Oldman Watershed Headwaters Indicator Project

FINAL REPORT – Version 2014.1

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Executive Summary

As designated by the Watershed Planning and Advisory Council under Alberta's Water For Life, the Oldman Watershed Council (OWC) is mandated to develop a rigorous, understandable and scientifically-defensible framework for watershed assessment and reporting. This watershed assessment process must be transparent and repeatable, requiring the development of a set of standardized tools and reporting strategies.

The Oldman Watershed covers an area of approximately 23,000 km^2 in southwestern Alberta, covering three natural regions, including the Rocky Mountains, Foothills, and Grassland. The Headwaters Region of the Watershed is located along the eastern slopes of the Rocky Mountains, and maintaining the ecological integrity of this area is crucial to the health of the Oldman Watershed. As a result, the OWC has recognized the management of the Headwaters Region, with particular attention being given to source water protection as a priority goal. Therefore, the OWC has decided to focus the initial development of a watershed assessment framework specifically on the Headwaters Region. This framework will be tested and implemented in Headwaters Region as a first step, and then adapted and rolled out to the larger Oldman Watershed in future years. This project is the initial stage of the development and implementation of a watershed assessment framework for evaluating the watershed condition of the Headwaters Region. Specifically, the objectives of this project are to:

1. Develop a watershed assessment approach for standardized reporting on watershed and ecological condition that is relevant and meaningful in the context of local and regional stewardship initiatives in the OWC Headwaters Region
2. Evaluate and/or quantify a subset of watershed assessment indicators that will serve as an initial starting point for future management, research, and monitoring action
3. Develop an indicator rating scheme that will allow for the direct comparison of indicator condition across the Oldman Watershed on a go-forward basis.

The Oldman Watershed Indicators Headwater project used a Criteria & Indicators (C&I) conceptual framework to assess current conditions in the watershed. The five criteria developed were: Criterion 1: Landscape Composition and Condition; Criterion 2: Biological Diversity; Criterion 3: Surface Water Quality; and Criterion 4: Water Levels and Flow.

A preliminary list of 25 indicators was selected within these four criteria. The majority of these indicators are aspirational, and actually measuring, monitoring or reporting on all the indicators listed will require additional data and/or substantial effort by the OWC and other stakeholders. Five indicators which were relevant to identifying hydrologically significant areas or highlighting threats to source water and biodiversity maintenance in the Headwaters Region were selected for assessment. An additional constraint on selecting indicators for this current assessment was that information and/or data had to currently exist, and be freely available. The six indicators were: 1) Intact Landscapes; 2) Road Density; 3) Density of All Linear Features; 4) Sedimentation/Erosion Potential; 5)

Riparian Condition, and 6) Stream Flow Regime. The first four indicators listed here are pressure indicators, while the last two are condition indicators.

For the four pressure indicators, indicator data “modeling” was conducted. This entailed creating indicator models in a Geographic Information System (GIS) that allows for the visual presentation (mapping) of the data across defined 4th Strahler order sub-watershed boundaries. Pressure indicators were directly compared between 4th order watersheds by assigning a “pressure” rating to each indicator. These pressure ratings were derived from scientifically-based thresholds that were taken from empirical peer-reviewed research studies or government management documents. Each 4th order watershed was rated as being at Negligible Pressure, Low Pressure, Moderate Pressure, or High Pressure from human land-use activities for each of the four indicators.

Cows and Fish riparian assessment data was summarized at the scale of 11 large watersheds to examine the Riparian Condition indicator. Stream flow regime was assessed using measures related to the magnitude and timing of flow for this indicator, including: 1) total annual flow, 2) spring flow, 3) summer flow, 4) base flow (the lowest daily flow), 5) date of spring melt initiation, and 6) the date of the 1st peak of the hydrograph. Hydrographs are plots of the temporal variation in discharge, typically over a year. These flow measures were individually assessed for every available hydrograph, and the resulting time-series of flow measures over time were assessed for significant trends using the Mann-Kendall test. Results of the long-term pattern in flows were then used to evaluate if flow measures were decreasing, increasing or showing no change over the period assessed.

Results of the pressure indicator modeling demonstrate that varying levels of risk exist across the Headwaters Region. The Intact Landscape indicator highlighted the watersheds where extensive forestry activity has occurred. The three pressure indicators related to linear features (Road Density, Density of All Linear Features, and Sedimentation/Erosion Potential) all indicated that linear features pose a Moderate to High risk in many areas of the Headwaters Region. The stream flow regime indicators demonstrated that there is general pattern of declining flow magnitude for total flow, and in the spring, and that the initiation date of spring melt is occurring early in the year in many watersheds.

Finally, a Watershed Integrity Index (WII) was constructed to summarize the information from the pressure indicators (combining Criteria 1 – 3). Based on this assessment, many areas in the Headwaters are experiencing high amounts of human land-use, and maybe be demonstrating significant biological and ecological impairments. This report also identifies data and knowledge gaps in the Oldman Watershed, with recommendations on future research and management priorities. In conclusion, this report provides a preliminary *large-scale* overview of the hydrological condition, and various human land-use factors (pressure indicators) that may be impacting the ecological condition of the watershed. Importantly, this Headwaters Indicators project should not be considered a definitive statement on the condition of the Headwater Region of the Oldman Watershed, but rather, a starting point for further management, research, and monitoring action.

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Report Disclaimer

This report represents a preliminary assessment of the status and ecological integrity of the Headwaters Region of the Oldman Watershed. Importantly, this Headwaters Indicators project should considered a starting point for further management, research, and monitoring action, and be viewed as a first step in creating a rigorous and robust watershed assessment framework within the larger Oldman Watershed. It is based on the best available science, research, and spatial data products. The assessment conducted in this report relies heavily on research pertaining to the responses of the wildlife and other biodiversity to human activity on the landscape. For many aspects of watershed health, the information required for a more thorough watershed assessment is either insufficient or is not accessible. Finally, this reports documents knowledge and data gaps hindering watershed assessment in the Headwaters Regions, and the OWC will work to address these in future updates of this report.

1. Watershed Assessment

Water is fundamental to all aspects of human life, prosperity, and ecological integrity in Alberta. The crucial role of water in the long-term sustainability of both human life and the environment is recognized by the Alberta Water for Life Strategy (Government of Alberta 2008). Maintaining healthy aquatic ecosystems, a secure supply of drinking water, and a secure supply of water for a sustainable economy are main goals of the strategy. A key approach to achieving these goals is through the establishment of Watershed Planning and Advisory Councils (WPAC's) for each major watershed in the province.

The role of WPACs is to provide guidance to the government on the management of water and watershed health. One of the major tasks of WPACs is to report on the current ecological state of the watershed using available and accessible monitoring data to identify major threats and concerns, and potential problems to water quality, water supply, and biodiversity. The Government of Alberta has developed guidance documents for watershed assessment (AENV 2008a, AENV 2008b) which provide general recommendations on environmental indicators that can be used to measure and monitor watershed conditions as part of an adaptive ecological management system. However, it is the responsibility of each WPAC to develop a rigorous, understandable and scientifically-defensible framework for watershed assessment and reporting, tailored to the specific needs and human land-uses existing within each watershed. Moreover, this watershed assessment process must be transparent and repeatable, requiring the development of a set of standardized tools and reporting strategies (Alberta Environment 2008a, Davies and Hanley 2010).

The end goal of the watershed assessment process is to inform government and the public about the condition of a watershed relative to what is desired, and secondarily to monitor the effectiveness of environmental mitigation and management activities over time (Alberta Environment 2008b). Typically, determining the "desired condition" of the watershed is done in a collaborative process that includes participation from scientists and stakeholders specific to each watershed. In Alberta, watershed assessments are benchmark tools that are designed to give decision makers and communities scientifically rigorous information for use in making decisions about the integrated management of land and water resources (AENV 2008a, Davies and Hanley 2010). Integral to the process is the concept that watershed assessment is iterative and repeated regularly on a define time interval. This framework allows for:

1. Regular updates on the ecological condition of watershed,
2. A comparison to previous watershed assessments to identify areas with improvement, areas that have not improved, or new threats.
3. A comparison of watershed condition to be made among smaller watersheds (i.e., tertiary watershed) within a larger watershed (i.e., river basin).

The Oldman Watershed Council (OWC) is currently in the process of developing an Integrated Watershed Management Plan (IWMP) and has set 8 goals for the IWMP to achieve:

Goal 1: Improve the understanding and strengthen the commitment of residents to the health of the Oldman watershed.

Goal 2: Optimize the availability of water for the natural ecosystem while supporting the social and economic needs of the community.
Goal 3: Manage and protect the integrity of headwaters and source waters.
Goal 4: Identify and prioritize thresholds to manage threats and impacts on terrestrial and aquatic habitat.
Goal 5: Understand groundwater and how it interacts with surface water.
Goal 6: Identify water quality outcomes and assess factors impacting them for adaptive watershed management.
Goal 7: Prevent and control invasive species.
Goal 8: Understand the status and implications of emerging contaminants.

These 8 goals encompass critical pieces of a watershed including surface water quantity and quality, habitat, groundwater and biodiversity. An IWMP is intended to respond to the needs and wishes of the community and thus the 8 goals reflect the top priorities of the community. As part of the IWMP, a priority goal for the OWC is the management of the Headwaters Region, with particular attention being given to source water protection (OWC 2011). As a result, the OWC has decided to focus the initial development of a watershed assessment framework specifically for the Headwaters Region of the Oldman Watershed (Goal 3). This framework will be tested and implemented in Headwaters Region as a first step, and then adapted and rolled out to the larger Oldman Watershed in future years. This project is the initial stage of the development and implementation of a watershed assessment framework for evaluating the watershed condition of the Headwaters Region. Specifically, the objectives of this project are to:

1. Develop a watershed assessment approach for standardized reporting on watershed and ecological condition. We are proposing a watershed criteria and indicators framework that is relevant and meaningful in the context of local and regional stewardship initiatives in the OWC Headwaters Region;
2. Evaluate and/or quantify a subset of watershed assessment indicators that will serve as an initial starting point for future management, research, monitoring, and guiding local stewardship action in the Headwaters Region;
3. Develop an indicator rating scheme that will allow for the direct comparison of indicator condition across the Oldman Watershed on a go-forward basis.

2. The Oldman Watershed

The Oldman Watershed covers an area of approximately 23,000 km^2 in southwestern Alberta, with an area of approximately 2,100 km^2 extending south into northern Montana (Figure 1; OWC 2010). The Watershed consists of three Natural Regions, including the Rocky Mountains, Foothills, and Grassland, which are divided into seven Natural Subregions: Alpine, Subalpine, Montane, Foothills Fescue, Foothills Parkland, Mixedgrass and Dry Mixedgrass.

The Headwaters Region of the Watershed is located along the eastern slopes of the Rocky Mountains (Figure 1) and maintaining the ecological integrity of this area is crucial to the health of the Oldman Watershed. The eastern boundary of the headwaters region in this project is defined by major highways, and it should be noted that montane areas extend outside the study area. The Headwaters Region is characterized by a high density of small streams and rivers that flow from high-elevation alpine and subalpine areas, down towards lower elevation montane regions. The accumulation of snow in the

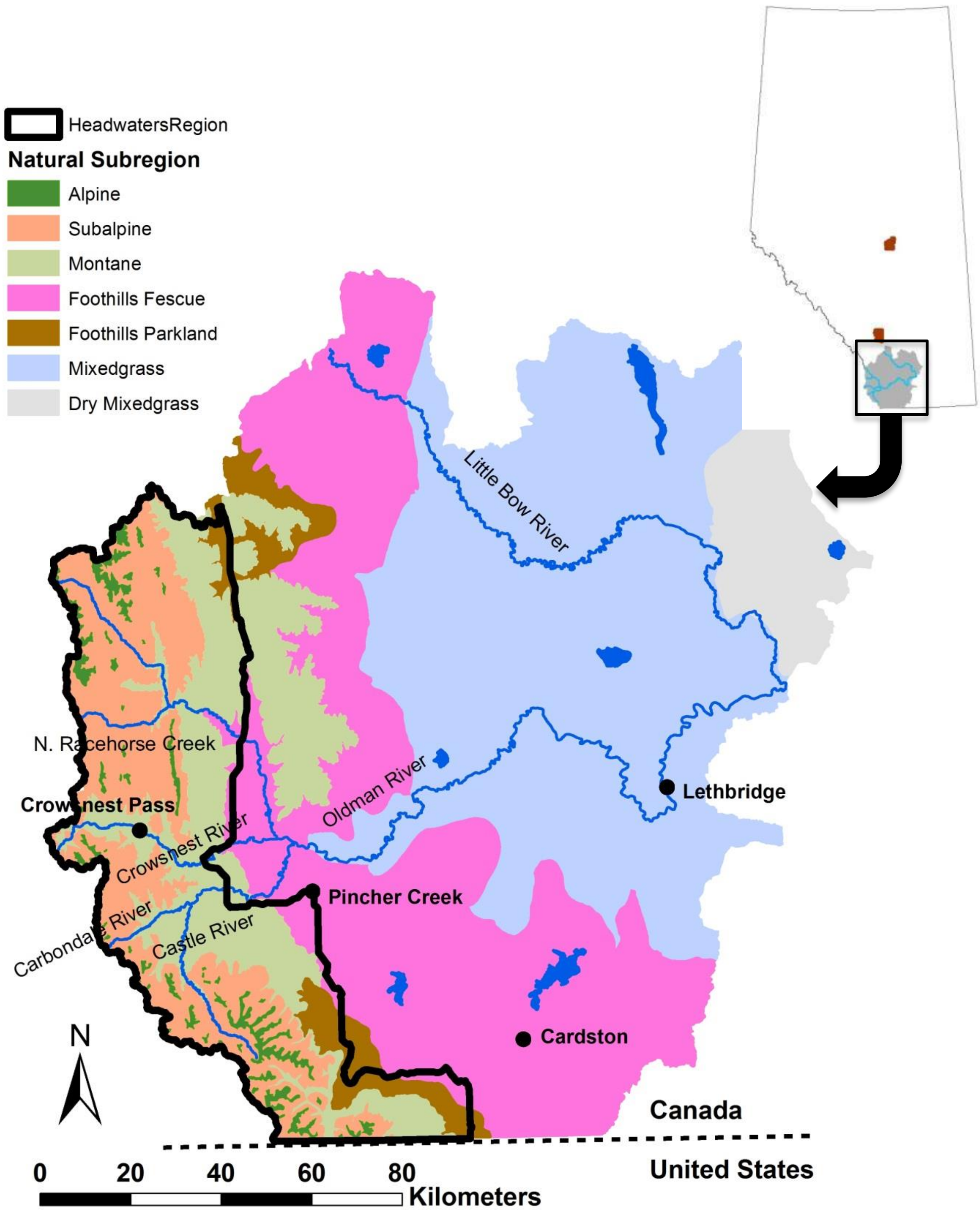


Figure 1. Location of the Oldman Watershed and the Headwaters Region in the province of Alberta. For this project the eastern boundaries of the Headwaters Region are delineated along Highways 22, 3 and 6.

alpine and subalpine regions is the primary source of water for the majority of the watershed (Crowsnest, Oldman, and Castle Rivers), with the Headwaters Region contributing approximately 75% of the total flow to the Oldman River (OWC 2010). The Waterton and Belly Rivers in the southern portion of the Watershed originate from Glacier National Park in Montana.

Forestry is the dominant industrial activity in the Headwaters Region, with forest harvest operations concentrated in areas along Livingstone Creek, upper Oldman River, the central Castle River, and along the tributaries flowing into the upper Crowsnest River (including Allison Creek, Star Creek, McGillvary Creek, Nez Perce Creek, Blairmore Creek and Todd Creek). Cattle grazing is the dominant agricultural land-use, with grazing leases issued throughout the Headwaters Region (including in alpine areas). Some crop and hay production occurs along the eastern boundary of the Headwater Region at lower elevations. Recreational activity is another major human disturbance in the Headwater Region, with off-road vehicle (ORV) use being widespread and concentrated in areas that have been previously disturbed by forestry and oil and gas operations. These industrial activities create a network of linear features (e.g., roads, haul-trails, seismic lines, and pipelines) that have been abandoned, and are now used as ORV trails.

3. Criteria and Indicator Framework

This project uses a criteria and indicators conceptual framework to evaluate the watershed integrity of the Headwaters Region. This approach is well established in forest and watershed management in Canada and the United States, and the resulting framework provides the Oldman Watershed Council with a set of overarching goals and objectives to help maintain the ecological integrity of the watershed (Davies and Hanley 2010; AEVN 2008b; CCFM 2005, 1995; EPA 1996, 1990). The criteria and indicators approach first identifies ecological *criteria* that are critical for maintaining watershed health, and second, identifies related *indicators* that can be used to evaluate changes in the selected criteria over time (Box 1; definitions adapted from CCFM 2005, 1995). The goal of using a criteria and indicator framework is to simplify and summarize complex ecological information to ensure ecological values are effectively communicated, such that this information can be better integrated into land-use planning policies and processes (CCFM 2005; Overton et al., 2002). This is accomplished using standardized rules to combine criteria and indicators into a Watershed Integrity Index (see Section 6).

Box 1. Criteria & Indicators Definitions

Criteria: A criterion is representative of a specific watershed element and embodies the collective conservation values and goals for management of the watershed. Criteria are categories of conditions or processes that characterize the aquatic environment and can be used to evaluate watershed condition. Criteria are related to, and representative of, a specific watershed element (e.g. water quality, water quantity, etc.), are often narrative or aspirational, and embody the collective goals or objectives for the management of the watershed.

Indicator: An indicator is a measureable (quantitative) or descriptive (qualitative) variable that can be used to observe, evaluate, or describe trends as a criterion changes over time. Each specific indicator is associated with a parent criterion.

3.1 Criteria and Indicators Principles

The following principals were used by the Oldman Watershed Indicators Team (OWIT) to help guide the selection of criteria and indicators for the Oldman Watershed:

1. **Ecologically relevant**: Criteria and indicators must provide a meaningful measure of ecological integrity and watershed health, and should be useable in the short-term (i.e., information is available within the past 5 years, which provides a snap-shot of current conditions) and over the long-term (i.e., appropriate for long-term trend analysis (typically requiring a minimum of 20 years of data).
2. **Meaningful and relevant to the public**: Criteria and indicators must be reflective of the views and management goals of the Oldman Watershed Council, as well as other stakeholders in the watershed.
3. **Scientifically defensible:** Criteria and indicators must be scientifically rigorous and reflect the best and most current scientific understanding of watershed management. In addition, indicators must be scalable (i.e. meaningful at multiple spatial scales), repeatable, and effective (i.e. have sufficient power to detect temporal and spatial changes).
4. **Interpretable and understandable**: Indicators must be understandable by a broad audience and should convey information in a way that is accessible to managers, policy makers, and the general public.

3.2 Criteria Definition

The following four Criteria were selected by the Oldman Watershed Indicators Team to provide the basis for evaluating and managing the ecological integrity of the Oldman Watershed and Headwaters Region:

CRITERION 1: Landscape Composition and Condition

Watersheds are a natural functioning ecological unit on the landscape, and both terrestrial and aquatic systems are connected through transfers of energy, water, and matter (Lathrop et al. 2007). The integrity of a watershed is based on the overall physical condition of the watershed, including bedrock, landforms, soils, and drainage ways, within which transfers of energy, matter and water occur. Human activity alters these pathways, and can negatively impact ecosystems functioning, including modifying nutrient balances which can result in contamination of surface and ground water, lead to increased soil erosion and sedimentation, and deleteriously impact wildlife populations, demographics and movement (Brabec et al. 2002, Chapin et al. 2000; Weijters et al. 2008). One of the dominant human impacts globally is habitat loss, where the natural vegetation is removed, and converted to a human land-use (i.e. agriculture, urban/rural development, forestry, industrial development, linear features; Chapin et al. 2000, Booth et al. 2002, Brinkman 1997). Human land conversion alters the permeability of soils and ground cover to runoff water, with impervious surfaces (paved area or areas with extensive soil compaction) being particularly detrimental (Brabec et al. 2002). The change in soil permeability results in increased stormwater runoff and sedimentation loads. Concurrent with the impacts of human land conversion is the loss of natural habitat, such as forest, riparian areas and wetlands, which absorb and clean stormwater and other runoff, and provide critical habitat for wildlife. Hence, understanding landscape composition in a watershed is critical to assessing if a watershed can support healthy terrestrial and aquatic ecosystems, and maintain the long-term sustainability of wildlife populations and other biodiversity.

CRITERION 2: Biological Diversity
Biological diversity is defined as the variation of available habitats and species, and the genetic diversity within those species populations (Chapin et al. 2000). Biological diversity is considered to be a key component of watershed health because biological species have the ability to directly influence the physical environment and alter chemical and nutrient cycling in natural systems. In addition, biological communities and populations with higher species diversity are more resilient to ecosystem disturbance, pest-outbreaks, and disease (Balvanera et al. 2006; Chapin et al. 2000). Furthermore, interactions between species and their environment are complex, with many non-additive processes (e.g., bio-accumulation of chemicals) that are often difficult to understand and measure through physical factors alone (Dube et al. 2006). Thus, measuring and monitoring the health of biological populations and communities is a critical component of understanding and managing watershed condition.

CRITERION 3: Surface Water Quality
Surface water quality is a key concern for maintaining safe and secure drinking water sources for human communities, as well as for conserving and maintaining aquatic and terrestrial biodiversity (CCME 2007). A wide range of anthropogenic activities can impact surface water quality through both point and non-point sources. For example, the removal or clearing of vegetation can increase water velocity, water temperatures, and loadings of sediments, nutrients, and /or contaminants (Pike et al. 2009). Given the potential risks posed by contamination of surface water, the maintenance of surface water quality is a priority goal in the Oldman Watershed.

CRITERION 4: Water Levels and Flow
A key component of watershed health is the maintenance of ecologically significant water flows in lentic (i.e., wetlands and lakes) and lotic (i.e., creeks and rivers) systems (Poff and Zimmerman 2010). Aquatic and semi-aquatic organisms are adapted to intra-annual (i.e., within year) and inter-annual (i.e., between years) fluctuations in water flow and water level (Poff et al. 1997). Thus, when hydrological systems experience changes in water flow or water levels that are outside the range of natural variation, many organisms can be negatively impacted or may be completely lost from the system. Maintaining water flow and water levels within the natural range of variation is an integral part of any watershed management framework (Richter et al. 1996). The main threats to the maintenance of ecologically significant water levels and flows in the Oldman Watershed include changing climate regimes (e.g. change in the amount, timing, and type of precipitation), changes in land cover (e.g. forest harvest, linear features), and the uses of surface water for human consumption, agriculture, or industrial use (e.g. Forbes et al. 2011).

3.3 Indicator Properties and Selection

An indicator is a measureable (quantitative) or descriptive (qualitative) variable that can be used to observe, evaluate, or describe trends as a criterion changes over time. Indicators are very rarely measured or quantified directly; instead, surrogate measures, which can be measured directly, are selected to represent a given indicator. There are two types of indicators that are commonly used to evaluate watershed criteria: condition indicators and pressure indicators (Box 2; definitions adapted from CCFM

2005, 1995, and Davies and Hanley 2010). For any given criterion, multiple indicators may be selected to measure the current state of that criterion, or to quantify changes to a criterion over time.

Box 2. Definition of Indicator Types

Condition Indicators: Condition indicators measure the quality or quantity of ecosystem structure or function (e.g., riparian condition or health), or can measure changes in the structure or persistence of natural flora and fauna populations in response to a gradient of human disturbance.

Pressure Indicators: Pressure indicators focus on measuring the extent or intensity of natural or anthropogenic impacts or stressors (e.g. the density of roads) that pose a risk to ecosystems or ecosystem elements.

A total of 25 indicators were selected to represent and measure condition in the Oldman Watershed (Table 1 and Appendix A). It is important to note that there is no definitive or “correct” way of selecting or categorizing indicators as measures for any given criteria. This is because indicators are often related to one another, thereby resulting in an overlap of the ecological elements being measured or quantified for each criterion. Thus, it is possible that a single indicator may be representative of more than one criterion.

It must be recognized that the indicator list in Table 1 is a preliminary list of indicators. This list has been developed to use as a starting point for watershed assessment in the Oldman Watershed, and it is expected this preliminary list will be modified and refined as work progresses, and specific management goals or targets are developed. While all the indicators in Table 1 have been selected using scientific principles (as defined in Section 3.1), actually measuring, monitoring or reporting on all the indicators listed will require substantial effort by the OWC and other stakeholders. For many indicators (and the condition indicators in particular), appropriate data either does not exist at present or requires extensive effort to assemble the existing information into a suitable format. In addition to data limitations, a robust methodology and reporting approach needs to be developed for each individual indicator. As an example, there are multiple ways to assess and report on the condition of fish communities, and part of the reporting process requires tailoring these methodologies to the specific geography, geology, and community needs and data constraints existing in the Oldman Watershed (Einheuser et al. 2013, Weigel and Robertson 2007).

From the preliminary list of criteria and indicators, a subset of six indicators was selected to evaluate the condition of the Headwaters Region (Table 1 and Appendix A). Indicators included in this phase of the project were selected because they provide an understanding of hydrologically significant areas in the Headwaters Region, as well as highlight threats to source water and biodiversity maintenance within the Headwaters Region. In addition, indicators selected for current evaluation in this project had to be:

1. Measurable: information and/or data must currently exist and be freely available or accessible in order to meaningfully quantify the indicator;

2. Time-bound: the information and/or data used to quantify a selected indicator must be available into the foreseeable future, such that trends in the state or condition of the indicator can be monitored over time.

Table 1. Preliminary list of indicators for the Headwaters Region selected by the Oldman Watershed Council. See Appendix A for more details on each indicator.

Indicator	Indicator Type	Indicator Evaluated in this Report
CRITERION 1: Landscape Composition and Condition		
1.1 Intact Landscapes	Pressure	Yes
1.2 Human Population Density & Growth	Pressure	
1.3 Urban and Industrial Human Land Use	Pressure	
1.4 Land Conversion of Natural Habitat	Pressure	
1.5 Changes in Climate Regime (Past to current)	Pressure	
CRITERION 2: Biological Diversity		
2.1 Road Density	Pressure	Yes
2.2 Density of All Linear Features	Pressure	Yes
2.3 Riparian Condition	Condition	Yes
2.4 Stream Connectivity	Condition	
2.5 Fish Community	Condition	
2.6 Amphibian Community	Condition	
2.7 Macroinvertebrate Community	Condition	
2.8 Rate of Wetland Loss	Condition	
2.9 Rangeland Health	Condition	
CRITERION 3: Surface Water Quality		
3.1 Sedimentation/Erosion Potential	Pressure	Yes
3.2 Stream Crossing Density	Pressure	
3.3 Surface Water Quality	Condition	
3.4 Point Source Contamination	Pressure	
3.5 Non-point Source Contamination	Pressure	
3.6 Sediment Quality	Condition	
CRITERION 4: Water Levels & Flow		
4.1 Stream Flow Regime	Condition	Yes
4.2 Lake or reservoir water level	Condition	
4.3 Lake or reservoir open water area	Condition	
4.4 Water availability (climatic input)	Condition	
4.5 Potential Surface Water Use	Pressure	

3.4 Indicators Evaluated in the Report

Six indicators were evaluated to assess the Headwaters Region of the Oldman Watershed (Table 1). The rational and scientific justification for each indicator is outlined below.

Indicator 1.1: Intact Landscapes (Criterion 1)
In watershed assessment science, the term “intact” means that “all the critical ecosystem components are present and structured in such a way that processes function within normal limits, and that component populations and functions will be maintained over time” (Lee et al. 2003 pg12). Simply put, areas within intact landscapes are better able to maintain native biodiversity and ecosystem functions over time, and are more resilient to disturbance, i.e. are better able to recover from disturbance and return to the original ecological “state” (Lee et al. 2003). Thus, intact landscapes are considered to be relatively pristine, with minimal human disturbance, and these areas should support a

high diversity of plants and animals relative to areas experiencing more intense human activity.

Watersheds are holistic systems that act as catchments for all precipitation, stream flow, and terrestrial runoff (AENV 2008b). This interaction makes freshwater aquatic systems particularly vulnerable to anthropogenic disturbance, given their role in receiving run-off from the surrounding terrestrial land base. It has been clearly demonstrated that the amount of the watershed covered with native vegetation has a strong, positive influence on aquatic habitat condition and water quality (Allen et al. 1997, Booth et al. 2002, Clapcott et al. 2013, Dalm et al. 2013, Linke et al. 2007). For example, healthy riparian habitat is more likely to be found surrounded by landscapes with high amounts of forest and wetland cover (Findlay and Houlahan 1997, Nel et al. 2007, Norris et al. 2007).

In addition to landscape influences, many fish, mammal, and avian species in Alberta require large tracts of undisturbed habitat, including bull trout (*Salvelinus confluentus*), Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*), grizzly bear (*Ursus arctos)*, American marten (*Martes americana*), and northern goshawk (*Accipiter gentiles atricapillus*; Alberta Grizzly Bear Recovery Plan (2008-2013) 2008, Alberta Westslope Cutthroat Trout Recovery Plan 2012-201, Chapin et al. 1998, Dunham et al. 1997, Finn et al. 2002, Patla, 1987, Proctor et al. 2012, Ripley et al. 2005). The species listed here are often considered umbrella species. Umbrella species are typically large, wide-ranging species with large home ranges that are sensitive to human disturbance and habitat change. The protection of umbrella species is a commonly implemented conservation strategy, where by conserving habitat for wide-ranging species with large habitat requirements, the protection of many smaller co-occurring species can be ensured (Roberge and Angelstam 2003).

Indicator 2.1 & 2.2: Road Density & Density of All Linear Features (Criterion 2)

Linear features are a pervasive aspect of human development and land-use. Linear features often penetrate into previously undisturbed areas, and can lead to many unintended consequences including reduced water quality, increased wildlife mortality, increased hunting pressure on game and fish species, and the introduction of non-native species (Trombulak and Frissell 2000). The impact of roads on wildlife and water quality is relatively well documented (see Forman et al. 2003, Trombulak and Frissell 2000), but the negative effects of linear disturbances are not limited to roads. All other linear features, such as rail lines, seismic lines, pipelines, and off-road vehicle trails can have negative influences on water quality, nutrient management, and biodiversity (Ouren et al. 2007).

Increased soil erosion is one of the major ecological concerns of roads and other linear features. Vehicle traffic, the removal of natural vegetation, and soil compaction along linear features can all cause increased runoff and erosion of soil flowing into aquatic habitats, leading to changes in flow regime and an overall reduction in water quality (Rieman and McIntyre 1993, Ouren et al. 2007). Soil erosion introduces deleterious materials into aquatic systems, which can have serious impacts to fish populations. For example, the runoff of fine particles in small spawning streams reduces water clarity, and the subsequent sedimentation can decrease the fish egg survival and spawning success of adult females (Henley et al. 2010). Bull trout stocks in particular are negatively impacted by road development which results in increased soil erosion, sedimentation, and decreased stream habitat quality (Dunham and Rieman 1999, Eaglin and Hubert 1993, Ripley et al. 2005).

Roads and other linear features also impact terrestrial wildlife. Roads increase mortality risk for wildlife as a result of collisions with vehicles (Lode 2000) and fundamentally alter the amount and arrangement of habitat patches (Carr and Fahrig 2001, Forman et al. 2003). Linear features can act as barriers to dispersal for many terrestrial and semi-aquatic species (e.g. amphibians) that either behaviorally avoid roads or are physically unable to cross roads (Carr et al., 2001, Trombulak and Frissell 2000). Many large mammals, including elk (*Cervus elaphus*) and grizzly bears (*Ursus arctos*) avoid landscapes with a high density of both roads and other linear features (including seismic lines and ORV trails; Alberta Grizzly Bear Recovery Plan 2013 2008, Forman et al. 2003, Holroyd 2008, Proctor et al. 2012).

Indicator 2.3: Riparian Condition (Criterion 2)

Riparian lands exist adjacent to streams, rivers, lakes and wetlands, and exhibit vegetation and soil types that are strongly influenced by the presence of water (Sikina and Ambrose 2012). They protect aquatic ecosystems by filtering out sediments and nutrients originating from upland areas (AENV 2003), and directly contribute to fish habitat by providing shade, cover and food production areas (Government of Alberta 2012). Riparian lands provide essential habitat for wildlife (Petry and Palechek 2010), and can be locations of groundwater discharge or recharge (Ambrose et al 2004). Their surface and subsurface hydrology connect water bodies with their adjacent uplands, producing gradients in biophysical conditions, ecological processes, and biota between the two (NRC 2002).

These areas represent a transition from wet (open water) to dry (uplands), and therefore can buffer the transfer of materials between terrestrial and aquatic ecosystems. In addition to acting as natural filters and sponges for terrestrial runoff and flood water, intact riparian areas improve stream bank stability which reduces further erosion and sedimentation (Brabec et al. 2002, Government of Alberta 2012). Given these properties, riparian areas have a disproportionately greater influence on aquatic ecosystems than other terrestrial areas, and their loss can have major impacts on overall watershed health

The evaluation of riparian condition considered in this report focuses on the ecological functions that are occurring, in relation to its expected normal capacities (Clare and Sass 2012). For example, the status of full cover by native vegetation with minimal anthropogenic disturbance is typically interpreted as indicating that a wide range of functions are occurring, such as bank stabilization, erosion prevention, and habitat provision.

Indicator 3.1: Sedimentation/Erosion Potential (Criterion 3)

As discussed above in the section on Road Density/Density of All Linear Features, roads and other linear features can negatively impact watershed condition as a result of soil erosion. All of the concerns outlined above are amplified on the steep slopes found in the Alpine and Subalpine areas of the Headwater Region. These regions are characterized by thin soil depth with very low water absorption capabilities (Natural Regions Committee 2006). Here topography, and in particular terrain slope, is a major driver of soil erosion (Blanco and Lal 2008). The velocity of runoff water increases as slope increases, more than doubling in steep mountain areas relative to landscapes with flat grades (Blanco and Lal 2008).

The protection of these headwater streams along the eastern slopes of Alberta is of vital importance for surface water protection, and the protection of fish spawning habitat. Small headwater streams in the Headwaters provide important habitat for several threatened fish species including bull trout, Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*). The goal of this indicator is to highlight areas of the Headwaters Region which may be highly vulnerable to erosion and sedimentation risk. This indicator documents the amount of linear feature development in habitats with a high potential for soil erosion and increased sedimentation, including 1) steep slopes (slope >40% grade), and 2) wet habitats, which includes permanent and semi-permanent water bodies and their riparian zones.

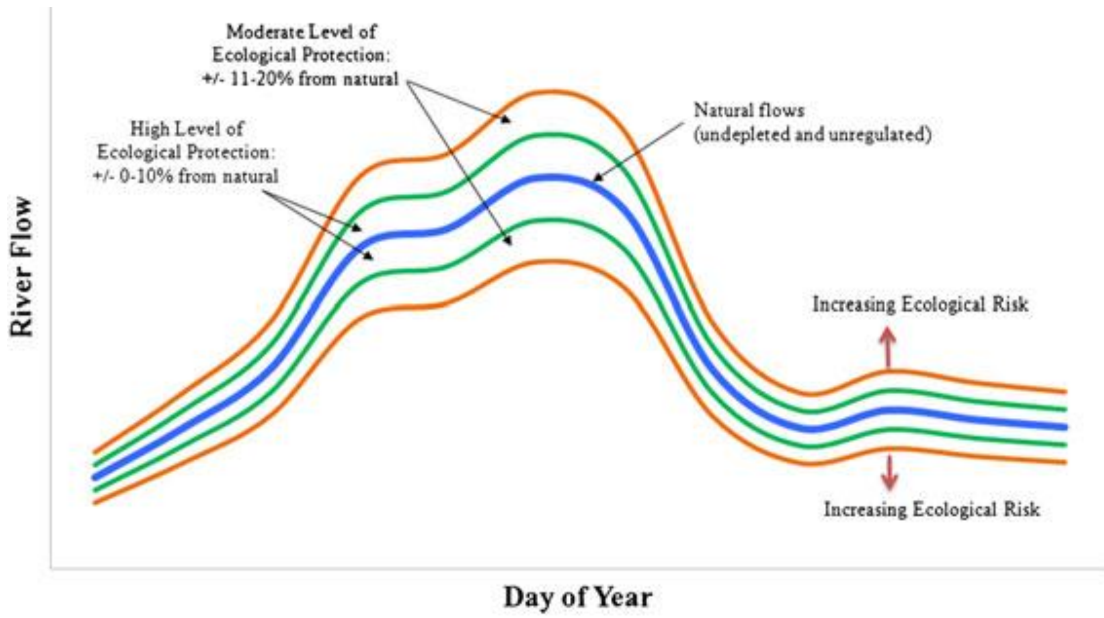
Indicator 4.1: Stream Flow Regime (Magnitude and Timing; Criterion 4)
River ecosystems are structured by the natural variability in the quantity and timing of water flows (Alberta Environment 2008b, Poff et al. 1997, Figure 2). In Alberta, water flows peak in the spring as a result of snow melt and reach their lowest point (base flow) in the winter. Understanding and quantifying this "natural flow regime" is the basis for assessing whether flow patterns are deviating from natural patterns, and are being impacted by human land-use. Natural flow volume (detailed by the central blue line in Figure 2) can either increase or decrease as a result of anthropogenic land-use. The red and green lines in Figure 2 represent an acceptable range of deviation above or below natural flow magnitude. However, as flow magnitude varies further from natural flow, there are increased ecological and economic risks (Poff and Zimmerman 2012). Increased flow magnitude can be observed due to increased runoff from industrial operations (i.e. forestry) or urban development, while decreases in flow may be caused by anthropogenic water consumption (NRC 2008, Pomeroy et al. 2012). Human land-use can also result in changes to the timing of flows, potentially leading to rapid high volume releases of run-off water). In the Headwaters Region, increased runoff and changes in the timing of flow are predicted to be the dominant issues, while water consumption will be a major issue in the developed agricultural regions of the Oldman Watershed.

4. Methods

Separate analytical approaches were required for pressure and condition indicators due to differences in data sources, data types, and constraints on data availability in the Headwaters Region. The data sources for pressure indicators tend to be based on spatial mapping products with broad-scale coverage. In contrast, condition indicators usually require field-based sampling information, and as a result of limited funding for many hydrological, biodiversity, and wildlife monitoring programs, the geographic coverage for condition indicators is limited.

4.1 Pressure Indicator "Modeling"

Four pressure indicators were assessed here: 1) Intact Landscapes; 2) Road Density; 3) Density of All Linear Features and 4) Sedimentation/Erosion Potential (Table 1). For these, we conducted indicator "modeling". This entailed creating indicator models in a Geographic Information System (GIS) that allows for the visual presentation (mapping) of



Winter Spring Summer Fall

Figure 2: Conceptual model for defining annual flow regime for streams, and how this may change from the natural range of variation, requiring ecologically meaningful protection of natural flows (from Richter et al. 2011).

the data across defined sub-watershed boundaries. For this assessment, indicator data models were developed using existing spatial data collected from various sources, and integrated together to derive new spatially explicit data models.

In evaluating indicators, a key goal of the Headwaters Indicator Project is to provide *spatially explicit* information that allows for *direct comparisons* of indicators across the Headwaters Region. Determining an appropriate unit of analysis (spatial scale and unit of assessment) was a primary objective of this project. A relevant unit of analysis is crucial in the effectiveness of the indicator, and in informing appropriate management action. The spatial scale of assessment will influence the ecological patterns and trends detected, the appropriate species or physical characteristics to use as indicators, as well any thresholds used in rating indicators. Most importantly in implementing a watershed assessment program, the spatial scale will determine the appropriate data sources (Beechie et al. 2013) that can be practically measured and/or monitored (CoP 2005). Watersheds are a commonly used and recommended unit of analysis because they are ecologically relevant in State of the Watershed assessments (USDA 2011). Watersheds are considered an effective unit to summarize complex ecological issues because of the fundamental connection among terrestrial and aquatic components of the landscape along stream networks (Williams et al. 1997, USDA 2011). Moreover, watersheds do not change much over time and a readily recognized unit by local communities.

Based on the spatial scale of information available in this assessment, and a desire for information on local scales, we derived a fourth (4^{th}) order watershed (Strahler 1964) spatial layer (see Appendix B for full methodological details). Within this watershed layer, the 4^{th} order watershed is the minimum unit, however not all parts of the

Headwaters Region belong to a 4th order watershed. Especially at lower elevations, the major river systems (Oldman River, Crowsnest River, Castle River, and Waterton River) belong to 6th or 7th order watersheds. In order to achieve wall-to-wall mapping within the Headwaters, we included watersheds ranging from 4th to 7th Strahler orders.

There are 178-fourth order watersheds in the Headwaters Region, ranging in size from 2.7 to 201.6 km^2 (median size of 20.9 km^2; Figure 3a). The smallest watersheds represent high elevation areas where headwater streams rapidly flow together into larger rivers. The larger watersheds are areas along the major rivers (i.e. Oldman River, Castle River, Crowsnest River), where small tributaries contribute water from higher elevations.

4.2 Pressure Indicator Ratings

Pressure indicators were directly compared between fourth order watersheds by assigning a “pressure” rating to each indicator. These pressure ratings were derived from scientific thresholds that were taken from empirical studies primarily conducted in Alberta or neighbouring US states (Idaho, Montana; see Section 5 for complete details). In the context of this study, we define zone-type thresholds which represent categories within which there is a gradual shift or transition from one state to another rather than an abrupt change at a specific point (i.e. critical thresholds. The threshold values defined here imply ranges or continuum of values at which increasing negative impacts have a high probability of being detected (Booth et al. 2002). The thresholds are adapted from species commonly considered indicator and/or umbrella species, including fish species (bull trout), and wildlife species (grizzly bears, northern goshawks, American marten), and from ecological theory (summary analyses of the effects of habitat fragmentation).

Four rating categories were derived for each pressure indicator evaluated, including: high, moderate, low, and negligible (Table 2). The values used to differentiate between the pressure rating categories are indicator specific, and it is important to note that indicators ratings do not measure watershed health or condition directly. Rather, ratings measure the magnitude and/or extent of one or more human land-use stressors that have the potential to impair watershed health.

For assessing pressure indicators, those Fourth Order Watersheds that are rated as “Negligible Pressure” represent areas at lower risk to anthropogenic disturbance, relative to other watersheds in the Headwaters Region. Based on the best available data, these areas are considered to be largely undisturbed with healthy ecosystems, while indicators ranked as ‘”High Pressure” are considered to be at high risk due to extensive human activity and land conversion (see Appendix B for full details).

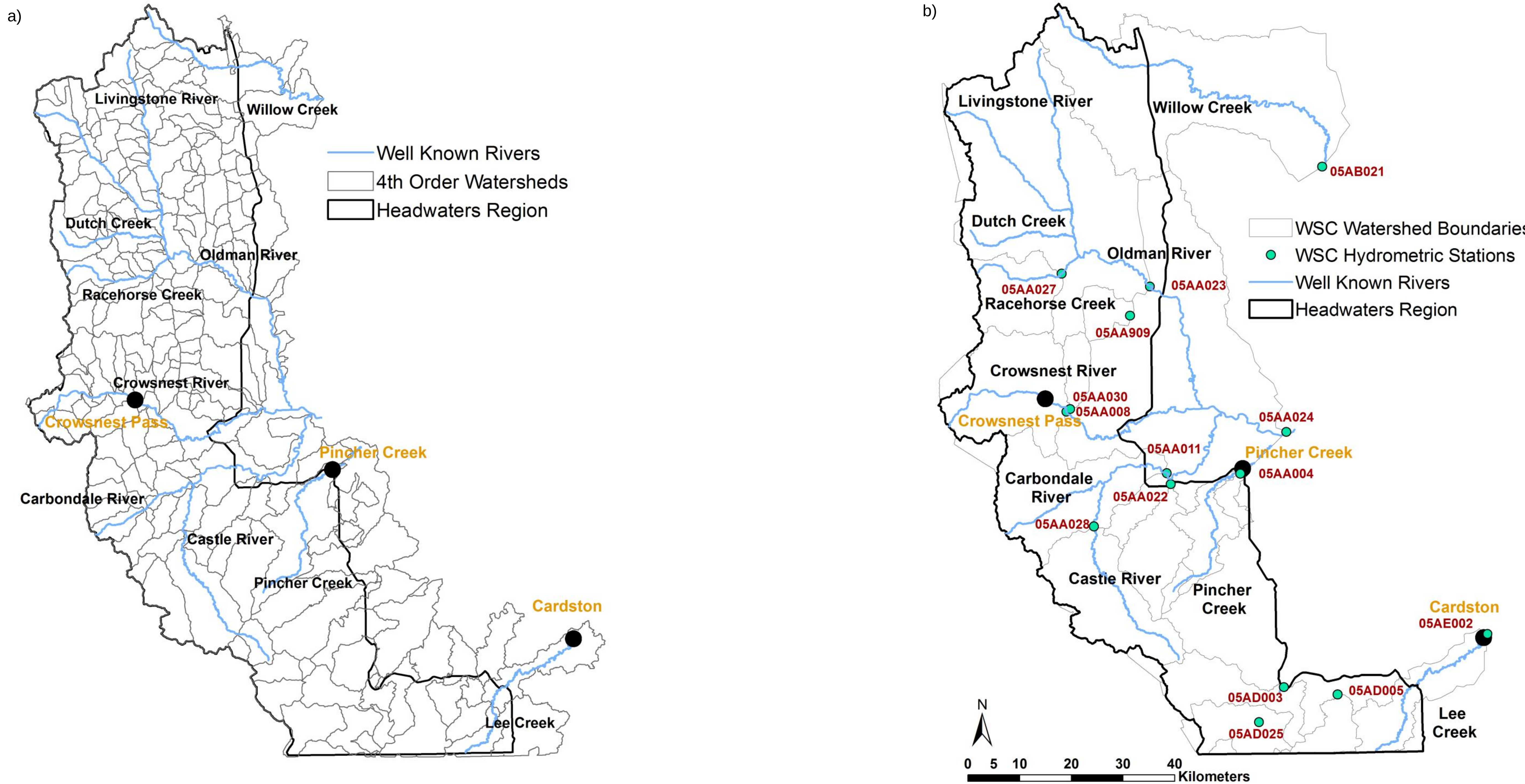


Figure 3. Description of the two scales of watershed assessment in the Headwaters Indicator Project, where: a) Map of fourth (4th) order watersheds, and b) Map of Water Survey of Canada (WSC) Watershed Boundaries (individually derived for each WSC Hydrometric station used for the mapping of the Stream Flow Regime Indicator).

Table 2. Thresholds used to differentiate Pressure Indicator Rating Categories.

Indicator	Unit	High	Moderate	Low	Negligible
Intact Landscapes	% aerial coverage of watershed with intact habitat patches	<30%	>30 – 50%	>50 – 75%	>75%
Road Density	km/km^2	≥0.87	>0.5 to 0.87	>0.1 to 0.5	0 to 0.10
All Linear Feature Density	km/km^2	>3	>1.2 to 3	>0.6 to 1.2	0 to 0.6
Sedimentation/Erosion Potential	km/km^2	>1.5	>0.6 to 1.5	>0.3 to 0.6	0 to 0.3

4.3 Analysis of Condition Indicators

Two condition indicators were assessed for the Headwaters Region here: 1) Riparian Condition and 2) Stream Flow Regime. While pressure indicators can be summarized at consistent, small spatial scales (using the fourth order watershed), the data used for riparian condition and for the flow regime indicators were each measured at different spatial scales.

Riparian Condition (Criteria 2)

The overall condition of riparian lands within the Headwaters Region was determined by field-based assessments of waterbodies conducted by Cows and Fish (also called the Alberta Riparian Habitat Management Society). These assessments were not comprehensive across the Headwaters, and as a result there are areas with no data. The riparian assessments evaluated riparian condition based on various indicators, including canopy and foliar cover, native plant assemblages, invasive weed prevalence, bank alteration and size of the riparian area. This level of assessment was not meant to include in-depth quantification of most indicators, but consisted of an overall impression by an experienced riparian biologist on the intactness of the study area, when considering the listed indicators (see Fitch et al. (2003, 2001) for a more detailed description of the Cows and Fish methods). Using this method, Cows and Fish assigned scores out of 100 to each riparian area, and placed them in categories of:

Healthy (80-100% score range): Little to no impairment of any riparian functions
Healthy with problems (60-79% score range): Some impairment to riparian functions due to management or natural causes
Unhealthy (<60% score): Severe impairment to riparian functions

Cows and Fish summarized those 4th order watersheds with field-based riparian assessment data into eleven larger watersheds (called Cows and Fish Watershed Boundaries; Figure 7), and assigned health categories based on the average scores of the assessed riparian areas they contained (Sikina and Ambrose 2012).

Stream Flow Indicators (Criteria 4)

The flow regime data are measured at Water Survey of Canada (WSC) hydrometric stations, which have limited geographic coverage and variable hydrological scale. As a result, this information had to be analyzed at the scale at which the hydrologic data were collected (i.e. Strahler orders). Watershed boundaries for this analysis were thus derived based on the location of the hydrometric stations (Figure 3b; see Appendix B for full details). Of the 25 active* (we made on exception in the case of 05AA023 which was a long-term station closed in 2008) WSC stations located within or at the edge of the Oldman Headwaters region, only 15 had at least 30 years of available data between 1971 and 2010, and these stations were used for the analyses.

Stream Flow Regime was described using indicators related to magnitude and timing of flow (Poff et al. 1997; Table 3). Magnitude was characterized by five measures: 1) total annual flow, 2) spring flow, 3) summer flow, 4) base flow (the lowest daily flow), and 5) peak flow (the highest daily flow). Timing of flow was characterized by three measures: 1) date of spring melt initiation, 2) the date of the 1^{st} peak of the hydrograph, 3) and the date of the 2^{nd} peak of the hydrograph. Hydrographs are plots of the temporal variation in discharge, typically over a year. These eight measures (see Table 3) were individually assessed for every available hydrograph (consisting of approximately 800 hydrographs). The resulting time-series of flow measures over time were assessed for significant trends using the Mann-Kendall test (Helsel and Hirsch 1992). Results of the long-term pattern in flows were then used to evaluate if flow measures were decreasing, increasing or showing no change over the period assessed. Two of the 15 hydrometric stations were water level recording stations (located on lakes or reservoirs) which meant that only the timing indicators were assessed for these stations.

There were four hydrometric stations (out of 15) with regulated flows (Table B-1). For these stations, we obtained a naturalized flow dataset at the weekly time interval from Alberta Environment who derived naturalized flows from stream flow records, reservoir data, recorded and estimated irrigation withdrawals, and climate data using the Stream-flow Synthesis and Reservoir Regulation (SSARR) model from U.S. Army Corps of Engineers [AENV 1998]. This is also referred to as the Project Depletion Method [AENV 1998]. Weekly data meant that the precision of timing indicators as well as base flow and peak flow were not at the same level as for the stations with daily data but still provided a useful dataset for trend analysis.

Table 3. Flow regime indicators, the measures used to characterize them and their ecological significance (from Richter et al. 1998; see Appendix B for more detailed methodology)

Indicator	Measure	Ecological significance
Stream Flow Regime	**Flow Magnitude**	
	Total annual flow (mm)	Habitat availability for aquatic organisms Soil moisture availability for plants Availability of water for terrestrial animals Availability of food/cover for fur-bearing animals Access by predators to nesting sites Influences water temperature, oxygen levels, photosynthesis in water column
	Total spring flow (mm)	
	Total summer flow (mm)	
	Base flow (mm/day)	Creation of sites for plant colonization
	Peak flow (mm/day)	Balance of competitive, ruderal and stress-tolerant organisms
	Flow Timing	
	Initiation of spring melt (day-of-year)	Compatibility with life cycles of organisms Predictability/avoidability of stress for organisms Access to special habitats during reproduction or to avoid predation Spawning cues for migratory fish Evolution of life history strategies, behavioural mechanisms
	1^{st} major peak of melt (day-of-year)	
	2^{nd} major peak of melt (day-of-year)	

4.4 Flow Regime (Condition Indicator) Ratings

The long-term pattern in flows (using all available hydrographic data) for each WSC station and each of the eight flow measures were rated on the pattern and significance of the temporal trend (based on Mann-Kendall correlation results; Yip et al. 2012) (Table 4).

Table 4. Flow regime rating categories (positive, neutral or negative trends values) and significance (p-values) used to evaluate Stream Flow Regime in the Headwaters Region.

Rating		Significance Value
No Data		
Strong Decreasing Trend		- (p <0.05)
Moderate Decreasing Trend		- (p <0.10)
No Trend		(p >0.1)
Moderate Increasing Trend		+ (p <0.10)
Strong Increasing Trend		+ (p <0.05)

5. Indicator Results

Understanding Pressure Indicator Models

This project represents a preliminary assessment of a small group of indicators in the Headwaters Region of the Oldman Watershed. The results below provide an initial assessment of the ecological integrity of the Headwater Region relative to scientifically established thresholds and methods, and most importantly, provide a comparison amongst subwatersheds of the condition and land-use pressures that currently exist in the Headwaters Region. In interpreting the indicator results below, a key caveat to understand is that the pressure indicator models displayed are descriptive models, which represent a simplified summary of the current state of human land-use stressors. The models do not provide information on future scenarios or management outcomes, but are important tools to guide future planning, management (see Section 7), and can important tools for public outreach and education.

Importantly, it must be understood that the pressure indicators do not directly measure changes in biological populations and communities or trends in physical/chemical characteristics. Instead, pressure indicators are correlative, based on well-established relationships between human land-use, industrial activity and other stressors to declines in watershed health. Hundreds of studies investigating the effects of human land-use on biodiversity, habitat condition or water quality and quantity have demonstrated that human land use can have profound negative impacts on all aspects of ecosystems function, including changes in chemical and nutrient balances, increased runoff and sedimentation, and alterations in biotic community composition (Booth et al. 2002, Brabec et al. 2002, Chapin et al. 2000, Clapcott et al. 2011, England and Rosemond 2004, Haines-Young 2009, Johnson et al. 1997; Weijters et al. 2008). While based on strong science, the existence of a human land-use stressor does not necessarily ensure negative impacts are occurring (AENV 2008), but that there is a high probability of impairments to biological and environmental integrity of the watershed.

This spatial comparison among watersheds identifies areas within the Headwaters Region that are currently experiencing at high pressure due to human-land use stressors, in addition to identifying areas that appear to be in good ecological condition. At local scales, those areas at high pressure are priority candidates for stewardship activity and focused mitigation activities. The identification of areas in good condition is important to ensure the protection or conservation of intact, healthy ecosystems on the landscape. In the long-term, maintaining undisturbed, intact habitat is a much simpler and cost-effective method for ensuring ecological integrity, rather than undertaking the time and costs associated with habitat restoration. By identifying those areas that are currently in good condition, their protection or conservation can be safeguarded in regional planning exercises.

The results of indicator data modeling and pressure rating classification are shown below. The full methodology, and the data sources used to derive, model, analyze, and rate each indicator can be found in Appendix B.

5.1 Intact Landscapes (Criterion 1)

Indicator Context

This indicator identifies areas on the landscape that are largely undisturbed by human activity, and are of a sufficient size to maintain populations of wildlife that require large tracts of native, intact habitat. Intact habitat patches on the landscape were considered to be a minimum size of 500 hectares (see Appendix B), containing no mapped human disturbance (Figure 4a). This indicator additively sums all mapped human disturbances (all linear features, forest harvesting, agriculture, industrial areas, and urban and rural development) on the landscape, and then "subtracts" these areas to identify Intact Landscapes.

The thresholds used to develop the pressure rating categories for Intact Landscapes were derived from scientific literature on wildlife response to landscape intactness (Table 2). The high pressure category (where <30% of the area in a 4th order watershed contains habitat identified as Intact Landscapes) was taken from a review paper conducted by Andren (1994). This paper focused on studies on birds and mammals, concluding that landscapes with <30% remaining suitable habitat area were more likely to experience greater species loses or population declines due to the synergetic effects of combined habitat fragmentation and habitat loss. In landscapes with >30% remaining native habitat, species loses or population declines were primarily impacted due to simple habitat loss, and experienced negligible additional effects due to the fragmentation and isolations of habitat areas.

The moderate pressure rating threshold came from studies on the impacts of land-use on wetland species richness, which demonstrated that the species richness of mammals and amphibians declined by 50% when approximately 50% of the surrounding forest cover has been removed (Findlay and Houlahan 1997). In addition, research from western Canada and the United States has demonstrated that highly settled areas (where >50% of the landscape has been converted urban, rural and agricultural land-use) leads to significant reductions in grizzly bear movement (Proctor et al. 2012). Finally, low pressure rating threshold was taken from studies on American marten, which have shown that marten respond negatively to small amounts of forest fragmentation and rarely use sites where >25% of forest cover has been removed (Hargis et al. 1999, Chapin et al. 1998).

Results

Intact landscapes are most common in high-elevation alpine and sub-alpine areas removed from the major towns, and the major road corridors associated with Oldman and Crowsnest Rivers. After calculating the amount of intact landscape found within each fourth order watershed and applying the pressure rating classification, the following results indicate that the majority (64%) of the fourth order watersheds fall within the Low and Negligible pressure categories (Figure 4b):

67 watersheds (38%) with Negligible Pressure
52 watersheds (30%) with Low Pressure
37 watersheds (20%) with Moderate Pressure
22 watersheds (12%) with High Pressure

Generally, watersheds along the eastern, more highly developed boundary of the Headwaters Region, and along Racehorse Creek and the Crowsnest River were at High to Moderate Pressure. Extensive forestry activity has occurred in the watersheds located between North Racehorse Creek, and the upper Oldman River, and at the north-western most extent of Oldman River, resulting in the Moderate – High pressure. Areas at low pressure were concentrated in the southwest or north-central area of the Headwaters Region.

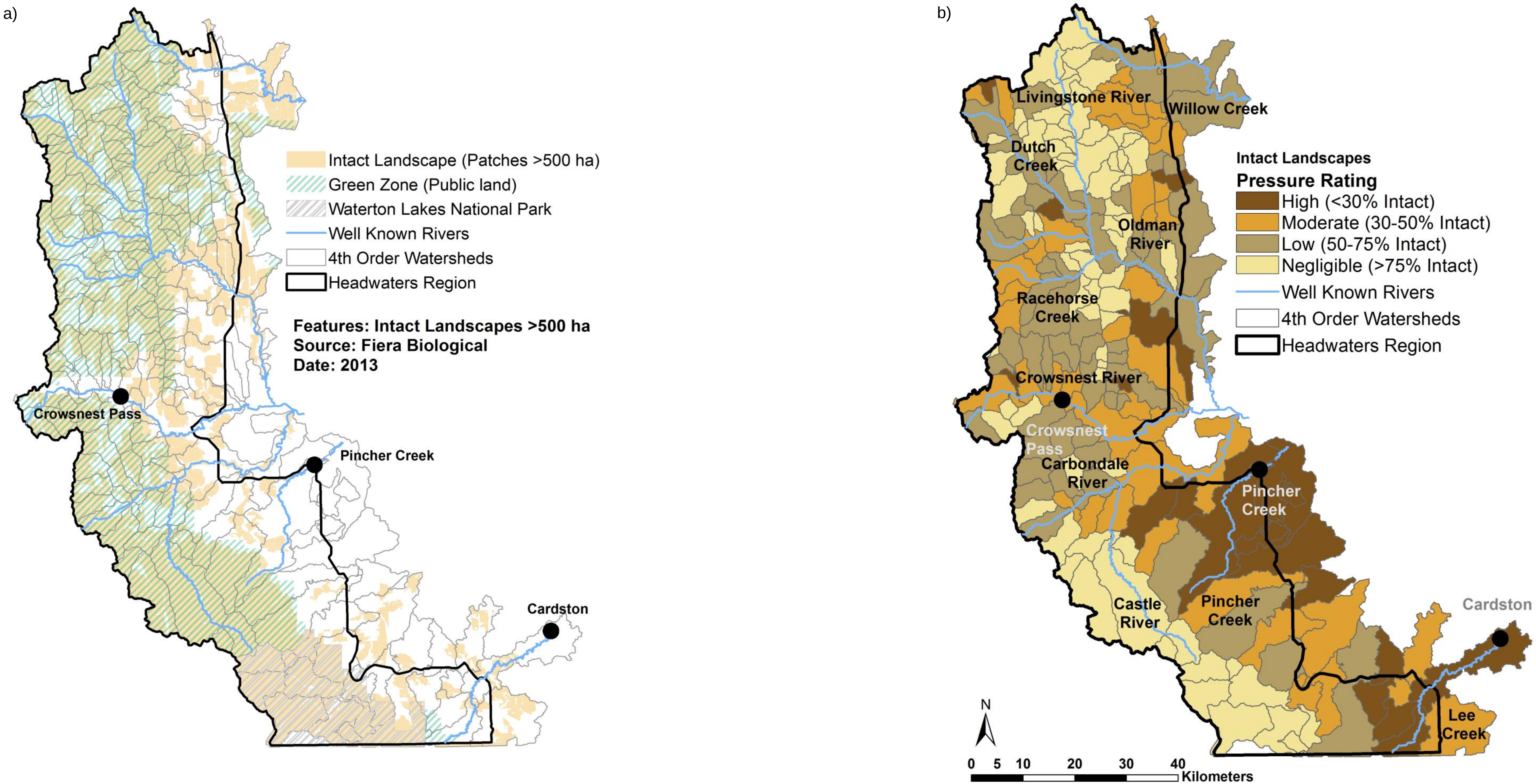


Figure 4. Input data used in pressure indicator data modeling and pressure rating classification results for Intact Landscapes in the Oldman Watershed. The area identified as Intact Landscapes (a) was used to calculate rating categories for each 4th order watershed based on scientific thresholds (b). Public lands (Green Zone) are overlaid in green hatching in (a), while private land comprises the remainder of the Headwaters outside of Waterton Lakes National Park.

5.2 Road Density & Density of All Linear Features (Criterion 2)

Two indicators related to linear features are presented here: 1) Road Density; and 2) the Density of All Linear Features (includes all roads, seismic lines, pipelines, power-lines, railroads, cutlines, and ORV vehicle trails). Road density is presented as a stand-alone indicator separate from all other linear feature types because the science around the impacts of road density on biodiversity and water quality is well established, and roads can potentially have much greater negative effects on water quality and biodiversity at lower densities than other linear features. These possible impacts include direct mortality of wildlife (through vehicle collisions), and the contamination of aquatic systems through the introduction deleterious materials in run-off water. A wide range of contaminants has been measured in water run-off from roads including sand, dust and other particulates, as well as heavy metals such as lead, cadmium, and zinc (Spellerberg 2002).

5.2.1 Road Density

Indicator Context

This indicator measured the density of roads in the Headwater Region. Roads are defined as improved linear features based on the classification in the Alberta Base Feature layer for roads (including improved forestry access roads (those which are maintained through grading), gravel roads, and all paved roads; see Appendix B for exact methods)). Any change to the surface material on roads (through soil compaction, paving or the additional of gravel) reduces or removes the ability of the ground to absorb water, and alters (typically increasing) water run-off patterns (Figure 5a).

The road density (km/km^2) was calculated for each 4th order watershed, and then classed in pressure rating categories based on thresholds taken from the scientific literature and government management documents for wildlife and fish species (Table 2), where: road densities as low as 0.1 km/km^2 have been shown to have negative impacts on bull trout spawning (BCMWLAP 2002, Ripley et al. 2005), while elk and amphibian species richness all show reduced activity or richness at road densities of 0.5 km/km^2 (Frair et al. 2008, Findlay and Houlahan 1997), and finally bull trout demonstrate depressed population at average road densities of 0.87 km/km2 (USFW 1998).

Results

Areas at high pressure from road density are centered around Pincher Creek, Cardston, and along the length of the Crowsnest Pass (Figure 5b). The road density pressure is low throughout most of the Headwater Region. In summary, the majority of 4th order watersheds currently fall into low or negligible pressure categories, with 51 (28%) of the forth order watersheds being rated as High or Moderate Pressure:

71 watersheds (40%) with Negligible Pressure
57 watersheds (32%) with Low Pressure
32 watersheds (18%) with Moderate Pressure
18 watersheds (10%) with High Pressure

5.2.2 Density of All Linear Features

Indicator Context

The density of all linear features was assessed for each 4th order watershed. In the Headwaters Region, cutlines (which includes seismic lines, and some haul trails from forestry activities) and ORV trails comprise the majority of existing linear features. The goal of this indicator is to highlight watersheds at high risk due to intensive linear feature development which can negatively influence many fish (cutthroat trout, bull trout), and mid-to-large size mammal species. Based on known wildlife responses to linear feature density from the scientific literature and government management plans, the following thresholds were used to class watersheds in pressure rating categories (Table 2), where: 1) high quality grizzly bear habitat within Grizzly Bear Priority Areas must have a linear features density at or below 0.6 km/km^2, and linear features densities at or below 1.2 km/km^2 are recommended in all remaining grizzly bear range (Alberta Grizzly Bear Recovery Plan 2008); and 2) the occupancy rate for American marten (*Martes americana*) in Alberta, and northern Idaho decline to 50% at linear features densities around 3 km/km^2 (Tigner 2012, Wasserman et al. 2012).

Results

Linear features are ubiquitous throughout the Headwaters Region, with the exception of the extreme southwestern portion of the study area (Figure 6a). As a result, the majority (77%) of Headwater Region is rated to be at High or Moderate Pressure from the combined density of all linear features (Figure 6b). Overall, the breakdown of pressure ratings across the Headwater Region for density of linear features was:

19 watersheds (11%) with Negligible Pressure
23 watersheds (13%) with Low Pressure
103 watersheds (58%) with Moderate Pressure
33 watersheds (19%) with High Pressure

An important implication of this pressure rating assessment is that nearly all the critical spawning creeks for cutthroat trout and bull trout in the Headwaters Region occur in watersheds with Moderate – High pressure from linear feature development (see Section 7).

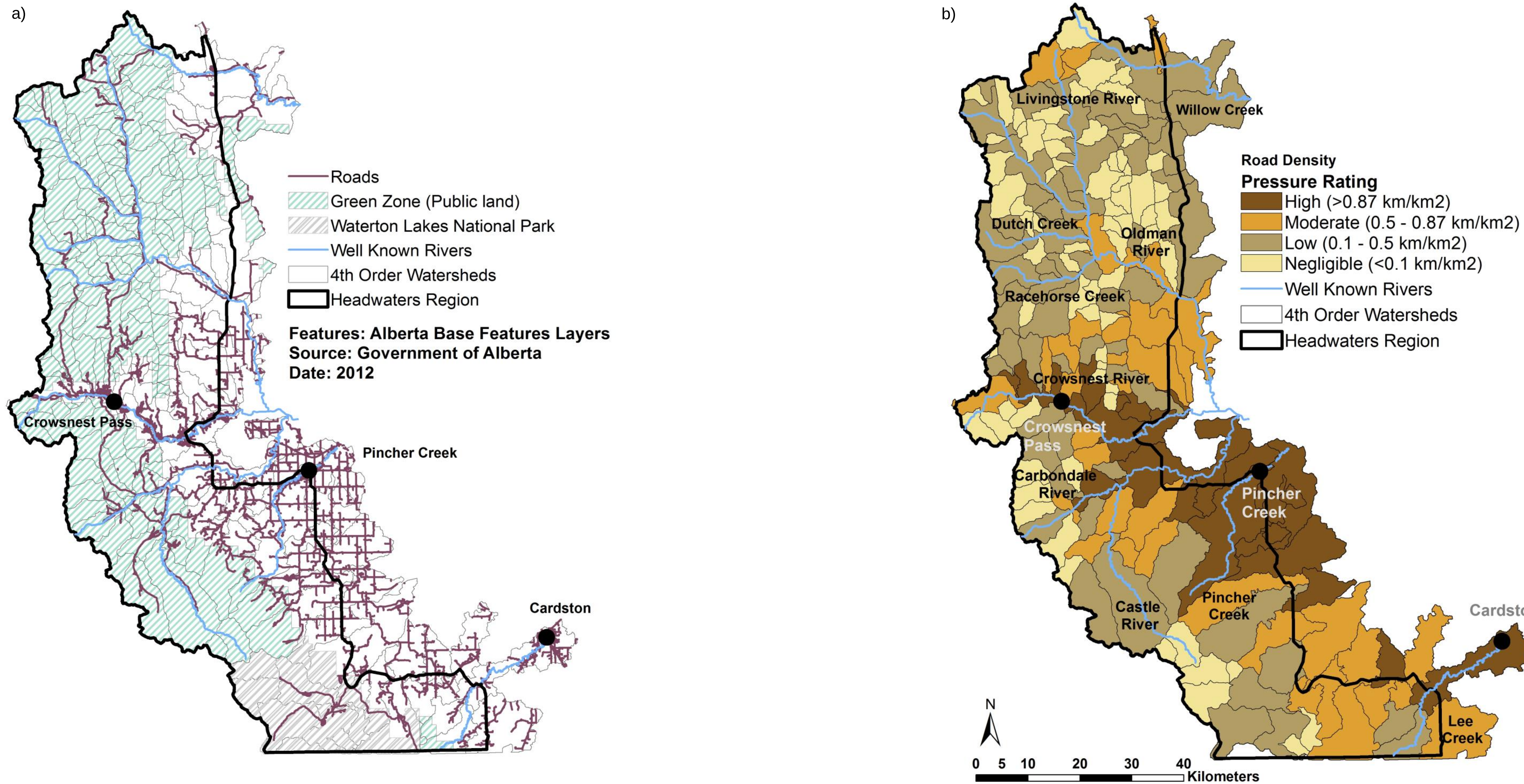


Figure 5. Input data used in pressure indicator data modeling and pressure rating classification results for the Road Density Indicator in the Oldman Headwater Region. The Government of Alberta base feature road layer (a) was used to model and rate road density based on scientific thresholds (b). Public lands (Green Zone) are overlaid in green hatching in (a), while private land comprises the remainder of the Headwaters outside of Waterton Lakes National Park.

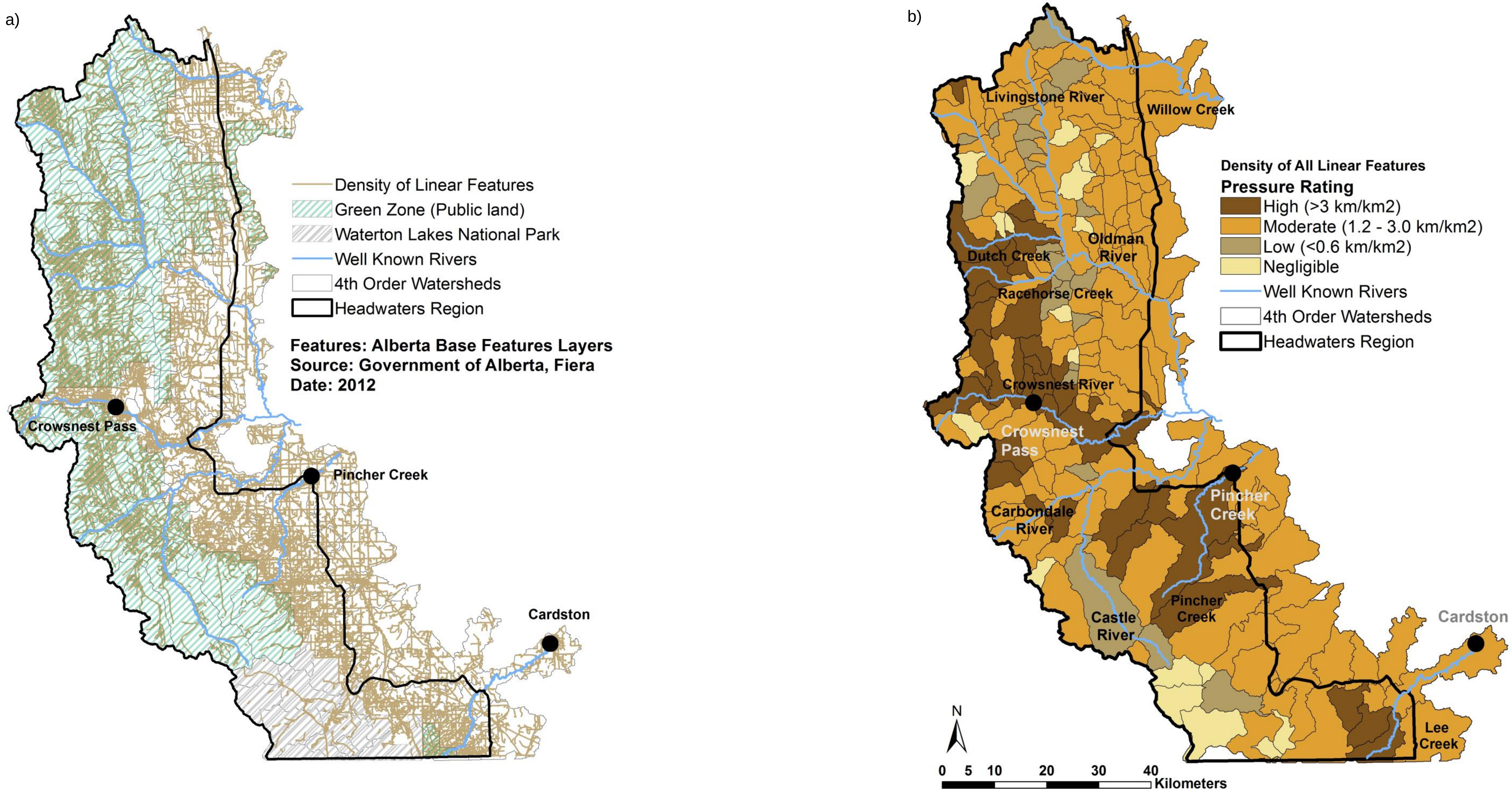


Figure 6. Input data used in pressure indicator data modeling and pressure rating classification results for the Density of All Linear Features in the Oldman Headwaters Region. The Government of Alberta base feature layers for roads, seismic lines, pipelines, power-lines, railroads, cutlines, ORV vehicle trails, and a spatial layer of previously unmapped features created by Fiera Biological (a) were combined together and used to model and rate the Density of All Linear Features based on scientific thresholds (b). Public lands (Green Zone) are overlaid in green hatching in (a), while private land comprises the remainder of the Headwaters outside of Waterton Lakes National Park.

5.3 Riparian Condition (Criterion 2)

Indicator Context

The overall condition of riparian lands within the Headwaters Region was determined by 213 field-based assessments of waterbodies conducted by Cows and Fish (see Sikina and Ambrose 2012) between 1998 and 2011. Cows and Fish identify 3 classes of riparian health: Healthy, Healthy with problems, or Unhealthy.

Cows and Fish summarized those 4th order watersheds with field-based riparian assessment data into eleven larger watersheds (called Cows and Fish Watershed Boundaries), and assigned health categories based on the average scores of the assessed riparian areas they contained (Table 5). Due to the post-hoc assembly of these scores, some of the Cows and Fish watersheds boundaries contained a greater proportion and extent of assessed sites than others. For this reason, some are noted as "data deficient", although they are still included in the summary of data.

Table 5. Scoring of watershed within each Cows and Fish designated boundaries of the Oldman Headwaters Region (from Sikina and Ambrose 2012).

Cows and Fish Watershed Boundary	Health Score		Data Adequacy	
	Number of field assessments	Average Health Score	# of waterbodies assessed	Data Status*
Belly river watershed	4	62.5	2	Data deficient
Castle river watershed	10	77.4	8	Data deficient
Crowsnest river watershed	27	75.6	7	Data deficient
Oldman River Watershed (Racehorse Creek Confluence to HWY 22)	31	66.8	6	**Data adequate**
Pincher Creek Watershed	26	65.5	7	Data deficient
Racehorse Creek Watershed	2	82.5	2	Data deficient
South Willow Creek Watershed	39	65.8	8	**Data adequate**
St. Mary River Watershed	12	73.3	4	Data deficient
Upper Oldman River Watershed	15	83.8	6	Data deficient
Waterton River Watershed	36	74.2	8	Data deficient
Willow Creek Watershed	11	72.7	5	Data deficient

*Data adequate or deficient: this was determined based on the number of waterbodies (lotic systems primarily) and length and number of field assessment sites in each watershed by Cows and Fish.

Results

At the scale of the Cows and Fish watershed boundaries, the 11 watersheds were assessed as (Table 5; Figure 7):

2 watersheds (18%) rated as "Healthy.
9 watersheds (82%) rated as "Healthy with problems"
0 watersheds (0%) rated as Unhealthy.

The majority of the assessed watersheds were considered "Healthy with problems", meaning that these riparian areas are believe to be functioning, however they are currently impacted by human activity, and are at risk of losing some ecosystem functions.

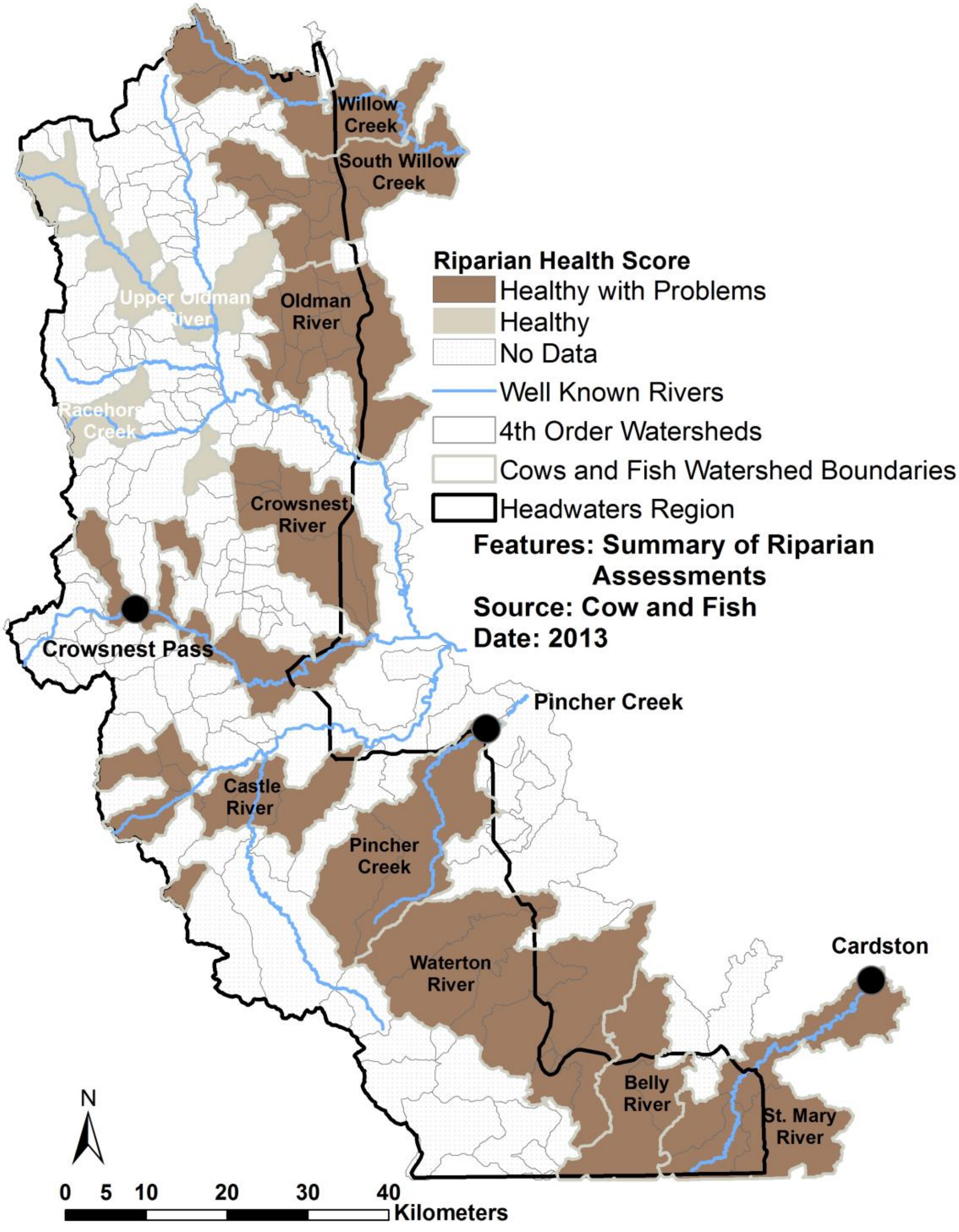


Figure 7. Riparian condition assessment ratings for 11 watershed boundaries defined by Cows and Fish in the Oldman Headwaters Region.

5.4 Sedimentation/Erosion Potential (Criterion 3)

Indicator Context

The Sedimentation/Erosion Potential indicator estimates the amount of linear features (all linear features type including roads, seismic lines, pipelines, power-lines, railroads, cutlines, and ORV vehicle trails) that occur in areas that are at high risk for both increased rates of soil erosion, and sedimentation into adjacent water-bodies. This included areas with steep slopes (>40% slope – high elevation areas) or wet habitats (lakes and wetlands including both permanent and semi-permanent water bodies). The wet area mapping layer was used to identify wet habitat; however this spatial data was not available for the entire Headwater Region, and as a result indicator mapping was only calculated for 4th order watersheds with full spatial data coverage (data was available for 129 out of 178 fourth order watersheds).

The length of linear features with high erosion/sedimentation pressure was standardized into a density measure (km/km^2) for each fourth order watershed. The thresholds developed for the Sedimentation/Erosion Potential indicator were adapted from those developed for the Density of All Linear Features Indicator. This approach was used because there is little scientific literature focusing specifically on the impacts of linear features at high elevations, and in aquatic habitats. Therefore, based on the conservative assumption that the pressures associated with linear features in these high elevation habitats are at least double that found with lower grades (Blanco and Lal 2008), the thresholds used above for the Density of All Linear Features halved to determine Sedimentation/Erosion Potential thresholds.

Results

Linear features in habitats with high Sedimentation/Erosion Potential were pervasive across the Headwaters Region (Figure 8a). The majority of Headwater Region was rated as Moderate Pressure (65%; Figure 8b), with the breakdown by pressure category as follows:

11 watersheds (11%) with Negligible Pressure
26 watersheds (20%) with Low Pressure
83 watersheds (64%) with Moderate Pressure
9 watersheds (7%) with High Pressure

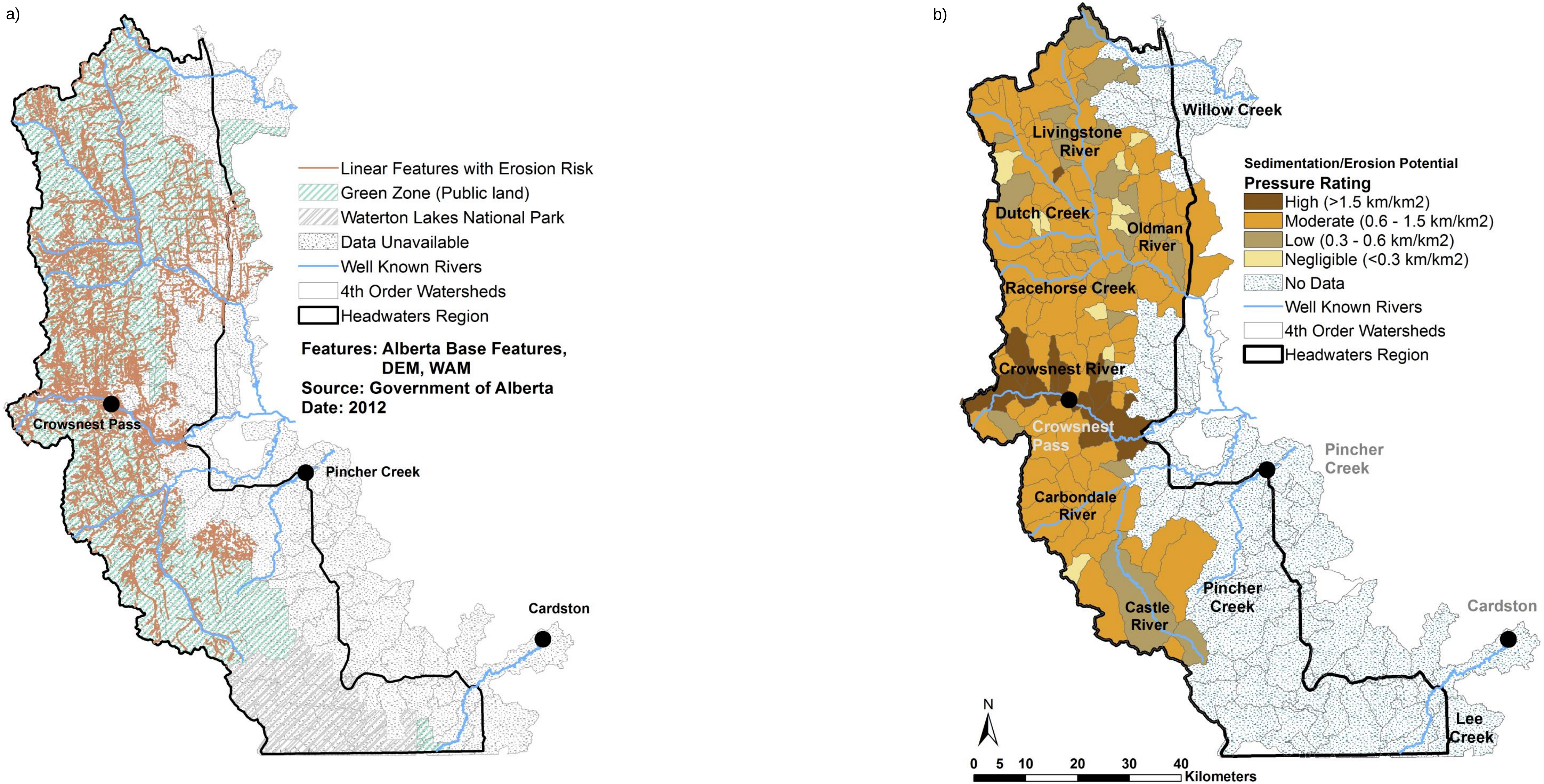


Figure 8. Input data used in pressure indicator data modeling and pressure rating classification results for the Sedimentation/Erosion Potential Indicator in the Oldman Watershed. The amount of linear features in areas vulnerable to erosion (a) was used to calculate pressure rating categories for each 4th order watershed using derived scientific thresholds (b). Public lands (Green Zone) are overlaid in green hatching in (a), while private land comprises the remainder of the Headwaters outside of Waterton Lakes National Park.

5.5 Flow Regime (Magnitude and Timing; Criteria 4)

Of the eight flow regime measures assessed in this study, two of the measures (daily peak flow, and date of the 2^{nd} hydrograph peak) did not demonstrate any strong trend patterns (see Table B-2 in Appendix B). For the remaining magnitude measures, total annual flow and summer flow demonstrated nearly identical results (Figure 9a and Table B-2; only total annual flow is mapped below). For both, the overall magnitude of flows has declined over time for many WSC watersheds based on hydrometric station records. In the same vein, total spring flows were significantly decreasing at 5 of 13 stations (2 of the stations did not collect April flow data; Figure 9b). At this point, one can only speculate about the driving factor behind these trends, but smaller snowpack (due to either less snow falling or increased sublimation) is most likely a dominant contributing factor. The pattern for daily base (lowest) flow is inconsistent across the Headwaters Region (Figure 9c), with some watersheds demonstrating increasing trends, and others demonstrating a decreasing flow trend.

For the flow regime timing measures, decreasing trends in initiation date of spring melt are apparent. This decreasing trend result means that the initiation date of spring melt is starting to occur sooner at some of the stations, with 6 out of 15 (40%) showing significant decreasing trends (Figure 10a and Table B-2). Correspondingly, the 1^{st} peak of the hydrograph is occurring sooner at some stations (Figure 10b). Earlier thaws have now been documented across much of the temperate and boreal zones in both terrestrial and aquatic systems across North America as a direct result of a warming climate (Magnuson 2001).

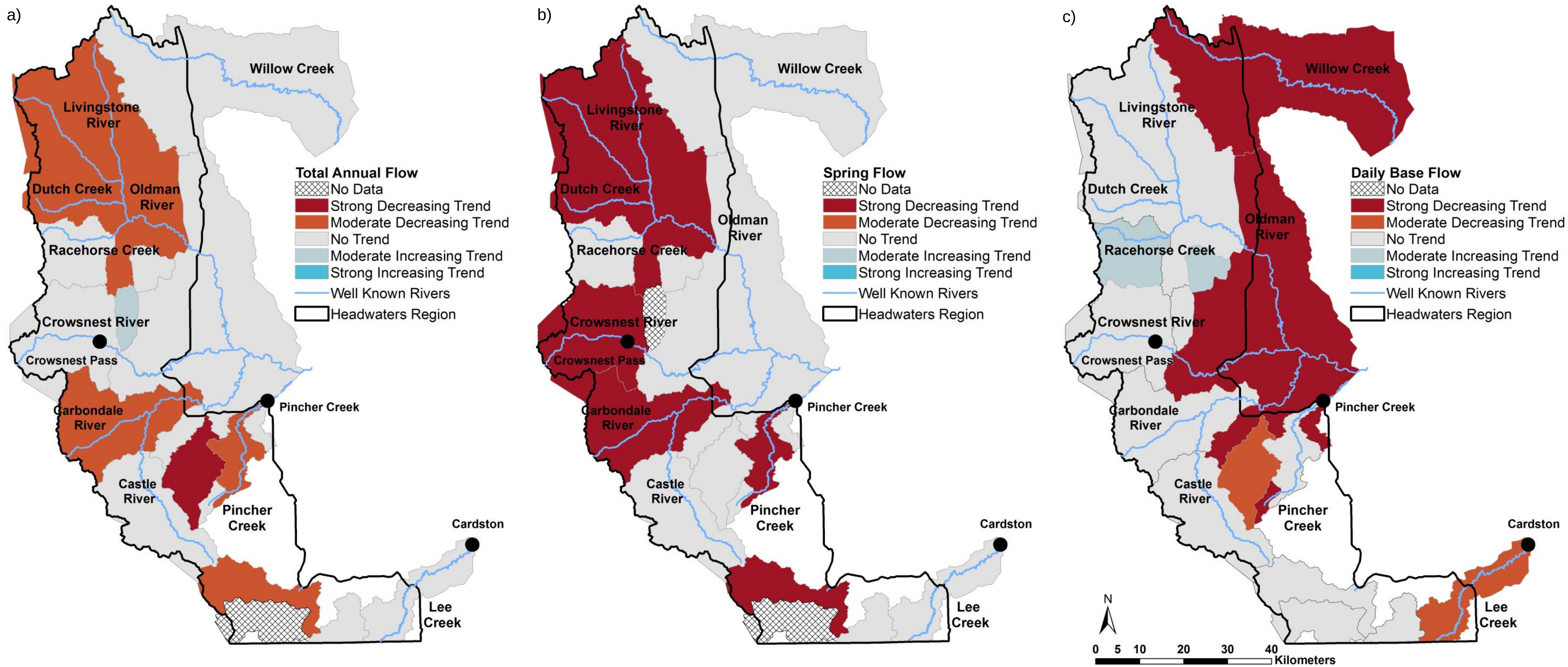


Figure 9: Flow regime trend rating maps for Magnitude measures for: (a) total annual flow, (b) spring flow, and (c) daily base flow for WSC watershed boundaries with all available data.

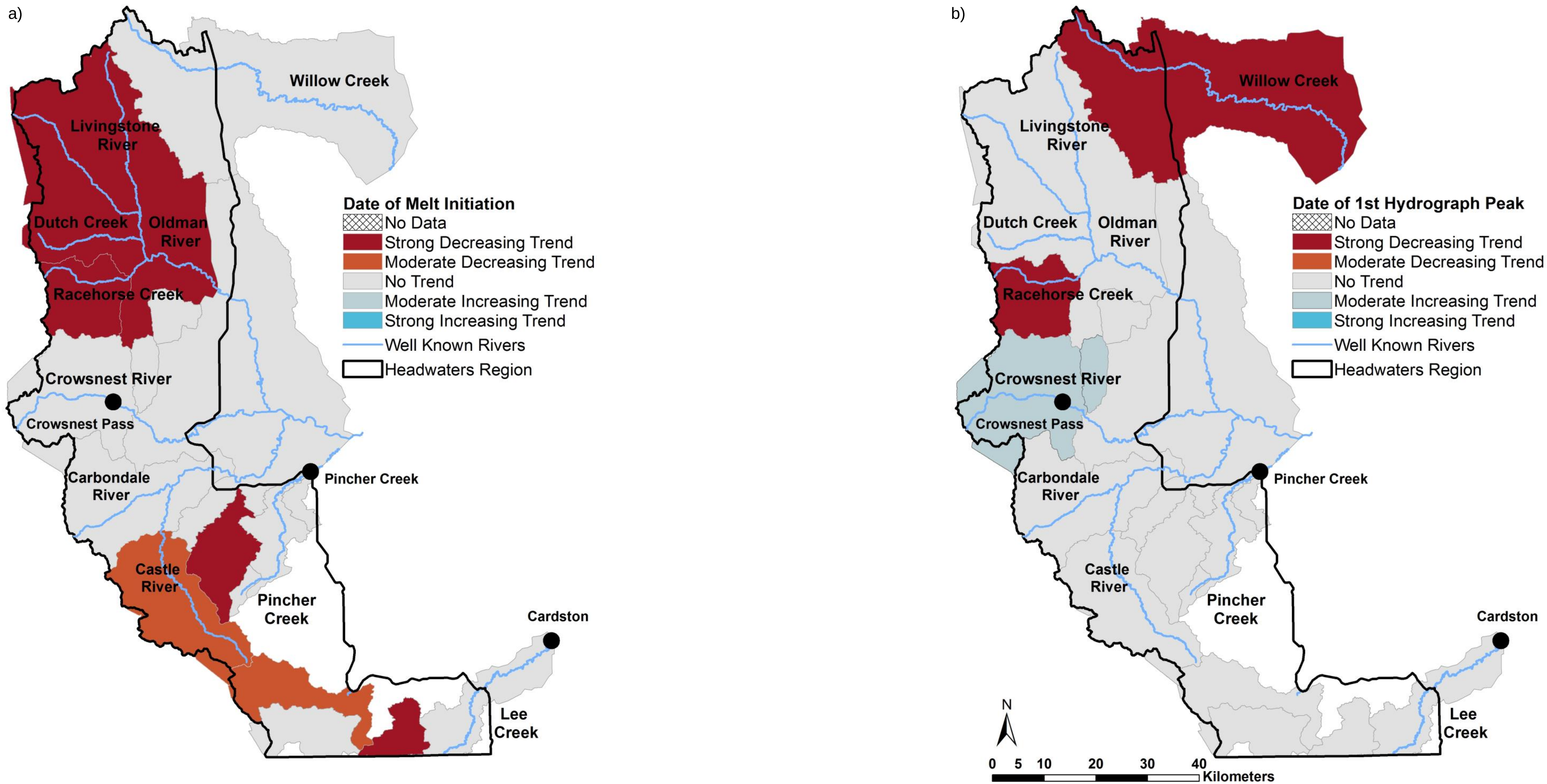


Figure 10: Flow regime trend rating maps for Timing measures for: (a) initiation date of spring melt and (b) date of the 1st hydrographic peak for WSC watershed boundaries with available data.

5.6 Limitations of Indicator Models and Caveats

Every attempt was made to use the best and most reliable data in the development of indicator models for this Oldman Headwaters Indicator Project; the base feature spatial data provide by the Government of Alberta (for roads and other linear features) was current up to 2011 or 2012, while the Water Survey of Canada data was current to 2010 or 2011. A major information source for the Intact landscape indicator (Section 5.1) is the Alberta Biodiversity Monitoring Institutes' human footprint map for Alberta. This spatial layer was created based on satellite imagery from between 2007 and 2010. It must be recognized that the models are only as good or as accurate as the data used to produce them. The caveats, assumptions, and limitations of the indicators modeled are outlined below to ensure an accurate interpretation of the results.

Intact Landscapes (Criterion 1)

This indicator is an areal measure of human disturbance, where the distribution of large-scale human land-uses such as forestry, urban development, and agriculture are the dominant factors in determining the indicator results. Unlike the indicators related to linear disturbances (Road Density & Density of All Linear Features), it is important to understand that while linear features may have many indirect effects related to habitat fragmentation, and cause behavioral avoidance by some wildlife species, on an areal basis they comprise only a small proportion (<10%) of the landscape in the Oldman Watershed which has been disturbed by human activity. In the Headwater Region, the extent and location of firstly forestry, and secondarily urban development and agricultural activity are the major drivers dictating where Intact Landscapes occur.

Road Density & Density of All Linear Features (Criterion 2)

The Alberta Base Features data for linear features effectively capture larger and persistent linear features (such as roads, pipelines, powerlines), but are missing many smaller linear features (and more recent linear features). These include quad trails, some cutlines, and in particular, in-block logging roads. The Forestry Division does not require logging trails/roads which occur on harvest blocks to be tracked in the central provincial database. This is a concern in the Headwaters Region because many of these in-block logging trails are later converted to quad trails, and remain a persistent disturbance on the landscape. Given this concern, as part of the Headwaters Indicators project, Fiera Biological mapped all visible unmapped linear features based on 2012 imagery (see Appendix B for full details). This new inventory may overestimate the amount of ORV accessible trails due to linear feature closures, and forest regeneration along trails. However, without any supplementary information regarding the location of trail closures, and ground verification of forest successional recovery, this is the best estimate of potential ORV accessible trails available.

A factor not measured in this assessment is the intensity of use (i.e. number of vehicles/hours). It is known that roads with high traffic volume can have far greater mortality and avoidance rates by wildlife than lower traffic (Dodd and Gagnon 2011, Colescott and Gillingham 1998), in addition to increased erosion. In addition, these two indicators assume all roads and linear features are equal in their impact in terms of soil erosion/sedimentation rates. Well-constructed and maintained roads/trails can significantly reduce erosion rates and the volume of sediments being washed into adjacent water bodies (Blanco and Lal 2008).

Riparian Condition (Criterion 2)

The overall condition of riparian lands within the Headwaters Region was determined by 213 field-based assessments of waterbodies conducted by Cows and Fish. There are limitations to the Cows and Fish methodology because the location of site-specific assessments is nonrandom. The program relies on volunteer and community support, and occurs in collaboration with participating land-owners. A large portion of the eastern Headwaters Region is private land, hence this limits where riparian assessments occur to participating communities and/or persons.

Sedimentation/Erosion Potential (Criterion 3)
The intent of this indicator was to provide a simple model of areas at very high risk from sedimentation and erosion. In the future we recommend detailed hydrological models integrating run-off, slope, and soil type be developed.

Flow Regime (Magnitude and Timing; Criteria 4)
It must be recognized that hydrological modeling is very complex, and is impacted both human factors and by multi-year global climate phenomena (i.e. Pacific Decadal Oscillation PDO, El Nino-Southern Oscillation, North Atlantic Oscillation). In the Headwaters, there is a reasonable distribution of hydrometric stations across the region. However, the data record is not complete and many stations may not have enough data for identification of long-term trends. These limitations make the estimation of natural flow variability difficult and challenging.

6. Cumulative Watershed Integrity Index

The last step in the Criteria and Indicator Framework is the construction of an overall Watershed Integrity Index (WII; USDA 2011; Davies and Hanley 2010). This index combines together all the information captured by the individual criteria and indicators into a single index. This type of index (also called Multi-metric Indices) is a common approach to synthesizing complex ecological data into a composite index of status and trend (Boyd and Murray 2001; Buckland et al. 2005; Moyle and Randall 1998). The WII is used to assess the current and future state of areas of interest, and can be effective in measuring the success of management activities to improving ecological integrity.

The construction of a WII is based on a standardized rule-based methodology for objectively identifying, assessing, and ranking watershed indicators. A schematic for building and calculating the WII in the Headwaters Region of the Oldman Watershed is outlined in Figure 11 (adapted from the USDA Watershed Condition Framework (2011)). This standardized framework ensures the methods are scalable, repeatable, and consistent across all watersheds. Moreover, users are able to drill down to the individual unit of analysis scale, and identify specific regions that are in poor condition (i.e. specific 4th Order Watershed requiring management actions).

Criteria can be weighed equally, or differential weights can be assigned to specific criteria based on the goals and any management objectives of the Oldman Watershed. Given the time constraints in the project, we used equal weights as the simple base case. Criteria weights can be reviewed and revised in future assessments of the Headwaters Indicators based on expert opinion, or using consensus approaches such as Delphi evaluations.

At present, only 4 pressure indicators have been evaluated at the 4th order watershed scale. As a result, the WII constructed here should be viewed a preliminary WII model, integrating the best information available. As more information, especially for biological condition indicators becomes available, the WII model will be updated and revised to integrate new indicators, and updates of the existing indicators.

Methodology for Constructing WII

The cumulative Watershed Integrity Index (WII) focused only on the pressure indicators (from Criteria 1, 2, and 3) at present. Given the differences in scale of assessment, data types, and identified issues with data deficiencies used in the riparian condition indicator, and the flow indicators, it would be a challenging task to combine these 2 indicators with the 4 pressure indicators.

Criterion was the basis of combining indicators (see Figure 11), with each Criterion weighted equally. At present, there is only 1 indicator each for Criteria 1 (Intact Landscapes) and Criteria 3 (Sedimentation/Erosion Potential), and two for Criteria 2 (Density of All Linear Features and Road Density). Because road density is double counted (roads are included in the Density of All Linear Features indicators), only the Density of All Linear Features was included for Criteria 2.

To construct the WII, the following steps were taken:

1. Each 4th order watershed indicator rating (negligible, low, moderate, high) was be converted to a corresponding numeric value (1, 2, 3, and 4) respectively (where low scores are good).
2. A complication of the WII at present is that the Sedimentation/Erosion Potential indicator does not have full coverage of the entire 4th order watershed layer (due to limitations in the Wet Area Mapping data). For those 4th order watersheds with data on the Sedimentation/Erosion Potential indicator, the WII included Criteria 3 in the index. However, therefore in order to standardize the WII between 4th order watersheds (some which included Criteria 3, and which did not), the final WII value was calculated as an average value across the component Criteria. Hence, a score of 1 – 4 will occur for each criteria, and then an average value was taken across all input Criteria (the summed scores of all Criteria, divided by the number of criteria included; see Figure).
3. The final WII scores for the 178 - 4th order watersheds ranged from 1 – 4. This distribution of values was differentiated into 3 categories based on a Jenks Natural Classification Analysis (Jenks 1977), where **High Integrity** = 1 – 1.99, **Moderate Integrity** = 2 – 2.99, and **Low Integrity** = 3 – 4 (see Figure 12 for final WII scores at the 4th order watershed level).

   A Jenks analysis is based on natural groupings that are inherent in the data and identifies break points that group similar values to maximize the differences between classes (i.e., identifies breaks in the ordered distribution of values that minimizes within-class sum of squared differences). This approach has been used in other State of the Watershed Assessments (for example “The Saskatchewan State of the Watershed Report”; Davies and Hanley 2010).

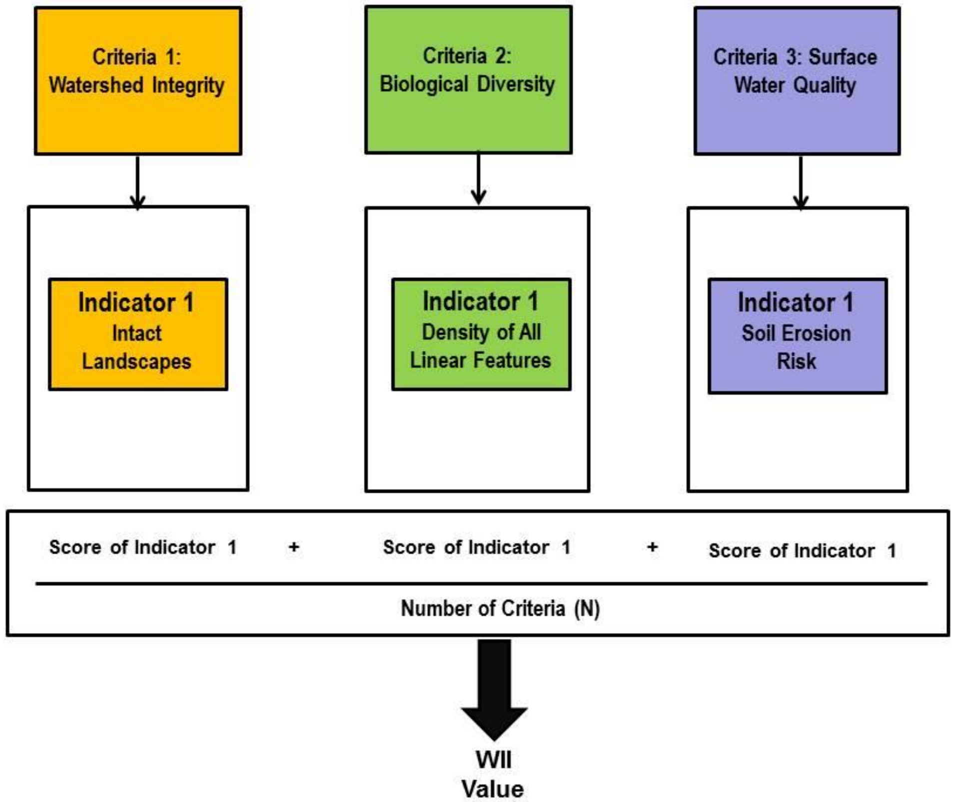


Figure 11. Schematic of Watershed Integrity Index (WII) to be constructed in the Headwaters Region of the Oldman Watershed.

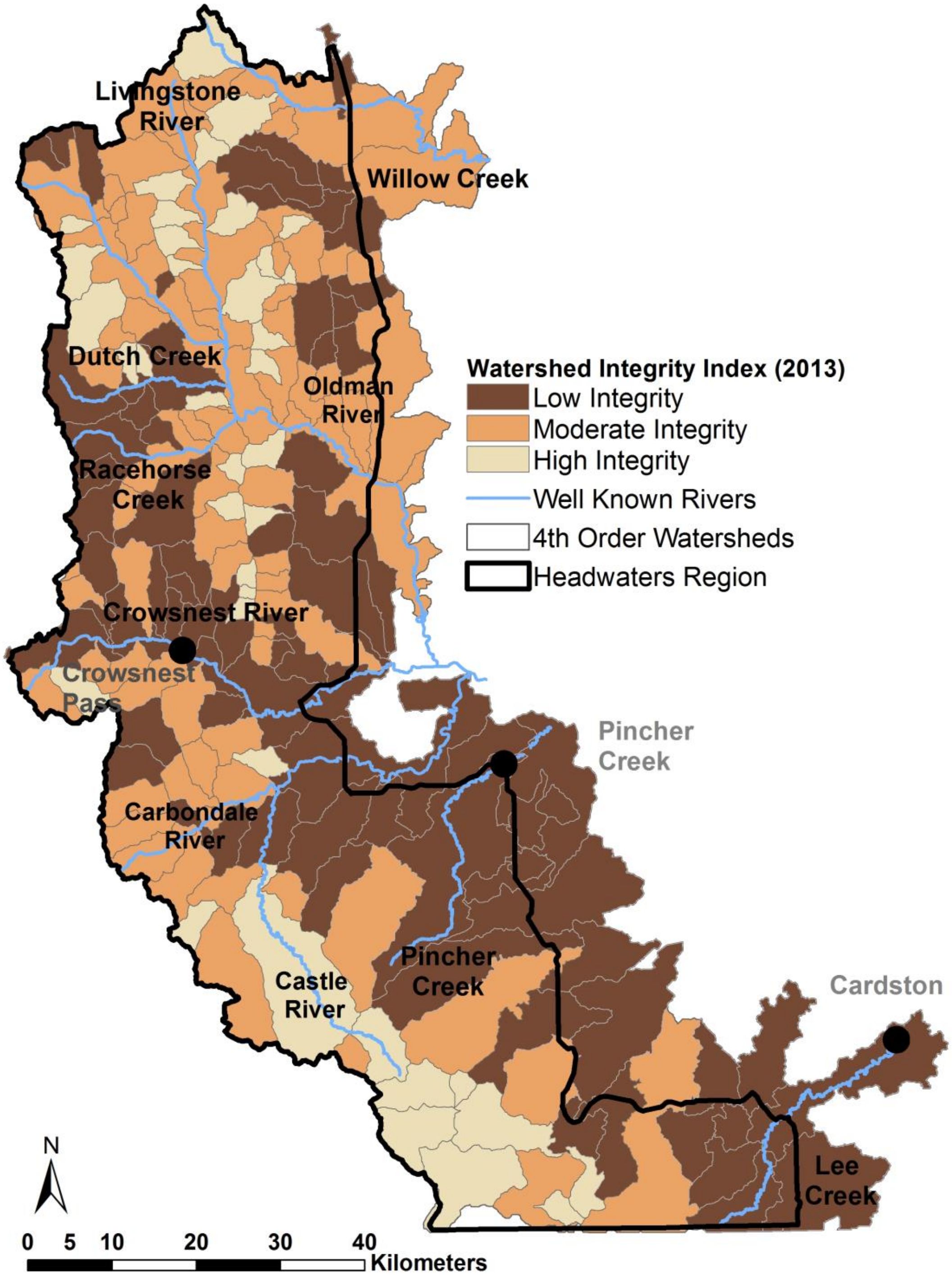


Figure 12. Results of the Watershed Integrity Index (WII) across the 178 - 4th order watersheds. Three categories of integrity are differentiated: High, Moderate, and Low based on average values across the input Criteria.

7. Application of Indicators and Watershed Integrity Index

A key purpose of the indicators and WII is to identify areas within the Headwaters Region that are currently at high pressure due to human land-use stressors. An example of how this assessment is conducted is outlined below for Headwaters Fisheries. This is a descriptive habitat based assessment which does not include on-the-ground information about the condition of fish populations. What is does provide is strong guidance on which watersheds are predicted to be at high risk for fisheries based on current land-use practices.

Bull trout and Westslope cutthroat trout are designated as threatened in Alberta by both the federal and provincial governments (Coombs 2013). Under Alberta's Management/Recovery Plans for bull trout and Westslope cutthroat trout, a common goal is to maintain populations throughout the species' historic ranges in the province at viable, self-sustaining levels (Alberta Westslope Cutthroat Trout Recovery Plan 2012 – 2017, 2013, Alberta Bull Trout Conservation Management Plan 2012 – 17, 2012). Both trout species are negatively impacted by increasing linear feature densities, and the cumulative impacts of multiple human disturbances (Coombs 2013; also see Section 3.4 for full details). In order to demonstrate the land-use threats currently affecting identified critical habitat for bull trout and Westslope cutthroat trout, a spatial analysis examining the distribution of critical trout habitat compared with: 1) the Density of All Linear Features; and 2) the cumulative WII was conducted

Alberta Environment and Sustainable Resource Development (AESRD) has identified critical stream habitat for the 2 trout species. The data is based on two different sampling methods, primarily on genetic data or sampling for juvenile trout (redds). Three different types of critical habitat are recognized: 1) important bull trout spawning areas, 2) critical habitat for Westslope cutthroat trout, and 3) genetically pure or near-pure population of Westslope cutthroat trout. Important spawning areas are characterized by a high density of trout redds. As an important caveat, these streams identify known critical habitat, but do not document the full extent of bull trout and Westslope cutthroat trout populations throughout the Headwaters.

When overlaid with the Density of All Linear Features Indicator (Figure 13a) and the cumulative WII (Figure 13b), only 18 – 27% of identified critical stream sections (by stream length) occur in either areas rated as High Integrity by the WII, or in Negligible - Low Pressure categories for the Density of All Linear Features (Table 5). In fact, the majority of stream sections identified as critical habitat for bull trout and cutthroat trout occurred in watersheds identified as being at High Pressure based on the Density of All Linear Features (Table 5, Figure 13a).

Table 5. Summary of % stream length of known critical stream sections broken down by WII Integrity Rating, and Density of All Linear Features Pressure Ratings for bull trout (BLTR) and Westslope cutthroat trout (CTTR).

Index/Indicator	Index/Indicator Rating	BLTR Spawning Areas (%)	Critical CTTR Habitat (%)	CTTR Near Pure Populations (%)
WII	High Integrity	26.6	17.5	25.3
	Moderate Integrity	50.0	44.0	49.4
	Low Integrity	23.4	38.5	25.3
Density of All Linear Features	Negligible Pressure	0.0	5.9	0.8
	Low Pressure	26.6	11.6	26.2
	Moderate Pressure	23.4	32.6	25.3
	High Pressure	50.0	49.9	47.8

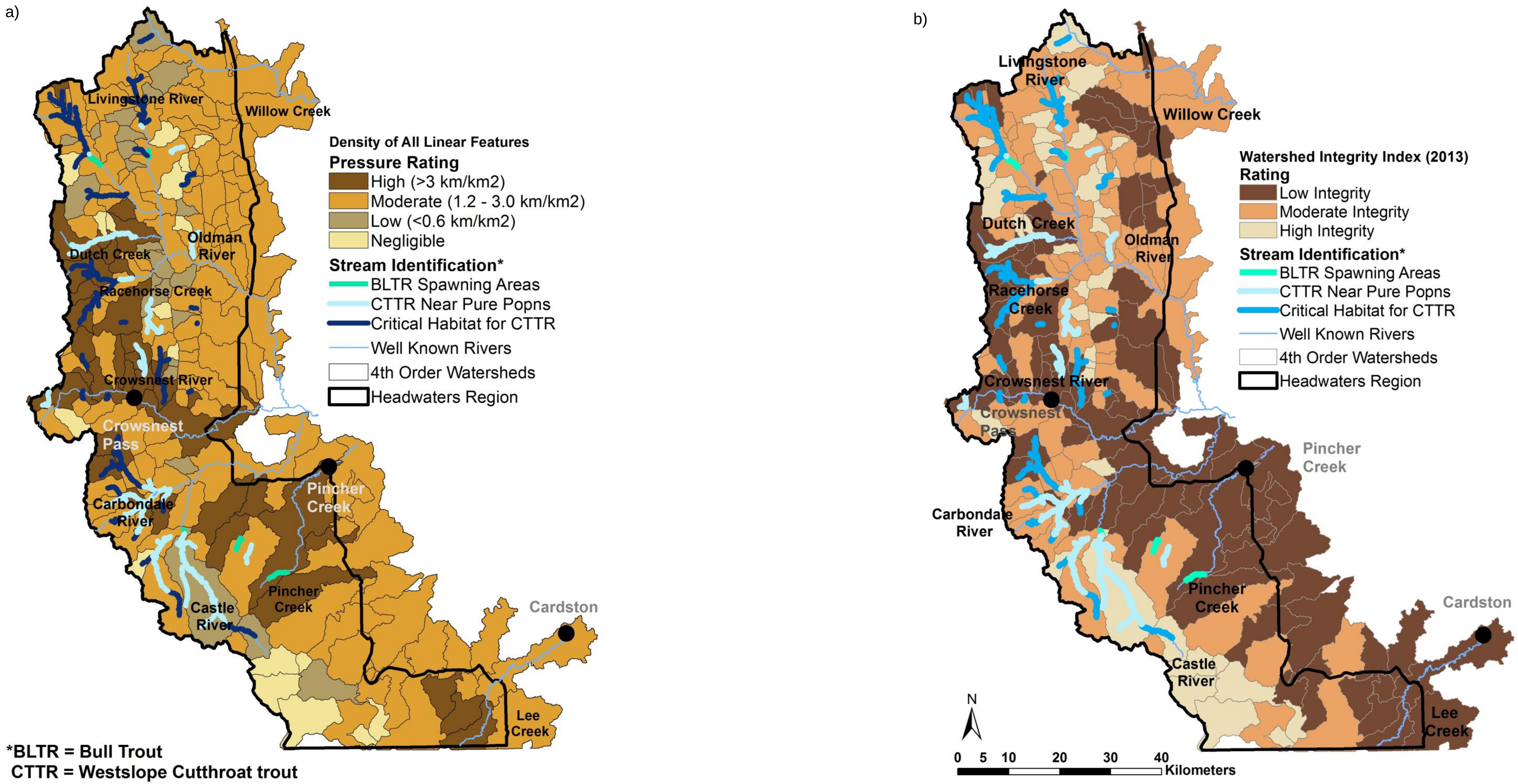


Figure 13 Comparison between streams identified as critical habitat for bull trout (BLTR) and Westslope cutthroat trout (CTTR) compared with **(a)** Pressure Ratings for the Density of All Linear Features and **(b)** the Integrity Ratings for the cumulative Watershed Integrity Index (WII) in the Headwaters Region.

8. Data Gaps and Future Priorities

Watershed assessments in an area as diverse as the Oldman Watershed Headwaters Region is a complex and challenging task. Obtaining and compiling appropriate, comparable, and reliable data from stakeholders and other third parties for many indicators is difficult and time consuming. As a result, this project focused on indicators where spatial and non-spatial data were readily available. In the future, additional work will be challenged by constraints associated with data ownership, data sharing, and data organization. All these factors can present major barriers to evaluating indicators and watershed assessment over the timeframes of many projects. For each criterion listed below, the data gaps, and priorities for future work are outlined to help guide future work of the OWC.

CRITERION 1: Landscape Composition and Condition

The intent of this criterion is to document the current state of land-use pressures, as well as past, present, and future trends in human activity and climate in the Headwaters Region. The indicator that we evaluated for this criterion is strongly related to ALCES modeling that is currently being conducted by Brad Stelfox in the Oldman Watershed. Because the goal and scales of assessment differ between this Headwaters Indicator project (small local scale) and the ALCES (township scale) project, the results of each should be complementary. In future, a key priority for the OWC is to better understand how climate change, and the associated shifting patterns in natural disturbances impact hydrology (see Criteria 4 below), and the implications of these potential impacts on wildlife, water quality, and human land-use (Einheuser et al. 2013). As part of this research avenue, it is crucial to ensure that accurate and up-to-date land cover and human land-use data is available. A key data gap recognized by the OWC is the need to better understand the extent and intensity of use of linear features and OHV trails throughout the Headwaters Region. This information is critical to developing a regional management plan, and working with OHV user groups to create maintained and well-designed trail networks which will reduce soil erosion and other environmental impacts.

CRITERION 2 & 3: Biological Diversity and Surface Water Quality

Watersheds are incredibly complex, and teasing apart direct mechanistic linkages between species responses and anthropogenic stressors is a challenging and time consuming task. Within all monitoring programs, most ecological indicators measure the response of watersheds and ecosystems to anthropogenic stressors, but do not necessarily identify specific anthropogenic stresses causing impairment (EPA 2002). However, having good information on biological condition indicators is crucial because they directly measure the state of biological populations or communities, and moreover because they act as early warning signals of negative human impacts on aquatic biodiversity (Barbour et al. 2000, Niemi and McDonald 2004). Changes in species composition or declines in the physical condition of aquatic organisms are often detectable well before noticeable changes in water quality (EPA 1990). Within these 2 criteria, the majority of the aspirational indicators are condition Indicators that require extensive field-based biological and habitat sampling (e.g., Fish Community, Amphibian Community, Macro-Invertebrate Community, Surface Water Quality parameters, and Sediment Quality parameters). Although the Oldman Headwaters Region is a small area (23,000km^2) relative to other Watersheds in Alberta (e.g. North Saskatchewan or

Athabasca Watersheds), it is still orders of magnitude larger than the average research study or monitoring program. While there has been extensive research and monitoring work done on fish and wildlife in the Headwaters Region by government and university researchers, there are several challenges in using these data for a larger watershed assessment project, including:

1. This information is typically conducted at relatively small spatial scales (typically less than 500 hectares).
2. Each project/monitoring program has different objectives, research methodologies, and sampling efforts.
3. Much of this information is not readily accessible. It exists as Master's or PhD theses, academic papers, and government or consulting reports. Assembling and compiling this information together into a standardized and comparable format requires extensive effort.
4. Much of the data is considered proprietary and getting permission to use the raw data from many of these studies can be difficult (or not possible) and time consuming.

In moving forward on these indicators, the OWC can take two approaches which are complementary. The first is to select priority indicators (i.e. fish communities) and commit the effort, time, and funding to assemble a standardized regional database. Secondly, the OWC can work with partners and stakeholders to begin a monitoring program to collect the necessary field data needed to address the information gaps for priority indicators. The science on the development, management, and data analysis of fish and aquatic macro-invertebrate monitoring programs is extensive and rigorous. In the United States, monitoring programs on aquatic invertebrates and fish have been running since the 1970's under the umbrella of the federal Clean Water Act (EPA 1990). Under conventional regulatory processes, watershed assessment based on condition indicators (typically fish and macro-invertebrates) are frequently conducted (EPA 2002). The survey information is stored in national and/or state databases, and available to the scientists. The critical difference between the United States and Canada is funding and assistance from federal agencies, where watershed assessment funding has been available to government scientists, university researchers, and local communities (EPA 2001).

CRITERION 4: Water Levels and Flow

In the Headwaters Region, the available hydrological information is applicable only at relatively large spatial scales. Most of the hydrometric stations are measuring flow and level at the fifth order watershed, or higher. At this scale, there is a substantial amount of hydrological averaging is occurring, meaning that localized effects, especially important for land cover change, are not being detected. From the perspective of water supply for downstream communities (ecological and human), and how this supply might be impacted by climate change (which would have more of a blanket effect), the current distribution of stations is most likely adequate; however, identifying local ecologically important changes at the smaller watershed scale (first to fourth order) requires much more information than is currently available.

This study, like many others, highlights the limited information available on lower order systems. If understanding small-scale land use impacts on hydrology is a priority for the OWC, more hydrometric stations will need to be installed and run within lower order systems. This could be a collaborative area of research and stewardship conducted in association with universities and/or local conservation organizations (i.e. University of Alberta, University of Lethbridge). A good distribution of discharge stations coupled with hydrological modeling (which can be 'taught' to predict flow in ungauged systems), could provide an adequate assessment of the hydrologic conditions in the Headwaters Region. Good first order approximations of the effects of forest fire on flow regime are already available based on paired-watershed work (Silins et al. 2009). These types of observational data are crucial but might miss the integrated effects of climate, land cover and land use change across the larger Headwaters region. Based on the analysis completed in this study, the next step would be to link the observed hydrological trends to both climatic indicators as well as land cover indicators.

9. Conclusions

This report provides a framework for evaluating the watershed and ecological integrity of the Headwaters Region of the Oldman Watershed, as well as a preliminary assessment of a small subset of watershed indicators for this region, and an initial watershed integrity index (WII). Results from these indicators and the WII demonstrate that significant land-use pressures exist in many areas of the Headwaters, with an associated high potential for ecological impairments occurring in these areas.

We have recommended a Criteria and Indicator approach for the Headwaters Region, which can be expanded and applied to assess condition throughout the Oldman Watershed. The work conducted as part of this project forms the basis for local and regional stewardship initiatives in the Headwaters Regions, and provides information to help prioritize future research and assessment projects.

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Appendix A - Preliminary Criteria and Indicator List

Table A-1. Aspirational list of pressure and condition indicators selected to assess the current state of the Headwaters Region in the Oldman Watershed for Criteria 1. The list was adapted from the Indicator Guide for Watersheds in Southern Alberta (AENV 2008b) and USDA Watershed Condition Framework (USDA 2011).

Name of Indicator	Indicator Type	Potential Measures	Data	Potential Threshold Source
CRITERIA 1. Landscape Composition and Condition				
Intact Landscapes	Condition	% Area of Watersheds with Intact Landscapes (no human disturbance)	AVI/GVI/ABMI footprint data, Alberta Base Feature Data, Wildfire Data	Landscape Fragmentation Theory/Threatened Species Responses
Human Population Density and Growth	Pressure (Trend)	Watershed Human Population Density and Growth Rate (% change over time)	Canada Censure Data (2001, 2006, 2011)	TBA
Urban and Industrial Human Land Use	Pressure	% Area of Watersheds with Forestry, Agriculture, and Oil and Gas Development	AVI/GVI/ABMI footprint data, Alberta Base Feature Data	Threatened Species Responses to Landuse
Land Conversion from Natural Habitat	Pressure (Trend)	% Change in Human Land-use Over Time (i.e. % change in forestry activity between 1971 and 2011)	Landsat remote sensing imagery (available from ≈ 1970 – present)	TBA, Biodiversity Research Studies
Changes in Climate Regime (Past to Current)	Pressure (Trend)	Long-term Trends in Precipitation, Temperature, # of Growing Degree Days (GDD), Timing and Length of Growing Season	Environment Canada - National Climate Data and Information Archive	Range of natural variability paradigm (Poff et al. 1997)

Table A-2. Aspirational list of pressure and condition indicators selected to assess the current state of the Headwaters Region in the Oldman Watershed for Criteria 2. This list was adapted from the Indicator Guide for Watersheds in Southern Alberta (AENV 2008b) and USDA Watershed Condition Framework (USDA 2011).

Name of Indicator	Indicator Type	Specific Measures	Data	Potential Threshold Source
CRITERION 2. Biological Diversity				
Road Density	Pressure	Road Density (km/km^2)	Alberta Base Feature Data	Threatened Species Responses (i.e. Established Grizzly Bear/Bull Trout thresholds)
Density of All Linear Features	Pressure	Linear Feature Density (km/km^2)	Alberta Base Feature Data	Threatened Species Responses (i.e. Established Grizzly Bear thresholds)
Stream Connectivity	Pressure	Watershed Culvert Density (no/km^2), Culvert Stream Fragmentation Metrics	Alberta Base Feature Data	Fish/Aquatic Invertebrate Landuse Research Studies
Fish Community	Condition	Community Composition Indicators (IBI's), Indicator Species RSF (i.e. Bull trout, Cutthroat trout)	Standardized, regional dataset of fish sampling and research studies	Modification of existing IBIs or RSF models
Amphibian Community	Condition	Community Composition Indicators, Species Abundance/ RSF models	Standardized, regional dataset of amphibian sampling and research studies	Modification of existing IBIs
Macroinvertebrate Community	Condition	Community Composition (Abundance of Indicator Taxa): i. Ephemeroptera, Plecoptera, & Trichoptera (EPT), ii. Oligochaetes, Molluscs, Chironomids	Standardized, regional dataset of macro-invertebrate monitoring, and research studies (EEM, AENV – LTNR, University studies)	Modification of existing IBIs
Rate of Wetland Loss	Condition	Historical Time Series Analysis of Wetland Loss (i.e. % wetland area loss between 1971 and 2011)	Landsat remote sensing imagery (available from ≈ 1970 – present)	Wetland Research Studies
Riparian Condition	Condition	Condition Measures of Wetland and Riparian Health – i. *ARHMS Index (Cows & Fish)* ii. Wetland Physical Condition Indicators (hydrological connectivity, emergent zone slope and distance)	ARHMS surveys, high resolution modeling of wetland condition (modeling of LiDAR imagery)	Existing ARHMS methodology, Wetland Research Studies
Rangeland Health	Condition	Range Health Condition Measures i. Alberta Rangeland Health	Alberta Rangeland Health Database	Existing Alberta methodology, TBA

Table A-3. Aspirational list of pressure and condition indicators selected to assess the current state of the Headwaters Region in the Oldman Watershed for Criteria 3. The list was adapted from the Indicator Guide for Watersheds in Southern Alberta (AENV 2008b) and USDA Watershed Condition Framework (USDA 2011).

Name of Indicator	Indicator Type	Specific Measures	Data	Potential Threshold Source
CRITERION 3. Surface Water Quality				
Sedimentation/Erosion Potential	Pressure	i. Regional Model of Soil Erosion ii. Area with High Erosion/Sedimentation Risk	i. Headwater model needs to be created i. Alberta Base Feature Data, DEM, Wet Areas Mapping	i. TBA ii. TBA
Stream Crossing Density	Pressure	Density of Stream/Wetland Crossing Density	Alberta Base Feature Data, Wet Areas Mapping	Forestry Guidelines (BCME), Threaten Species Responses
Surface Water Quality	Condition	Water Quality Measures, including: i. Nutrients (Nitrogen, Phosphorous) ii. Trace Metals (i.e. Mercury, Aluminum, Iron, Vanadium) iii. Base Chemistry (Dissolved Oxygen. Total suspend solids, (TSS)) iv. Major Elements (Sulfate, Chlorine, Sodium) v. Organics (Pesticides, Organochlorine Pesticides)	Alberta Environment LTRN Stations, EEM Monitoring, Parks Canada, Individual Research Studies	CCME/EPA guidelines
Point Source Contamination	Pressure	Effluent Discharges (Municipal and Industrial)	Effluent discharge reports (to Alberta Environment under the Water Act)	CCME/EPA guidelines, Contaminant regulations
Non-point Source Contamination	Pressure	Chemical Application (Fertilizer, Pesticides, Manure),	2011 Census, Fertilizer Sales Statistics, Contained Feedlot Density	TBA
Sediment Quality	Condition	Sediment Quality Measures, including: i. Trace Metals (Selenium, Mercury, Lead) ii. Organic Compounds (Pesticides, Organochlorine Pesticides)	Alberta Environment LTRN Stations, EEM Monitoring, Parks Canada, Individual Research Studies	CCME/EPA guidelines

Table A-4. Aspirational list of pressure and condition indicators selected to assess the current state of the Headwaters Region in the Oldman Watershed for Criteria 4. The list was adapted from the Indicator Guide for Watersheds in Southern Alberta (AENV 2008b) and USDA Watershed Condition Framework (USDA 2011).

Name of Indicator	Indicator Type	Specific Measures	Data	Potential Threshold Source
CRITERION 4. Water Levels & Flows				
Stream Flow Regime	Condition	Magnitude i. Total annual flow ii. Total spring (melt), summer flow iii. Peak annual flow rate (/day) Timing i. Initiation of melt ii. 1st and 2nd peak Frequency i. No. of low and high pulses Duration i. Mean duration of low and high pulses Rate of Change **i.** Means of all positive/negative changes between consecutive daily values	Water Survey of Canada	Range of natural variability paradigm (Poff et al. 1997)
Lake or reservoir water level	Condition	Lake Level at Spring Peak (depth (m)) Lake Level at Fall Low (depth (m))	Water Survey of Canada	Range of natural variability paradigm (Poff et al. 1997)
Lake or reservoir open water area	Condition	Lake Area at Spring Peak (depth (m)) Lake Area at Fall Low (depth (m))	Remote sensing analysis of Landsat imagery	Range of natural variability paradigm (Poff et al. 1997)
Water availability (climatic input)	Condition	Effective Precipitation (P-PET) Snow Pack Depth at Initiation of Melt	Environment Canada - National Climate Data and Information Archive	Range of natural variability paradigm (Poff et al. 1997)
Potential surface water use	Pressure	Rate and Timing of Water Extraction	OWC	Range of natural variability paradigm (Poff et al. 1997)

Appendix B - Detailed Indicator Assessment Methods

Derivation of Fourth (4th) Order Watersheds

Data Sources:

1) Alberta Base Features - Simplified Linear Stream Network (SLN)
2) Alberta Base Features - Simplified Hydropolygons Grouping
3) Alberta Base Features - Strahler Stream Order
4) Alberta Base Features Derived – 1st Strahler Order Watershed Boundaries for the Oldman Watershed (bfd_pfwtrr0) produced by Alberta Environment and Sustainable Resource Development (AESRD)
5) Digital Elevation Model (DEM) for the Oldman Watershed

Modeling steps:

1. The Strahler Stream Order was joined to all streams in Simplified Linear Stream Network spatial layer to determine the stream Strahler Order
2. All contributing watersheds associated with lower order streams that flow into 4th or high order streams were grouped together to define a 4th Order Watershed. This was accomplished by dissolving all lower order streams (orders 1,2, and 3) from the SLN spatial layer and all connecting hydropolygon features (lakes, wetlands) into the higher orders streams (4th Order or higher). Multiple dissolve calculations were conducted because in many instances small streams (i.e. 2nd order) flow directly into 5th or 6th order rivers (the major rivers in the Headwaters where:
    a. Stream orders 1 - 3 and all connected hydropolygon features were dissolved in all connected 4th Order streams
    b. Stream orders 1 - 3 and all connected hydropolygon features were dissolved in all connected 5th Order streams
    c. Stream orders 1 - 3 and all connected hydropolygon features were dissolved in all connected 6th Order streams
    d. Stream orders 1 - 3 and all connected hydropolygon features were dissolved in all connected 7th Order streams
    e. A unique identifier was assigned to all stream segments dissolved into 4th or higher order watershed branches, and this information was added to the 1st Strahler Order Watershed Boundaries layer using spatial joining techniques. This process identified all the corresponding 1st Order watersheds which comprised the larger 4th Order Watershed.
3. This GIS stream analysis approach captured and assigned a 4th Order or higher watershed grouping to approximately 95% of the 1st Order Watersheds in the Headwaters Region. The remaining 5% of watersheds did not contain streams, and are upslope terrestrial areas containing small lakes and wetlands. Based on elevation (using a DEM), all upslope (higher elevation areas) were joined to nearest downslope adjacent 4th order watershed. The final 4th order watershed map, and the associated stream order is displayed in Figure B-1

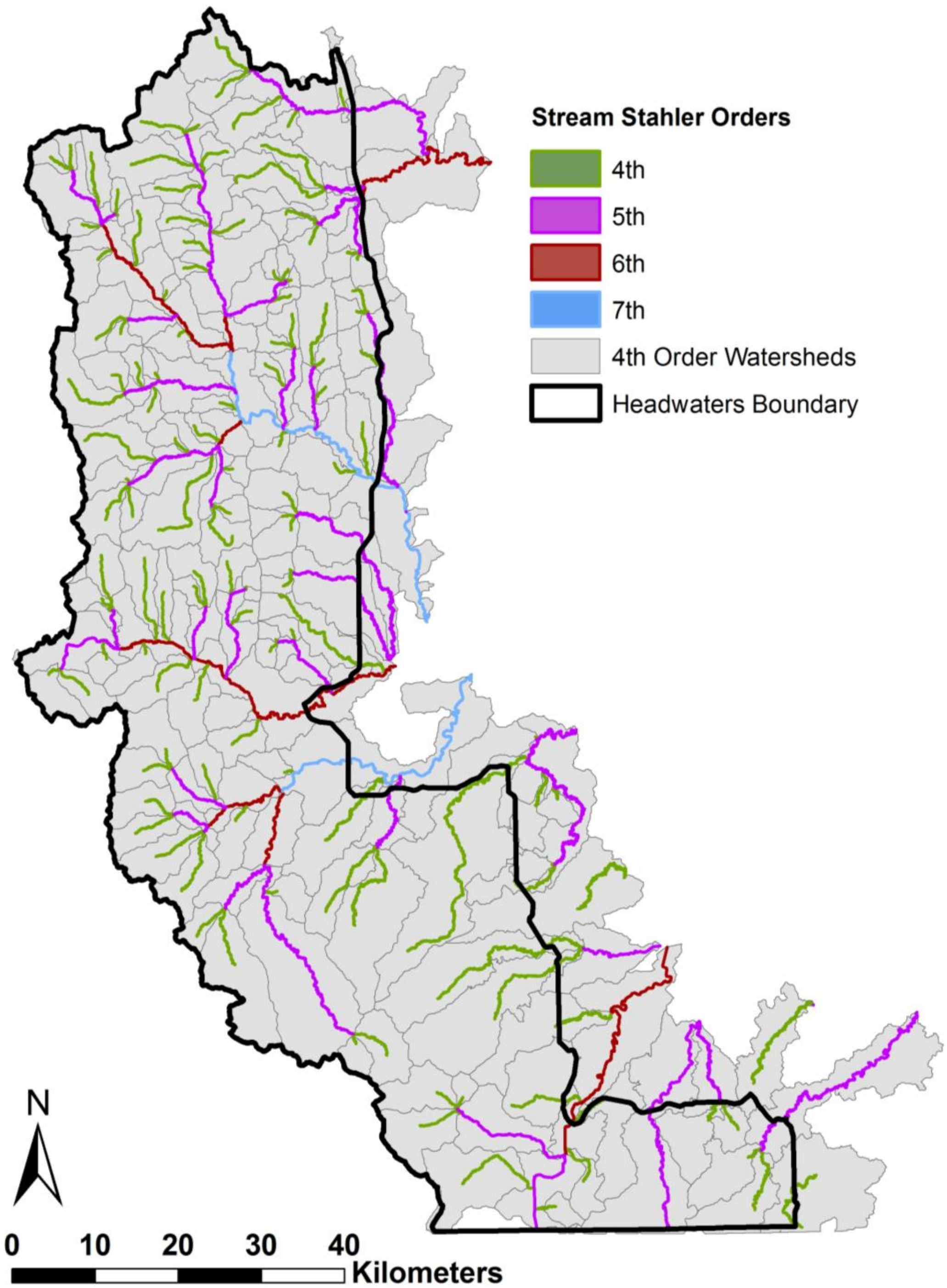

Figure B-1. Final 4th order watershed boundaries for the Headwaters and associated major streams (those 4th to 7th order).

CRITERION 1: Landscape Composition and Condition

Intact Landscapes

Data Sources:

1) Alberta base features layer for roads (ab.base.SDE.roads)
2) Alberta base features layer for pipelines (ab.base.SDE.pipelines)
3) Alberta base features layer for powerlines (ab.base.SDE.powerlines)
4) Alberta base features layer for raillines (ab.base.SDE.raillines)
5) Alberta base features layer for cutlines (ab.base.SDE.cutlines)
6) SRA_Cutlines_South_93.gdb (Inventory of ORV trails)
7) SRA_Cutlines_North_93.gdb (Inventory of ORV trails)
8) Unmapped Linear Features in the Headwaters Region (spatial layer created by Fiera Biological – see Item #1 below)
9) Crown Alberta Vegetation Inventory (AVI) and Crown Cutblocks (current to 2011)
10) Grassland Vegetation Inventory (GVI)
11) 2007 – 2010 Alberta Biodiversity Monitoring Institute (ABMI) Human Footprint Layer (developed by ABMI)

Indicator Modeling:

1. The existing Alberta Base Features for linear features do a good job of capturing larger linear features (roads, pipelines, powerlines), but are missing many smaller linear features (and more recent linear features). These include quad trails, some cutlines, and in particular, in-block logging roads. The Forestry Division does not require logging trails/roads which occur on harvest blocks to be tracked in the central provincial database. This is a concern in the Headwaters Region because many of these in-block logging trails are later converted to quad trails, and remain a persistent disturbance on the landscape. In addition, those trails which are considered reclaimed under AESRD standards can still be sources of sediment and can interrupt ground water flow and wildlife movements long after they are reclaimed.

2. Given this concern, as part of the Headwaters Indicators project, Fiera Biological mapped all visible unmapped linear features based on 2012 imagery. The steps were:
    a. The major imagery source was 2.5 m resolution Spot Imagery from Blackbridge from 2012. However, in some regions of the Headwaters the imagery resolution was lower, and this was supplemented by Bing Imagery (freely available with an ArcGIS license), which had a superior resolution to the 2.5 m Spot in some regions of the Headwaters. Because photo age in the Bing imagery was variable, all mapped features had to be visible on the 2012 2.5m Spot. However, where the Bing was superior, it was used to map linear features.
    b. In conducting the mapping, a grid with 1-kilometer cells was overlaid on the Headwaters Region, and searched systemically for unmapped linear features. Greater search effort was placed in areas with existing linear features, and industrial activity (oil and gas, and forestry).

c. The final spatial layer of new linear features in the Headwaters Region was edge-tied to the existing Alberta Base Features for Roads, Pipelines, Powerlines, and Cutlines following AESRD standards.

d. All new linear features were assigned a feature type of cutline (Alberta Base Feature field FEATURE_TY = CUTLINE-TRAIL) because of the unknown history of these features. This is the smallest type of mapped linear feature. The spatial layer of unmapped linear features created by Fiera Biological is the best available product given the limitation of the imagery and the air-photo interpretation process. There is an inherent uncertainty in the process, and the interpreter required a reasonably high certainty of linear feature presence before any features were mapped. Unmapped linear features which connected to currently mapped linear features were more likely to be interpreted because they were easier to detect. Possible linear features with a high uncertainty as to their actual presence, particular in high elevation areas, were not mapped.

3. All linear feature spatial layers (i.e. roads, power lines, rail lines, pipelines, seismic lines, cutlines, and including the new linear layer) were converted into polygon areas by buffering each line type by the average feature type widths specified by the Alberta Biodiversity Monitoring Institute (ABMI 2012).

   a. In order to account for edge effects and indirect habitat loss, seismic lines, cutlines, pipelines, powerlines and ORV trails were buffered by an additional 10 m, while all roads were buffered by an additional 25 m (Esseen and Renhorn 2008, Muria 1995).

4. All forest harvesting which has occurred in the last 30 years (between 1983 – and 2011; Figure B-2a) was classified as a human disturbance based on AVI and forest harvest data. This value was derived from the scientific literature examining successional patterns observed in young post-fire and post-logged forest stands. For both forest songbirds and understory plant species, a convergence in species abundance and composition is observed between post-burned and post-logged stands at approximately 30 years since disturbance (Hart and Chen 2008, Hobson and Schieck 1999, Kurulok and Macdonald 2007). These species groups respond in large part to the redevelopment of the overstory canopy cover which creates similar light condition under both disturbance histories. However, it must be recognized that post-fire and post log stands exhibit strong structural differences, in terms of features characteristic of old forests (including snag density, density of large veteran overstory tree, and downed woody material; Lee and Crites 2006). All of these features are significantly reduced in post-logged forest compared with post-fire forests. These structural features offer important habitat for cavity nesting wildlife species, and act as nutrient sources to old growth forests. Post-logged stands therefore require a much longer succession period to regenerate in these capacities (Lee and Crites 2006).

   a. Finally all forest harvests were buffered 25 meters to account for edge effects (Muria 1995).

5. The spatial footprints of extraction industry, heavy industry, urban, rural and agricultural areas were derived primarily from the ABMI human footprint layer, where:
    a. Extraction industry was classed as oil and gas well sites, mining sites, gravel pits, burrow-pits/sumps, and other disturbed vegetation (Figure B-2b).
    b. Heavy industry was considered rural industrial sites (i.e. fertilizer factories and agricultural processing facilities), high-density livestock operations, oil and energy processing facilities, and energy generating facilities (including well generation facilities; (Figure B-2b).
    c. Urban areas were considered high-density population areas including towns and hamlets, while rural sites were rural farmyards and homesteads (Figure B-2a).
    d. For agricultural landuse, the areas primarily represented lands with cultivated crops, hay, and other extensive evidence of human modification (i.e. tilling). Only extensively impacted agricultural lands are included in the ABMI layer because it can be difficult to distinguish pasture from natural grasslands in aerial photos. Pasture with intensive land use (i.e. high cattle density of 250 – 400 animals/km^2) should be considered a human disturbance because of the potential for negative impacts on water quality (OMOE 2009, Tate 2012); however there is no existing spatial inventory for pasture land which incorporates the intensity of use and/or management practices. Low-impact pasture systems were not considered a human disturbance here, and hence all pasture was excluded given the inability of existing spatial data to differentiate different pasture management systems and practices.

    The only available information for pasture is an assessment of overall rangeland health for grazing dispositions within the Oldman Watershed (Figure B-3). These health ratings were determined by field assessments conducted by agrologists using health assessment guidelines for tame pasture (Adams et al. 2009). Similar to the Cow and Fish riparian assessment methods, a ranking of Healthy, Healthy with Problems, and Unhealthy are assigned to individual grazing dispositions. This information is provided to demonstrate the existing health rankings of grazing leases in the Oldman Headwaters. However, this information has **not** been included in the calculation of the Intact Landscapes indicator.

6. A small amount of human disturbance is missing from the ABMI human footprint layer. This information was extracted from the GVI Site View spatial layer using the same classification (light industry, heavy industry, urban, rural and agricultural). Only polygons missing from the ABMI layer, but present in the GVI Site View were classified and extracted from the GVI.

7. All human footprint types derived in Steps 3 – 5 (forestry, light industry, agriculture), except urban and heavy industrial development were buffered by 25 meters (Esseen and Renhorn 2008, Muria 1995). Urban and heavy industrial development was buffered by a larger area (100 meters) due to their potential for greater edge effects and habitat loss (McGarigal et al. 2001).

8. Each of the human disturbance layers created in Steps 2 through 6 were UNIONED together to create a single Human Footprint layer.

9. All polygons in the Human Footprint layer were subtracted (deleted) from the Headwaters boundary layer to create an “intact vegetation” layer.

10. The intent of this indicator is to identify large contiguous patches of intact habitat suitable to a variety of wildlife species; therefore, intact landscapes were considered to be areas ≥500 hectares (Scott et al. 2002; Findlay and Houlahan 1997; Mensing et al. 1998). This landscape patch size is appropriate for many avian species and meso-carnivores, including northern goshawk (Squires and Reynolds 1997), barred owl (Mazur et al. 1998), and American marten (Buskirk and McDonald 1989). However, this is smaller than that recommend for grizzly bears (1000 ha; Holroyd 2008) and bull trout (2500 ha; Rieman and McIntyre 1995). This indicator only considered landscape patch size. No measure of patch connectivity was included in identifying intact landscapes.

11. Finally, all polygons smaller than the above size criteria were deleted from the Intact Vegetation layer to create a layer depicting Intact Landscape in the Headwaters Region >500 ha.

12. The total area of intact vegetation was summarized by each 4th Order Watershed, and was expressed as a percentage of the total area of each watershed ranging from 0 – 100%.
13. This range was split into four rating categories, based on values from peer-reviewed scientific literature:

    a. In a review of studies on birds and mammals, Andren (1994) concluded that landscapes with <30% remaining suitable habitat area were more likely to experience greater species loses or population declines due to the synergetic effects of combined habitat fragmentation and habitat loss. In landscapes with >30%, species loses or population declines were primarily impacted due simple habitat loss, and experienced negligible additional effects due to the fragmentation and isolations of habitat areas.

    b. Studies of the impacts of land-use on wetland species richness has demonstrated that the species richness of both mammals and amphibians decline by 50% when approximately 50% of the surrounding forest cover has been removed (Findlay and Houlahan 1997). In addition, in a large-scale analysis across Western Canada, and the north-western United States, genetic research on grizzly bears demonstrated that highly settled areas (where >50% of the landscape has been converted urban, rural and agricultural land-use) leads to significant reductions in grizzly bear movement, and increases in population fragmentation (Proctor et al. 2012). Finally, American marten studies has shown the marten respond to small amounts of forest fragmentation and rarely use sites where more than 25% of forest cover has been removed (Hargis et al. 1999, Chapin et al. 1998 and others 1999).

14. The following thresholds were used to differentiate between pressure rating categories for Intact Landscape based on scientific thresholds, where:

    Negligible Pressure was >75% aerial coverage of Intact Habitat
    Low Pressure was >50 to 75% aerial coverage of Intact Habitat
    Moderate Pressure was >30 **–** 50% aerial coverage of Intact Habitat
    High Pressure was <30% aerial coverage of Intact Habitat

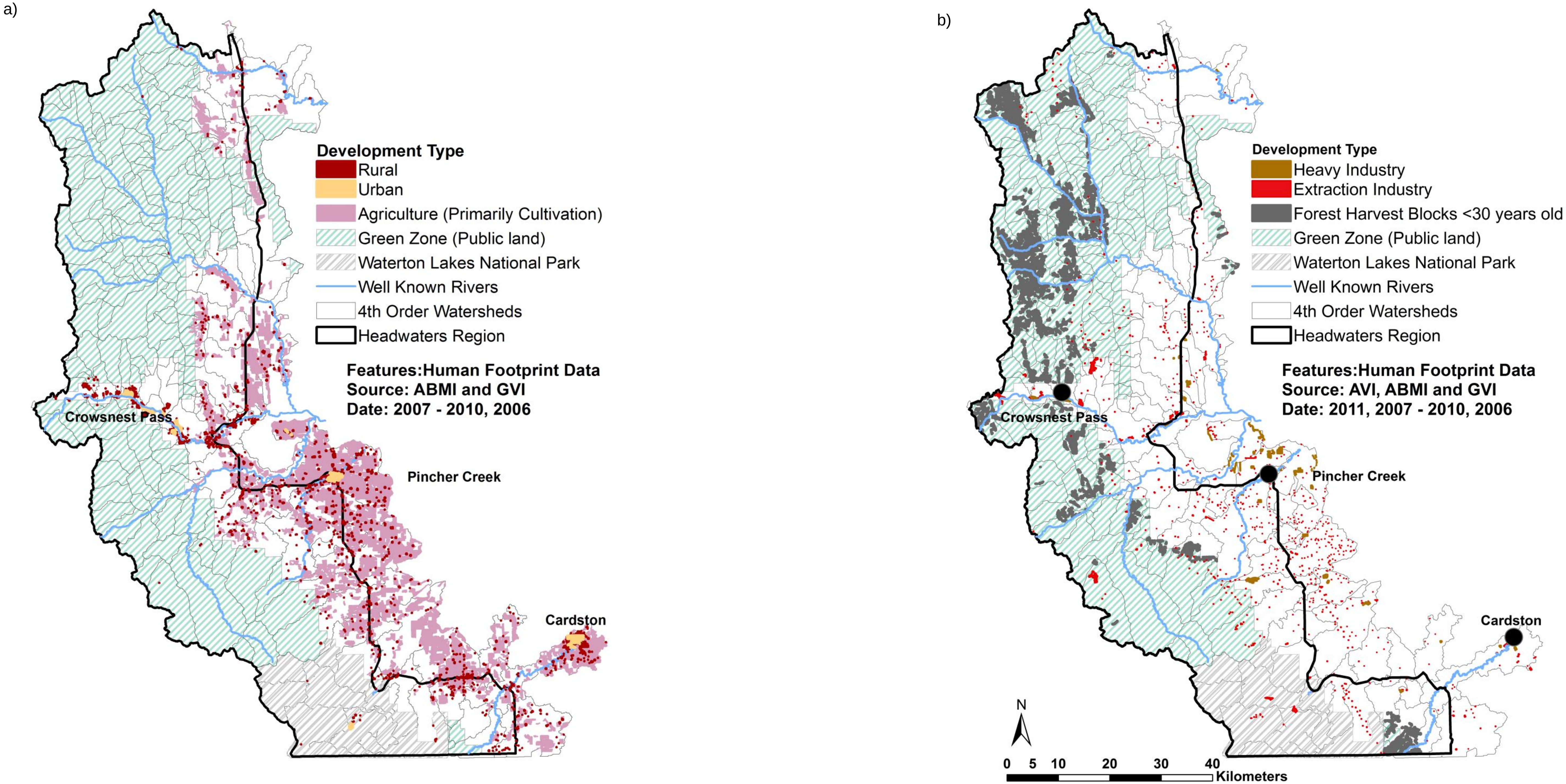

Figure B-2. Human footprint data used to generate the Intact Landscape Indicator. Only human footprint data for urban and rural development, agriculture, and industrial development are displayed here (the linear features data is displayed in Figure 5a and 6a). The data is derived primarily from the Alberta Biodiversity Monitoring Institute (ABMI) Human Footprint layer (created using imagery from 2007 – 2010), displaying (a) areas with agricultural land-use and urban and rural development, and (b) areas with industrial development including extraction industry (mining, gravel pits), heavy industry, and forest harvest activity. Public lands (Green Zone) are overlaid in green hatching, while private land comprises the remainder of the Headwaters Region.

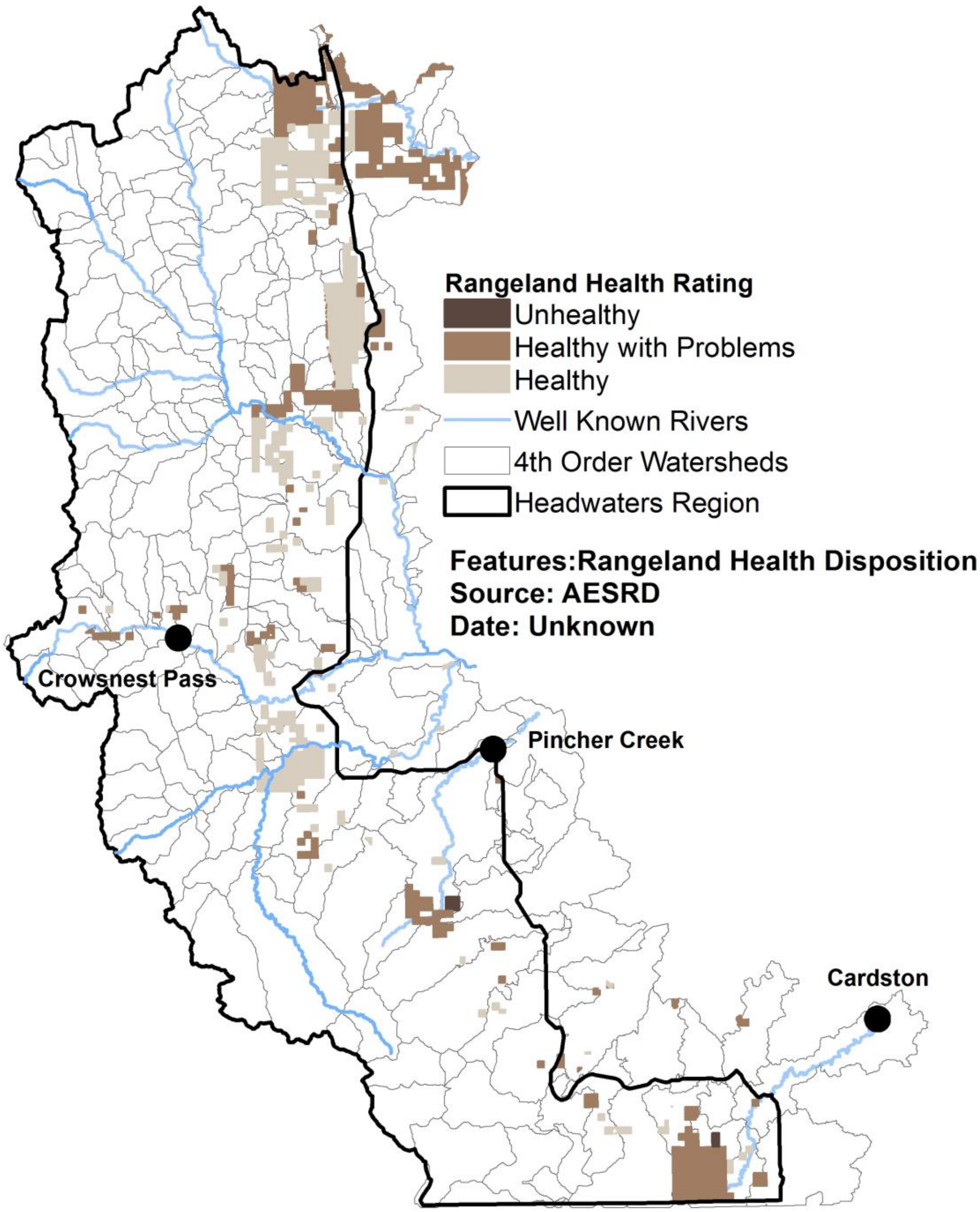

Figure B-3. Overall rangeland health ratings for grazing dispositions within the Oldman Watershed. Grazing leases are assigned a rank of Healthy, Healthy with Problems, or Unhealthy based on field assessments by field agrologists using assessment guidelines by Adams et al. (2009).

CRITERION 2: Biological Diversity

Road Density and Density of All Linear Features

Data Sources:

1) Alberta base features layer for roads (ab.base.SDE.roads)
2) Alberta base features layer for pipelines (ab.base.SDE.pipelines)
3) Alberta base features layer for powerlines (ab.base.SDE.powerlines)
4) Alberta base features layer for raillines (ab.base.SDE.raillines)
5) Alberta base features layer for cutlines (ab.base.SDE.cutlines)
6) SRA_Cutlines_South_93.gdb (Inventory of ORV trails)
7) SRA_Cutlines_North_93.gdb (Inventory of ORV trails)
8) Unmapped Linear Features in the Headwaters Region (spatial layer created by Fiera Biological – see Intact Landscape Indicator Item #1)

Indicator Modeling:

1. Using the Alberta base feature road layer, the total length of all roads (those feature navigable by trucks, defined as FEATURE_TY = Interchange-Ramp, Road-Gravel-1L, Road-Gravel-2L, Road-Paved-Div, Road-Paved-Undiv-1L, Road-Paved-Undiv-2L, Road-Paved-Undiv-4L, Road-Unclassified, Road-Unimproved) was calculated for each 4th Order Watershed.
2. Using all the data sources listed above, the total length of all linear features was calculated for each 4th Order Watershed.
3. Both road length and length of linear features were standardized into a density measure (km/km^2) by taking the total length of linear features in a watershed, and dividing that value by the area of the 4th Order Watershed.
4. The **Density of Roads** by 4th Order Watershed ranged from 0 to 1.7 km/km^2. Road densities as low as 0.1 km/km^2 have been shown to have negative impacts on Bull trout spawning (BCMWLAP 2002, Ripley et al. 2005), while elk and amphibian species richness all show reduced activity or richness at road densities of 0.5m/km^2 (Frair et al. 2008, Findlay and Houlahan 1997), and finally bull trout demonstrate depressed population at average road densities of 0.87 km/km2 (USFW 1998). Consequently, the following road density thresholds were used to differentiate Pressure Rating Categories:

   Negligible Pressure: ≤0.1 km/km^2
   Low Pressure: >0.1 to 0.5 km/km^2
   Moderate Pressure: >0.5 to 0.87 km/km^2
   High Pressure: >0.87 km/km^2
5. **Density of All Linear Features** ranged from 0 to 6.2 km/km^2. This range was split into three categories based on values from peer-reviewed scientific literature and government management guidelines. High quality grizzly bears habitat within Grizzly Bear Priority Areas must have a linear features density at or below 0.6 km/km^2, and linear features densities at or below 1.2 km/km^2 is recommended in all remaining grizzly bear range (Alberta Grizzly Bear Recovery Plan 2008). The

occupancy rate for American marten (*Martes americana*) in Alberta, and northern Idaho have been shown to decline to 50% at linear features density around 3 km/km^2 (Tigner 2012, Wasserman et al. 2012). The following thresholds were used to differentiate between Pressure Rating categories for the density of linear features:

Negligible Pressure: ≤0.6 km/km^2
Low Pressure: >0.6 to 1.2 km/km^2
Moderate Pressure: >1.2 to 3.0 km/km^2
High Pressure: >3.0 km/km^2

CRITERION 3: Surface Water Quality

Sedimentation/Erosion Potential Indicator

Data Sources:

1) Alberta base features layer for roads (ab.base.SDE.roads)
2) Alberta base features layer for pipelines (ab.base.SDE.pipelines)
3) Alberta base features layer for powerlines (ab.base.SDE.powerlines)
4) Alberta base features layer for raillines (ab.base.SDE.raillines)
5) Alberta base features layer for cutlines (ab.base.SDE.cutlines)
6) SRA_Cutlines_South_93.gdb (Inventory of ORV trails)
7) SRA_Cutlines_North_93.gdb (Inventory of ORV trails)
8) Unmapped Linear Features in the Headwaters Region (spatial layer created by Fiera Biological – see Intact Landscape Indicator Item #1)
9) 25-m Federal Digital Elevation Map (DEM)
10) Wet Area Mapping product (LiDAR derived)

Indicator Modeling:

1. Using all the linear features data sources listed above (1-8), the total length of all linear features was calculated for each 4th Order Watershed.
2. The 25m federal DEM was converted to a raster layer measuring percent slope using Spatial Analyst tools in ArcGIS, and then all areas with slope >40% were converted to a polygon features (SlopesGT40).
3. We used the Wet Areas Mapping (WAM) product to define all permanent and semi-permanent water bodies and their riparian zones in the Headwaters Regions. The Wet Areas mapping product (all areas which have a high probability of being wet) was converted to a polygon feature, and then buffered by 30 meter to estimate the riparian zone. In Alberta, 30 meters is recommended as a standard guide to riparian setbacks (Government of Alberta 2012).
4. The Wet Area Mapping product did not have complete coverage for all of the 178 - 4th order watersheds. As a result, all following analysis was restricted to 129 watersheds. There was complete coverage for 127 of the 4th order waters. An additional two large watersheds with incomplete coverage by WAM data (the two long sinuous watersheds which extended along the montane portions of the Oldman and the Crowsnest Rivers) were also included. This was done because WAM data existed for >75% of each watershed, and these are important watersheds to examine given the intensive human land-use along both. However, to account for the missing WAM data, each watershed was clipped at boundary of the Headwaters Region (along Hwy 22). The included portions of the watersheds had complete coverage by the WAM data.
5. The combined linear feature layer created in step 1 was intersected with the SlopeGT40 layer, and the buffered Wet Area Mapping layer to determine the length of linear features which occurred in habitats with a high erosion/sedimentation potential.
6. The length of linear features with a high Sedimentation/Erosion Potential was standardized into a density measure (km/km^2) by taking the total length of linear

features in a watershed, and dividing that value by the area of the 4th Order Watershed.

7. The density of linear features with high Sedimentation/Erosion Potential ranged from 0 to 2.8 km/km^2 (Figure 8a). There is little scientific literature focusing specifically on the impacts of linear features at high elevations, and in aquatic habitat. However, based on the assumption that the risks associated with linear features in these high elevation habitats are at least double that found with lower grades (Blanco and Lal 2008), the following pressure ratings were applied to the 4th Order watersheds. The thresholds derived above for the Density of All Linear Features was divided by two to determine Sedimentation/Erosion Potential thresholds, where:

   Negligible Pressure: ≤0.3 km/km^2
   Low Pressure: >0.3 to 0.6 km/km^2
   Moderate Pressure: >0.6 to 1.5 km/km^2
   High Pressure: >1.5 km/km^2

CRITERION 4: Water Levels and Flow

Stream Flow Regime

Data Sources:

1) Hydrological flow data was collected from 25 Water Survey of Canada hydrometric stations, most of which were located within or just outside of the Headwaters Region study boundary (Figure B-4).
2) Federal 25-meter resolution digital elevation model (DEM).

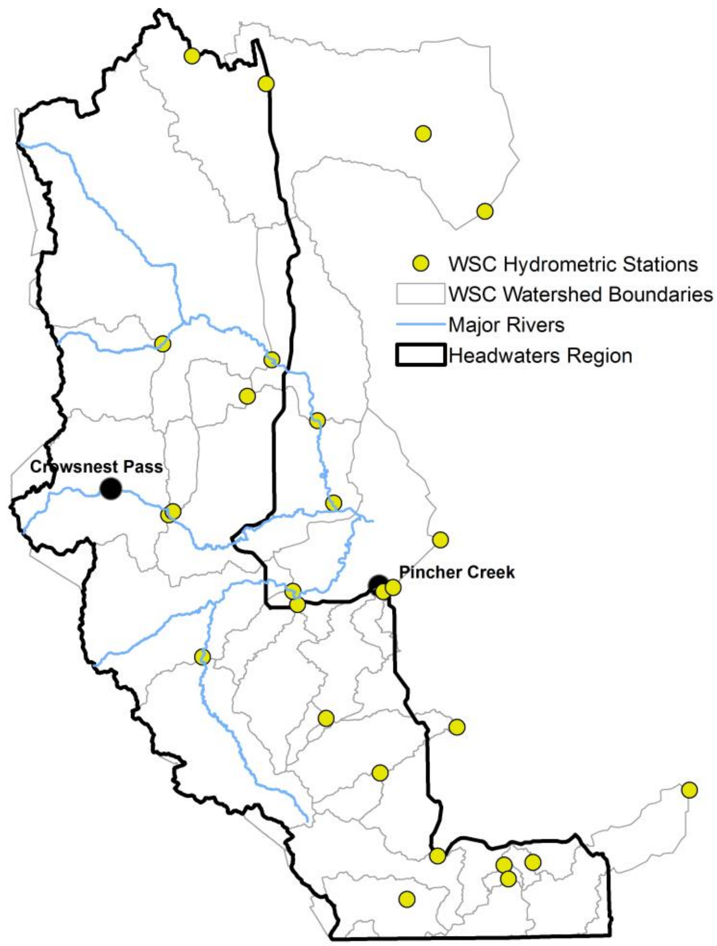

Figure B-4: Location of the Water Survey of Canada hydrometric stations that were considered in assessing water flow and water level in the Headwaters Region of the Oldman Watershed.

Indicator Analysis and Modeling:

1. In order to characterize the flow regimes within the Headwaters Region, all available hydrometric data (water flow and water level) compiled by the Water Survey of Canada (WSC) from stations active as of 2011 was obtained (see Table B-1 for station details).
2. The hydrologic fluctuations at these stations measure the cumulative hydrologic response to climatic forcing (precipitation and evaporation) across the land area that 'sheds' water to the hydrometric station. The boundaries of WSC watersheds used in this analysis were identified using the federal DEM, and a digital terrain analysis (Lindsay et al. 2004).
3. Digital terrain analysis was also used to identify the stream network from which we could identify the "scale" of the hydrological system based on the Strahler stream classification. Scale considers how much water flows past a given point, with considerably less water flowing per unit of time past locations in the "headwaters" than, for example, locations located along the Oldman River near Lethbridge. In the Strahler stream classification system, streams that contain a lower volume of water per unit time (e.g., the headwaters) would have a class of 1 (or 2), whereas the Oldman River at Lethbridge would be classified as class 8. On average within the Oldman Headwaters region, the WSC stations are measuring flow of mostly 5th order (Strahler) streams (Figure B-5). Most WSC stations are on higher order streams (order ≥5), with on one 3rd order stream with WSC station. This distribution limits our information and understanding of anthropogenic impacts on smaller headwater streams.
4. In order to derive indicators of flow, the annual hydrographs for all of the stations collecting data were analyzed. An example hydrograph is shown in Figure B-6). There were in excess of 800 annual hydrographs. Of the five main ways to describe the hydrograph, we chose the two most important indicators: 1) magnitude or how much water is available within the hydrological system, and 2) the timing of key events within the annual hydrologic cycle. A recent study analyzed stream water quantity and quality after the Lost Creek fire also focused on these two indicators and found significant changes between burned and unburned catchments (Silins et al. 2011).
5. In this study, magnitude was characterized by five measures: total annual flow; spring flow (April – May); summer flow (June – August); base flow (the lowest daily flow); and peak flow (the highest daily flow). Flow is measured as volume per unit of time (m^3/s). In order to allow for per unit area comparisons amongst watersheds of different sizes, the flow data was converted to a water depth (mm/day) using the area of the watershed. In order to characterize the timing of flow, we assessed the date of melt initiation, the first peak of the hydrograph as well as the second peak of the hydrograph). The date of melt initiation corresponded to the first day of significant increase in flow, doubling or tripling in flow within a few days; Figure B-6).

Table B-1: Descriptive information for the Water Survey of Canada hydrometric stations that were compiled initially to assess water flow and water level in the Headwaters Region of the Oldman Watershed. The final results shown in Section 5.4 above only included stations with at least 30 years of data between 1971 and 2010 (15 stations which are shaded in grey). Note: We included station 05AA023, which had over 30 years of data, but was closed at the end of 2008. Due to the low sample size we also added 05AA909 which had 28 years of data available. For stations where the flow regime is regulated we used a 'naturalized' (using the Project Depletion Method) weekly dataset obtained from Alberta Environment (all stations except 05AD010).

Station ID	Station Name	Strahler order	Area (km^2)	From	To	Regulated	Flow	Operation
05AA004	PINCHER CREEK AT PINCHER CREEK	4	157.5	1910	2010	NO	YES	Seasonal
05AA008	CROWSNEST RIVER AT FRANK	6	402.7	1911	2011	NO	YES	Continuous
05AA011	MILL CREEK NEAR THE MOUTH	5	179	1911	2010	NO	YES	Seasonal
05AA022	CASTLE RIVER NEAR BEAVER MINES	7	820.7	1945	2011	NO	YES	Continuous
05AA023	OLDMAN RIVER NEAR WALDRON'S CORNER	7	1446	1949	2008	NO	YES	Continuous
05AA024	OLDMAN RIVER NEAR BROCKET	8	4401.1	1966	2011	YES	YES	Continuous
05AA027	RACEHORSE CREEK NEAR THE MOUTH	5	217.6	1967	2010	NO	YES	Seasonal
05AA028	CASTLE RIVER AT RANGER STATION	6	375.3	1967	2010	NO	YES	Seasonal
05AA030	GOLD CREEK NEAR FRANK	5	63.3	1976	2011	NO	YES	Seasonal
05AA032	OLDMAN RESERVOIR NEAR PINCHER CREEK	7	4375.3	1992	2011	YES	LEVEL	Continuous
05AA033	KETTLES CREEK AT PINCHER CREEK	3	38.4	2005	2010	NO	YES	Seasonal
05AA034	PINCHER CREEK AT FRONT RANGE ROAD	4	24	2005	2011	NO	YES	Seasonal
05AA035	OLDMAN RIVER AT RANGE ROAD 13A	7	1834.1	2009	2010	NO	YES	Continuous
05AA909	TODD CREEK NEAR HIGHWAY NO.22	5	74	1983	2011	NO	YES	Seasonal
05AB021	WILLOW CREEK NEAR CLARESHOLM	6	1180.6	1908	2011	YES	FLOW	Continuous
05AB037	CHAIN LAKES RESERVOIR NEAR NANTON	5	213.4	1979	2011	YES	LEVEL	Continuous
05AB040	WILLOW CREEK AT SECONDARY 532	5	65.3	1996	2010	NO	YES	Seasonal
05AB041	WILLOW CREEK AT OXLY RANCH	6	832.9	1997	2010	YES	YES	Seasonal
05AD003	WATERTON RIVER NEAR WATERTON PARK	6	612.7	1908	2011	NO	YES	Continuous
05AD005	BELLY RIVER NEAR MOUNTAIN VIEW	5	319.2	1912	2011	YES	YES	Continuous
05AD010	DRYWOOD CREEK NEAR THE MOUTH	5	238.6	1920	2010	YES	YES	Continuous
05AD025	WATERTON LAKE AT WATERTON PARK	5	403.3	1959	2011	NO	LEVEL	Continuous
05AD042	YARROW CREEK AT SPREAD EAGLE ROAD	4	47.9	2005	2010	NO	YES	Seasonal
05AD940	PAYNE LAKE RESERVOIR NEAR MOUNTAIN VIEW	3	18.7	2002	2010	YES	LEVEL	Seasonal
05AE002	LEE CREEK AT CARDSTON	5	312.3	1909	2011	YES	YES	Continuous

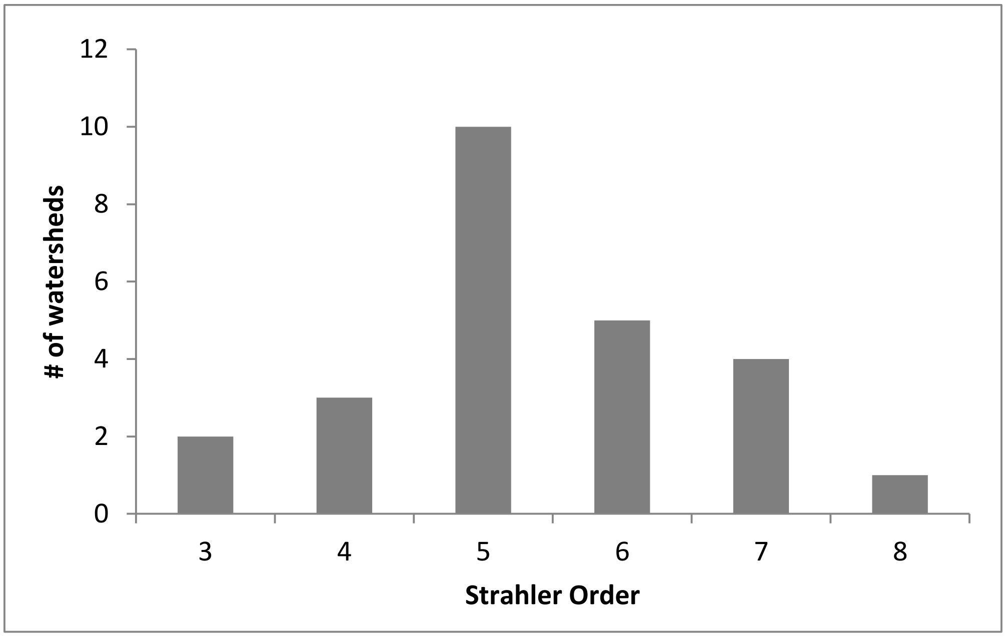

Figure B-5: Strahler order distribution of streams being monitored by the 25 WSC in or near the Headwaters of the Oldman Watershed.

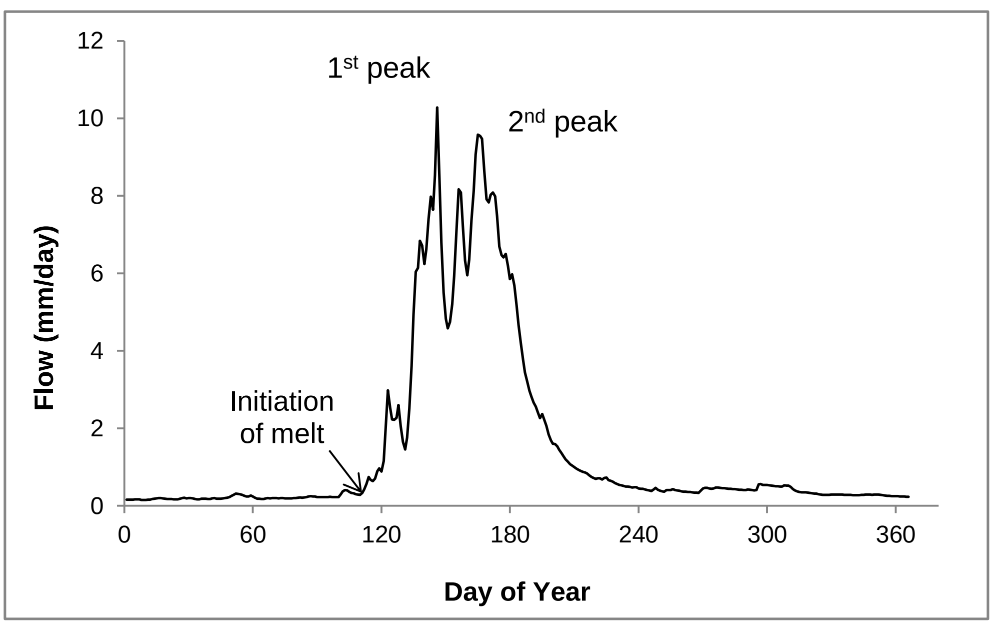

Figure B-6: Example of annual hydrograph from WSC stations. Initiation of melt, and timing of the flow peaks are measures used to assess the flow regime timing.

6. Once these measures were automatically computed or visually assessed, they were analyzed for temporal trends (Figure B-7). The appropriate statistical test for time-series data is the Mann-Kendall test (Helsel and Hirsch 1992). Kendall's tau (τ) uses a rank-based procedure to determine the correlation between two variables. The test was run twice for all WSC stations with a minimum of 30 years of data. A significance value of $p<0.05$ was used to identify highly significant correlations, meaning that there is a 5% or smaller probability that the observed results occurred by chance only. We also identified moderate significance correlations at $p<0.10$ (Table B-2).
7. The flow results shown above in Section 5.4 used all the data available for a given WSC station (as per Table B2) with the caveat that the stations had at least 30 years of data within the 1971-2010 window.

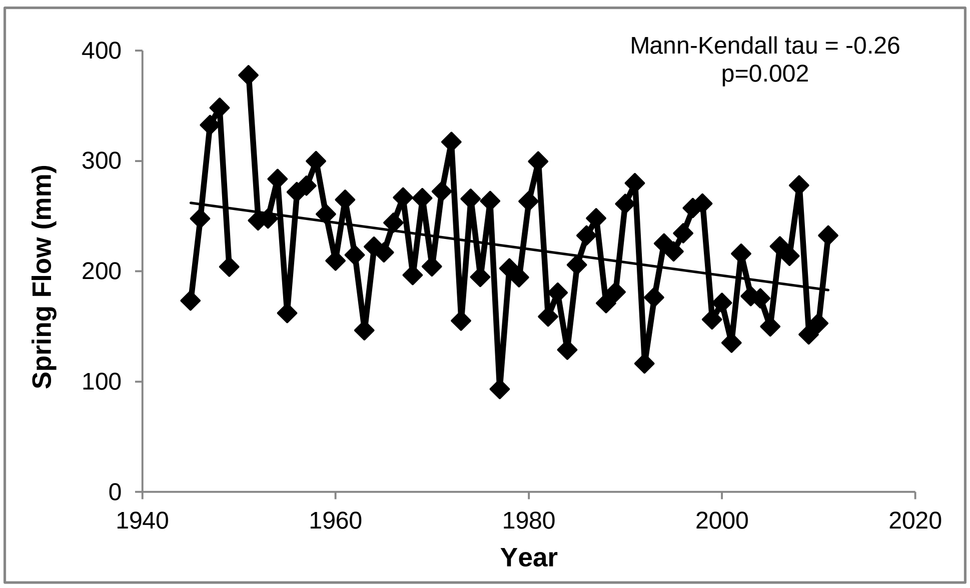

Figure B-7. Example for the temporal trends analysis conducted using the Mann-Kendall test. This is the result for spring flow for WSC station AA022.

Table B-2. Summary of Mann-Kendall (M-K) correlation (tau) coefficients assessing the sign (indicating decreasing or increasing trend) and strength (p-value) of trend relationship over time for 8 different flow regime measures. Tests are based only on WSC stations with a minimum of 30 years of data (see Table B1 for station details). The M-K correlation coefficients and regression p-value (in brackets, with significant correlations (p<0.1) in bold font) are shown below for each station and magnitude/timing measures.

WSC Station ID	WSC Station Name	Flow Magnitude Measures					Flow Timing Measures		
		Total Annual Flow	Spring Flow	Summer Flow	Daily Base Flow	Daily Peak Flow	Date of Melt Initiation	1st Hydrograph Peak	2nd Hydrograph Peak
05AA004	PINCHER CREEK AT PINCHER CREEK	**-0.15 (0.09)**	**-0.18 (0.04)**	-0.05 (0.57)	-0.02 (0.84)	0.03 (0.69)	0.03 (0.73)	0.04 (0.69)	0.09 (0.31)
05AA008	CROWSNEST RIVER AT FRANK	-0.13 (0.11)	**-0.29 (0.00)**	**-0.14 (0.09)**	-0.03 (0.72)	-0.09 (0.27)	0.00 (1.00)	**0.14 (0.09)**	-0.07 (0.39)
05AA011	MILL CREEK NEAR THE MOUTH	**-0.24 (0.04)**	-0.15 (0.23)	-0.18 (0.13)	**-0.21 (0.08)**	-0.04 (0.75)	**-0.24 (0.05)**	0.00 (1.00)	-0.10 (0.43)
05AA022	CASTLE RIVER NEAR BEAVER MINES	**-0.16 (0.06)**	**-0.26 (0.00)**	-0.11 (0.20)	0.13 (0.12)	-0.11 (0.20)	-0.08 (0.36)	-0.07 (0.42)	-0.02 (0.80)
05AA023	OLDMAN RIVER NEAR WALDRON'S CORNER	**-0.15 (0.10)**	**-0.20 (0.03)**	**-0.15 (0.10)**	-0.08 (0.40)	-0.04 (0.66)	**-0.22 (0.02)**	-0.06 (0.53)	-0.01 (0.30)
05AA024	OLDMAN RIVER NEAR BROCKET	-0.08 (0.24)	-0.08 (0.23)	-0.07 (0.31)	**-0.26 (0.00)**	-0.02 (0.82)	-0.05 (0.54)	-0.10 (0.17)	**0.16 (0.03)**
05AA027	RACEHORSE CREEK NEAR THE MOUTH	-0.11 (0.32)	-0.07 (0.54)	-0.14 (0.19)	**0.17 (0.10)**	-0.13 (0.23)	**-0.22 (0.04)**	**-0.23 (0.03)**	-0.16 (0.13)
05AA028	CASTLE RIVER AT RANGER STATION	-0.14 (0.19)	-0.16 (0.14)	-0.07 (0.51)	0.11 (0.31)	-0.08 (0.46)	**-0.20 (0.06)**	-0.05 (0.64)	0.05 (0.65)
05AA030	GOLD CREEK NEAR FRANK	**0.22 (0.07)**	na	**0.22 (0.10)**	-0.06 (0.65)	0.13 (0.30)	-0.03 (0.84)	**0.21 (0.09)**	0.06 (0.63)
05AA909	TODD CREEK NEAR HIGHWAY NO.22	0.18 (0.18)	-0.06 (0.68)	0.12 (0.37)	**0.26 (0.05)**	0.11 (0.40)	-0.03 (0.84)	0.01 (0.94)	-0.15 (0.27)
05AB021	WILLOW CREEK NEAR CLARESHOLM	-0.02 (0.76)	-0.07 (0.30)	-0.03 (0.62)	**-0.30 (0.00)**	0.02 (0.75)	0.08 (0.30)	**-0.15 (0.04)**	-0.06 (0.39)
05AD003	WATERTON RIVER NEAR WATERTON PARK	**-0.14 (0.07)**	**-0.14 (0.05)**	**-0.12 (0.10)**	-0.12 (0.11)	-0.11 (0.16)	**-0.14 (0.07)**	0.05 (0.54)	0.01 (0.86)
05AD005	BELLY RIVER NEAR MOUNTAIN VIEW	-0.04 (0.53)	-0.02 (0.83)	-0.04 (0.53)	-0.04 (0.56)	0.02 (0.78)	**-0.18 (0.01)**	-0.05 (0.47)	-0.06 (0.39)
05AD025	WATERTON LAKE AT WATERTON PARK	na	na	na	0.06 (0.48)	-0.03 (0.77)	-0.01 (0.93)	-0.01 (0.90)	na
05AE002	LEE CREEK AT CARDSTON	-0.025 (0.72)	-0.093 (0.17)	0.017 (0.81)	**-0.12 (0.08)**	0.01 (0.90)	-0.06 (0.40)	-0.04 (0.60)	0.08 (0.23)

Appendix C – Occurrence of rare and unique habitat or biota

Occurrence of rare/unique habitats or biota in the Headwaters

The occurrence of rare and unique habitats or biota as recognized by the Alberta Conservation Information System (ACIMS) is provided as additional information to identify priority watersheds for conservation or stewardship focus by the OWC. The occurrence elements for rare or unique landforms is shown below in Figure C-1a. Rare landforms are uncommon landscape features resulting from unique geological, erosional and/or sedimentation processes. The occurrence elements for rare or unique plant communities is shown in Figure C-1b. These mapped occurrences are for plant communities which are ranked as threatened or at risk by ACIMS based on the S-rank (Table C-1). S-ranks ranges between S1 and S5, with plant communities listed are S1 being the most at risk.

Table C-1. Threatened or at risk plant communities identified by ACIMS in Headwaters Region of the Oldman Watershed, and their associated S-ranks.

Plant Community Common Name	Plant Community Scientific Name	ACIMS S_RANK
Alder-leaved buckthorn shrubland	Rhamnus alnifolia shrubland	S1S2
Aspen / thimbleberry forest	Populus tremuloides / Rubus parviflorus forest	S2
Balsam poplar - aspen / alpine foxtail - bluejoint	Populus balsamifera - P. tremuloides / Alopecurus alpinus - Calamagrostis canadensis	S1S2
Bear-grass herbaceous vegetation	Xerophyllum tenax herbaceous vegetation	S1S2
Big sagebrush - alder-leaved buckthorn	Artemisia tridentata ssp. vaseyana - Rhamnus alnifolia	S1
Big sagebrush - saskatoon	Artemisia tridentata ssp. vaseyana - Amelanchier alnifolia	S1
Bolander's quillwort aquatic community	Isoetes bolanderi aquatic community	S1
Douglas-fir - limber pine / ground juniper / mountain rough fescue	Pseudotsuga menziesii - Pinus flexilis / Juniperus communis / Festuca campestris	S2
Drummond's willow / bluejoint shrubland	Salix drummondiana / Calamagrostis canadensis shrubland	S1
Idaho fescue - bluebunch wheat grass grassland	Festuca idahoensis - Pseudoroegneria spicata grassland	S1S2
Limber pine / common bearberry - creeping juniper	Pinus flexilis / Arctostaphylos uva ursi - Juniperus horizontalis	S2
Limber pine / common bearberry woodland	Pinus flexilis / Arctostaphylos uva-ursi woodland	S2
Subalpine fir - limber pine - aspen / veiny meadow rue	Abies bifolia - Pinus flexilis - Populus tremuloides / Thalictrum venulosum	S2?
Subalpine fir - whitebark pine - Engelmann spruce / crowberry	Abies bifolia - Pinus albicaulis - Picea engelmannii / Empetrum nigrum	S2
Western larch / thimbleberry	Larix occidentalis / Rubus parviflorus	S1
Whitebark pine / ground juniper - common bearberry	Pinus albicaulis / Juniperus communis - Arctostaphylos uva ursi	S2S3

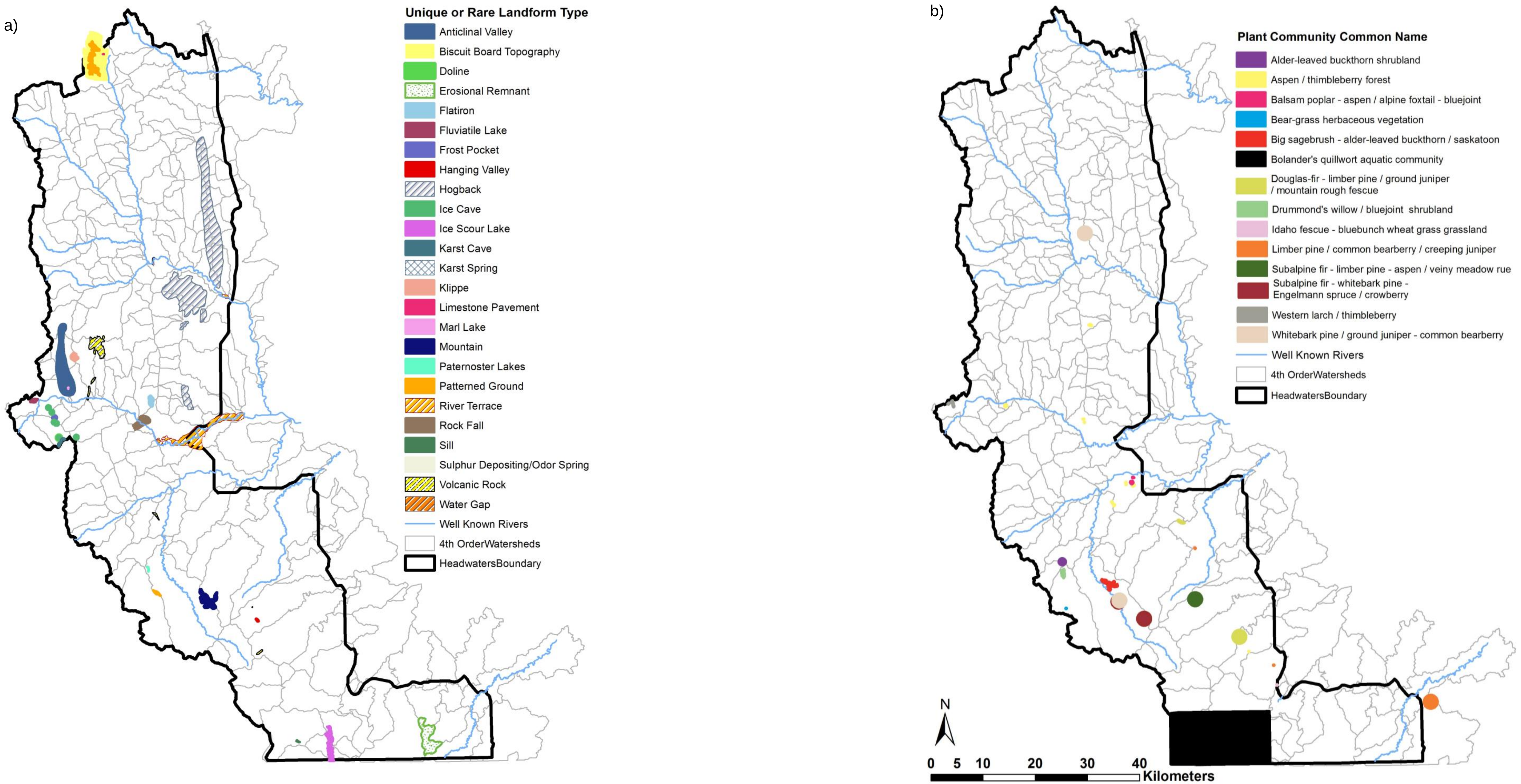

Figure C-1. Occurrence of unique or rare landforms (a), and plant communities (b) as classified by the Alberta Conservation Information Management System (ACIMS) in the Headwaters Region of the Oldman Watershed.