, watershed inputs, watershed process group) and data required to complete the analysis.

Watershed value	Relevant watershed process group and type	Data source	Data quality	Data suitable for use in the CWEA?	Action to acquire suitable data
Capital improvements: roads	Erosion – surface erosion	AESRD	Good	yes	
Capital improvements: crossings	Upstream fish migration	None	NA	No	Acquire crossing type data
Capital improvements: building	Inundation	None	NA	No	Acquire data
Native fish and fish habitat	All	AESRD and Peterson et al. 2008	Good	Yes	
Water quality	Erosion – surface erosion of roads and bare areas. Riparian veg modification	AESRD road layer. Sediment source survey. Riparian health – no data. Trails no data.	Roads – good. Bare areas good.	Yes for roads and bare areas. No for riparian health and ATV trails.	Consult advisory team to determine status of ongoing riparian health assessment program on public and private lands. Consult advisory team to determine if ATV trails are known risk in Todd Creek.
Recreational use random camping					Todd Creek is not designated for random camping.

Table 14. Summary of risks to watershed values from erosion and altered riparian processes.

Risk	Extent	Next steps
Roads within floodplains	20% of all roads in the watershed lie within floodplain.	Communicate to stakeholders and determine interest in follow-up.
Streambed alterations at culverts and motorized vehicle fords	72 crossings in total with 13 in high value fish habitat.	Communicate to stakeholders and determine interest in follow-up. Complete stream crossing inspections.
Sedimentation from roads	67.9 km of road in the watershed. 29% of all roads have high slope class and present sedimentation risk.	Communicate to stakeholders and determine interest in follow-up. Inspect road segments with high slope to identify ongoing erosion and impacts.
Erosion of bare ground	8 sites with bare ground within the floodplain, including 6 livestock feeding areas that present potential sediment and pathogen sources.	Communicate to stakeholders and determine interest in follow-up. Complete site visits to identify potential for runoff and delivery of sediment and pathogens to stream channel.

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