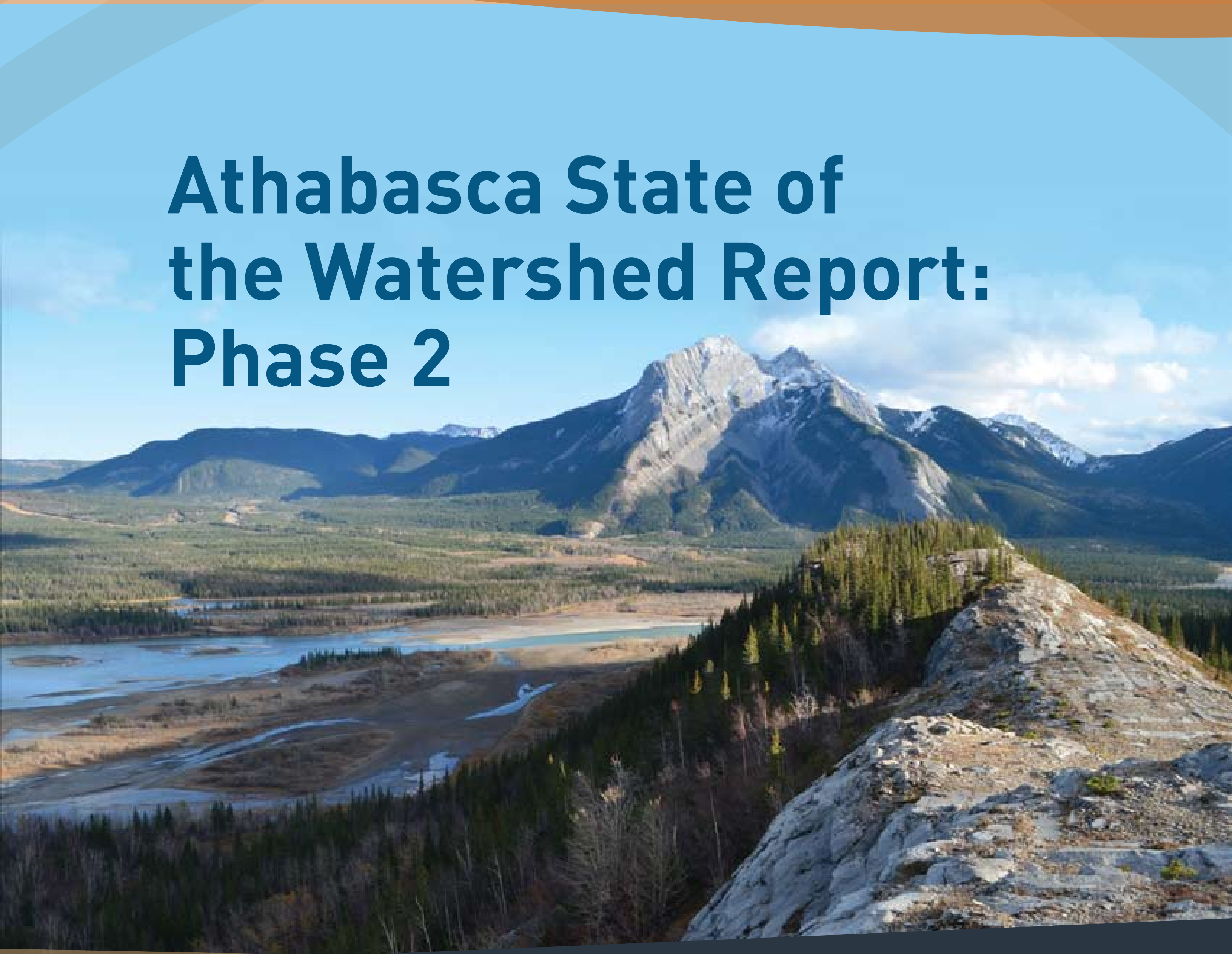
Athabasca State of the Watershed Report: Phase 2



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Front Cover Photo: Athabasca River at the Jasper National Park Boundary
(photo credit: Connie Simmons)

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Executive Summary

The Athabasca Watershed covers an area of approximately 151,015 km^2 and is comprised of ten subwatersheds, which range in size from 6,138 km^2 to 27,077 km^2. Ecologically, the Athabasca basin contributes significantly to the biodiversity of the province, containing rare and unique land forms and wildlife habitat. Human settlement and economic activity in the basin is varied, and common land uses include agriculture, forestry, surface mining (oil sands, coal, and sand and gravel), in situ and conventional oil and gas, and recreation and tourism.

As designated by the Watershed Planning and Advisory Council under Alberta's Water For Life, the Athabasca Watershed Council (AWC) has been mandated by the provincial government to develop a State of the Watershed (SoW) report. The overall objective of a state of the watershed report is to provide an overall assessment or description of the current condition of the watershed (Alberta Environment 2008). This information may be used by land and water managers to identify priority areas for further research and assessment. To this end, Phase 2 of the Athabasca State of the Watershed Report is focused on providing a *large-scale* overview of the various factors that *may be* impacting the ecological condition of the watershed. In addition, this assessment has focused on identifying knowledge and/or data gaps that have limited the ability to assess watershed condition at a large spatial scale. **At present, this State of the Watershed Report should not be considered a definitive statement on the condition of the Athabasca Watershed, but rather, a starting point for further management, research, and monitoring action**.

The Athabasca State of the Watershed assessment utilized a Criteria & Indicators (C&I) conceptual framework to assess current conditions in the watershed. Five criteria were developed including:

CRITERION 1: Conservation of Biological Diversity

CRITERION 2: Maintenance of Surface Water Quality

CRITERION 3: Maintenance of Ecologically Significant Water Levels and Flow

CRITERION 4: Maintenance of Groundwater Quality and Quantity

CRITERION 5: Maintenance of Watershed Integrity

Within these five criteria, 32 individual indicators were selected. While all 32 of the indicators were considered by the AWC to be reflective of critical elements of watershed condition, many of the indicators were data-limited, and were thus excluded from this phase of the assessment. Further, several indicators were excluded due to the complexity involved with developing rigorous data models, and the relatively limited time available for completing this assessment. As a result, 18 indicators were excluded from this Phase of the State of the Watershed assessment and considered to be "Aspirational". These indicators should be included in future state of the watershed assessments if data and resources permit. For the remaining 14 indicators (Table 2), all data that was publically available within the specified timeline for this project was compiled and examined, and GIS data models were developed, such that the distribution and composition of each indicator could be mapped and compared throughout the Athabasca Watershed. Specifically, this assessment focused on the 31 tertiary watersheds present in the Athabasca Watershed as the unit of analysis.

The ultimate goal of the Athabasca State of the Watershed assessment is to develop a rating scheme that allows for a direct comparison of indicators across subwatersheds. For this project, a Pressure Rating was developed to categorize the extent to which selected indicators exert pressure on each of the six watershed criteria. It is important to note that Pressure Ratings *do not* measure watershed health or condition directly, but rather, the existence of one or more pressure identifies the *potential* for watershed health to be impaired. This report focused on mapping pressure indicators because at present, data for modeling and mapping biological condition indicators at a large-scale (i.e., watershed-wide) is limited. Pressure ratings were divided into three categories: high pressure, moderate pressure, and low pressure. The values used to differentiate between the pressure categories are indicator specific, and were drawn from the scientific literature. In total, Pressure Ratings were assigned at the tertiary watershed scale for six indicators using scientifically derived pressure threshold values.

Six indicators were not assigned a Pressure Rating, but were still modeled and mapped because they represent areas in the Athabasca Watershed where ecological condition may be compromised. These indicators were assigned a Relative Disturbance Classification, which was divided into three categories: Minimal, Moderate, and Elevated. Scientifically derived thresholds were not available for these indicators, so the boundaries between categories were assigned using a Jenks Natural Classification Analysis. It is important to note that Relative Disturbance Classifications are *relative values*, meaning that these ratings are *not* set against an absolute or ecological threshold value. Instead, using Jenks Classification Analysis, individual tertiary watershed are identified as a Minimal, Moderate, and Elevated Relative Disturbance Classification for each indicator based on the relative occurrence, density, or distribution of the indicator being considered. Finally, three indicators were modeled but were not rated due to limitations associated with the data or the scale of modeling.

This report also identifies data and knowledge gaps in the Athabasca Watershed, with particular attention given to indicators measuring water quality and biological condition, which are currently limited in the scope and detail of modeling and assessment in this report. The state of knowledge of each indicator was summarized, with recommendations on the steps for addressing the data gaps for each indicator.

In conclusion, this report provides a preliminary *large-scale* overview of the various factors (pressure indicators) that may be impacting the ecological condition of the watershed.

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1.0 The Athabasca Watershed

Originating from the Columbia Glacier in Jasper National Park Alberta, the Athabasca River flows more than 1,500 km to the northeast, discharging into Lake Athabasca and eventually flowing into the Arctic Ocean via the MacKenzie River. Within Alberta, the Athabasca Watershed covers an area of approximately 151,015 km^2 and is comprised of ten subwatersheds, which range in size from 6,138 km^2 to 27,077 km^2 (Table 1). As it flows through the province, the Athabasca River passes through four major Natural Regions, including the Rocky Mountains, Foothills, Boreal Forest, and Canadian Shield (Figure 1). Ecologically, the Athabasca basin contributes significantly to the biodiversity of the province, containing rare and unique land forms and wildlife habitat, such as the Cardinal River headwaters, Peace Athabasca Delta, McClelland Lake, and the Richardson Sand Dunes, to name only a few.

Table 1. Description of the ten subwatersheds that make up the Athabasca Watershed.

SUB-WATERSHED NAME	TOTAL AREA (KM2)	COMMON LAND USES
Upper Athabasca	25,195	Forestry , Conventional Gas Extraction, Recreation and Tourism
McLeod	9,658	Forestry, Agriculture, Coal and Aggregate Mining, Conventional Gas Extraction,
Pembina	14,324	Forestry, Agriculture, Conventional Gas Extraction
Central Athabasca (Upper Watershed)	6,138	Agriculture, Forestry, Conventional Gas Extraction, Aggregate mining
Central Athabasca (Lower Watershed)	16,412	Forestry, In-Situ Oil Extraction Conventional Oil and Gas Extraction
Lesser Slave	20,084	Forestry, Agriculture, Recreation and Tourism
La Biche	8,671	Agriculture, Conventional Oil and Gas Extraction, Recreation and Tourism
Clearwater	16,893	Forestry, Oil Extraction, In-Situ Oil Extraction
Lower Athabasca	27,077	Forestry, Oil Extraction, Aboriginal Traditional Use
Lake Athabasca	6,562	Aboriginal Traditional Use

Culturally, the basin is vibrant and diverse, and is home to more than 150,000 residents, 13% of who are Aboriginal peoples (Walsh 2008). Human settlement and economic activity in the basin is varied, and common land uses include agriculture, forestry, surface mining (oil sands, coal, and sand and gravel), in situ and conventional oil and gas, and recreation and tourism (Table 1). Conventional oil and gas extraction occurs throughout much of the Athabasca Watershed, while non-conventional oil extraction, including oil sands mining and in-situ extraction, is largely restricted to the Lower Athabasca, Clearwater, and Central Athabasca subwatersheds. Agriculture is common in the central portion of the watershed (Lesser Slave, Pembina, McLeod and Upper Athabasca subwatersheds), while forestry is a common land-use in the western and eastern areas (Upper Athabasca, McLeod, Pembina, Lesser Slave, Clearwater and Lower Athabasca subwatersheds). In recent decades, the Athabasca Watershed has come under increasing pressure as a result of rapid economic and population growth, and there are increasing concerns over what impacts these pressures may have on watershed health at both the local and regional scales, and how changes in the condition of the Watershed may impact both human and ecosystem health.

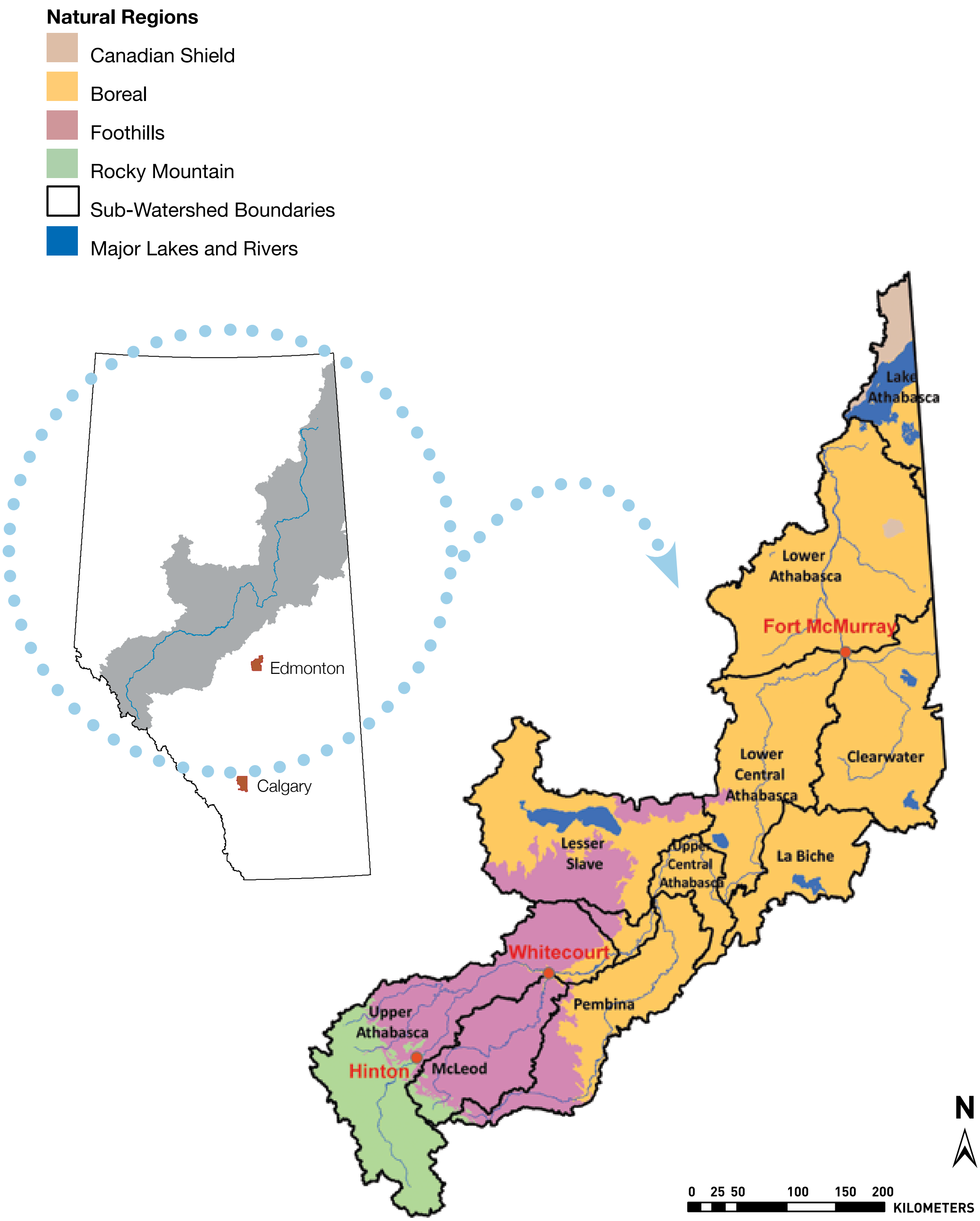


Figure 1. Location of the Athabasca Watershed in the province of Alberta, with its ten sub-watersheds and four natural regions.

STATE OF THE WATERSHED REPORTING

As designated by the Watershed Planning and Advisory Council under Alberta's Water For Life: Alberta's Strategy for Sustainability policy, the Athabasca Watershed Council has been mandated by the provincial government to develop a State of the Watershed (SoW) report. The overall objective of a state of the watershed report is to provide an **overall assessment** or description of the **current condition** of the watershed (Alberta Environment 2008). To this end, Phase 2 of the Athabasca State of the Watershed Report is focused on providing a *large-scale* overview of the various factors that *may be* impacting the ecological condition of the watershed. Specifically, this assessment focused on the tertiary watershed as the unit of analysis. The tertiary watershed is a finer-scale ecological drainage boundary than the subwatershed, and is delineated based on river flow and elevation (PFRA 2008). Within the ten subwatersheds present in the Athabasca Watershed, there are 31 smaller tertiary watersheds (Figure 2).

This large-scale macro view has informed all aspects of this state of the watershed assessment, from the selection of indicators and data sources, to the analysis and reporting of results. In addition, this assessment has focused on identifying knowledge and/or data gaps that have limited the ability to assess watershed condition at a large spatial scale (see Section 4). The primary intent of this report is to provide an *overview* of the state of the Athabasca Watershed, such that this information may be used by land and water managers to identify priority areas for further research and assessment. In addition this report will serve as a basis for measuring watershed condition on a go-forward basis. Thus, this State of the Watershed Report should not be considered a definitive statement on the condition of the Athabasca Watershed, but rather, a starting point for further management, research, and monitoring action.

LAND USE AND LAND COVER IN THE ATHABASCA WATERSHED

Land use is defined as the area on the landscape that has been modified by human activity, while land cover is an inventory of the native vegetation cover. Over the last several decades, there have been hundreds of studies that have documented the negative effects of human land use on biodiversity, and surface water and groundwater quality and quantity. As a result, accurate and up-to-date land use and land cover information is critical to understanding the current condition of the Athabasca Watershed. Given that most of the existing land use and land cover information in the province of Alberta is old (pre-2000) and has spotty coverage, this assessment focused on creating an up-to-date and complete land use/land cover spatial layer for the Athabasca Watershed. In addition, a historical land use/land cover layer was created in order to compare changes in land use/land cover in the watershed over time. The Athabasca Watershed land use/land cover layer was created using Landsat satellite imagery, which is archived and available at no cost by the Unites States Geological Survey (USGS). Two time-periods were targeted for this analysis: Historical (1973/74) and Current (2009). The available imagery differed between the two time periods due to the type of satellite sensors used to collect the images; consequently, imagery for the Historical period was taken using Landsat Multispectral Scanner sensors with 60 m resolution, while imagery for the Current period used Landsat Thematic Mapper sensors with 30 m resolution.

Assembling a land use/land cover layer for the Athabasca Watershed required piecing together 13 to 15 satellite image tiles for each time period. Landsat imagery was selected from the summer period (July to September), and assessed for image quality (i.e. only selecting cloud-free images). Image processing and classification was performed in PCI's Geomatica 10.0 using an unsupervised classification approach. The ISODATA algorithm was selected, which is one of the standard unsupervised methods available in all image processing software. The classification process creates clusters attributable to the dominant land covers or land uses of the Athabasca region. Using the Clearwater subwatershed as a testing area, the clusters were classified based on Alberta Vegetation Inventory (AVI) data available for this watershed. Two of the land cover classes had to be manually identified given the spectral overlap between them and other classes. These were agriculture and built-up (including both urban and industrial development [defined as oil extraction and larger oil infrastructure sites]). Finally, due to difficulty in distinguishing non-forested vegetation classes, they were merged in one class for a total of nine classes derived in this analysis, including Open Water, Coniferous Forest, Deciduous Forest. Open Low Vegetation, Built-up, Recent Burn, Agriculture, Mountain, and Ice. Verification and clean-up work of the Open Low Vegetation and Recent Burn categories are required to verify the accuracy of classifying recent burns, and to split out the Open Low Vegetation class into wetland categories, cutblocks, and upland shrub/herbaceous areas.

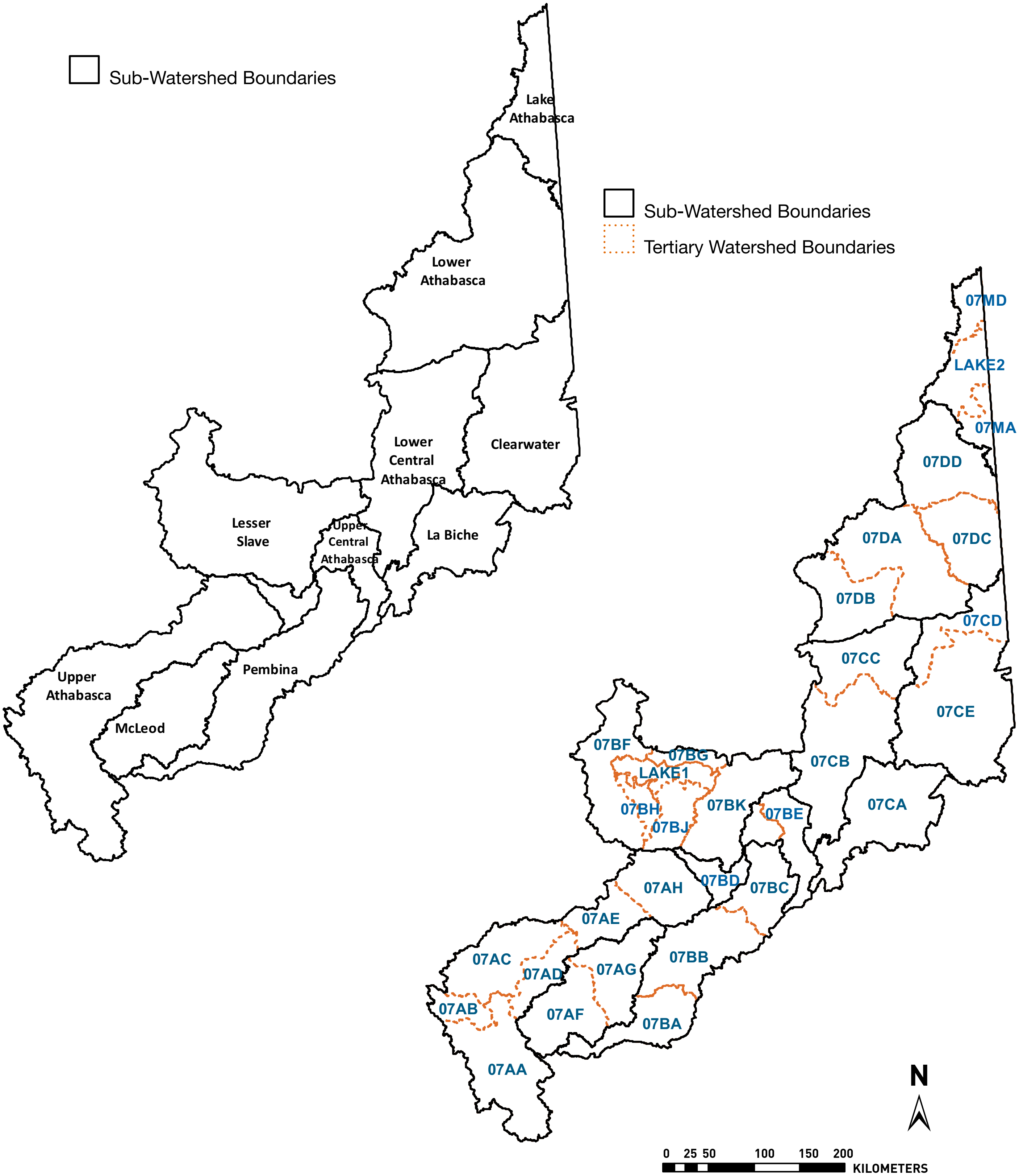


Figure 2. Map of the 10 subwatersheds and 31 tertiary watersheds in the Athabasca Watershed. The tertiary watershed was used as the unit of analysis for all modeling and mapping completed for this assessment.

A **criterion** is representative of a specific watershed element and embodies the collective conservation values and goals for management of the watershed.

An **indicator** is a measureable or descriptive variable that can be used to observe, evaluate, or describe trends as a criterion changes over time.

While indicators from the basis of watershed condition assessments, it is often very difficult to measure them directly. Instead, **surrogate metrics** are selected to represent an indicator.

CRITERIA AND INDICATOR FRAMEWORK

The Athabasca State of the Watershed assessment utilized a Criteria & Indicators (C&I) conceptual framework to assess current conditions in the watershed. Criteria and indicators are science-based tools that facilitate a common understanding of "sustainable watershed management", and this approach is well established in forest and watershed management in Canada and the United States (Davies and Hanley 2010; Alberta Environment 2008; CCFM 2005, 1995; EPA 1996, 1990).

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.), and are often narrative or aspirational, and embody the collective goals or objectives for the management of the watershed. Each criterion is in turn association with one or more specific indicator, which 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 often further characterized as being one of three "types" of indicators: condition, pressure, or response. Condition indicators focus on measuring the quality or quantity of ecosystem structure or function (i.e. riparian health), or the structure or persistence of natural flora and fauna populations in response to a gradient of human disturbance (e.g. fish community structure). Pressure indicators focus on measuring natural or anthropogenic impacts or stressors (e.g. human population growth, road density) that pose a risk to ecosystems or ecosystem elements. Response indicators measure the effectiveness or existence of collective actions or management programs that have been put in place in response to pressures that may be negatively impacting watershed condition.

While indicators are often characterized as being one of condition, pressure, or response, in reality, indicators are closely related, and there may some overlap in what indicators measure. As a result, there is no definitive or "correct" way of categorizing indicators. Ultimately, the goal of this approach is to simplify and summarize complex ecological information such that it may be used to help inform land management decisions at all levels.

This State of the Watershed assessment focused exclusively on selecting and measuring *condition* and *pressure* indicators in the Athabasca Watershed, and each indicator that was selected had to meet the following criteria:

1. **Scientifically defensible:** Indicators had to be scientifically rigorous, and based on the best available science. In addition, indicators had to be scalable (i.e. meaningful at multiple spatial scales), repeatable, and effective (i.e. have sufficient power to detect temporal and spatial changes).
2. **Interpretable and understandable**: Indicators had to be understandable by a broad audience, and convey information in a way that was accessible to managers, policy makers, and the general public.
3. **Comparable across subwatersheds**: Indicators had to be relevant at large spatial scales, and had to have sufficient information to allow for comparisons between subwatersheds, meaning that *reliable and comparable* data for each indicator had to be available for *every* subwatershed.
4. **Relevant to stakeholders**: Indicators had to be reflective of the views and management goals of the AWC-WPAC, the Technical Committee, the Athabasca Watershed Science Advisory Team, and other stakeholders in the watershed.

Although indicators form the basis of watershed condition assessments, they are very rarely measured or quantified directly. Rather, most indicators are measured using appropriate *surrogate metrics* that are relevant to, or representative of, each selected indicator. As a result, indicators may be measured using a single metric, or several metrics may be combined into an index.

A **GIS data model** takes existing spatial information and creates new information that can be mapped to help explain or understand a complex system

Often, the metrics selected to measure a given indicator are limited by the quality or availability of appropriate and/or comparable data, and in some cases, there may be a complete absence of appropriate metrics for measuring a given indicator. In such cases, these indicators must be excluded from consideration until such a time as appropriate data becomes available.

INDICATOR "MODELING"

One of the primary objectives of this State of the Watershed assessment is to provide *spatially explicit* information that allows for *direct comparisons* of indicators between subwatersheds. In order to accomplish this, a Geographic Information System (GIS) was used to create indicator models that allow for the visual presentation (mapping) of the data. For this assessment, indicator data models were developed using existing data collected from various sources, and new spatially explicit data were derived from these models. This new information allows for the creation of maps that visualize the distribution and/or composition of each indicator by subwatershed, allowing for direct comparisons between subwatersheds. It is important to note that the data models produced for this state of the watershed assessment are *descriptive*, not predictive. Consequently, these models represent a simplified summary of the current state or condition of the indicator, and do not provide information on the distribution, composition, or probability of any future scenario or outcome. In addition, these data models effectively identify the geographic areas where pressure indicators may be present, but in most cases, these models do not measure or quantify the *intensity* of a given pressure indicator. Despite this, the mapping outputs derived from these data models can be used to guide future planning and management, and are important tools for public outreach and education.

INDICATOR SELECTION

Following a focused literature review and extensive consultation with the AWC-WPAC Technical and Scientific Committees, a comprehensive list of criteria and indicators were selected to assess the current state of the Athabasca Watershed. In total, five criteria were selected to help define, measures, and report on the state of the Athabasca Watershed, including the following:

CRITERION 1: Conservation of Biological Diversity

Biological diversity is a key component of ecological integrity and function, and is measured at a variety of levels, from the diversity of available habitats, to the abundance and diversity of species within those habitats, to the genetic diversity within those species populations (Chapin et al. 2000). Species have the ability to directly influence the physical environment and alter chemical and nutrient cycling in natural systems. Moreover, diverse communities and populations are more resilient to ecosystem disturbance, pest-outbreaks, and disease. The state of biological physical condition, survival and reproductive rates, populations, and communities is the ultimate indicator of watershed "health" because they act as early warning signals of environmental degradation (Barbour et al. 2000). This is because changes in species composition or the physical condition of aquatic organisms is often the first observable signal of negative human impacts on biodiversity, typically occurring well before noticeable changes in water quality. In addition, the interaction between species and their environment is complex, with many non-additive processes (bio-accumulation of chemicals, altered predation and parasitism) that are not reflected by simply understanding physical factors, such as water quality and quantity (Dube et al. 2006). As a result, it is critical to understand the cumulative impacts of multiple stressors on biodiversity. Therefore, the maintenance of healthy biological and ecological communities, populations, and habitats is a key management priority in the Athabasca Watershed.

CRITERION 2: Maintenance of Surface Water Quality

Surface water quality has long been a public concern, both in terms of drinking water for human consumption, as well as for the protection and persistence of aquatic life, and other terrestrial biodiversity. Many human activities on the landscape pose risks to surface water quality, both from point and non-point sources. For example, runoff from agricultural land use can introduce nutrients and chemicals, such as phosphorus, nitrogen, pesticides, and fecal organisms into surface water. This nutrient and chemical loading can lead to algal blooms, increased pathogens and nitrates in drinking water, and the emission of odors and gases into the air. Common industrial contaminants "(e.g. from oil sands, pulp mills, coal mining, and municipal sewage treatment) discharged or leaked into surface water may lead to disease, reduced survival and reproduction, deformities in aquatic life and can pose a risk to human health (Timoney and Lee 2009, Evan and Muir 2004). Given the potential risks posed by contamination of surface water, the maintenance of surface water quality is a high management priority in the Athabasca Watershed.

CRITERION 3: Maintenance of Ecologically Significant Water Levels and Flow

In Alberta, surface water from lakes and rivers is the main source of water for domestic, agricultural, and industrial consumption (AWRI 2011). In recent years, concerns have been raised about the availability of surface water for both human consumption and aquatic life given the rapid declines in the size of headwater glaciers, increased frequency of summer drought conditions, and the increasing use of water by industry (e.g., in situ bitumen extraction and oil sands processing). In lentic systems, maintaining ecologically significant water flows that that include seasonal fluctuations between high (flooding) and low (drought) flow periods is critical to supporting a high diversity of aquatic life (Seneka 2006). Given this, the sustainable management of Instream Flow Needs (IFN) to achieve ecological protection of the Athabasca River is a priority of the Water Management Framework (AENV/DFO 2007), and is a key management focus for the Athabasca Watershed.

CRITERION 4: Maintenance of Groundwater Quality and Quantity

Groundwater is a critical resource in rural Alberta, with 23% of Albertans relying on groundwater for domestic and/or farm use (AWRI 2011, McKenna 2008). In the future, the importance of groundwater is expected to increase due to: 1) declining surface water availability; 2) greater rural/suburban development occurring outside of established urban centers, and 3) increased industrial development in remote areas (Ko and Donahue 2011). In the Athabasca watershed, there is a projected 88% increase in groundwater use by 2025 (AWRI 2011), making the maintenance of groundwater quality and quantity a major focus of management in the Athabasca Watershed. In addition, the connection of groundwater to surface water must be recognized; groundwater supplies the base flow of rivers and streams, and is the main water source for many wetlands. Thus, information on groundwater recharge areas should be considered as part of project planning to ensure the maintenance of groundwater quantity and quality.

CRITERION 5: Maintenance of Watershed Integrity

Over the past two decades, there have been hundreds of studies investigating the effects of human land use on biodiversity or surface and ground water quality and quantity. In general, these studies 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 (Brabec et al. 2002, Chapin et al. 2000, Eaglin and Hubert 1993, Findlay and Houlahan 1997, Haines-Young 2009, Johnson et al. 1997; Weijters et al. 2008). For example, in a comprehensive review of studies investigating watershed land use and stream biodiversity, Weijters et al. (2009) found that for every 10% loss of natural watershed land cover, there was an average loss of nearly 6% of the native freshwater fish and macro-invertebrate species. Given the large body of research that has shown a strong correlation between land cover/use and ecological condition, the amount and intensity of human disturbance in the watershed and the impact of use on watershed integrity is a focus of management in the Athabasca Watershed.

Within each of the five criteria, one or more indicators were selected to represent what the AWC-WPAC considered to be the important elements of watershed function and condition. In total, 32 different condition and pressure indicators were selected to qualitatively or quantitatively measure the condition of the Athabasca Watershed over time (Table 2).

While all 32 of the indicators were considered by the AWC-WPAC to be reflective of critical elements of watershed condition, many of the indicators were data-limited, and were thus excluded from this phase of the assessment. Further, several indicators were excluded due to the complexity involved with developing rigorous data models, and the relatively limited time available for completing this assessment (see Section 4). As such, indicators that were excluded from this Phase of the State of the Watershed assessment due to data or time constraints (18 indicators) are considered to be **"Aspirational",** meaning that these indicators should be included in future state of the watershed assessments if data and resources permit. For the remaining 14 indicators (Table 2), all data that was publically available within the specified timeline for this project was compiled and examined, and GIS data models were developed, such that the distribution and composition of each indicator could be mapped and compared throughout the Athabasca Watershed.

Table 2. Pressure and conditions indicators selected to assess the current state of the Athabasca Watershed.

NAME OF INDICATOR	INDICATOR TYPE	INDICATORS MODELED IN REPORT
Criterion 1. Conservation of Biological Diversity		
Road Density	Pressure	Δ
Seismic Line, Pipeline, Power Line & Railroad Density	Pressure	Δ
Large Patches of Natural Vegetation	Condition	Δ
Stream Connectivity	Pressure	Δ
Fish Community*	Condition	
Aquatic Bird Community*	Condition	
Amphibian Community*	Condition	
Macroinvertebrate Community*	Condition	
Mammal Community*	Condition	
Rare Species*	Condition	
Focal Habitat Condition*	Condition	
Wetland Condition and/or Rate of Loss*	Condition	
Criterion 2. Maintenance of Surface Water Quality		
Stream Crossing Density	Pressure	Δ
Surface Water Quality	Condition	Δ
Point Source Contamination	Pressure	Δ
Non-point Source Contamination	Pressure	Δ
Lake Trophic Status*	Pressure	
Riparian Condition*	Pressure	
Sediment Quality*	Condition	
Water Clarity*	Condition	
Acid Sensitive Lakes*	Pressure	
Criterion 3. Maintenance of Ecologically Significant Water Levels & Flows		
River Water Flow	Pressure	Δ
Potential Surface Water Use	Pressure	Δ
Lentic Water Availability*	Pressure	
Criterion 4. Maintenance of Groundwater Quality and Quantity		
Potential Groundwater Use	Pressure	Δ
Groundwater Quality*	Condition	
Criterion 5. Maintenance of Watershed integrity		
Human Population Growth	Pressure (Trend)	Δ
Human Land Use	Pressure	Δ
Land Conversion	Pressure (Trend)	Δ
Changes in Climate Regime*	Pressure (Trend)	
Surface & Subsurface Mining*	Pressure	
Traditional Land Use*	Pressure	

* Aspirational Indicators

Pressure Ratings do not directly measure watershed health or condition. Instead, these ratings identify areas where there is the potential for watershed health to be impaired.

INDICATOR RATINGS

The ultimate goal of the Athabasca State of the Watershed assessment is to develop a rating scheme that allows for a direct comparison of indicators across subwatersheds. Ideally, this rating system would also be used to develop an Index of Watershed Health, which would measure the cumulative effects of multiple stressors on watershed condition, both for individual subwatersheds and for the Athabasca Watershed as a whole.

Within the scope of this work, a **Pressure Rating** was developed to categorize the extent to which selected indicators exert pressure on each of the five watershed criteria. It is important to note that Pressure Ratings do not measure watershed health or condition directly, but rather, the existence of one or more pressure identifies the potential for watershed health to be impaired. This report focused on pressure indicators at present because large-scale (watershed-wide) data on biological condition indicators does not exist in a usable form at present (see Section 4 below).

Pressure ratings were divided into three categories: high pressure, moderate pressure, and low pressure (Table 3). The values used to differentiate between the pressure categories are indicator specific, and were drawn from the scientific literature. Where possible, these values were drawn from empirical studies conducted in Alberta; however, in cases where there was no empirical work to draw from in Alberta, values were taken from scientific work conducted in comparable regions and ecosystems, and at a scale comparable to that of the Athabasca Watershed. In total, Pressure Ratings were assigned at the tertiary watershed scale for six indicators with scientifically derived pressure values (Table 3).

Table 3. Indicators for which Pressure Ratings were developed based on thresholds derived from the scientific literature.

INDICATOR	UNIT	HIGH PRESSURE	MODERATE PRESSURE	LOW PRESSURE
Road Density	km/km^2	≥0.5	>0.1 to 0.5	0 to 0.10
Seismic, Pipeline, Power Line & Railroad Density	km/km^2	>3	>1.2 to 3	0 to 1.2
Large Patches of Natural Vegetation	% aerial coverage of tertiary watershed with large patches	≤30%	<30 – 65%	>65%
Stream Crossing Density	# of road crossings/km^2	>0.6	>0.4 – 0.6	≤0.4
Human Population Density	Growth rate by tertiary watershed (%)	>5.67	>0 to 5.67	≤0
Human Land Use - Agriculture	% aerial coverage of tertiary watershed	>60	>25 to 60	≤25

Relative Disturbance Classification highlights areas where the occurrence, density, or distribution of the indicator is Elevated, relative to all other tertiary watersheds. This classification is not based on ecological thresholds. An Elevated Relative Disturbance Classification may not reflect an area where a threshold value has been exceeded; rather, simply that this classification score is higher relative to all other scores in the Athabasca Watershed

Indicators that were not assigned a Pressure Rating were still modeled and mapped because they represent areas in the Athabasca Watershed where ecological condition may be compromised, and special management may be required. Thus, these indicators were assigned a **Relative Disturbance Classification**, which was divided into three categories: Minimal, Moderate, and Elevated Disturbance Classification (Table 4). Rather than using threshold values to assign boundaries between categories, Jenks Natural Classification Analysis was used to differentiate between categories for each indicator (Jenks 1977).

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). Assigning categories in this way results in boundaries between each category that tends to be set where there are relatively big jumps in data values. This approach has been used in other State of the Watershed Assessments to assign boundaries between stress indicators (for example "The Saskatchewan State of the Watershed Report"; Davies and Hanley 2010).

It is important to note that Relative Disturbance Classifications are ***relative values***, meaning that these ratings are not set against an absolute or ecological threshold value. Instead, using Jenks Classification Analysis, individual tertiary watershed are identified as a Minimal, Moderate, and Elevated Relative Disturbance Classification for each indicator based on the **relative** occurrence, density, or distribution of the indicator being considered. A Elevated Relative Disturbance Classification may not reflect an area where a threshold value has been exceeded; rather, this rating reflects a tertiary watershed that has a higher indicator score **relative** to all other scores in the Athabasca Watershed. Conversely, a tertiary watershed rated as Minimal Relative Disturbance Classification has the lowest rating score relative to all other tertiary watersheds, but it is conceivable that ecological thresholds have been reached or surpassed in that watershed, despite a Minimal Relative Disturbance Classification.

Table 4. Indicators for which Relative Disturbance Classification were developed based on Jenks Natural Classification Analysis.

INDICATOR	UNIT	ELEVATED DISTURBANCE CLASSIFICATION	MODERATE DISTURBANCE CLASSIFICATION	MINIMAL DISTURBANCE CLASSIFICATION
Stream Connectivity	# of culverts/100 km^2	>8.3	>3 - 8.3	≤ 3
Non-point Source Contamination				
Livestock Density	animals/km^2	>25	>10 - 25	≤10
Fertilizer Application	% aerial coverage of tertiary watershed	>50	>25 -50	≤25
Manure Application	% aerial coverage of tertiary watershed	>7	3-7	≤3
Chemical Application	% aerial coverage of tertiary watershed	>15	>5 -15	≤5
Potential Surface Water Use	% total flow allocated	>1.5	>0.5-1.5	≤0.5
Potential Groundwater Use				
Unlicensed Well Density	Well/km^2	>0.5	>0.25-0.5	≤0.25
Maximum allocated water volume	m^3/annum/km^2	>1000	>500-1000	≤500
Human Land Use – Built-up Cover	% aerial coverage of tertiary watershed	>2.25	>1-2.25	≤1
Land Conversion				
Agricultural Conversion	% aerial coverage of tertiary watershed	>12	>3.5-12	≤3.5
Built-up Conversion	% aerial coverage of tertiary watershed	>1	>0.05-1	≤0.05

2.0 Pressure Ratings: Modeling Methods & Results

CRITERION 1: CONSERVATION OF BIOLOGICAL DIVERSITY

Road Density & Seismic Line, Pipeline, Power Line & Railroad Density

Linear features such as roads, seismic lines, pipelines, power lines, and railroads greatly extend human development and activities into natural habitats, leading to potentially negative impacts for both fish and wildlife populations (Forman et al. 2003). Roads have been found to increase sedimentation and erosion in lentic habitats, which can lead to changes in flow regime and water stability, stream channel instability, and reduced water quality (Rieman and McIntyre 1993). An increase in fine sediments, particularly in small spawning streams, can have negative impacts on fish egg survival and spawning success (Shepard et al. 1984) and may directly kill aquatic organisms (Newcombe and Jensen 1996). Roads can also increase the risk of overharvesting for many game fish species (i.e. lake trout and bull trout); for example, road densities as low as 0.1km/km2 have been found to negatively influence trout populations (BCMWLAP 2002), and new road access into previously remote aquatic habitats can increase angling and poaching mortalities (Furniss et al. 1991; Lee et al. 1997). In addition to the negative impacts of roads on aquatic habitats, roads directly increase mortality risk for wildlife as a result of collisions with vehicles (Lode 2000), and fundamentally alter the amount and arrangement of habitat patches (Forman et al. 2003). Roads 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, which can lead to genetically isolated populations (Trombulak and Frissell 2000). Roads also create indirect habitat loss, with the negative ecological impacts of roads extending as far as 500 m from the road proper (Nellemann et al. 2003; Muria 1995). In particular, large mammals such as woodland caribou (*Rangifer tarandus caribou*), elk (*Cervus elaphus*), and grizzly bears (*Ursus arctos*) require large undisturbed habitat patches, and can be negatively impacted in areas with very low road densities (Forman et al. 2003).

The negative effects of linear disturbance are not limited to roads. Other linear features, such as seismic lines, pipelines, and rail lines, have been shown to have both direct (increased mortality) and indirect (avoidance of high quality habitat in proximity to features) impacts on a variety of wildlife species (Alberta Grizzly Bear Recovery Plan 2013 2008, Holroyd 2008, McCutchen 2006). For example, seismic lines are believed to play a significant role in increasing access to caribou habitat by wolves, moose, and deer thereby increasing caribou mortality risk (James et al. 2004, Latham 2009).

Given the demonstrated negative effects of linear features on the biological diversity of aquatic habitats and watershed integrity, road density, as well as the density of seismic lines, pipelines, power lines, and railroads were selected as pressure indicators.

Indicator Modeling:

1. Using the Alberta base feature layer, the total length of all roads and the combined length of all other linear features (excluding roads), was calculated for each tertiary watershed.
2. Both data sources were standardized into a density measure (km/km^2) by taking the average length of the linear feature and dividing that value by the area of the tertiary watershed.
3. The **Density of Roads** by tertiary watershed ranged from 0 to 0.85 km/km^2 (Table 5). Road densities as low as 0.1 km/km^2 have been shown to have negative impacts on Bull trout spawning, while elk, grizzly bears, and caribou all show reduced activity at road densities of 0.43 to 0.65 km/km^2 (Alberta Grizzly Bear Recovery Plan 2008, BCMWLAP 2002, Frair et al. 2008, McCutchen, 2006). Consequently, the following road density thresholds were used to differentiate Pressure Rating categories (Figure 3):
    a. Low Pressure: ≤0.1 km/km^2
    b. Moderate Pressure: >0.1 to 0.5 km/km^2
    c. High Pressure: >0.5 km/km^2
4. **Seismic Lines, Pipelines, Power Lines & Railroad Density** ranged from 0 to 7.35 km/km^2 (Table 5). This range was split into three categories based on values from peer-reviewed scientific literature and government management guidelines (Figure 4). High quality grizzly bears habitat within Grizzly Bear Priority Areas must have linear features density at or below 1.2 km/km^2 (Alberta Grizzly Bear Recovery Plan 2008), while caribou will generally tolerate linear features densities below 3.0 km/km^2 (McCutchen 2006). The following thresholds were used to differentiate between stress categories for linear feature density (Figure 4):
    a. Low Pressure: ≤1.2 km/km^2,
    b. Moderate Pressure: >1.2 to 3 km/km^2
    c. High Pressure: >3 km/km^2

Table 5. Linear features results for tertiary watersheds in the Athabasca Watershed.

SUBWATERSHED	TERTIARY WATERSHED	WATERSHED AREA (KM^2)	ROAD DENSITY (KM/KM^2)	SEISMIC, PIPELINE, POWER LINE, & RAILROAD DENSITY (KM/KM^2)	ROAD DENSITY PRESSURE RATING	SEISMIC, PIPELINE, POWER LINE, & RAILROAD DENSITY PRESSURE RATING
Upper Athabasca	07AA	7,909	0.06	0.09	Low	Low
	07AB	1,597	0	0	Low	Low
	07AC	5,669	0.36	2.96	Moderate	Moderate
	07AD	2,385	0.69	4.93	High	High
	07AE	2,892	0.61	6.19	High	High
	07AH	4,744	0.6	4.84	High	High
McLeod	07AF	4,913	0.51	3.89	High	High
	07AG	4,745	0.73	5.03	High	High
Pembina	07BA	4,209	0.83	7.35	High	High
	07BB	6,232	0.85	2.94	High	Moderate
	07BC	3,884	0.85	2.33	High	Moderate
Central Athabasca (Upper Watershed)	07BD	2,960	0.35	3.06	Moderate	High
	07BE	3,178	0.61	3.21	High	High
Central Athabasca (Lower Watershed)	07CB	10,528	0.17	2.41	Moderate	Moderate
	07CC	5,884	0.05	1.48	Low	Moderate
Lesser Slave	07BF	6,621	0.34	4.1	Moderate	High
	07BG	1,082	0.24	3.04	Moderate	High
	07BH	1,175	0.24	1.53	Moderate	Moderate
	07BJ	2,563	0.53	2.88	High	Moderate
	07BK	6,503	0.26	3.47	Moderate	High
	LAKE1	2,141	0.29	1.21	Moderate	Moderate
La Biche	07CA	8,671	0.35	2.7	Moderate	Moderate
Clearwater	07CD	3,832	0.11	1.23	Moderate	Moderate
	07CE	13,060	0.11	2.41	Moderate	Moderate
Lower Athabasca	07DA	9,164	0.08	1.48	Low	Moderate
	07DB	5,577	0.02	1.13	Low	Low
	07DC	5,394	0.01	0.53	Low	Low
	07DD	6,942	0.07	0.16	Low	Low
Lake Athabasca	07MA	1,611	0	0.05	Low	Low
	07MD	1,623	0	0	Low	Low
	LAKE2	3,328	0.02	0.11	Low	Low

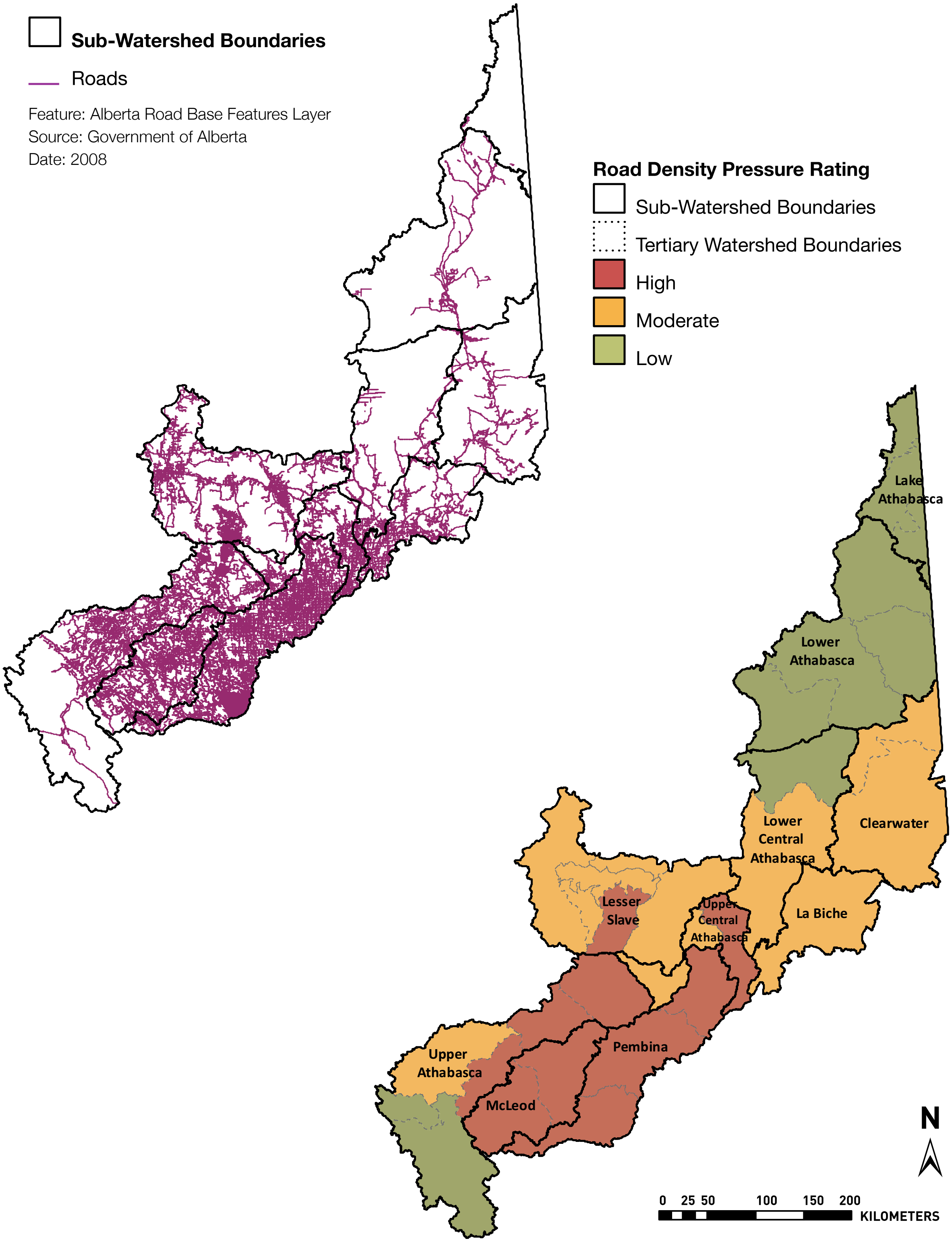


Figure 3. Input data used in the data modeling and pressure rating results for the Road Density indicator in the Athabasca Watershed. The Government of Alberta base feature road layer (Left Panel) was used to model and rate the road density based on scientific thresholds (Right Panel).

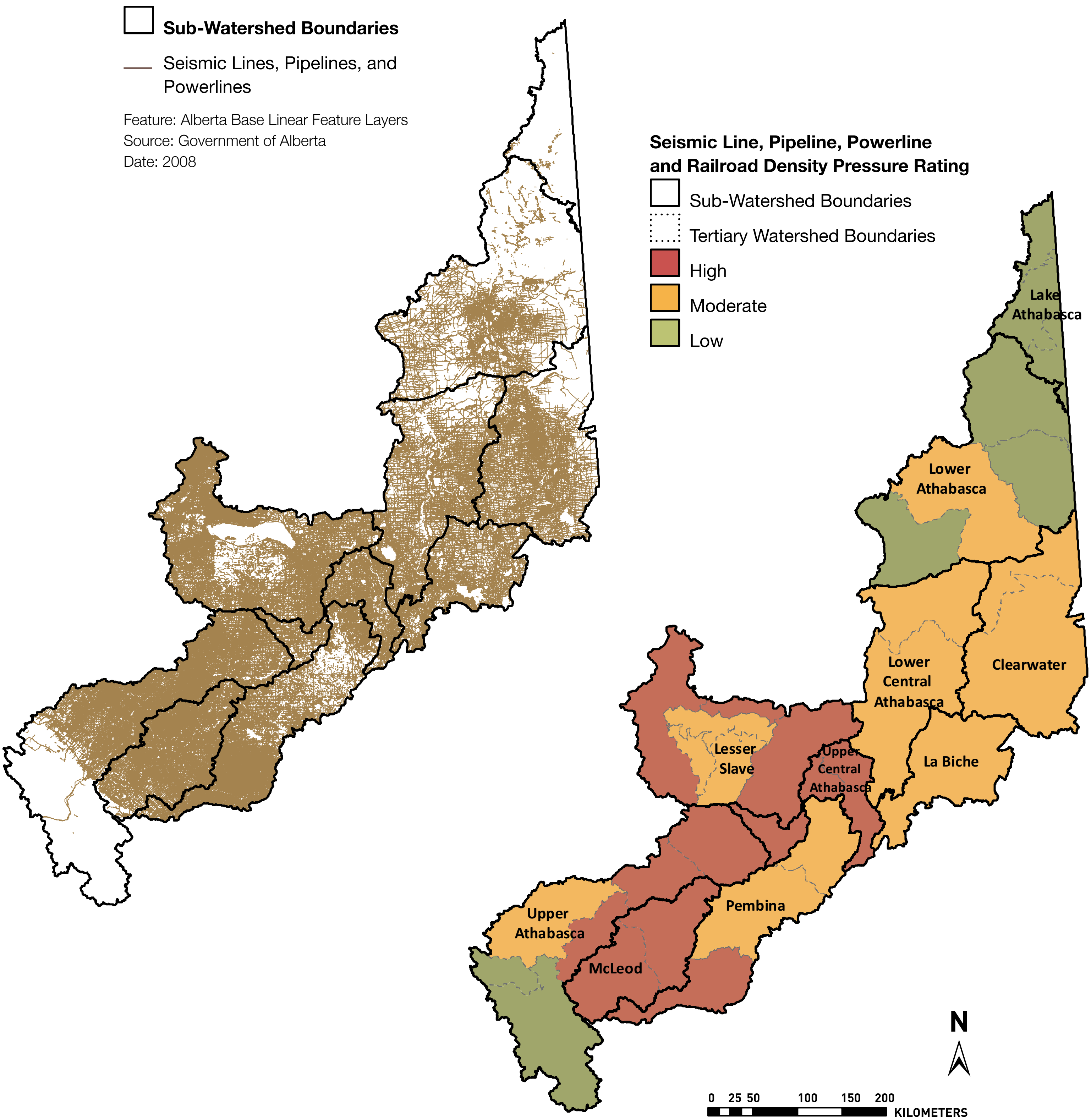


Figure 4. Input data used in the data modeling and pressure rating results for the Seismic Line, Pipeline, Power Line, and Railroad Density indicator in the Athabasca Watershed. The Government of Alberta base feature layers for seismic lines, pipelines, power-lines and railroads (Left Panel) were combined together and used to model and rate the density of seismic Line, pipelines, power-lines and railroads based on scientific thresholds (Right Panel).

LARGE PATCHES OF NATURAL VEGETATION

Watersheds are holistic systems where patchworks of terrestrial and aquatic habitats interact to create diverse ecosystems that support a diversity of species. The size and quality of terrestrial habitat on the landscape has been shown to influence aquatic habitat condition, with larger and less fragmented landscapes being of higher quality and condition (Linke et al. 2007, Johnson et al. 1997). Aquatic habitats with high ecological integrity are more likely to be found adjacent to less fragmented upland habitat (Nel et al. 2007; Norris et al. 2007; Johnson et al. 1997), and the amount of remaining forest and wetland cover at the watershed scale is a well establish indicator of aquatic health (Findlay and Houlahan 1997, Poiani et al. 1996, Scott et al. 2002). In addition, many large mammal and avian species in Alberta require large tracts of undisturbed habitat, including boreal caribou (Rangifer tarandus), grizzly bear (Ursus arctos), American marten (Martes americana), and northern goshawk (Accipiter gentiles atricapillus; Environment Canada 2011; Alberta Grizzly Bear Recovery Plan (2008-2013) 2008; Chapin et al. 1998). Caribou in particular are sensitive to human disturbance, and tend to avoid human infrastructure such as roads, timber harvest cut-blocks, pipelines, oil and gas well sites, and seismic lines for up to 500m (Environment Canada, 2011).

Given the reliance of wildlife on large, undisturbed patches of native vegetation, and the correlation between large patches and aquatic habitat condition, the percentage of the tertiary watershed covered by large patches of native vegetation was selected as an indicator of biological diversity in the Athabasca Watershed. The approach used to quantify this indicator was to create a human footprint layer (i.e., areas that have been impacted by agriculture, cities and towns, industrial activities, and forestry) and remove these human-impacted areas from the watershed to create a native vegetation layer. Patch size thresholds were then applied to this native vegetation layer to identify areas with large patches of native vegetation.

Modeling steps:

1. Linear features (i.e. roads, power lines, rail lines, pipelines, and seismic lines) were converted into polygon areas by buffering each line type by the average feature type widths specified by the Alberta Biodiversity Monitoring Institute (ABMI 2009).
    - In order to account for edges effects and indirect habitat loss, seismic lines were buffered by an additional 25 m (Esseen and Renhorn 2008; Muria 1995), while all other linear features were buffered by an additional 100 m (McGarigal et al. 2001).

2. All areas classified as built-up and agricultural from the land use/land cover layer were extracted and buffered by an additional 100 m to account for edges effects (McGarigal et al. 2001).

    - It is important to note that "agricultural" areas identified from the land use/land cover layer included only those areas with cultivated crops and extensive evidence of human modification (i.e. tilling). Therefore, areas in the White Zone that are composed of idle or tame pasture may not have been identified as agricultural land use, and thus, would be included in the area considered to be "native vegetation". Further refinement of what is considered "native vegetation" in agricultural areas is possible, but would require more extensive ground-truthing of the land use/land cover layer.

3. All well pads were converted into 50 m x 50m squares buffered by an addition 25 m to account for edges effects (Muria 1995).

4. All polygons with harvesting activity in the Alberta-Pacific Forest Management Area were extracted using Alberta Vegetation Inventory (AVI) data provided by Alberta Pacific Forest Industries Inc.

    - In Forest Management Areas where AVI data was not available, cutblocks were visually identified from Google Earth imagery and a land use/land cover layer derived from Landsat (2009, 30 m resolution), and areas with obvious forestry activity were excluded.

5. Each of the human disturbance layers created in Steps 1 through 4 were Unioned together to create a single Human Footprint layer.

6. All polygons in the Human Footprint layer were subtracted (deleted) from the Athabasca Watershed boundary layer to create an "intact vegetation" layer

    - The intent of this indicator is to identify large contiguous patches of intact vegetation; however, due to the extent of historic habitat loss in areas of the province impacted by agricultural land use, a much smaller size threshold was applied to vegetation patches in the White Zone, as compared to the Green Zone, where historic habitat loss has been less extreme.
    - Therefore, large intact vegetation patches in the Green Zone were considered to be areas ≥500 hectares, while large patches in the White Zone were considered to be areas ≥25 hectares (Scott et al. 2002; Findlay and Houlahan 1997; Mensing et al. 1998).

7. Using the Alberta Base Feature layer for Water Polygons, all large lakes (≥100 ha) were Unioned into the "intact vegetation" layer, and subtracted (deleted) to remove large water features.

8. Finally, all polygons smaller than the above size criteria were deleted from the Intact Vegetation layer to create a layer depicting Large Patches of Natural Vegetation (Figure 5).
9. The total area of intact vegetation was summarized by tertiary watershed and was expressed as a percentage of the total area of each tertiary watershed, which ranged from 3 to 99% (Table 6).
10. This range was split into three categories, based on values from peer-reviewed scientific literature:
    - 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. In independent studies, this threshold has been applied to species of concern in Alberta, including American marten (Hargis et al. 1999; Chapin et al. 1998).
    - For woodland caribou, a threshold of 65% undisturbed habitat at a landscape scale is identified as the minimum threshold needed to ensure a high probability (60%) that caribou herds remain self-sustaining, i.e., population numbers are not declining (Environment Canada 2011).
11. The following thresholds were used to differentiate between pressure categories for large patches of native vegetation where:
    - Low Pressure: >65% of the tertiary watershed is covered by large patches of natural vegetation
    - Moderate Pressure: >30 to 65% of the tertiary watershed is covered by large patches of natural vegetation
    - High Pressure: ≤30% of the tertiary watershed is covered by large patches of natural vegetation

Table 6. Tertiary watershed results for Large Patches of Natural Vegetation. This indicator was not applicable to two tertiary watersheds that were comprised mainly of the two largest lakes (Lesser Slave Lake and Lake Athabasca) and were not included.

SUBWATERSHED	TERTIARY WATERSHED	AREA (KM2)	AREA OF NATIVE VEGETATION (KM^2)	AERIAL COVERAGE (%)	PRESSURE RATING
Upper Athabasca	07AA	7909	7660	0.97	Low
	07AB	1597	1595	1.00	Low
	07AC	5669	1988	0.35	Moderate
	07AD	2385	226	0.09	High
	07AE	2892	84	0.03	High
	07AH	4744	436	0.09	High
McLeod	07AF	4913	746	0.15	High
	07AG	4745	261	0.06	High
Pembina	07BA	4209	182	0.04	High
	07BB	6232	401	0.06	High
	07BC	3884	256	0.07	High
Central Athabasca (Upper Watershed)	07BD	2960	442	0.15	High
	07BE	3178	590	0.19	High
Central Athabasca (Lower Watershed)	07CB	10528	3467	0.33	Moderate
	07CC	5884	4491	0.76	Low
Lesser Slave	07BF	6621	1400	0.21	High
	07BG	1082	336	0.31	Moderate
	07BH	1175	538	0.46	Moderate
	07BJ	2563	1059	0.41	Moderate
	07BK	6503	841	0.13	High
La Biche	07CA	8671	2616	0.30	High
Clearwater	07CD	3832	2844	0.74	Low
	07CE	13060	5821	0.45	Moderate
Lower Athabasca	07DA	9164	5232	0.57	Moderate
	07DB	5577	4549	0.82	Low
	07DC	5394	4785	0.89	Low
	07DD	6942	6141	0.88	Low
Lake Athabasca	07MA	1611	1544	0.96	Low
	07MD	1623	1427	0.88	Low

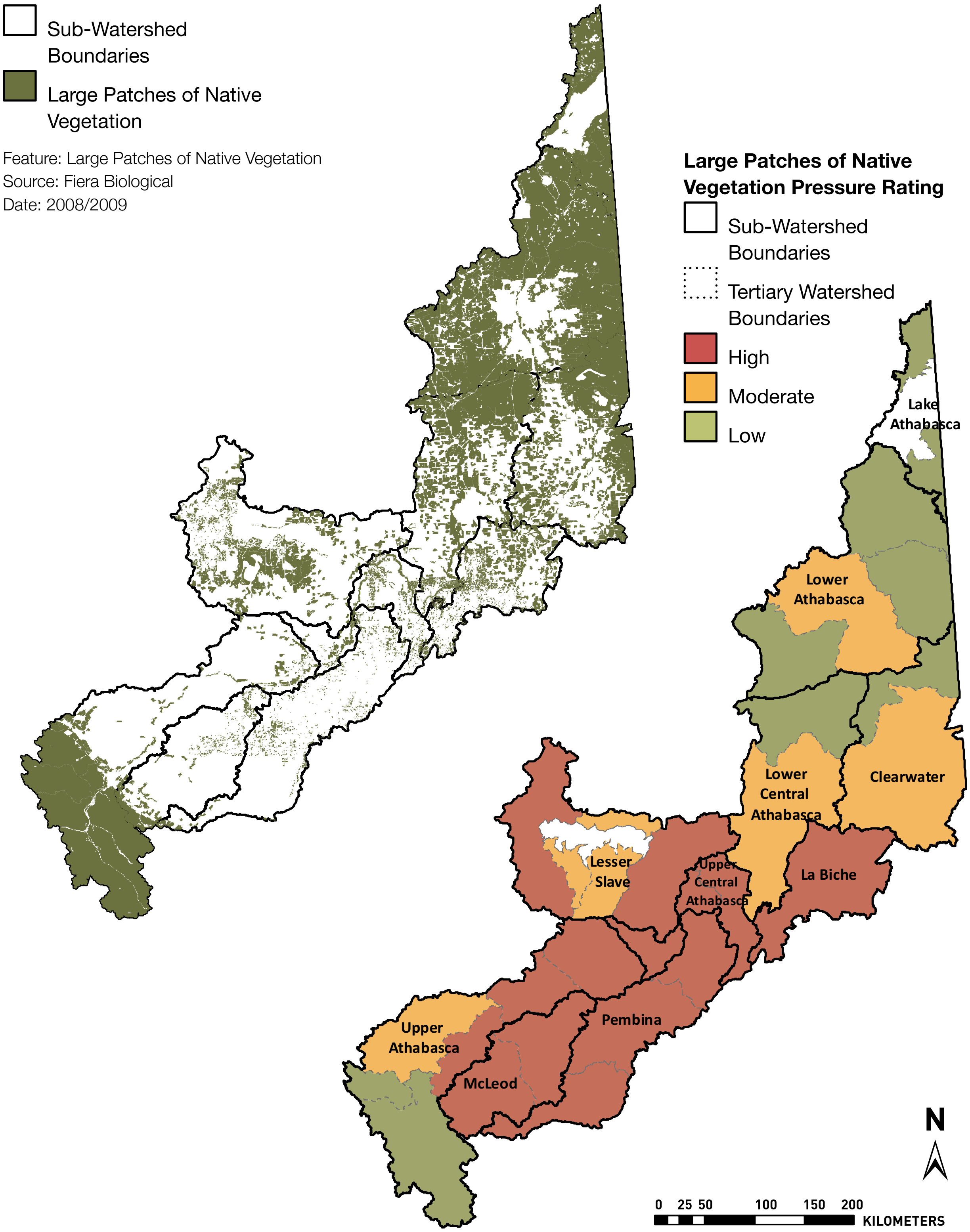


Figure 5. Input data used in the data modeling and pressure rating results for Large Patches of Natural Vegetation in the Athabasca Watershed. The results of modeling to identify large patches of native vegetation is shown in the Left Panel, while the pressure rating for each tertiary watershed based on scientific thresholds is shown in the Right Panel.

CRITERION 2:
MAINTENANCE OF SURFACE WATER QUALITY

Stream Crossing Density

Road crossings over streams have both short and long term effects on aquatic biodiversity by modifying water quality and fragmenting stream habitat. Soil erosion from roads, ditches, and other disturbed areas adjacent to rivers and streams can introduce deleterious materials that can result in increased sediment depth, reduced water clarity, and an overall decrease in stream habitat quality (Wellman et al. 2011; Eaglin and Hubert 1993). A wide range of contaminants has been measured in water run-off from roads including sand, dust and other particulates, as well as metals such as lead, cadmium, and zinc (Spellerberg 1998). Higher concentrations than expected of heavy metals have been recorded in plants up to 150 m from roads, and this uptake of contaminants can lead the secondary synergistic effects in biodiversity, with the physiological stress cause by contaminants making some plants species more susceptible to pest attacks and parasitism. In addition to impacting water quality, alteration of the physical environment of the adjacent habitat often results in the removal or fragmentation of riparian habitat (Trombulak and Frissell 2000). Impacts to riparian vegetation can lead to increased water temperature and evapotranspiration, and creates edge effects that alter the microclimate well beyond the active road area. Soil compaction has also been found to persist for decades after roads have been discontinued (Trombulak and Frissell 2000).

Stream crossing density is a relatively common indicator in landscapes subject to intense industrial development (Salmo 2003), and is an easily calculated proxy for understanding the impacts of run-off and sedimentation on water quality. As a result, Stream Crossing Density was selected as an indicator for the Athabasca Watershed. This indicator considers all stream crossings of roads (paved, gravel, and improved and unimproved forestry roads) and railroads on all classes of streams (Strahler Stream Orders 1 to Class 9; Strahler 1964).

Modeling steps:

1. Dissolved the Alberta Base features stream layer (Simplified Linear Stream Network) by stream order to define unique stream reaches for all stream orders ranging from Class 1 (small intermittent streams) to Class 9 (Athabasca River). Each stream reach was assigned a unique identification key and was used as the basis of all further analysis.

2. The stream reach layer and the Alberta base features road and rail layers were overlaid on one another to identify all locations where roads and railroads intercepted a stream.
3. The number of stream crossings was summed by tertiary subwatershed and then standardized by the area of the tertiary subwatershed to calculate stream crossing density by tertiary watershed (stream crossings/km^2).
4. The density of stream crossing ranged from 0 to 0.872 km^2. This range was split into three categories based on values from peer-reviewed scientific literature and government guidance documents that demonstrate negative impacts to water quality at stream crossing densities of 0.4/km^2 (BCF and BCE 1995a, 1995b), and negative impacts to bull trout populations at stream crossing densities of 0.6/km^2 (BCF 1995a; bull trout are a sensitive species found in the mountain and foothills regions of the Athabasca Watershed.
5. The following thresholds were used to differentiate between pressure categories for stream crossing density, where (Table 7 and Figure 6):
    a. Low Pressure: <0.4 stream crossings/km^2
    b. Moderate Pressure: ≥0.4 to <0.6 stream crossings/km^2
    c. High Pressure: ≥0.6 stream crossings/km^2

Table 7. Stream crossing results for each of the 31 tertiary watershed in the Athabasca Watershed.

SUBWATERSHED	TERTIARY WATERSHED	BASIN AREA (KM^2)	STREAM CROSSINGS (#)	STREAM CROSSING DENSITY	PRESSURE RANK
Upper Athabasca	07AA	7909	267	0.0	Low
	07AB	1597	1	0.0	Low
	07AC	5669	783	0.1	Low
	07AD	2385	637	0.3	Low
	07AE	2892	697	0.2	Low
	07AH	4744	651	0.1	Low
McLeod	07AF	4913	1082	0.2	Low
	07AG	4745	976	0.2	Low
Pembina	07BA	4209	949	0.2	Low
	07BB	6232	2182	0.4	Moderate
	07BC	3884	774	0.2	Low
Central Athabasca (Upper Watershed)	07BD	2960	147	0.0	Low
	07BE	3178	433	0.1	Low
Central Athabasca (Lower Watershed)	07CB	10528	283	0.0	Low
	07CC	5884	138	0.0	Low
Lesser Slave	07BF	6621	778	0.1	Low
	07BG	1082	55	0.1	Low
	07BH	1175	140	0.1	Low
	07BJ	2563	576	0.2	Low
	07BK	6503	471	0.1	Low
	LAKE1*	950	316	0.3	Low
La Biche	07CA	8671	638	0.1	Low
Clearwater	07CD	3832	119	0.0	Low
	07CE	13060	406	0.0	Low
Lower Athabasca	07DA	9164	179	0.0	Low
	07DB	5577	28	0.0	Low
	07DC	5394	3	0.0	Low
	07DD	6942	28	0.0	Low
Lake Athabasca	07MA	1611	0	0.0	Low
	07MD	1623	0	0.0	Low
	LAKE2*	1206	3	0.0	Low

* The area of the tertiary watershed for Lake 1 and Lake 2 includes a very large area of lake; therefore, the area of lake was excluded from the tertiary watershed area for this calculation.

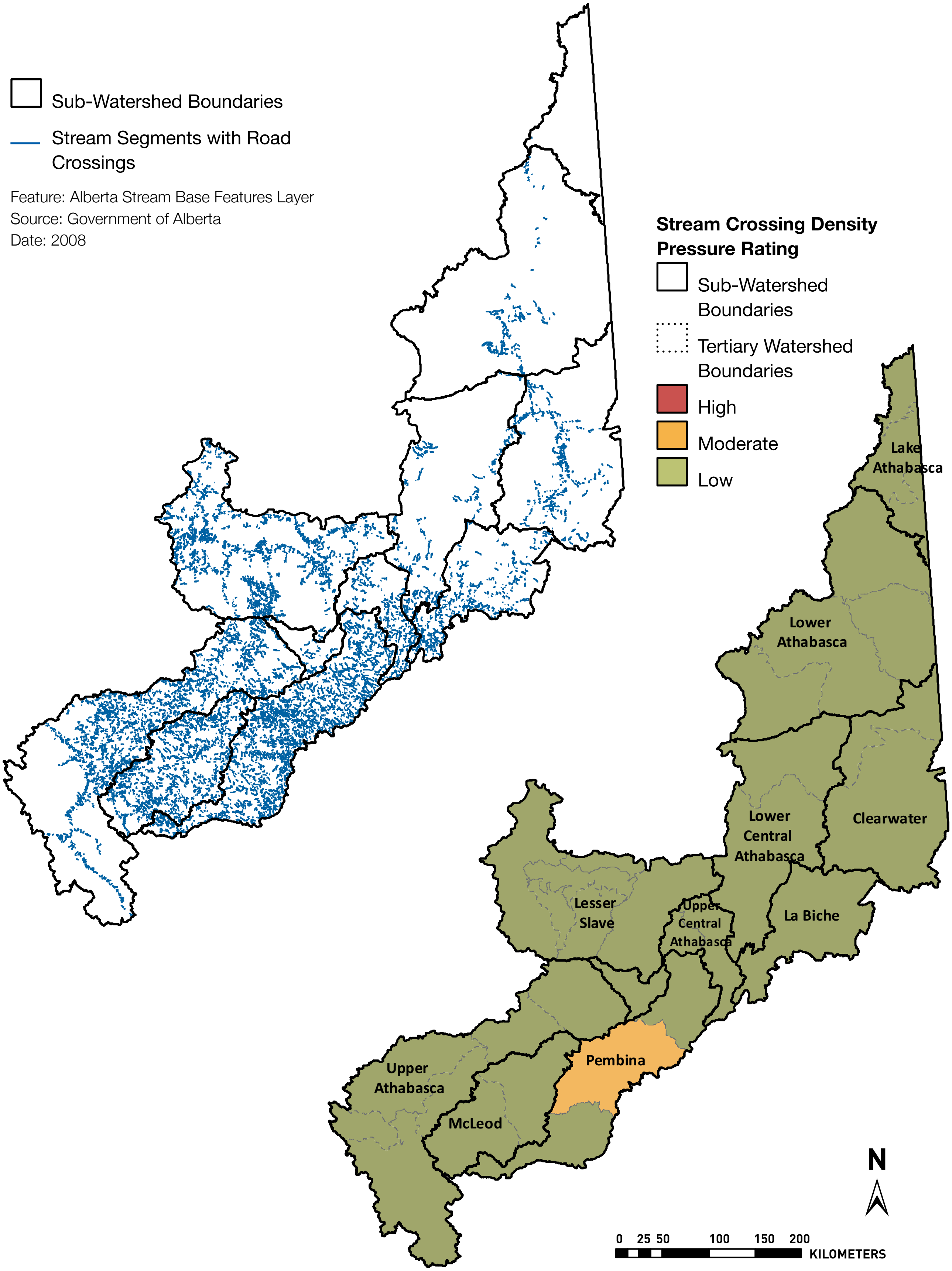


Figure 6. Input data used in the data modeling and pressure rating results for Stream Crossing Density in the Athabasca Watershed. Stream reaches crossed by one or more roads are shown in the Left Panel, while the pressure rating for each tertiary watershed based on scientific thresholds is shown in the Right Panel.

CRITERION 5: MAINTENANCE OF WATERSHED INTEGRITY

Human Population Growth

Human population growth and densely populated urban areas can have a major influence on water quality, water quantity, and biological diversity. Large population centers are major consumers of surface and ground water, and water quality is often compromised in proximity to large urban areas as a result of point-source releases of municipal effluents such as stormwater and wastewater. In addition, the built-up environment associated with human population centres results in major changes in surface run-off patterns and water infiltration as a result of increased cover of impermeable surfaces. Human populations also negatively impact biodiversity through direct and indirect habitat loss. As a result, Human Population Growth was selected as an indicator of Watershed Integrity, with the assumption that areas experiencing above average growth place greater pressures on the natural resources in the Athabasca Watershed.

Modeling steps:

1. The 2006 Federal census data reports population growth for a period of 5-years (between 2001 and 2006). Population growth by census subdivision was converted to the tertiary basin scale by calculating the area-weighted average, with the exception of the Municipality of Wood Buffalo.
    - Given that the majority of the population in the Municipality of Wood Buffalo (>95%) is associated with the human settlements of Fort McMurray and Fort McKay, only those tertiary basins that overlap with these towns were assigned the population growth rate from the census data. All remaining tertiary basins in the Municipality of Wood Buffalo that did not overlap with either Fort McMurray or Fort McKay were assigned a Human Population Growth Pressure Rating of Low (Declining, or no population growth).
    - Note: the 2011 Census was released on February 8, 2012. This indicator should be updated using the new census information at the next possible opportunity.

2. Population growth rates by tertiary basin ranged from declining populations (-50%) to rapidly growing centers (+24%). The largest population center, and the highest population growth in the watershed occurred in Fort McMurray, which grew to 47,705 in 2006 from 38,667 in 2001. The national average population growth rate for Canada between 2001 and 2006 was 5.67%; therefore, the following thresholds for population growth were used to assess Human Population Growth Pressure Ratings in the Athabasca Watershed (Figure 9 and Table 10):
    a. Low Pressure: ≤0% (zero or negative growth)
    b. Moderate Pressure: >0 to 5.67% growth
    c. High Pressure: >5.67% growth

Table 8. Human Population Growth by tertiary watershed between 2001 and 2006.

SUBWATERSHED	TERTIARY WATERSHED	WATERSHED AREA (KM²)	HUMAN POPULATION GROWTH RATE (%)	PRESSURE RATING
Upper Athabasca	07AA	7,909	2.0	Moderate
	07AB	1,597	-50.5	Low
	07AC	5,669	-0.4	Low
	07AD	2,385	1.7	Moderate
	07AE	2,892	4.9	Moderate
	07AH	4,744	5.1	Moderate
McLeod	07AF	4,913	1.6	Moderate
	07AG	4,745	2.8	Moderate
Pembina	07BA	4,209	3.2	Moderate
	07BB	6,232	3.8	Moderate
	07BC	3,884	0.7	Moderate
Central Athabasca (Upper Watershed)	07BD	2,960	3.9	Moderate
	07BE	3,178	0.0	Low
Central Athabasca (Lower Watershed)	07CB	10,528	2.3	Moderate
	07CC	5,884	15.0	High
Lesser Slave	07BF	6,621	-2.7	Low
	07BG	1,082	-0.7	Low
	07BH	1,175	-0.7	Low
	07BJ	2,563	-0.6	Low
	07BK	6,503	1.4	Moderate
	LAKE1	2,141	-0.5	Low
La Biche	07CA	8,671	13.4	High
Clearwater	07CD	3,832	24.3	High
	07CE	13,060	3.1	Moderate
Lower Athabasca	07DA	9,164	24.3	High
	07DB	5,577	-2.3	Low
	07DC	5,394	0.0	Low
	07DD	6,942	-0.3	Low
Lake Athabasca	07MA	1,611	0.0	Low
	07MD	1,623	0.0	Low
	LAKE2	3,328	0.0	Low

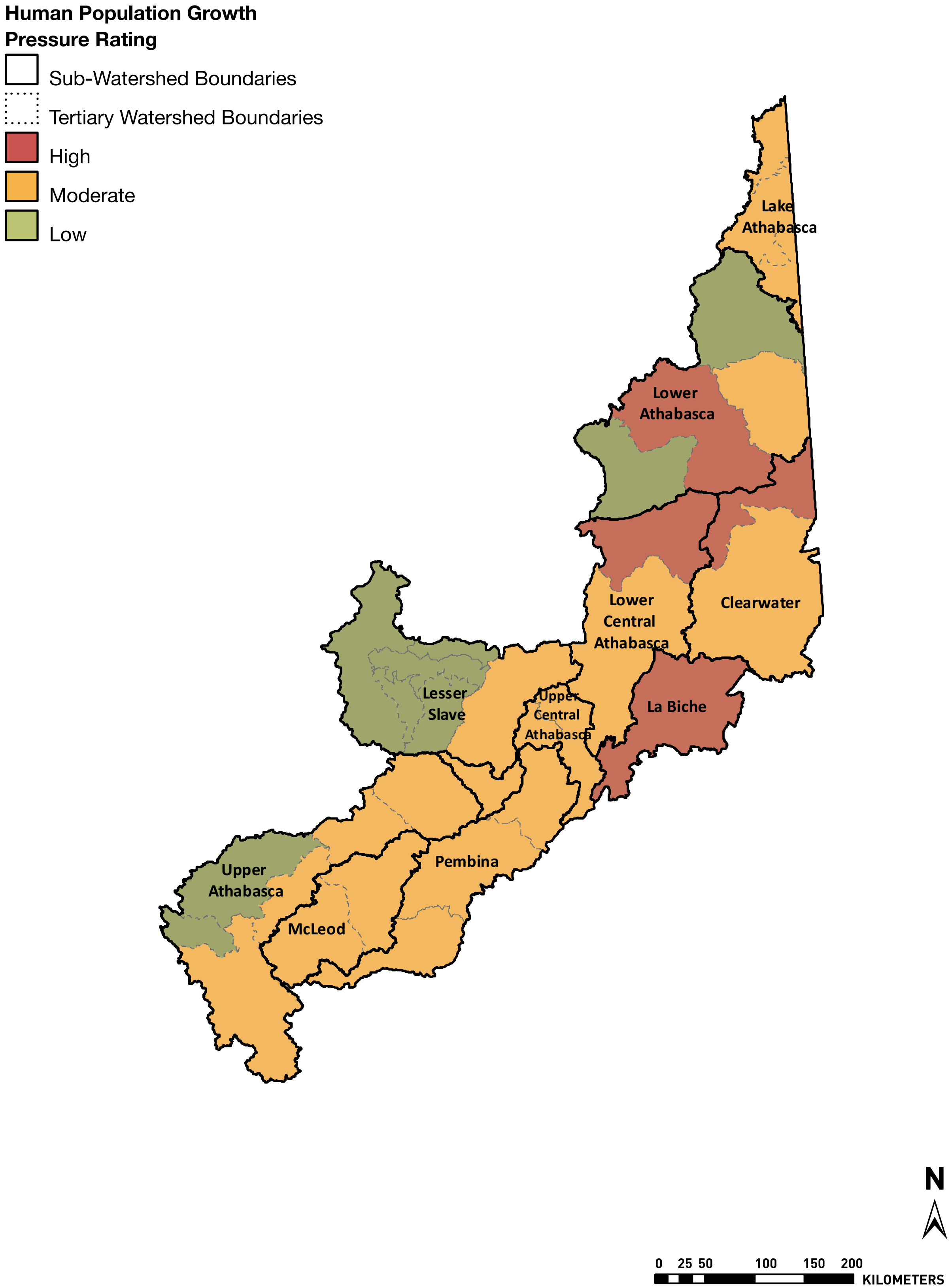


Figure 7. Pressure Rating modeling results for Human Population Growth indicator based on Federal Census data from Statistics Canada (2001 – 2006) in the Athabasca Watershed.

Human Land Use – Agriculture

The impact of agriculture land use on water quality and biodiversity is a well-studied field (Allen et al. 1997; Johnson et al. 1997). High intensity agricultural operations or improper agricultural practices can result in increased nutrient loadings and contamination of surface and ground water supplies. This leads to changes in chemical and nutrient balances, increased runoff and sedimentation, and an overall decrease in water quality (Brabec et al. 2002, Findlay and Houlahan 1997, Haines-Young 2009, Johnson et al. 1997; Weijters et al. 2008). In addition, the conversion of diverse native plant communities to mono-crop fields of commercial crops has profound effects on biodiversity with a multitude of impacts including decreases in resistant to pests and disease, reductions in soil micro-organisms critical to nutrient cycling, and the reduction of plant productivity (Chapin et al. 1998).

Modeling steps:

1. The total area of agricultural lands by tertiary watershed was calculated using the 30 m land use/land cover layer from 2009. Total area of agricultural lands by tertiary watershed was then standardized by calculating the percentage of each tertiary basin classified as agricultural land use.
2. Thresholds for agricultural lands were determined based on a literature review. Utz et al. (2008) found that sensitive macro-invertebrates species (Plecoptera species) in the state of Maryland were negatively impacted when agricultural land use in the surrounding catchments approached 25%, while large river basins with agricultural land use covering 60% or more of the upstream catchment area showed 50% declines in fish and habitat integrity (Allen et al. 1997; Johnson et al. 1997). Therefore, the following thresholds were used to assess agricultural land use pressure in the Athabasca Watershed (Figure 10 and Table 11):
    a. Low Pressure: ≤25% agricultural land use
    b. Moderate Pressure: >25 to 60% agricultural land use
    c. High Pressure: >60% agricultural land use

Table 9. Tertiary watershed results of Human Land Use – Agriculture

SUBWATERSHED	TERTIARY WATERSHED	WATERSHED AREA (KM^2)	AGRICULTURAL LAND COVER (%)	PRESSURE RATING
Upper Athabasca	07AA	7,909	0.00	Low
	07AB	1,597	0.00	Low
	07AC	5,669	0.00	Low
	07AD	2,385	0.00	Low
	07AE	2,892	0.06	Low
	07AH	4,744	7.21	Low
McLeod	07AF	4,913	0.25	Low
	07AG	4,745	14.95	Low
Pembina	07BA	4,209	3.09	Low
	07BB	6,232	66.53	High
	07BC	3,884	69.09	High
Central Athabasca (Upper Watershed)	07BD	2,960	11.70	Low
	07BE	3,178	32.72	Moderate
Central Athabasca (Lower Watershed)	07CB	10,528	3.64	Low
	07CC	5,884	0.00	Low
Lesser Slave	07BF	6,621	16.24	Low
	07BG	1,082	0.00	Low
	07BH	1,175	3.62	Low
	07BJ	2,563	4.57	Low
	07BK	6,503	0.00	Low
	LAKE1	2,141	9.75	Low
La Biche	07CA	8,671	18.63	Low
Clearwater	07CD	3,832	0.00	Low
	07CE	13,060	0.00	Low
Lower Athabasca	07DA	9,164	0.00	Low
	07DB	5,577	0.00	Low
	07DC	5,394	0.00	Low
	07DD	6,942	0.00	Low
Lake Athabasca	07MA	1,611	0.00	Low
	07MD	1,623	0.00	Low
	LAKE2	3,328	0.00	Low

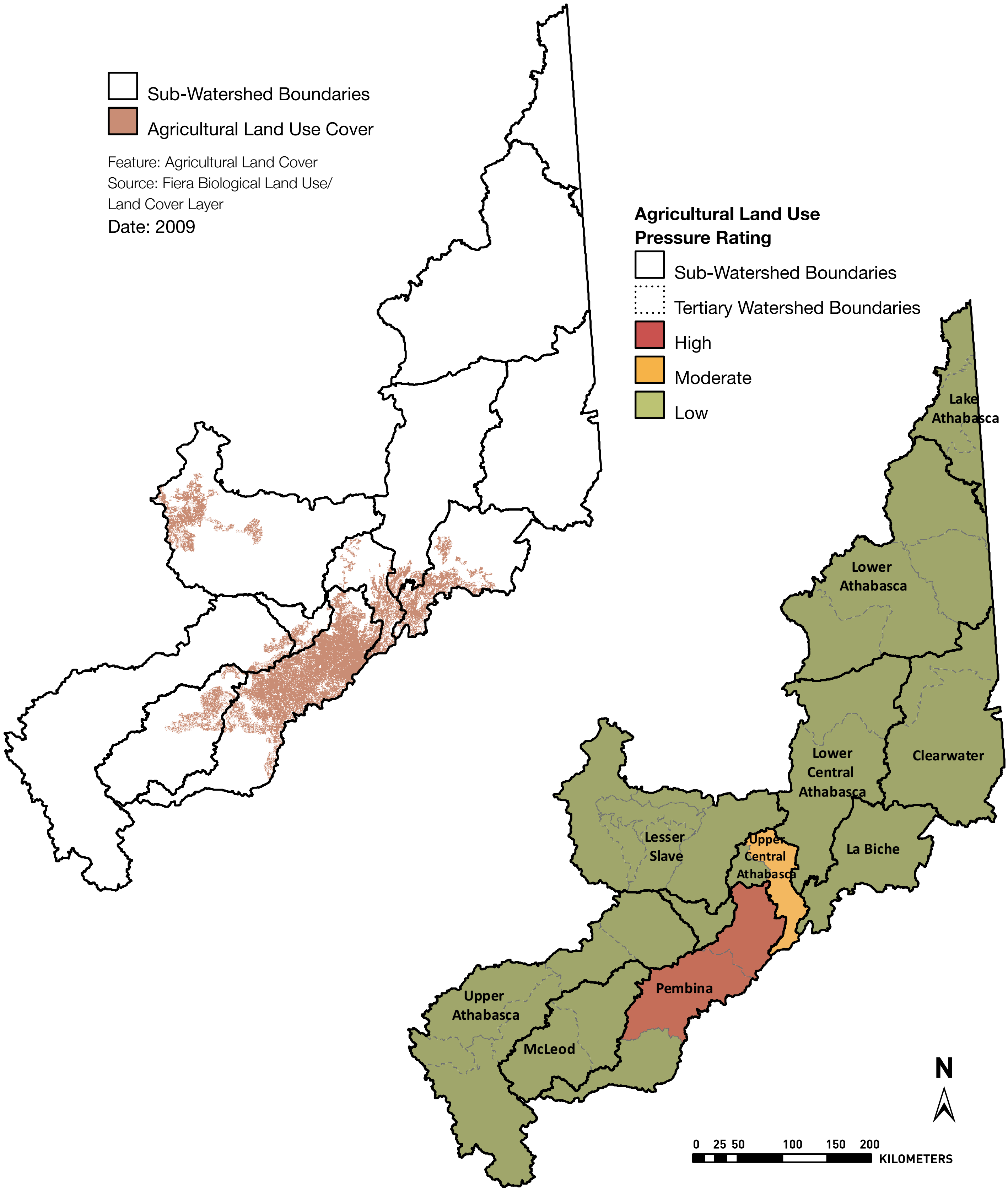


Figure 8. Input data used in the data modeling and pressure rating results for the Agricultural Land Use indicator in the Athabasca Watershed. The agricultural land use classification from the Land Use/Land Cover layer (Left Panel) created as part of this project was used to model and rate the amount of agricultural land use for each tertiary watershed based on scientific thresholds (Right Panel).

3.0 Relative Disturbance Classification: Modeling Methods & Results

CRITERION 1: CONSERVATION OF BIOLOGICAL DIVERSITY

Stream Connectivity

Whole watershed connectivity is critical for effective conservation of rivers and networks of wetlands to ensure natural processes (e.g. upstream connectivity, fish migratory routes, free-flowing rivers, significant water yield areas) are maintained along with all elements of biodiversity (Moilanen et al. 2009; Nel et al. 2009; Linke et al. 2007). Road-crossing structures over streams, and in particular culverts, are a common disturbance that have the potential to negatively impact fish populations (MacPherson 2011; Park 2006; Eaglin and Hubert 1993), as well other aquatic biodiversity (i.e. aquatic insects and macro-invertebrates; Blakely et al. 2006). Poorly installed or maintained culverts can fragment aquatic habitat by creating movement barriers, which can impede spawning and limit access to high quality habitat and can diminish genetic diversity through isolation of populations. In studies of the Athabasca Watershed, the proportion of hanging culverts ranged between 26 and 74% in the Swan Hills, Calling Lake, and Christina River watersheds (Park 2006; Tchir et al. 2004), and was 47% in a large-scale study of streams along the Foothills (MacPherson 2011). These studies indicate that hanging culverts were the most common type of barrier, acting as complete barriers to weak-swimming fish like Burbot (*Lota lota*), and as partial barriers to important forage fish such as Spoonhead Sculpin (*Cottus ricei*), sucker species (*Catostomus spp*.) and some minnow species (*Couesius plumbeus and Margariscus margarita*; MacPherson 2011; Tchir et al. 2004).

The goal of this indicator is to quantify the potential cumulative risk of culverts on small stream habitats in the Athabasca Watershed. Given that there is no provincial database that documents the location, age, and size of culverts installed at stream crossings, the number of road and railroad crossings on small streams was used as a proximate measure of stream connectivity. Streams with a Strahler order of 2 to 4 (Strahler 1964) were identified as those that were mostly likely to be both fish habitat and have culverts installed at road and rail crossings (Park 2006, Tchir et al. 2004). First order streams were excluded because of their ephemeral nature, making these streams less likely to support fish populations (Park 2006; Tchir et al. 2004). Higher order streams were also excluded because road and rail crossings over these streams and rivers were assumed to be primarily bridges, rather than culverts, and therefore, would pose a much lower risk to stream habitat connectivity (Tchir et al. 2004).

One of the assumptions of this indicator is that all stream crossings have an equal potential to fragment stream habitat, regardless of culvert age or maintenance status. While newly installed and properly maintained culverts may pose a lower risk of stream fragmentation, previous studies done in Alberta (MacPherson 2011; Park 2006; Tchir et al. 2004) and elsewhere (Furniss et al. 1997; Weaver et al. 1987) support the notion that streams crossed using culverts pose an overall higher risk to stream connectivity than crossings without culverts. Thus, this indicator was used as a measure of assessing risks to biodiversity in the Athabasca Watershed.

Modeling steps:

1. The Alberta Base features stream layer (Simplified Linear Stream Network) was dissolved by stream order to define unique stream reaches (continuous stream segments of the same stream order) for stream orders 2 to 4. Each stream reach was assigned a unique identification key and this was used as the basis of all further analysis.
2. The stream reach layer and the Alberta base features road and railroad layers were intersected to identify the location of road and rail crossings (hereafter referred to as culvert crossings; Figure 11). The road layer included all paved roads, gravel roads, and other improved forestry or access roads.
3. The number of culvert crossings was summed and standardized by tertiary basin (Table 12). The density of culvert crossings per tertiary watershed (culverts/km^2): calculated as the number of road crossing divided by total area of each tertiary watershed (km^2).

No rigorous scientific thresholds could be found for this indicator. While several studies have investigated the impact of culverts on fish and aquatic insects upstream and downstream of culverts (MacPherson 2011; Blakely et al 2006), little information exists on larger-scale regional impacts, particularly how culvert density effects fish stocks at a meta-population scale. Some information does exist for Brook trout and Brown trout in Wyoming, which suggests that strong negative pollution-level impacts occur at culvert densities >1 culverts/ km2 (Eaglin et al 1993); however, the drainage areas ranged between 1.7 and 18.7 km2, which is an order of magnitude smaller than the watershed areas used in the analysis for the Athabasca Watershed.

In order to identify those tertiary watersheds where culvert crossings are the most abundant relative to other tertiary watersheds, the number of culverts per 100 square kilometers was used to rate the Relative Disturbance Classification, and this value ranged between 0 and 16.7culverts/100 km^2. Based on Jenks classification, the category boundaries are as follows (Figure 11):

a. Minimal Disturbance Classification: ≤ 3.5 culverts/100 km^2

b. Moderate Disturbance Classification: >3 to ≤9.5 culverts/100 km^2

c. Elevated Disturbance Classification: >9.5 culverts/100 km^2

This indicator used a very simple metric as a measure of stream connectivity relative to all tertiary watersheds. Additional thought should be given to modifying this metric to calculate the total area of habitat located upstream of a culvert, to calculate to potential area of fish habitat lost as a result of culvert placement. This value could be further modified to reflect the probability of habitat loss based on the empirical values in the literature that quantify the proportion of culverts that were shown to be barriers to fish passage (MacPherson 2011; Park 2006; Tchir et al. 2004). Scientific studies should be reviewed and expert opinion should be solicited to develop thresholds for pressure ratings in the future.

Table 10. Stream Connectivity results and Relative Disturbance Classification based upon the density of culverts per 100 kilometers in each tertiary watershed.

SUBWATERSHED	TERTIARY WATERSHED	TERTIARY WATERSHED AREA (KM^2)*	ROAD CROSSINGS (#)	DENSITY OF CULVERTS (CULVERTS/ 100 KM^2)	RELATIVE DISTURBANCE CLASSIFICATION
Upper Athabasca	07AA	7909	145	1.8	Minimal
	07AB	1597	1	0.1	Minimal
	07AC	5669	295	5.2	Moderate
	07AD	2385	269	11.3	Elevated
	07AE	2892	295	10.2	Elevated
	07AH	4744	312	6.6	Moderate
McLeod	07AF	4913	455	9.3	Elevated
	07AG	4745	427	9.0	Elevated
Pembina	07BA	4209	350	8.3	Elevated
	07BB	6232	1043	16.7	Elevated
	07BC	3884	413	10.6	Elevated
Central Athabasca (Upper Watershed)	07BD	2960	75	2.5	Minimal
	07BE	3178	211	6.6	Moderate
Central Athabasca (Lower Watershed)	07CB	10528	138	1.3	Minimal
	07CC	5884	57	1.0	Minimal
Lesser Slave	07BF	6621	365	5.5	Moderate
	07BG	1082	32	3.0	Moderate
	07BH	1175	66	5.6	Moderate
	07BJ	2563	279	10.9	Elevated
	07BK	6503	229	3.5	Moderate
	LAKE1*	950	156	7.3	Moderate
La Biche	07CA	8671	315	3.6	Moderate
Clearwater	07CD	3832	57	1.5	Minimal
	07CE	13060	147	1.1	Minimal
Lower Athabasca	07DA	9164	75	0.8	Minimal
	07DB	5577	10	0.2	Minimal
	07DC	5394	1	0.0	Minimal
	07DD	6942	14	0.2	Minimal
Lake Athabasca	07MA	1611	0	0.0	Minimal
	07MD	1623	0	0.0	Minimal
	LAKE2*	1206	2	10.5	Elevated

* The area of the tertiary watershed for Lake 1 and Lake 2 includes a very large area of lake; therefore, the area of lake was excluded from the tertiary watershed area for this calculation.

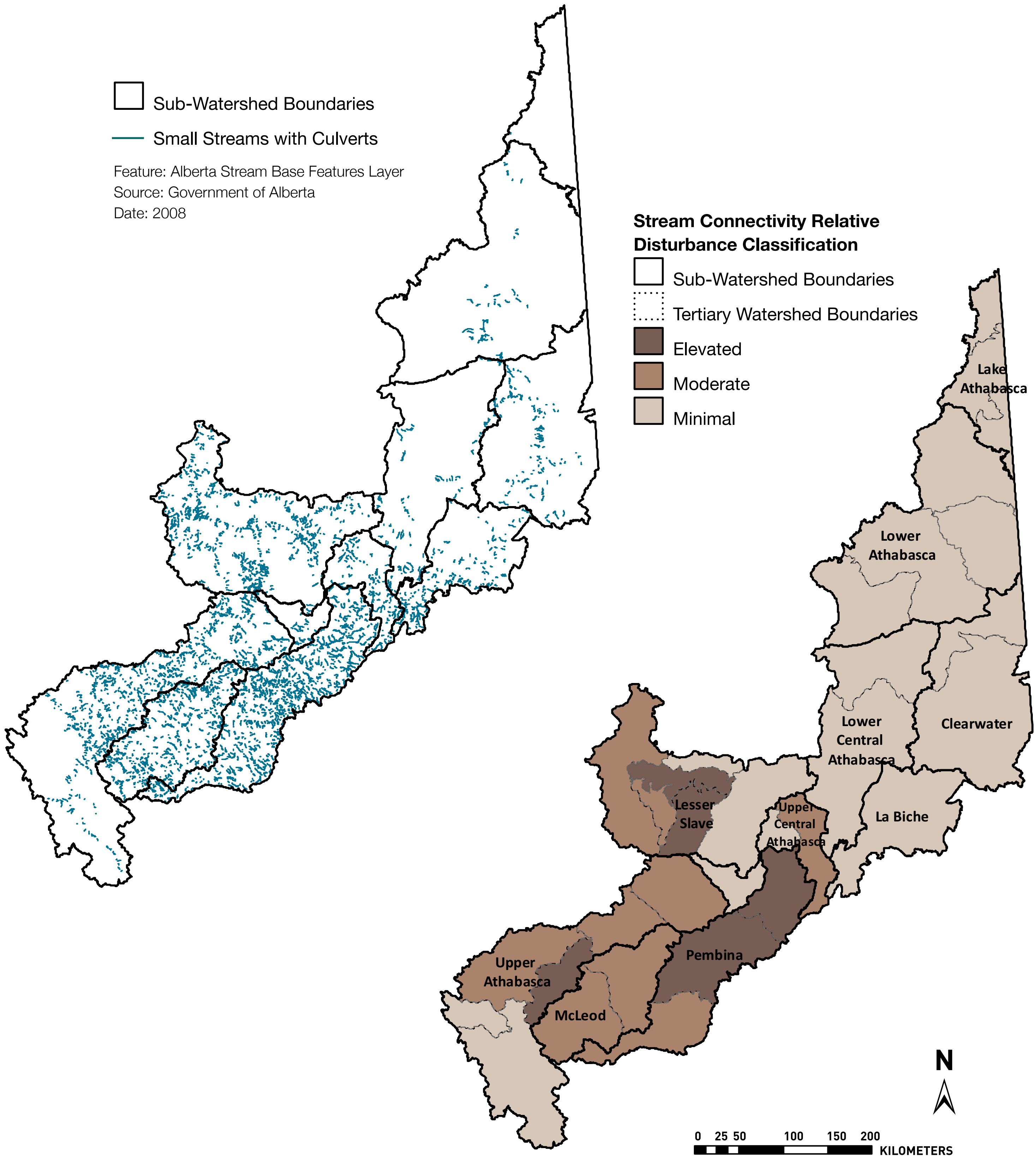


Figure 9. Input data used in the data modeling and Relative Disturbance Classification for the Stream Connectivity indicator in the Athabasca Watershed. Small stream reaches (Strahler Orders 2 to 4) that are crossed by one or more roads are shown in the Left Panel, while the Relative Disturbance Classification for each tertiary watershed based on Jenks Classification Analysis is shown in the Right Panel. This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

CRITERION 2:
MAINTENANCE OF SURFACE WATER QUALITY

Non-point Source Contamination

The agricultural sector is a major source of non-point contaminants in the Athabasca Watershed. Fertilizers and manure are applied to cropland to replace nutrients which has been lost by previous crop use, and chemical pest control chemical (herbicides, pesticides, and fungicides) are applied to control crop lost due insect pests, competing plants, and fungal diseases. Poor application and excess use of fertilizers and pesticides can result in surface run-off into lakes, rivers, and, streams, and leaching into ground water. These non-point contaminants can cause impairment of surface water quality by introducing excess nutrients (phosphorous and nitrogen) and contaminants (chemicals, pathogens, bacteria, and pharmaceuticals fed to livestock; (Davies and Hanley 2010)).

Given that agriculture largely occurs on private land, a comprehensive survey of agricultural input is not available. However, information on agricultural inputs is collected in the Federal Census. This information is collected at the scale of census sub-division so results must be interpreted at relatively large spatial scales. Federal census data from 2006 was used to assess the potential for non-point source contamination from agricultural lands in the Athabasca Watershed. Given that this indicator relies on census data, it likely underestimates the potential for surface water contamination because it relies on individuals to self-report; however, this data is still considered to be a good proxy for intensity of agricultural land use and the potential for impacts to water quality. Data on other non-point source contaminants, such as herbicide and pesticide applications used by the forest industry, are not publicly available and could not be included in this analysis.

Four metrics were used to quantify non-point source contamination from agricultural lands, including: the application (by area) of manure, fertilizer, and other chemicals to cropland, as well as livestock density.

Modeling steps:

1. The 2006 census data reports livestock (cattle and pigs) density, as well as application (by area) of fertilizers, manure, and chemical inputs (pesticides, herbicides, and fungicides) by census sub-division. In order to convert census information to the tertiary watershed boundary, area-weighted averages for each of the agricultural inputs was calculated, and then standardized by the area of the tertiary watershed.

    - Only those tertiary watersheds with agricultural land-use were considered in this analysis; all tertiary watersheds without agricultural land use were assigned a Relative Disturbance Classification of Minimal.

2. The density of livestock density ranged from 2.8 to 39.4 animals/km^2 (Table 13). Rangeland research suggests that livestock density in the Athabasca Watershed is well below densities at which strong impacts to water quality are observed (400 animals/km^2 ; Tate 2012). However, to examine the relative distribution of livestock density across the Athabasca Watershed, livestock density was split into three Relative Disturbance categories, as follows:

    a. Minimal Disturbance Classification: ≤10 animals/km^2

    b. Moderate Disturbance Classification: >10 to 25 animals/km^2

    c. Elevated Disturbance Classification: >25 animals/km^2

3. The aerial extent of fertilizer applied to agricultural lands in the tertiary watershed ranged from 6.4 to 90.6% (Table 13). This range was split into three Relative Disturbance categories, as follows:

    a. Minimal Disturbance Classification: ≤25%

    b. Moderate Disturbance Classification: >25 to 50%

    c. Elevated Disturbance Classification: >50%

4. The aerial extent of manure applied to agricultural lands in the tertiary watershed ranged from 1.1 to 10.3% (Table 13). This range was split into three Relative Disturbance categories, as follows:

    a. Minimal Disturbance Classification: ≤3%

    b. Moderate Disturbance Classification: >3 - 7%

    c. Elevated Disturbance Classification: >7%

5. The aerial extent of chemicals applied to agricultural lands in the tertiary watershed ranged from 0.5 to 20.2% (Table 13). This range was split into three Relative Disturbance categories, as follows:
   a. Minimal Disturbance Classification: ≤5%
   b. Moderate Disturbance Classification: >5 – 15%
   c. Elevated Disturbance Classification: >15%

It is important to note that all of the above metrics, with the exception of livestock density, examine agricultural inputs in the context of land area impacted, rather than the intensity of agricultural land use as it relates to the potential for non-point source contamination of surface water. Alberta Agriculture does have information on confined feeding operations in the Athabasca Watershed, and has rated surface water quality risk in the agricultural areas of (Alberta Agriculture 2005); however, this information could not be obtained for use in this analysis. In addition, retail sales statistics regarding the volume (metric tonnes) of nitrogen and phosphate from fertilizer sold exists from the Canadian Fertilizer Institute (http://www.cfi.ca/). With the addition of some or all of the information mentioned above, this indicator could be modified to assess surface water run-off potential and the risk of non-point contamination as it relates to agricultural land use intensity. Consultation with experts may also allow for the development of Pressure Ratings that could be applied to this indicator.

Table 11. Calculation of agricultural inputs for non-point source contaminants. This indicator was quantified based on standardized census data for four different agricultural practices, including: livestock density, and the aerial extent of the application of fertilizers, manure, and chemicals (pesticides, herbicides, and fungicides; measured as % area with the application/km^2). Only tertiary watersheds with agricultural land use are shown below.

SUBWATERSHED	TERTIARY WATERSHED	LIVESTOCK DENSITY		FERTILIZER APPLICATION		MANURE APPLICATION		CHEMICAL APPLICATION	
		ANIMALS/KM^2	RELATIVE DISTURBANCE CLASSIFICATION	% AREA	RELATIVE DISTURBANCE CLASSIFICATION	% AREA	RELATIVE DISTURBANCE CLASSIFICATION	% AREA	RELATIVE DISTURBANCE CLASSIFICATION
Upper Athabasca	07AC	13.2	Moderate	15.3	Minimal	2	Minimal	3.4	Minimal
	07AD	33.5	Elevated	13.1	Minimal	2.7	Minimal	5.8	Moderate
	07AH	8.6	Minimal	40.9	Moderate	6.3	Moderate	6	Moderate
	07AE	16.6	Moderate	32.8	Moderate	4.4	Moderate	6.6	Moderate
McLeod	07AF	16.2	Moderate	6.4	Minimal	1.3	Minimal	2.8	Minimal
	07AG	15.1	Moderate	8.3	Minimal	1.6	Minimal	2.6	Minimal
Pembina	07BA	16.1	Moderate	22	Minimal	3.6	Moderate	2.5	Minimal
	07BB	17.4	Moderate	67.8	Elevated	8.5	Elevated	4.5	Minimal
	07BC	32.2	Elevated	64.8	Elevated	7.9	Elevated	20.2	Elevated
Central Athabasca	07BE	18.9	Moderate	89.5	Elevated	8.3	Elevated	9.8	Moderate
(Upper Watershed)	07BD	13.1	Moderate	79.1	Elevated	10.3	Elevated	4.4	Minimal
	07BE	18.9	Moderate	89.5	Elevated	8.3	Elevated	9.8	Moderate
Lesser Slave	07BH	39.4	Elevated	23.5	Minimal	2.2	Minimal	20.2	Elevated
	07BG	27.2	Elevated	90.6	Elevated	4.2	Moderate	11.7	Moderate
	07BK	2.8	Minimal	7.7	Minimal	1.1	Minimal	0.5	Minimal
Lesser Slave	07BF	6.3	Minimal	46.9	Moderate	1.5	Minimal	3.8	Minimal
	07BJ	16.8	Moderate	12.6	Minimal	1.4	Minimal	8.4	Moderate
	LAKE	17.2	Moderate	15.1	Minimal	1.7	Minimal	8	Moderate
La Biche	07CA	6.1	Minimal	12.8	Minimal	1.2	Minimal	2.5	Minimal

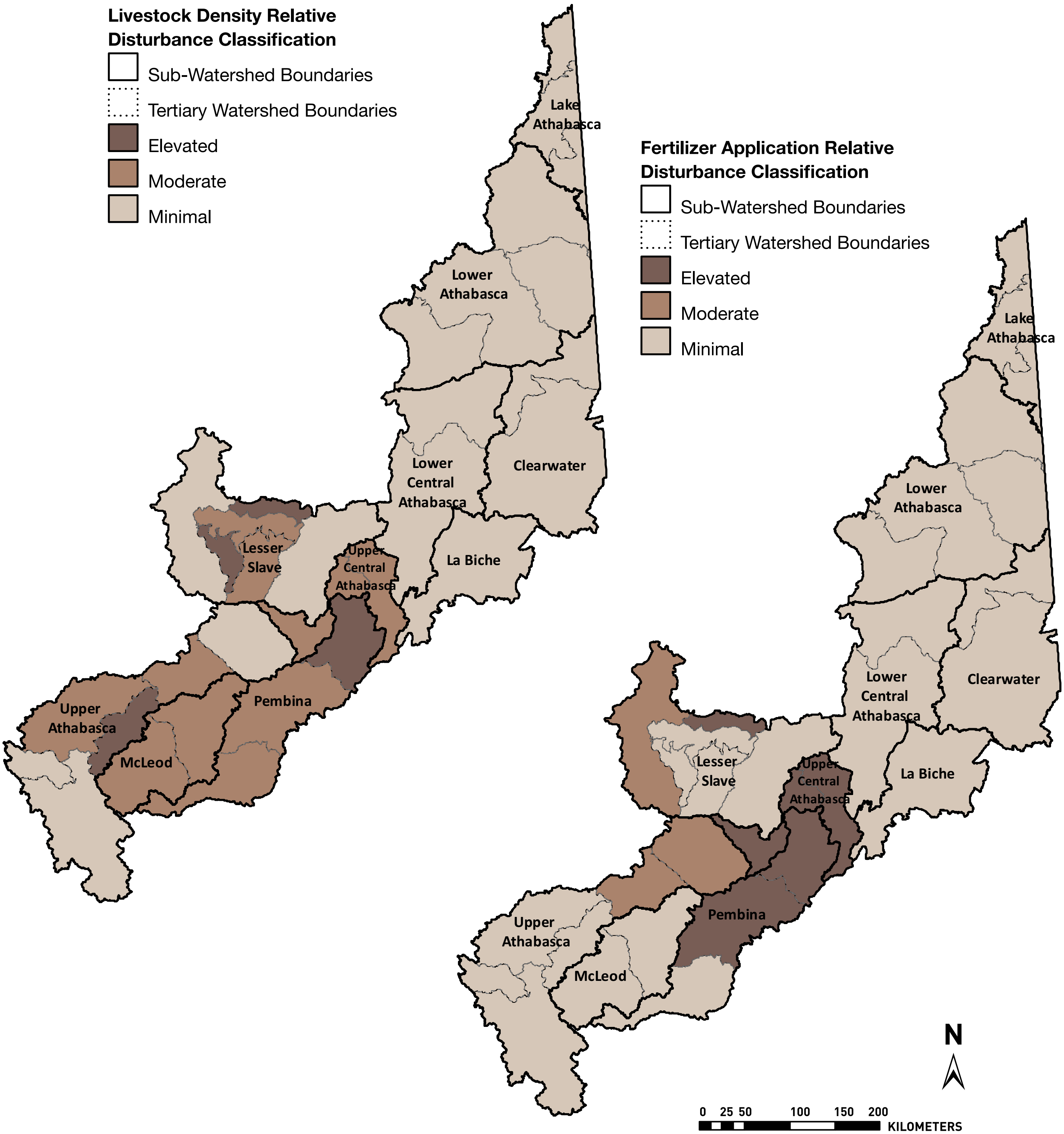


Figure 10. Results of data modeling to determine the Relative Disturbance Classification for Non-Point Contaminants for: 1) Livestock Density (Left Panel) and 2) Application of Fertilizer (Right Panel) based on 2006 Federal Census data from Statistics Canada. This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

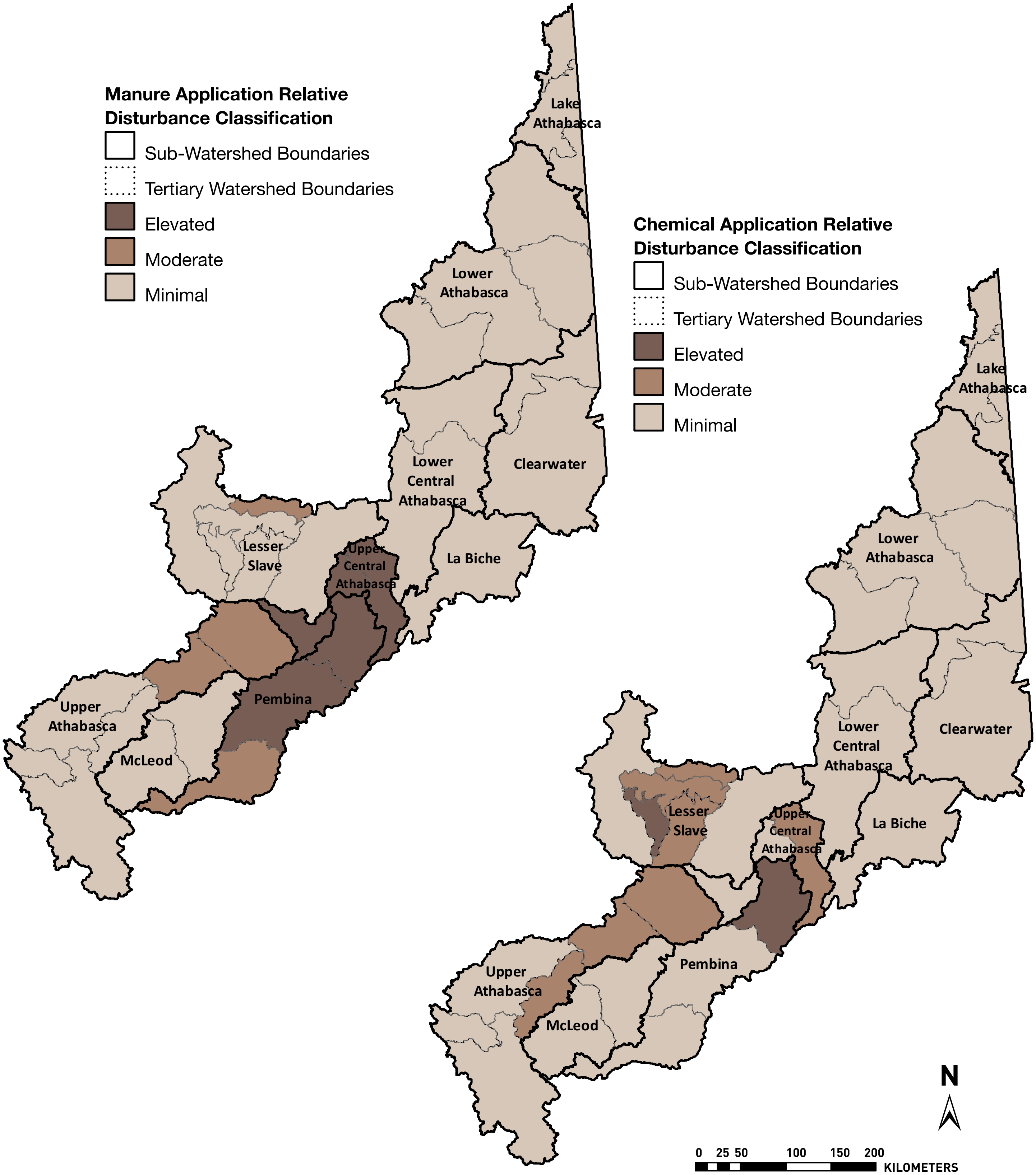


Figure 11. Results of data modeling to determine the Relative Disturbance Classification for Non-Point Contaminants for: 1) Application of Manure (Left Panel) and 2) Application of Chemicals (Right Panel) based on 2006 Federal Census data from Statistics Canada. This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

CRITERION 3: MAINTENANCE OF ECOLOGICALLY SIGNIFICANT WATER LEVELS AND FLOWS

Potential Surface Water Use

Surface water from lakes and rivers is the main source of water for domestic, agricultural, and industrial users in Alberta (AWRI 2011). Surface water withdrawals and diversions are regulated under the *Water Act*, which requires users to obtain a license for all surface water withdrawals, with the exception of basic household or domestic use (i.e., withdrawals under 1250 m^3/annum), or for the diversion of water of up to 5000 m^3 per project. This regulation is only applicable in the Green Zone, and is only allowed if the use of water is specified as a condition of a disposition issued by Alberta Sustainable Resource Development (ASRD). Otherwise, a Diversion License is required from Alberta Environment & Water. Under the terms of a water license, each licensee is allocated a maximum amount of water that may be used over a one-year period. Often the maximum amount allocated is not used because this maximum volume usually allows for future potential growth, which may or may not be realized, in addition to annual variation in water demand. While the government has records that track the total surface water that is *allocated* under a water license, there are no easily accessible digital records of the actual amount of water *used* by license holders. Therefore, in order to assess the pressure of surface water use on the maintenance of ecologically significant water levels and flows, the total amount of surface water *allocated* for withdrawal by tertiary watershed, rather than the actual amount *consumed*, was compared against the average amount available. This is then presented as the potential amount of surface water that may be used in a tertiary watershed as a percentage of the amount available.

This analysis used two data sources: the total amount of water allocated in water licenses was summed for each tertiary watershed to represent the maximum amount of water that may be used in a single year, which was compared against a water availability model developed for the Canadian Prairies based on median annual unit run-off probabilities (PFRA 1994). The model is based on data from 1950 to 1989, and may over-estimate current water availability; however, this indicator is considered to be a good proxy for measuring surface water use across the Athabasca Watershed.

Modeling steps:

1. The maximum allocated water volume (m^3/year) specified in Water Act approvals for each surface water allocation license) from 2010 was summed for each tertiary watershed (m^3/annum; Table 14).

2. Gross water availability was calculated as the total tertiary watershed runoff based on the water availability model from 1950 - 1989. This was calculated as the average median runoff value for each tertiary watershed, multiplied by the tertiary watershed area (Table 14). Because several of the tertiary watersheds in the Clearwater and Lake Athabasca subwatersheds extend into Saskatchewan, the full tertiary watershed areas were used here. In addition, the tertiary watershed with the two largest lakes (Lesser Slave Lake and Lake Athabasca) were corrected for the effects of the evaporation-precipitation deficit.

3. Watersheds are dynamic interconnected systems with some tertiary watersheds acting as primary sources (headwater watersheds), while others flow downstream into receiving watersheds. For each tertiary watershed, all of the upstream watersheds that contribute flow downstream were identified, and this information was used to determine the **Total Availability (TA)** (Eq. 1) of water in each tertiary watershed, as well as the **Net Flow (NF)** (Eq. 2):

   $TA = (R+F) - UA$ (Eq. 1)

   $NF = TA - TWA$ (Eq. 2)

Where R is the gross watershed runoff, F is the flow contribution from upstream watersheds, UA is the total upstream surface water allocation, TA is total availability and TWA is the tertiary watershed allocation.

4. Finally, the **Potential Surface Water Use (PU)** in each tertiary watershed was calculated as percentage of net flow versus total availability:

   $PU = \frac{NF}{TA} * 100\%$ (Eq. 3)

Where NF is the net flow and TA is the total available.

5. The potential surface water use for each tertiary watershed ranged between 0 and 3.4% of the total flow available (Table 14). In order to identify those tertiary watersheds where the potential for surface water use, versus the amount of water available, is the Relative Disturbance categories were assigned based on Jenks classification, as follows (Figure 14):
    a. Minimal Disturbance Classification: ≤ 0.5%
    b. Moderate Disturbance Classification: >0.5 to ≤1.5%
    c. Elevated Disturbance Classification: >1.5%

This indicator measured potential surface water use based on maximum allocation amount, not the actual amount of water used. At present, industrial water use is typically well below the allocation amount. Between 2005 and 2010 in the Lower Athabasca subwatershed, the net amount of water withdrawn by the major Oil Sands facilities was on average 16.7 to 27.5% of the maximum allocated amount (E. Kerkhoven pers. comm.).

Table 12. Potential surface water use by tertiary watershed, as calculated as a percentage of net flow versus total availability.

SUBWATERSHED	TERTIARY WATERSHED	UPSTREAM CONTRIBUTING WATERSHEDS	TERTIARY WATERSHED RUNOFF (M³/YEAR)	TOTAL WATERSHED ALLOCATIONS (M³/YEAR)	TOTAL AVAILABILITY (M³/YEAR)	NET FLOW (M³/YEAR)	POTENTIAL WATER USE (%)	RELATIVE DISTURBANCE CLASSIFICATION
Upper Athabasca	07AA	07AB	4,016,465,930	103,700	4,674,079,180	4,673,975,480	0.00%	Minimal
	07AB	-	657,613,250	0	657,613,250	657,613,250	0.00%	Minimal
	07AC	-	1,090,370,600	2,399,120	1,090,370,600	1,087,971,480	0.22%	Minimal
	07AD	07AA	408,425,860	74,426,710	5,082,401,340	5,007,974,630	1.46%	Moderate
	07AE	07AC, 07AD	375,171,380	17,055,724	6,471,117,490	6,454,061,766	0.26%	Minimal
	07AH	07AE, 07AG	524,568,410	17,000,515	8,582,067,979	8,565,067,464	0.20%	Minimal
McLeod	07AF	-	1,036,524,540	1,938,435	1,036,524,540	1,034,586,105	0.19%	Minimal
	07AG	07AF	585,870,620	17,018,922	1,620,456,725	1,603,437,803	1.05%	Moderate
Pembina	07BA	-	555,180,400	2,107,400	555,180,400	553,073,000	0.38%	Minimal
	07BB	07BA	381,430,110	11,915,957	934,503,110	922,587,153	1.28%	Moderate
	07BC	07BB	200,777,470	6,047,596	1,123,364,623	1,117,317,027	0.54%	Moderate
Central Athabasca (Upper Watershed)	07BD	07AH, 07BC	251,230,480	311,625	9,933,614,971	9,933,303,346	0.00%	Minimal
	07BE	07BD, 07BK	270,407,210	1,569,005	12,412,740,794	12,411,171,789	0.01%	Minimal
Central Athabasca (Lower Watershed)	07CB	07BE, 07CA	949,538,360	38,388,420	13,974,770,047	13,936,381,627	0.27%	Minimal
	07CC	07CB	585,966,650	26,089,937	14,522,348,277	14,496,258,340	0.18%	Minimal
Lesser Slave	07BF	-	691,186,020	8,357,790	691,186,020	682,828,230	1.21%	Moderate
	07BG	-	122,297,810	38,245	122,297,810	122,259,565	0.03%	Minimal
	07BH	-	200,146,540	90	200,146,540	200,146,450	0.00%	Minimal
	07BJ	-	484,689,120	4,504,845	484,689,120	480,184,275	0.93%	Moderate
	07BK	LAKE1	772,912,110	15,709,190	2,224,739,428	2,209,030,238	0.71%	Moderate
	LAKE1	07BF, 07BG, 07BH, 07BJ	-28,687,926	4,903,276	1,456,730,594	1,451,827,318	0.34%	Minimal
La Biche	07CA	None	618,529,540	4,469,642	618,529,540	614,059,898	0.72%	Moderate
Clearwater	07CD	07CE	1,779,521,830	360,916	2,896,767,010	2,896,406,094	0.01%	Minimal
	07CE	-	1,118,070,020	824,840	1,118,070,020	1,117,245,180	0.07%	Minimal
Lower Athabasca	07DA	07CC, 07CD, 07DB	916,376,000	608,775,716	18,866,592,879	18,257,817,163	3.23%	Elevated
	07DB	-	557,693,000	140,555	557,693,000	557,552,445	0.03%	Minimal
	07DC	-	617,023,000	345,000	617,023,000	616,678,000	0.06%	Minimal
	07DD	07DA, 07DC	865,370,000	0	19,739,865,163	19,739,865,163	0.00%	Minimal
Lake Athabasca	07MA	-	1,281,465,000	0	1,281,465,000	1,281,465,000	0.00%	Minimal
	07MD	-	250,597,000	0	250,597,000	250,597,000	0.00%	Minimal
	LAKE2	07MA, 07MA, 07DD	15,778,360,000	1,911,751	37,050,287,163	37,048,375,412	0.01%	Minimal

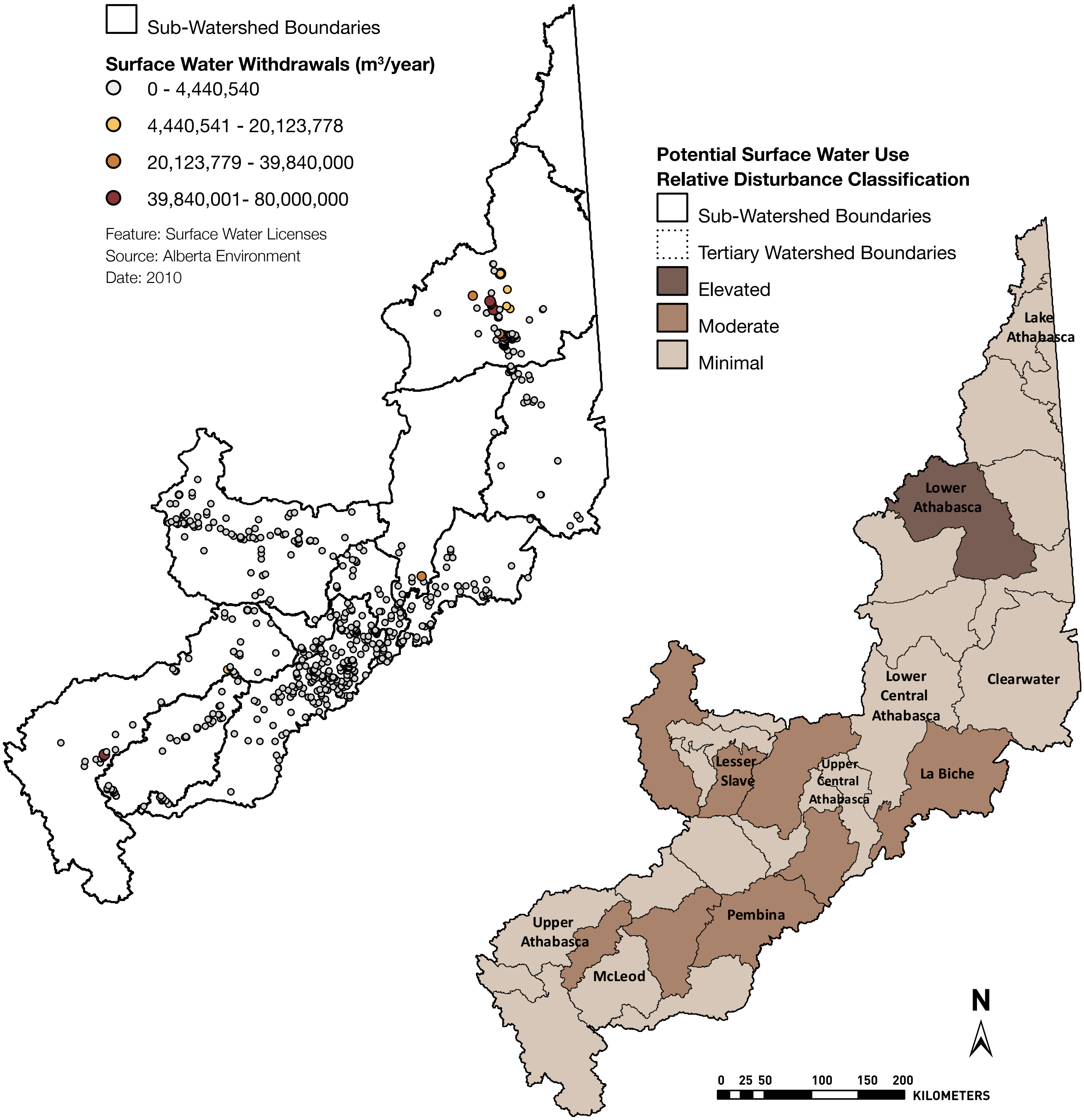


Figure 12. Input data used in the data modeling and Relative Disturbance Classification for the Potential Surface Water Use indicator in the Athabasca Watershed. The maximum water allocation for each Water Act License (Left Panel) was used to calculate the Relative Disturbance Classification for each tertiary watershed based on Jenks Classification Analysis (Right Panel). This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

CRITERION 4: MAINTENANCE OF GROUNDWATER QUALITY AND QUANTITY

Potential Groundwater Use

Managing groundwater is a complex challenge, and the current state of knowledge about the quality and quantity of Alberta's groundwater supply is limited at large scales (AWRI 2011, Ko and Donahue 2011). Given that underground aquifers recharge much more slowly than surface water bodies, there is increasing public concern over groundwater use, and calls for a much more comprehensive understanding of regional groundwater quantity and flow. Within the Athabasca Watershed, the Government of Alberta is actively conducting groundwater modeling and monitoring work. In 2009, a regional monitoring network was established in the Lower Athabasca Region (largely occurring in tertiary watershed 07DA). Initial work has focused on modeling the cumulative-drawdown effects of ground withdrawals in the Lower Athabasca region, as well as conducting modeling work to obtain estimates of groundwater quantity for the southern portion of the Athabasca Basin (tertiary watersheds 07CC and 07CD). In addition, groundwater vulnerability mapping has been completed for the Lower Athabasca region and in March 2011, the Government of Alberta released a draft Ground Water Framework for the Lower Athabasca Region (LAR-GWF 2011).

While there has recently been extensive work done on groundwater quality and quantity in the northern portion of the Athabasca Watershed, there is very little information available on groundwater quantity in other regions of the watershed. Consequently, a watershed-scale groundwater use versus availability assessment is not possible at this time. Instead, the indicator for this criterion is focused on assessing potential ground water use at the tertiary basin scale, as derived from water licence information and groundwater well densities. While these metrics are not the most desirable, the paucity of information available on groundwater across the entire basin makes it difficult to develop more sophisticated data models. While there is much more detailed information on groundwater available for the Lower Athabasca Region, the need to have comparable data from across the watershed has constrained the data that could be used for this analysis. Moving forward, existing information on groundwater quality and quantity in the Lower Athabasca region should be considered in any smaller-scale, regional assessment of groundwater use.

Two data sources were used to assess the potential groundwater use in the Athabasca Watershed:

a. The location of unlicensed water wells (Figure 15). In Alberta, only wells with an annual consumption ≥1250 m^3 are required to be licensed, and the majority of unlicensed wells are used for agricultural production (e.g. irrigation, consumption by livestock), or rural domestic residential use.

b. The maximum allocated water volume specified in *Water Act* approvals for each *licensed* well (Figure 16).

Modeling steps:

1. Data were standardized by tertiary watershed area.
   - Unlicensed wells were expressed as a density (wells/km^2)
   - Groundwater use was expressed as the maximum amount of water that may be used based on the licensed amount allocated (m^3/annum/km^2)

While it is acknowledged that the maximum amount of water allocated does not necessary reflect the actual amount of water used, the maximum water allocation was still used to assess risk, as this number represents the potential water use per km2 in any given year. In order to identify those tertiary watersheds where potential groundwater use is the highest, well density and maximum allocated water amount were used to rate The Relative Disturbance Classification, as follows:

1. The density of unlicensed wells ranged from 0.02 to 1.41 wells/km^2 (Table 15 and Figure 15). Based on Jenks classification, the Relative Disturnbance category boundaries are as follows:
   a. Minimal Disturbance Classification: ≤ 0.25 wells/km^2
   b. Moderate Disturbance Classification: >0.25 to ≤0.5 wells/km^2
   c. Elevated Disturbance Classification: >0.5 wells/km^2.
2. The total potential water allocations/km^2 for each tertiary basin ranged between 0 and 50,070,000 m3/annum/km^2 (Table 15 and Figure 16). Based on Jenks classification, the Relative Disturnbance category boundaries are as follows:
   a. Minimal Disturbance Classification: ≤500 m^3/annum/km^2
   b. Moderate Disturbance Classification: >500 to ≤1000 m^3/annum/km^2
   c. Elevated Disturbance Classification: >1000 m^3/annum/km^2

This model is a very simplistic assessment of groundwater use in the Athabasca Watershed, and should be interpreted with caution, as it does not account in any way for groundwater availability, or rates of groundwater recharge. Moreover, watershed boundaries may be not be the most appropriate hydrological units to model and present information on groundwater, as aquifers often cross watershed boundaries. For example, the Paskapoo formation occurs under the Athabasca, Peace, North Saskatchewan, Red Deer, Bow and Oldman watersheds (AWRI 2011).

It should be noted that the tertiary watersheds with highest potential groundwater use (07DA, 07AF, 07BA, 07BB; Table 16) are also the areas identified as research priorities by Alberta Environment and the Alberta Geological Survey (Lower Athabasca, Paskapoo region; see AWRI 2011). Thus, more detailed information on groundwater quality and quantity in these areas should be forthcoming. In addition, some cancelled licences have not been accounted for in the current data used in the groundwater data modeling. This will be updated in the next phase of the project.

Table 13. Groundwater results for groundwater use in the 31 tertiary watersheds and Relative Disturbance Classification.

SUBWATERSHED	TERTIARY WATERSHED	UNLICENSED WELLS	DENSITY OF UNLICENSED WELLS (WELLS/KM²)	RELATIVE DISTURBANCE CLASSIFICATION	TOTAL GROUNDWATER ALLOCATION (M³/YEAR)	POTENTIAL WATER WITHDRAWAL (M³/YEAR/KM²)	RELATIVE DISTURBANCE CLASSIFICATION
Upper Athabasca	07AA	330	0.04	Minimal	1,652,783	209	Minimal
	07AB	13	0.01	Minimal	0	0	Minimal
	07AC	1188	0.21	Minimal	33,958	6	Minimal
	07AD	1190	0.5	Moderate	84,862	36	Minimal
	07AE	1212	0.42	Moderate	182,798	63	Minimal
	07AH	1755	0.37	Moderate	1,333,886	281	Minimal
McLeod	07AF	2398	0.49	Moderate	3,370,660	686	Moderate
	07AG	6668	1.41	Elevated	2,727,489	575	Moderate
Pembina	07BA	5370	1.28	Elevated	5,707,252	1356	Elevated
	07BB	1044	0.17	Minimal	4,736,207	760	Moderate
	07BC	4662	1.2	Elevated	934,657	241	Minimal
Central Athabasca (Upper Watershed)	07BD	816	0.28	Moderate	478,347	162	Minimal
	07BE	4234	1.33	Elevated	443,614	140	Minimal
Central Athabasca (Lower Watershed)	07CB	1415	0.13	Minimal	735,081	70	Minimal
	07CC	163	0.03	Minimal	1,629,434	277	Minimal
Lesser Slave	07BF	1185	0.18	Minimal	192,838	29	Minimal
	07BG	58	0.05	Minimal	0	0	Minimal
	07BH	102	0.09	Minimal	0	0	Minimal
	07BJ	304	0.12	Minimal	7,325	3	Minimal
	07BK	596	0.09	Minimal	981,684	151	Minimal
	LAKE1	474	0.22	Minimal	74,483	35	Minimal
La Biche	07CA	3957	0.46	Moderate	324,085	37	Minimal
Clearwater	07CD	149	0.04	Minimal	1,230	0	Minimal
	07CE	674	0.05	Minimal	8,784,895	673	Moderate
Lower Athabasca	07DA	391	0.04	Minimal	50,070,000	5464	Elevated
	07DB	121	0.02	Minimal	1,217,634	218	Minimal
	07DC	62	0.01	Minimal	1,463,833	271	Minimal
	07DD	13	0	Minimal	0	0	Minimal
Lake Athabasca	07MA	1	0	Minimal	0	0	Minimal
	07MD	0	0	Minimal	0	0	Minimal
	LAKE2	36	0.01	Minimal	0	0	Minimal

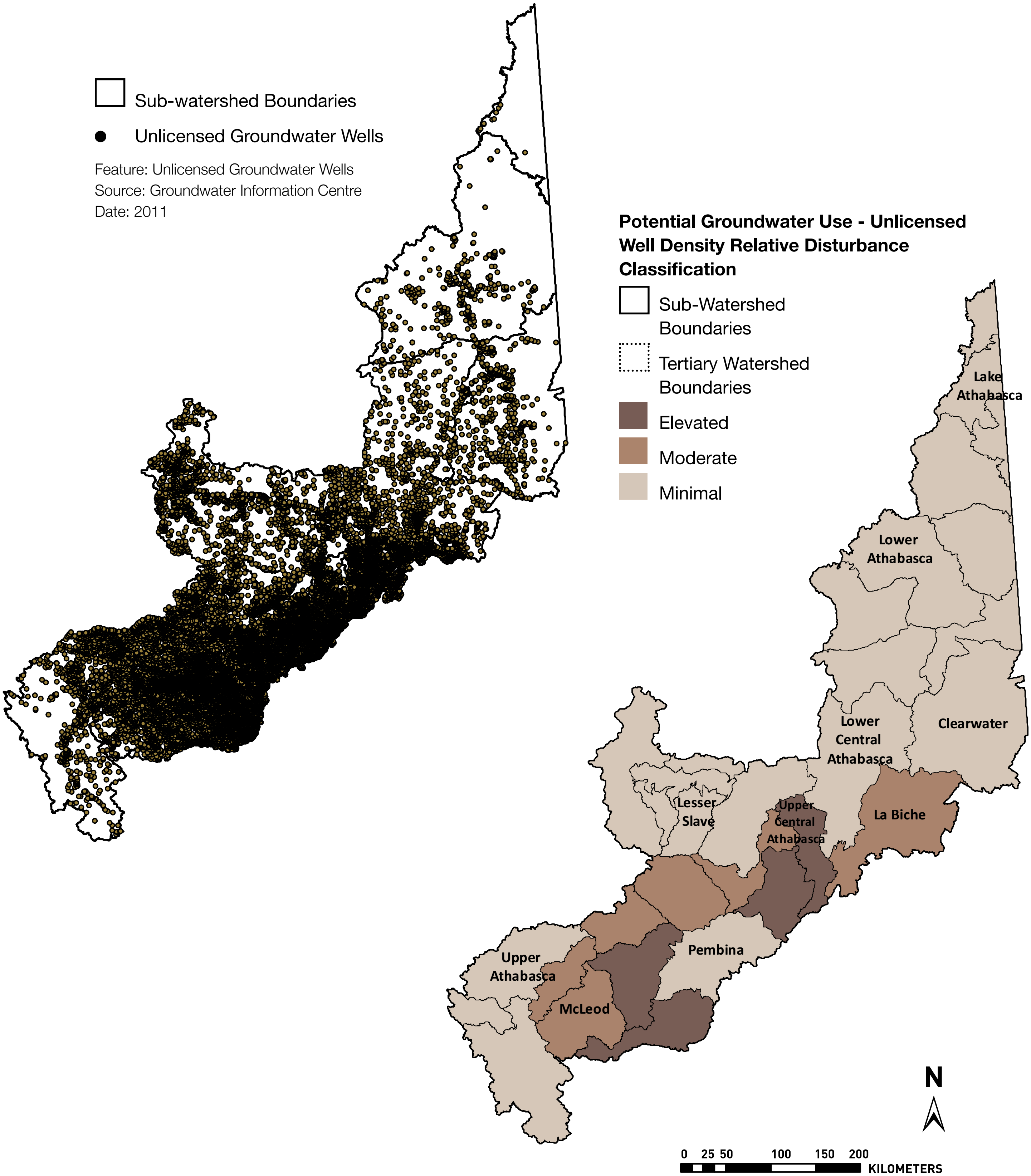


Figure 13 Input data used in the data modeling and Relative Disturbance Classification for the Potential Groundwater Use indicator in the Athabasca Watershed. The density of unlicensed wells (Left Panel) was used to calculate the Relative Disturbance Classification for each tertiary watershed based on Jenks Classification Analysis (Right Panel). This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

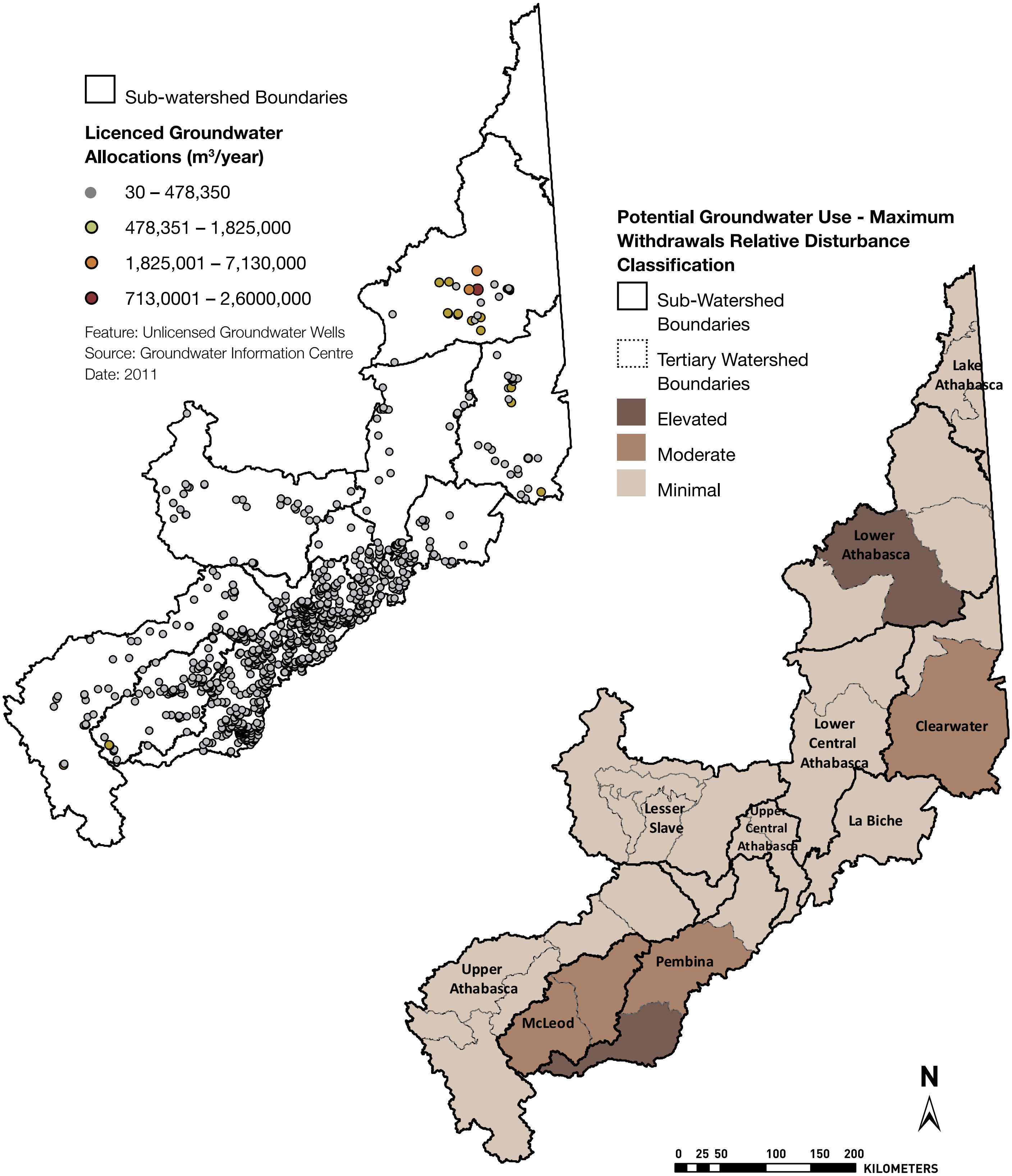


Figure 14. Input data used in the data modeling and Relative Disturbance Classification for the Potential Groundwater Use indicator in the Athabasca Watershed. The maximum water allocation for each Water Act License (Left Panel) was used to calculate the Relative Disturbance Classification for each tertiary watershed based on Jenks Classification Analysis (Right Panel). This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

CRITERION 5: MAINTENANCE OF WATERSHED INTEGRITY

Human Land Use – Built Up Areas

Land use is defined as the area on the landscape that has been modified by human activity. The impacts of land use on watershed health have been extensively studied over the last two decades, with a particular focus on those watersheds dominated by urban development. This urban focus is driven by the profound impact the extent of impervious surfaces can have on watershed health. Impervious surfaces are areas where the surface cover has been altered to become impermeable to water (i.e. any paved areas including roads, parking lots or sidewalks, and building roof tops; Brabec et al. 2002). This change leads to reductions in the quality of stormwater runoff due to increased pollution and sedimentation loads, and to changes in stormwater runoff patterns and volume. Concurrent with the impact of urban development is the loss of natural habitat, such as forest, riparian areas and wetlands, which absorb and clean stormwater and other runoff (Brabec et al. 2002). Industrial land use, such as oil sands extraction, and coal and aggregate mining, can also lead to changes in natural runoff patterns, as top soil and vegetation is removed from large areas of the landscape, and degraded by intensive traffic.

This indicator identifies all areas that have experienced a permanent or semi-permanent conversion of land to a “built-up” land use. Built-up areas are those that have been anthropogenically modified such that vegetation has been removed and the surface cover has been altered, resulting in modification to infiltration and/or surface run-off patterns (Brabec et al. 2002). The source for this data modeling is the 2009 Landsat land use/land cover layer (30 m resolution), and other base feature layers. At present this indicator includes: all paved roads, all urban areas (towns and cities), and all industrial development (including factories, and oil sand extraction areas).

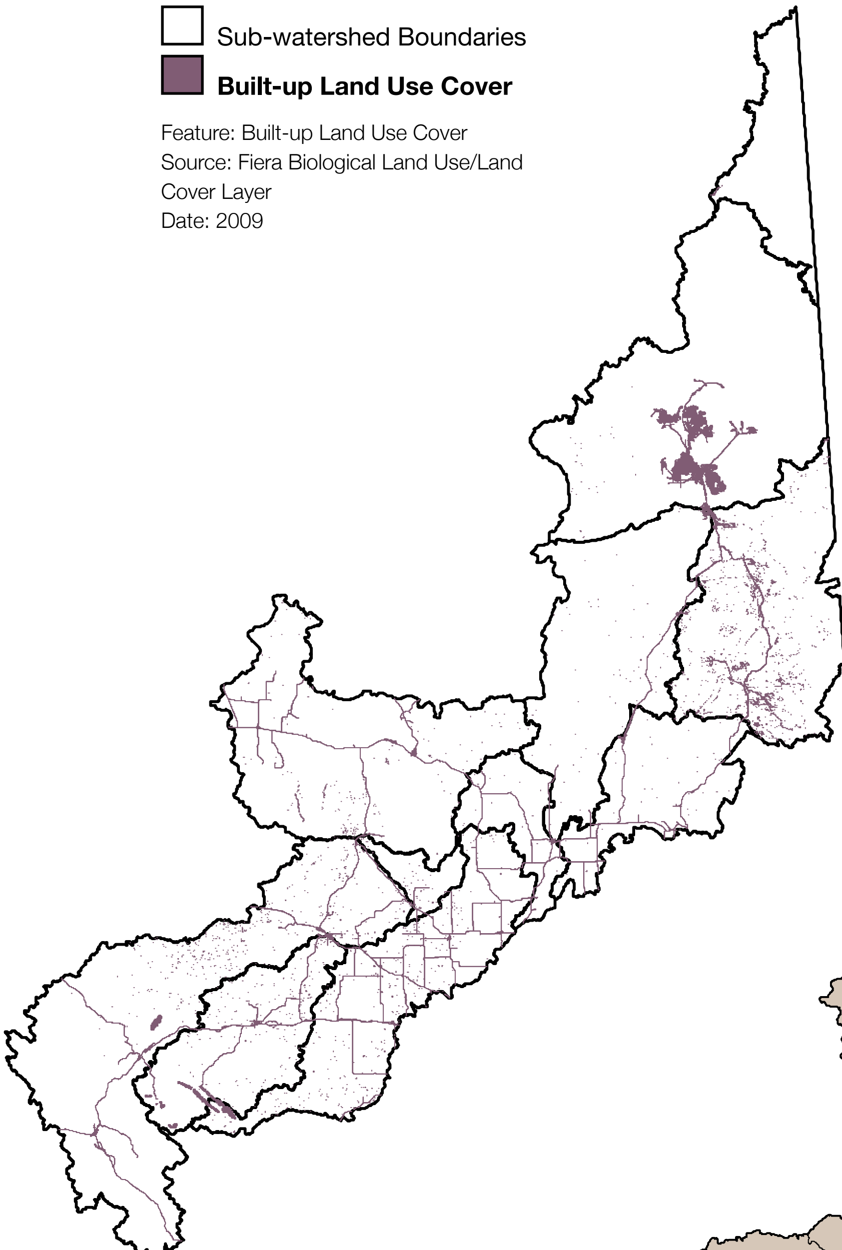
Modeling steps:

1. The Built-up indicator was created by combining together into a single layer the following information:
    a. The area of Built-up classification was extracted from the 2009 Land use/Land cover layer. This classification has a high accuracy for detecting large built-up features such as towns, cities, and large industrial developments, but is less accurate for narrow built-up features such as roads, and small facilities < 1ha in size.
    b. All paved roads from the Alberta road base feature 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 2009).
    c. All conventional oil and gas facilities from the National Pollution Release Inventory (see Point Contaminant section below for full details) were converted to 50 m^2 square polygons.
2. The total area of built-up land was standardized by calculating the percent aerial coverage in each tertiary basin (Table 16).
3. The cover of built-up land in tertiary watersheds ranged from 0 to 7.7%. In order to identify those tertiary watersheds where built land cover is the highest, Relative Disturbance Classification were established as follows (Figure 17):
    a. Minimal Disturbance Classification: ≤ 1.0%
    b. Moderate Disturbance Classification: > 1 to 2.25%
    c. Elevated Disturbance Classification: > 2.25%

In future iterations of this indicator, the amount of urban land cover (impervious surfaces) should be separated from industrial land cover. In addition, the land use/land cover layer that was used as the basis for this analysis should be further refined to more accurately reflect areas in the Athabasca Watershed that have been impacted by forest activity, such that this land use can be evaluated.

Table 14. Tertiary watershed results for the amount of Built-up human land use in the Athabasca Watershed.

SUBWATERSHED	TERTIARY WATERSHED	WATERSHED AREA (KM2)	BUILT-UP COVER (% AREA)	RELATIVE DISTURBANCE CLASSIFICATION
Upper Athabasca	07AA	7,909	0.17	Minimal
	07AB	1,597	0.00	Minimal
	07AC	5,669	0.34	Minimal
	07AD	2,385	2.25	Moderate
	07AE	2,892	0.97	Minimal
	07AH	4,744	0.76	Minimal
McLeod	07AF	4,913	2.05	Moderate
	07AG	4,745	1.02	Moderate
Pembina	07BA	4,209	2.17	Moderate
	07BB	6,232	1.58	Moderate
	07BC	3,884	1.20	Moderate
Central Athabasca (Upper Watershed)	07BD	2,960	0.35	Minimal
	07BE	3,178	0.93	Minimal
Central Athabasca (Lower Watershed)	07CB	10,528	0.17	Minimal
	07CC	5,884	0.30	Minimal
Lesser Slave	07BF	6,621	0.39	Minimal
	07BG	1,082	0.22	Minimal
	07BH	1,175	0.13	Minimal
	07BJ	2,563	0.45	Minimal
	07BK	6,503	0.27	Minimal
	LAKE1	2,141	0.59	Minimal
La Biche	07CA	8,671	0.64	Minimal
Clearwater	07CD	3,832	0.81	Minimal
	07CE	13,060	0.55	Minimal
Lower Athabasca	07DA	9,164	7.74	Elevated
	07DB	5,577	0.23	Minimal
	07DC	5,394	0.14	Minimal
	07DD	6,942	0.00	Minimal
Lake Athabasca	07MA	1,611	0.00	Minimal
	07MD	1,623	0.00	Minimal
	LAKE2	3,328	0.05	Minimal



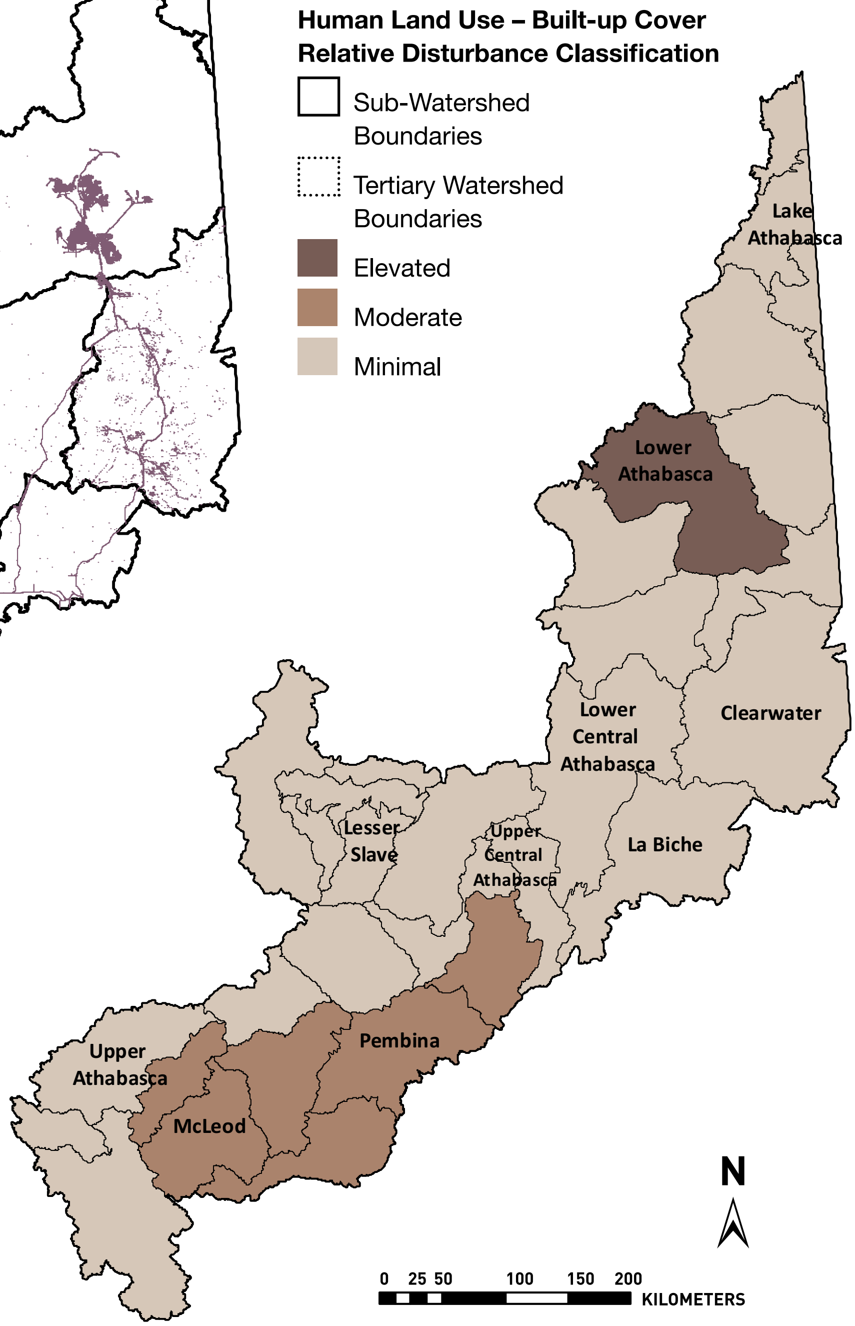


Figure 15. Input data (Left Panel) used in the data modeling and Relative Disturbance Classification (Right Panel) for the Built-up Human Land Use indicator in the Athabasca Watershed. The Relative Disturbance Classification for Built-up land use was determined using a Jenks Classification Analysis. This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

Land Conversion

Land conversion (or land-use change) refers to the rate of change over time in the distribution of land uses, and how the conversion and modification of vegetation impacts biodiversity, soil quality, runoff, erosion, sedimentation and land productivity change over time (Brinkman 1997). Both the amount of natural vegetation converted to anthropogenic land use (as described in the previous indicator: Human Land Use), and the rate of conversion over a given time period are important to understand. Thus, this indicator examines the temporal and spatial effects of human activity and land conversion over time, rather than simply measuring the static distribution of human activities. This approach is important because over the last several decades, the Athabasca Basin has been subjected to rapidly increasing development. Conventional oil and gas development, non-conventional energy exploration and extraction, coal mining, and forest harvesting activity have all increased dramatically since the 1980's. In addition, agriculture has been a long-standing practice in the central portion of the watershed, with modest increases in agricultural land use since the 1960s.

The intent of this indicator is to quantify the amount of land that has been converted from a natural vegetated state to an anthropogenic land use (built-up or agricultural) between 1973/74 and 2009. Given that this analysis is based solely on the Landsat land use/land cover layer, only larger features (>1 ha) in size are included because the lower resolution (60 m) of the Historical (1973/74) land cover layer limits the detection and comparability of smaller areas. In addition, this analysis only includes land conversions that have persisted since 1973, and only includes land conversion that is considered to be permanent or semi-permanent (i.e., persisting for a decade or more).

Modeling steps:

1. For each time period (1973/74 and 2009), the total cover of built-up and agricultural land use was extracted from the land use/land cover layer.
2. The information from the time periods were then Unioned together to identity land use areas common to both time periods. The spatial areas common to both time periods were then subtracted to identify areas where land conversion occurred between 1973/1974 and 2009.
3. The amount of new land area converted to both built-up and agricultural land use was standardized to an areal percentage of the tertiary watershed area.
4. Land conversion for agriculture between 1973/74 and 2009 ranged between 0 and 19%. In order to identify those tertiary watersheds where land conversion has been highest, Relative Disturbance Classification were established using a Jenks analysis as follows:
    a. Minimal Disturbance Classification: ≤ 3.5%
    b. Moderate Disturbance Classification: >3.5 to 12%
    c. Elevated Disturbance Classification: >12%
5. Land conversion for built-up area between 1973/74 and 2009 ranged between 0 and 7.4%. In order to identify those tertiary watersheds where land conversion has been highest, Relative Disturbance Classification were established using a Jenks analysis as follows:
    a. Minimal Disturbance Classification: ≤ 0.05%
    b. Moderate Disturbance Classification: >0.05 to 1%
    c. Elevated Disturbance Classification: >1%

Table 15. Tertiary watershed results of Land Conversion Change. The amount of land converted (shown as an areal % of each tertiary watershed) is calculated separately for agriculture and built-up land use between 1973/1974 and 2009.

SUBWATERSHED	TERTIARY WATERSHED	TERTIARY WATERSHED AREA (KM^2)	AGRICULTURAL		BUILT-UP	
			% CHANGE IN AGRICULTURAL LAND COVER	RELATIVE DISTURBANCE CLASSIFICATION	% CHANGE IN BUILT-UP LAND COVER	RELATIVE DISTURBANCE CLASSIFICATION
Upper Athabasca	07AA	7,909	0.00	Minimal	0.00	Minimal
	07AB	1,597	0.00	Minimal	0.00	Minimal
	07AC	5,669	0.00	Minimal	0.00	Minimal
	07AD	2,385	0.00	Minimal	0.00	Minimal
	07AE	2,892	0.05	Minimal	0.24	Moderate
	07AH	4,744	4.77	Moderate	0.04	Minimal
McLeod	07AF	4,913	0.16	Minimal	0.00	Minimal
	07AG	4,745	8.90	Moderate	0.04	Minimal
Pembina	07BA	4,209	2.29	Minimal	0.00	Minimal
	07BB	6,232	19.09	Elevated	0.00	Minimal
	07BC	3,884	15.58	Elevated	0.00	Minimal
Central Athabasca (Upper Watershed)	07BD	2,960	6.26	Moderate	0.00	Minimal
	07BE	3,178	14.16	Elevated	0.00	Minimal
Central Athabasca (Lower Watershed)	07CB	10,528	3.44	Minimal	0.00	Minimal
	07CC	5,884	0.00	Minimal	0.16	Moderate
Lesser Slave	07BF	6,621	9.42	Moderate	0.00	Minimal
	07BG	1,082	0.00	Minimal	0.00	Minimal
	07BH	1,175	2.27	Minimal	0.00	Minimal
	07BJ	2,563	2.06	Minimal	0.03	Minimal
	07BK	6,503	0.00	Minimal	0.05	Minimal
	LAKE1	2,141	5.37	Moderate	0.16	Moderate
La Biche	07CA	8,671	11.12	Minimal	0.04	Minimal
Clearwater	07CD	3,832	0.00	Minimal	0.26	Moderate
	07CE	13,060	0.00	Minimal	0.34	Moderate
Lower Athabasca	07DA	9,164	0.00	Minimal	7.36	Elevated
	07DB	5,577	0.00	Minimal	0.22	Moderate
	07DC	5,394	0.00	Minimal	0.14	Moderate
	07DD	6,942	0.00	Minimal	0.00	Minimal
Lake Athabasca	07MA	1,611	0.00	Minimal	0.00	Minimal
	07MD	1,623	0.00	Minimal	0.00	Minimal
	LAKE2	3,328	0.00	Minimal	0.01	Minimal

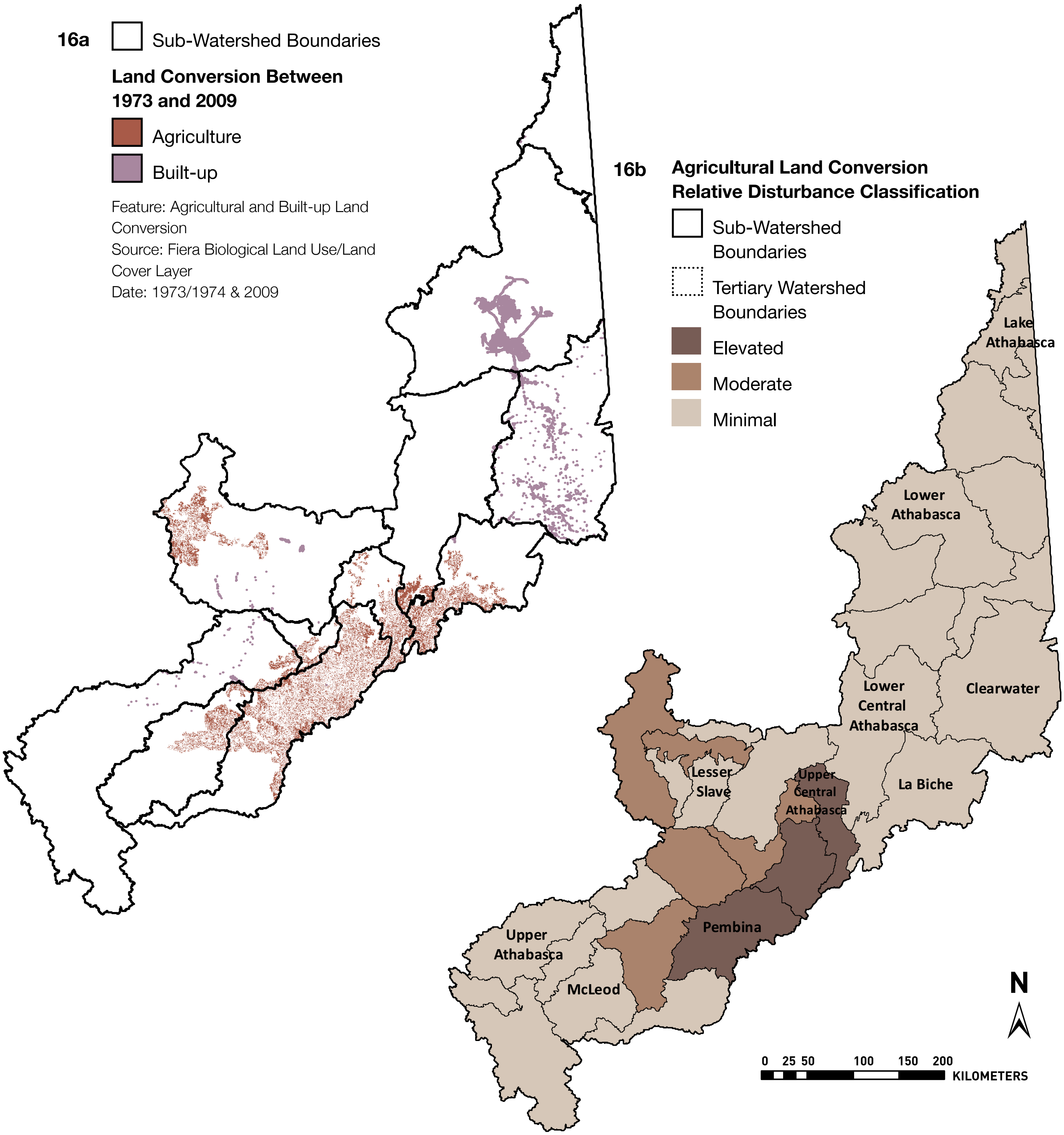
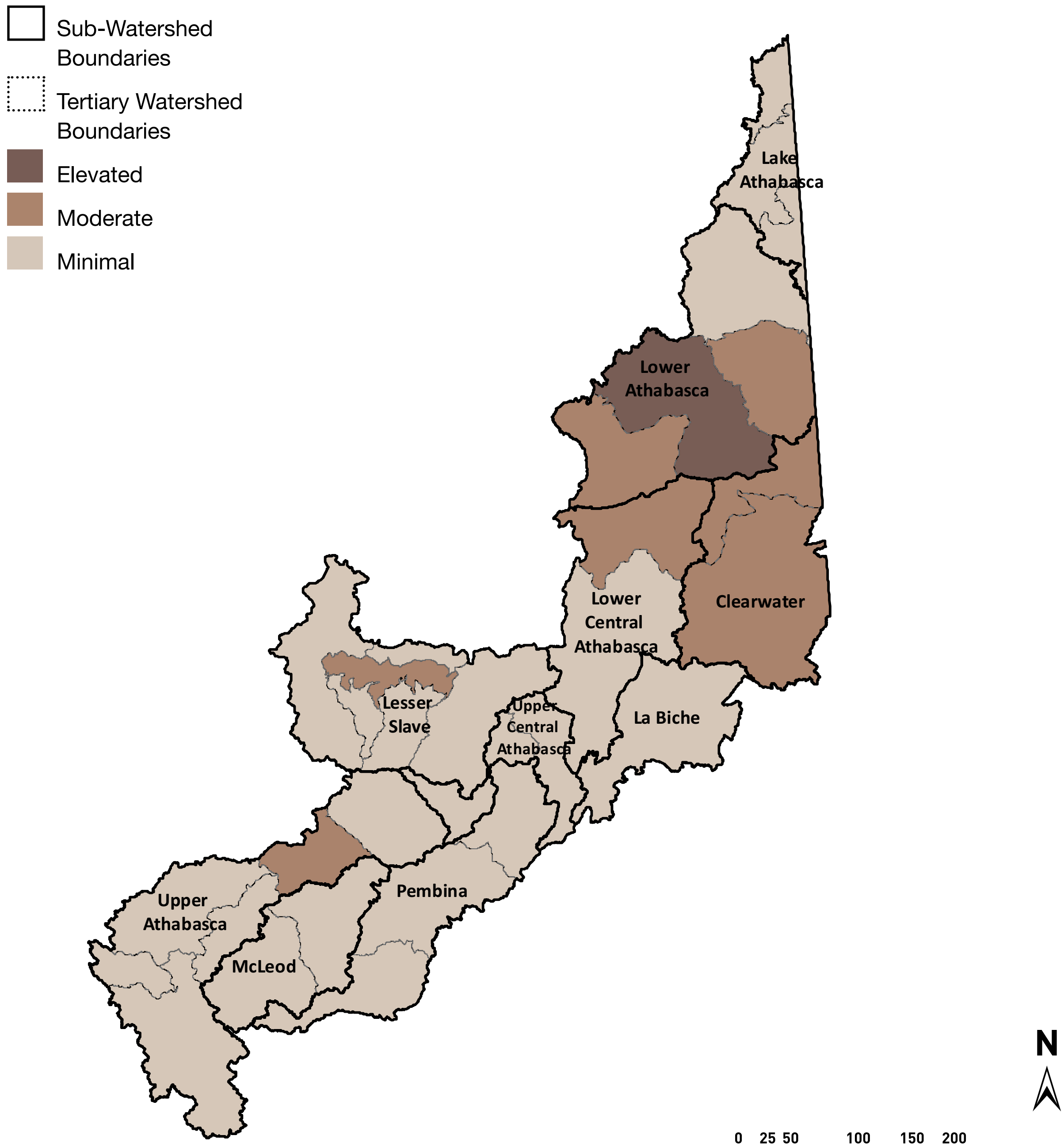


Figure 16. Input data used in the data modeling and Relative Disturbance Classification for the Land Conversion indicators for both Agricultural and Built-up land conversion between 1973/4 and 2009 in the Athabasca Watershed. The amount of land converted for agriculture and built-up (Figure 16A) was used to model and rate the amount of Agricultural Land Conversion (Figure 16B) and Built-up Conversion (Figure 16C) each tertiary watershed based on Jenks Classification Analysis. This classification is only relative to other tertiary watersheds within the Athabasca watershed and not based on ecological thresholds.

16c Built-up Land Conversion Relative Disturbance Classification



4.0 Non-Rated Indicators: Modeling Methods & Results

CRITERION 2: MAINTENANCE OF SURFACE WATER QUALITY

Surface Water Quality

The Alberta River Water Quality Index (RWQI; Alberta Environment 1995) was used to evaluate surface water quality in the Athabasca River, or its major tributaries. The RWQI summarizes information on up to 47 water quality variables into a single index. The index is designed to be calculated over a given time period (i.e. annual reporting), and needs to include multiple sampling events. The RWQI compares water parameter concentrations with established thresholds (CCME 2006), and then summarizes the following values into a single index based on: 1) the number of variables that exceed thresholds, 2) the number of individual tests that exceed thresholds, and 3) the amount by which each test exceeds thresholds.

Surface water quality could only be examined for 20 stations in the Athabasca Watershed for the years 2008/09 and 2009/10 because a minimum of three samples per station were required over the annual reporting period (October to April), and many of the stations in the watershed did not meet this requirement. Further, this indicator modeling could only include nutrients, metals, and bacteria, because pesticide concentrations were measured too infrequently to be included.

The RWQI results are reported by Alberta Environment as number between 0 and 100, where:

i) 96 to 100: Excellent water quality

ii) 81 to 95: Good water quality

iii) 66 to 80: Fair water quality

iv) 46 to 65: Marginal water quality

v) 0 to 45: Poor water quality

The RWQI scores for nutrients ranged between 15 and 100, while metals ranged from 91 to 100, and bacteria ranged between 20 and 100 (Table 18 and Figure 19). The overall RWQI results ranged between 72 (Fair) and 100 (Excellent). While the RWQI has been widely used across Canada, it is most effective for evaluating temporal trends at a given station over time, rather than for spatial comparisons (Dube et al. 2006). Moreover, it is an unbalanced index because different numbers of variables are tested for in each group: nutrients (up to 6), metals (up to 21), and bacteria (up to 3). The index is proportional, comparing the number of variables that fail to meet thresholds to the total number tested. For example, if one variable fails for nutrients (1/6 = 0.167), the resulting impact is far higher than for metals (1/21 = 0.048). As a result, the index is far more sensitive to tests failing to meet thresholds for nutrient than for metals.

No Jenks classification was conducted for this indicator; instead, results are presented for each station using Alberta Environment's rating system of Poor to Excellent.

Table 16. River Water Quality Index results for the Athabasca, Muskeg, Beaver, or Tar Rivers sampled at 20 stations in 2008/09 or 2009/10. Results of components for deriving RWQI for nutrients, metals and bacteria are presented for each station; however, only RWQI values are provided for bacteria given that consistent data between stations was only available for a single variable (fecal coliform concentration), which fell below the threshold in all but on instance.

DATA SOURCE	STATION	RIVER	YEAR	SAMPLES/YR	NUTRIENTS				METALS				BACTERIA RWQI	TOTAL RWQI
					VARIABLES TESTED (#)	FAILED TESTS (#)	FAILED PARAMETERS	RWQI	VARIABLES TESTED (#)	FAILED TESTS (#)	RWQI	FAILED PARAMETERS		
EC	AL07AA0023	Athabasca	2009/10	4	4	0	-	100	19	0	100	-	100	100
AENV	AB07AD0100	Athabasca	2009/10	12	5	2	Phosphorus	85	9	1	97	Iron	100	94
AENV	AB07BE0010	Athabasca	2009/10	12	5	3	Phosphorus	97	9	2	99	Lead	100	99
AENV	AB07CC0030	Athabasca	2009/10	12	5	3	Phosphorus	97	9	4	98	Iron, Lead	20	72
AENV	AB07DD0010	Athabasca	2009/10	7	5	4	Phosphorus	93	10	2	98	Iron, Lead	100	97
AENV	AB07DD0105	Athabasca	2009/10	5	5	0	-	100	9	6	92	Iron, Zinc	100	97
AENV	AB07DA0440	Muskeg	2008/09	3	3	6	Phosphorus, Dissolved Oxygen	28	21	6	94	Iron, Manganese	100	74
AENV	AB07DA0475	Muskeg	2008/09	3	3	6	Phosphorus, Dissolved Oxygen	15	21	3	97	Manganese	100	71
AENV	AB07DA0595	Muskeg	2008/09	3	3	3	Dissolved Oxygen	29	21	4	96	Iron, Manganese	100	75
AENV	AB07DA0600	Muskeg	2008/09	3	3	2	Phosphorus, Dissolved Oxygen	70	21	2	98	Iron, Manganese	100	89
AENV	AB07DA0610	Muskeg	2008/09	3	3	3	Dissolved Oxygen	36	21	4	96	Iron, Manganese	100	77
RAMP	ATR-DD-E	Athabasca	2009/10	4	3	0	-	100	20	2	98	Iron	100	99
RAMP	ATR-DD-W	Athabasca	2009/10	4	3	0	-	100	20	1	99	Lead	100	100
RAMP	BER-2	Beaver	2009/10	4	4	0	-	100	20	1	99	Iron	100	100
RAMP	MAR_1	MacKay	2009/10	3	4	1	Dissolved Oxygen	95	20	2	98	Iron, Lead	100	97
RAMP	MAR_2	MacKay	2009/10	3	4	0	-	100	20	2	98	Iron, Lead	100	99
RAMP	MAR-2A	MacKay	2009/10	4	4	0	-	100	20	7	91	Arsenic, Copper, Manganese, Selenium, Uranium	100	97
RAMP	TAR-1	Tar	2009/10	3	4	0	-	100	20	0	100	-	100	100
RAMP	TAR-2	Tar	2009/10	3	4	0	-	100	20	0	100	-		100

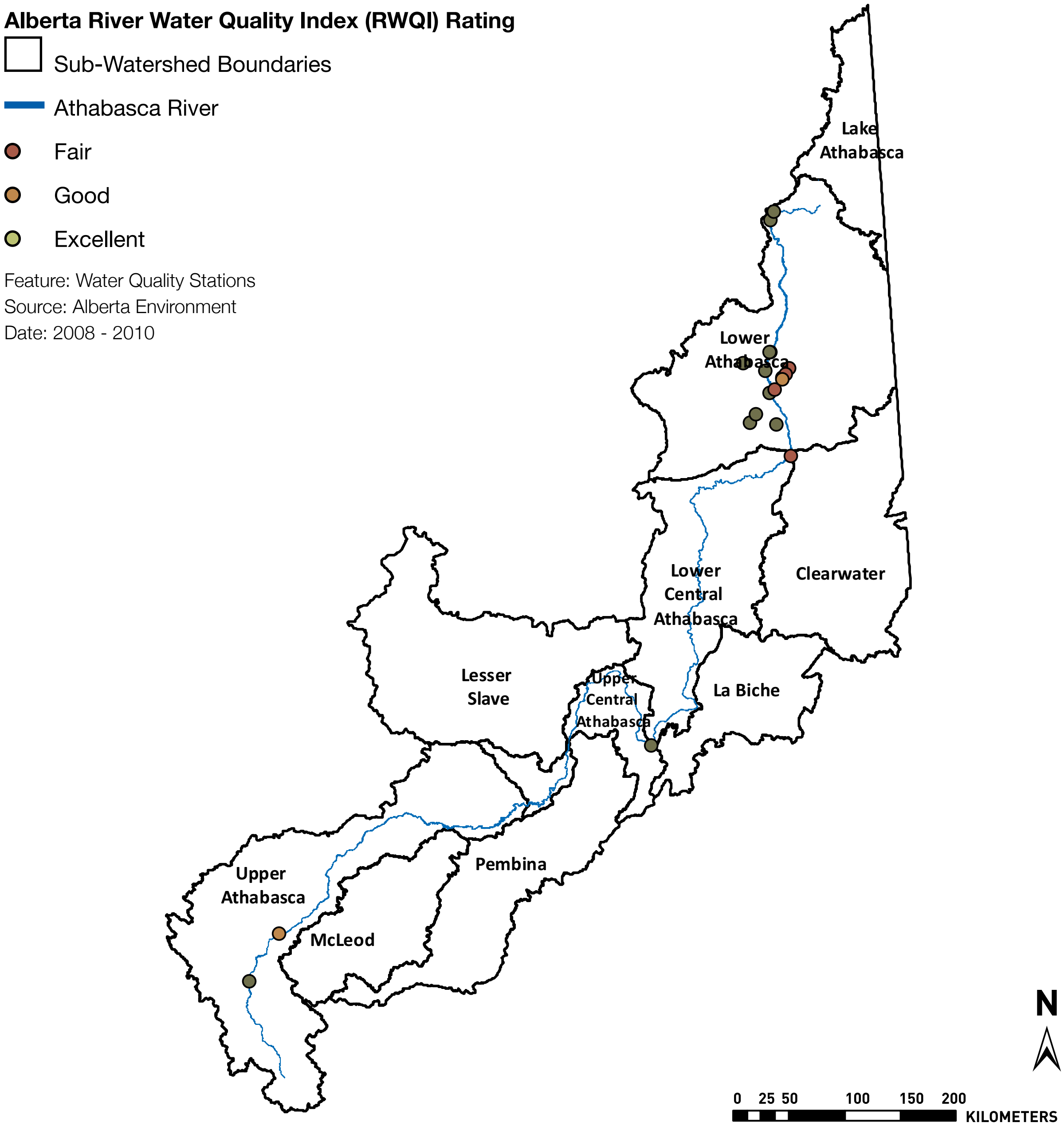


Figure 17 Alberta River Water Quality Index (RWQI) based on nutrients, metals, and bacteria, for 20 stations in the Athabasca Watershed.

Temporal Water Quality Trends

Due to concerns about the appropriateness and sensitivity of the RWQI to detect real trends, different approaches to tracking changes in water quality data over broad spatial scales should be explored. Using a benchmarking approach, Squires et al. (2009) compared water quality variables between a historical benchmark (the earliest available data 1966-1976), and current conditions for long-term water quality stations in the Athabasca Watershed. Benchmark values were considered the natural range of variation from 1966 to1976 (the 90th percentiles of water quality variables). A comparison of water quality variables from current 2009 water quality data assembled in this study with Squires et al (2009) benchmark values was conducted in Table 19 below for stations common to both analyses.

Table 17. Comparison of current water quality and historical benchmarks for long-term monitoring stations on the Athabasca River. If parameters fall within the historical 90th percentiles of water quality they are rated as normal.

WATER QUALITY PARAMETER	AL07AA0023	AB07AD0100	AB07BE0010	AB07CC0030
Total Organic Carbon (mg/L)	Normal	Normal	< benchmark	< benchmark
Dissolved Sodium (mg/L)	Normal	Normal	> benchmark	> benchmark
Dissolved Sulphate (mg/L)	Normal	Normal	Normal	> benchmark
Turbidity (NTU)	Normal	Normal	Normal	Normal
Total Phosphorous (mg/L)	Normal	Normal	Normal	Normal
Conductivity (uS/cm)	Normal	Normal	Normal	Normal
Dissolved Chloride (mg/L)	Normal	Normal	Normal	Normal
Dissolved Nitrogen (mg/L)	Normal	Normal	Normal	Normal

Due to delays in receiving the water quality data, there was insufficient time to test the full suite of analytical methods and approaches for summarizing this indicator. It is recommended that future work focus on developing a temporal trend (cumulative effects) analyses (circa Squires et al. 2009 and Dube et al. 2006), and to have an expert review of the suitability of the RWQI for broad-scale spatial modeling and the water quality thresholds used in the index.

CRITERION 3: MAINTENANCE OF ECOLOGICALLY SIGNIFICANT WATER LEVELS AND FLOWS

River Water Flow

Defining “natural flows” or the natural range of variation is particularly challenging in areas where human water use (e.g. domestic consumption, industrial and agricultural extraction, and diversions) is extensive and historical flow data is limited or not available (Seneka 2006). The Alberta River Flow Quantity Index (RFQI) is a metric that attempts to differentiate between natural and anthropogenically-influenced flow regimes using flow naturalization techniques (Seneka 2006). The index uses both a probability approach and a “percent of natural” (based on median monthly flow) for a standardized period in order to generate a normalized baseline natural average stream flow condition, against which annual recorded data can be evaluated (see Seneka 2006 for full methodological details). Any events above or below the normalized baseline natural average stream flow conditions may be anthropogenically-influenced flow regimes, and require futher investigation.

The RFQI requires long-term flow data and typically considers two seasons: Summer (May to September) and Fall/Winter (October to April). In calculating the River Water Flow indicator for the Athabasca Watershed, only those stations with a minimum of 40 years of flow data (1969 to 2009) were considered. For the Summer period, 40 flow stations had long-term data that were included in this analysis (Table 8), while only 15 stations had long-term flow data for the Fall/Winter period (Table 9). For this indicator, a recent snapshot of river flows across the Athabasca Watershed from 2005 – 2009 is presented. The winter flow data for individual water quality stations and river reaches is shown in Table 17, while the summer flow data is shown Table 18.

Modeling steps:

1. For each station, monthly average flows were calculated for the 40-year period of interest, and were then normalized by the 40-year median monthly values.

- The RFQI assumes that a natural average flow regime can be expected to occur 80 percent of the time, and is considered the “Normal Natural”; thus, the median monthly flow values were used to calculate the 90th percentile flow values at each station for the Summer and Fall/Winter time periods.

2. When the flow exceeds or falls below the range considered to be the “Normal Natural” for each of the seasonal time periods, the departure from the normal is ranked based on the degree of deviation from the calculated normal value (the 10th or 90th percentiles). For example, if seasonal flows are considered normal, the RFQI value is green; however, if seasonal flows fall well below what is considered to be the normal natural range (e.g. <15% of the 10th percentile), the assigned RFQI value is red (Figure 7).

- **Very High** Flow Seasonal flow exceeded outside of normal natural range (>115% or 90^{th} percentile)
- **High Flow** Seasonal flow exceeds normal natural (outside 90^{th} percentile)
- **NaturalFlow** Seasonal flow exceeds normal natural (within 10^{th} & 90^{th} percentile)
- **Low Flow** Seasonal flow within normal natural (outside 90^{th} percentile)
- **Very Low Flow** Seasonal flow much below normal natural (<85% of 10^{th} percentile)
- **Extremely Low Flow** Seasonal flow diminished outside of normal natural range (<15% of 10^{th} percentile)

River Flow Quantity Index (RFQI) ratings for the Athabasca Watershed (adapted from Alberta Environment’s River Flow Quality Index).

Table 18. Fall/ Winter Period (October to April) River Quantity Flow Index values calculated for each year between 2005 and 2009.

STATION ID	WATER COURSE NAME	RFQI SUMMER VALUE				
		2005	2006	2007	2008	2009
07AG003	Wolf Creek	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BE001	Athabasca River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BK001	Lesser Slave River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BK007	Driftwood River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07CD001	Clearwater River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07DA001	Athabasca River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AA001	Miette River	High Flow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AF002	Mcleod River	High Flow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AG007	Mcleod River	High Flow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AA002	Athabasca River	High Flow	High Flow	NaturalFlow	NaturalFlow	NaturalFlow
07AD002	Athabasca River	High Flow	High Flow	NaturalFlow	NaturalFlow	NaturalFlow
07BB002	Pembina River	Very High	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BF002	West Prairie River	Very High	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BJ001	Swan River	Very High	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BC002	Pembina River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow

Very High

High Flow

NaturalFlow

Low Flow

Very Low Flow

Extremely Low Flow

Table 19.
Summer Period (May to September) River Quantity Flow Index values between 2005 and 2009.

STATION ID	WATER COURSE NAME	RFQI SUMMER VALUE				
		2005	2006	2007	2008	2009
07AA002	Athabasca River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AF010	Sundance Creek	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AG003	Wolf Creek	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AG004	McLeod River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BK001	Lesser Slave River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BK007	Driftwood River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07CA006	Wandering River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07DA006	Steepbank River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07DA008	Muskeg River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AD002	Athabasca River	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07AE001	Athabasca River	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07AF002	Mcleod River	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AG007	Mcleod River	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07BB002	Pembina River	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07BE001	Athabasca River	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07BF001	East Prairie River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Low Flow
07BK009	Sawridge Creek	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07CD001	Clearwater River	High Flow	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07DA001	Athabasca River	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07AA001	Miette River	NaturalFlow	Low Flow	NaturalFlow	NaturalFlow	Low Flow
07BA002	Rat Creek	NaturalFlow	Low Flow	Low Flow	NaturalFlow	NaturalFlow
07CB002	House River	High Flow	NaturalFlow	NaturalFlow	High Flow	NaturalFlow
07CD005	Clearwater River	High Flow	NaturalFlow	NaturalFlow	NaturalFlow	High Flow
07AF003	Wampus Creek	Very High	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow
07AH002	Christmas Creek	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow
07BB004	Paddle River	NaturalFlow	Very Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07BB006	Paddle River	NaturalFlow	Very Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07BB011	Paddle River	NaturalFlow	NaturalFlow	Very Low Flow	NaturalFlow	NaturalFlow
07BC007	Wabash Creek	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow
07BF002	West Prairie River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow
07BJ001	Swan River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow
07BK005	Saulteaux River	NaturalFlow	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow
07CD004	Hangingstone River	NaturalFlow	Very Low Flow	NaturalFlow	NaturalFlow	NaturalFlow
07DA018	Beaver River	NaturalFlow	NaturalFlow	Very Low Flow	NaturalFlow	NaturalFlow
07DC001	Firebag River	Very High	NaturalFlow	NaturalFlow	NaturalFlow	High Flow
07AH003	Sakwatamau River	NaturalFlow	NaturalFlow	NaturalFlow	Low Flow	Very Low Flow
07BJ003	Swan River	NaturalFlow	NaturalFlow	NaturalFlow	Low Flow	Very Low Flow
07DD002	Richardson River	Very High	NaturalFlow	NaturalFlow	NaturalFlow	Very High
07AH001	Freeman River	NaturalFlow	NaturalFlow	NaturalFlow	Very Low Flow	Very Low Flow
07BB005	Little Paddle River	NaturalFlow	Very Low Flow	NaturalFlow	Very Low Flow	Low Flow

- Very High
- High Flow
- NaturalFlow
- Low Flow
- Very Low Flow
- Extremely Low Flow

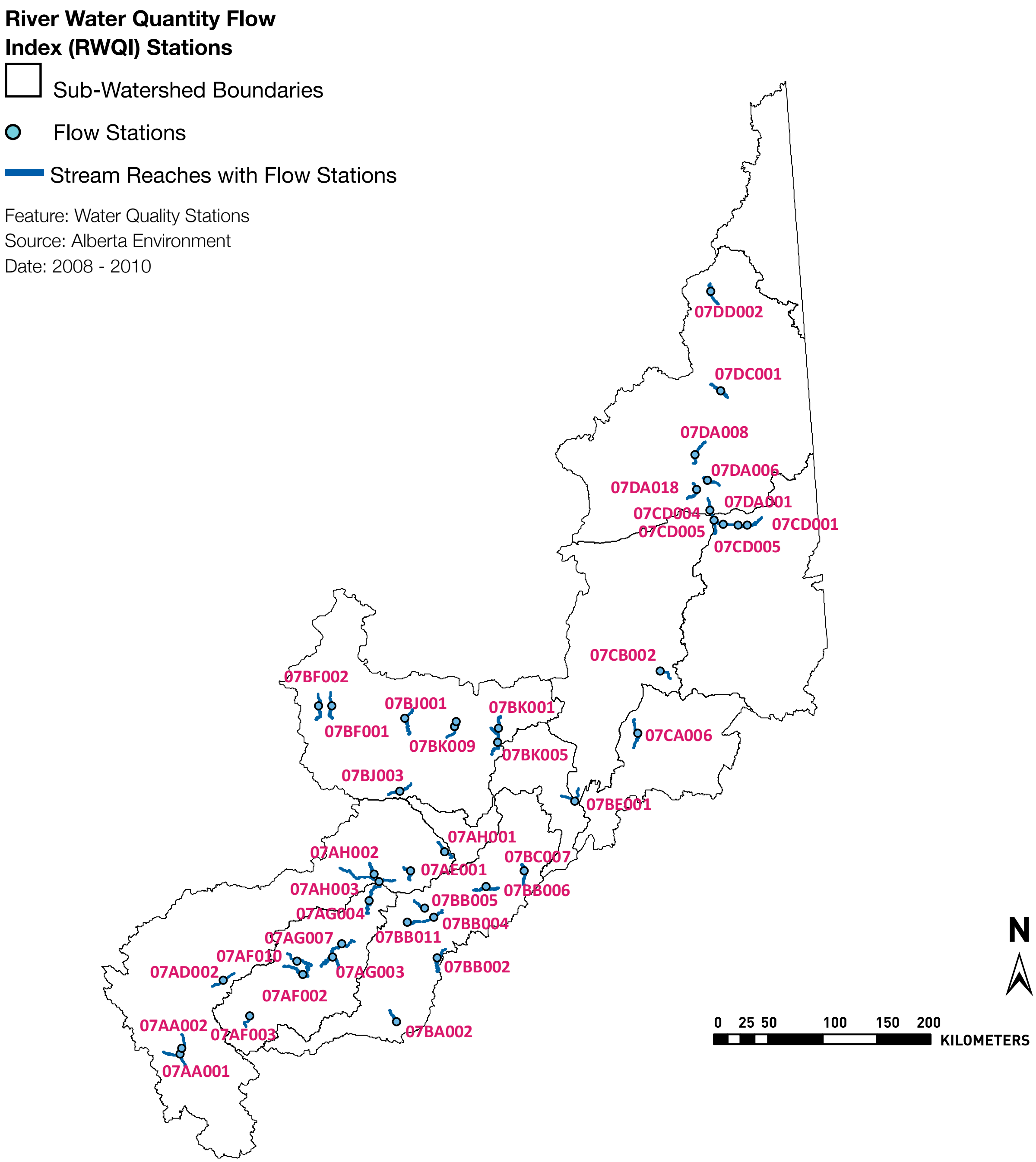


Figure 18. Location of river flow monitoring stations in the Athabasca Watershed.

CRITERION 5: MAINTENANCE OF WATERSHED INTEGRITY

Point Source Contamination

The risk of point-source contamination to surface water was assessed by examining the distribution of industrial and municipal facilities throughout the Athabasca Watershed. An attempt was made to use data from the National Pollution Release Inventory (NPRI) maintained by Environment Canada to track actual chemical releases; however, chemical releases from industrial and other sources are only reported to NPRI if they exceed the Canadian Environmental Quality Guidelines (CEQG 2003). In 2009, only 79 individual chemicals were reported from 58% of the total number of regulated facilities in the watershed), and the majority of these were released directly to the air. Further, the NPRI database does not contain information on the timing, volume, or concentration of the each individual release. As a result, it is difficult to quantify the true prevalence of chemicals released into the aquatic environment from these point sources. Given the difficulties associated with accurately quantifying point-source releases, this analysis focused only on identifying locations where the potential exists for a point source release that may negatively impact the aquatic environment.

Of the 564 regulated facilities (not including oil/gas wells) in the NPRI database, 87% are associated with conventional oil and gas operations, including compressor stations, oil battery facilities, and sour/sweet gas plants. The remaining 13% are a mix of municipal infrastructure (i.e. water/sewage treatment plants), factories and industrial facilities, and non-conventional oil and gas exploration and extraction sites (oil sands facilities and steam assisted gravity drainage (SAGD) operations). For the purposes of this assessment, locations where there is the potential for a chemical release to the aquatic environment have been mapped (Figure 20). Industrial facilities were split into two groups for mapping purposes: conventional oil and gas facilities and all other facilities.

To accurately assess point-source contamination in the Athabasca Watershed, the type and concentrations of contaminants released to the aquatic environment should be quantified. In the Athabasca Watershed, direct releases to water include municipal sewage and industrial effluent releases. While some of this information currently exists in a usable digital format, much of it is contained in paper reports. Consequently, extensive work must be done to compile this data into a digital format before it can be used for modeling purposes. Once this data is available, an analysis can be conducted examining the concentration of key parameters (e.g., mercury, phosphorous, nitrogen, dissolved oxygen) in effluent releases relative to ambient water quality monitoring stations and established guidelines for aquatic life and drinking water.

On a localized scale, chemical releases to the air can cause contamination of aquatic ecosystems through deposition. This is a major issue in some areas of the Watershed, particularly in the Lower Athabasca subwatershed; however, quantifying the impacts of this point-source is difficult. The Wood Buffalo Environment Association (WBEA) maintains 16 ambient air quality monitoring stations in the Lower Athabasca region, and the Athabasca Watershed Council will be exploring opportunities to achieve a better understanding of these impacts through partnerships with the Cumulative Effects Management Association (CEMA), WBEA, and other research groups.

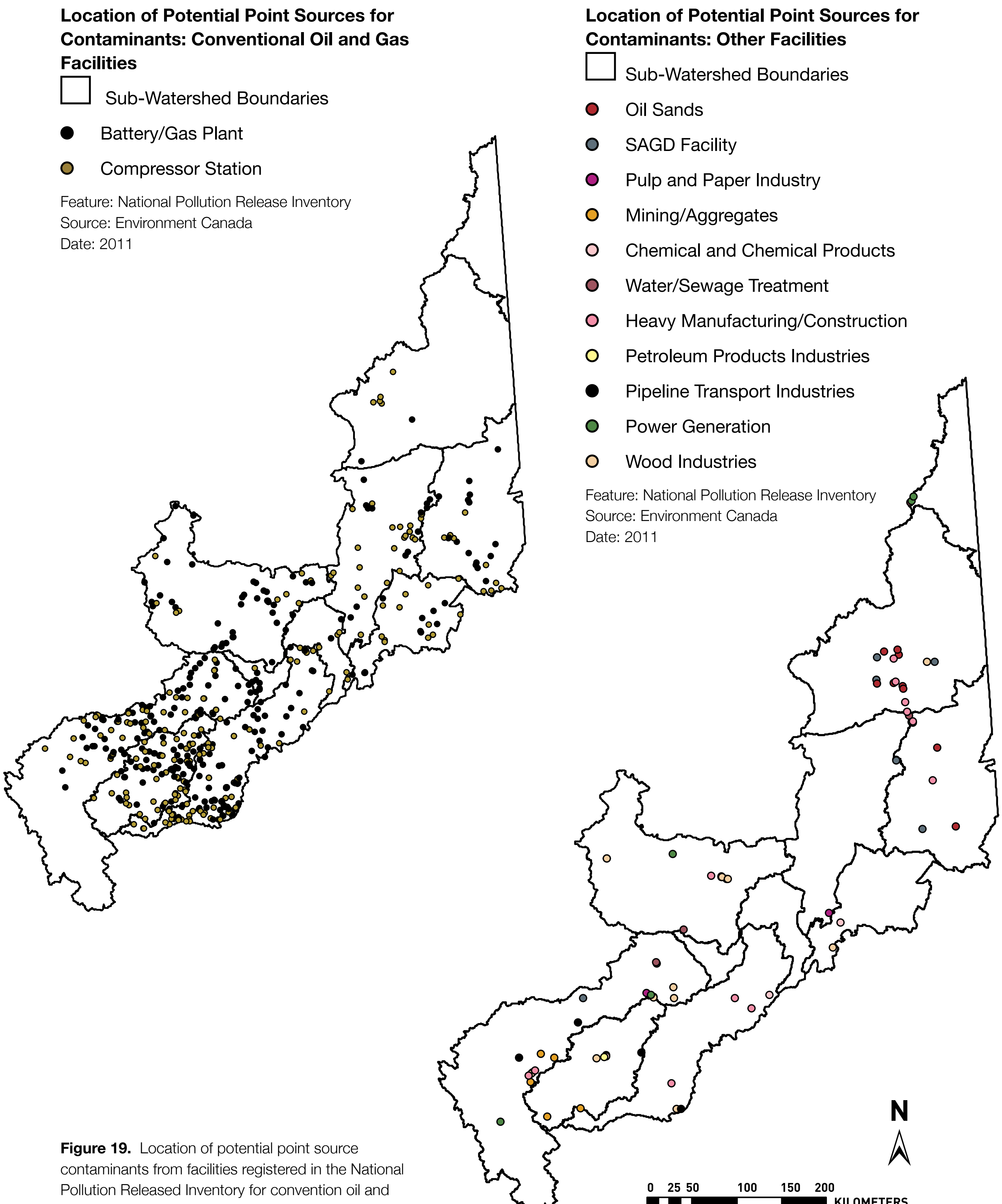


Figure 19. Location of potential point source contaminants from facilities registered in the National Pollution Released Inventory for convention oil and gas facilities (Left Panel), and all other facilities (Right Panel) in the Athabasca Watershed.

5.0 Limitations & Data Gaps:

Conducting a State of the Watershed assessment for a geographic area as large as the Athabasca Watershed is an enormously complex and challenging task. In particular, obtaining and compiling appropriate, comparable, and reliable data from stakeholders and third parties across such a vast area is difficult and time consuming. As a result, practical choices had to be made about what information could and could not be used in the development of data models, and these choices were often driven by constraints associated with obtaining third party data, rather than choices about what data was best suited for modeling selected indicators. Constraints associated with data ownership and data sharing presented a very real barrier to obtaining desired information over the relatively short project timeframe. In addition, how data is stored, and in what format, presented barriers to obtaining suitable information for this project.

While every attempt was made to use the best and most reliable data in the development of indicator models for this Athabasca State of the Watershed assessment, the models are only as good or as accurate as the data used to produce them. In many cases, the surrogate metrics used to measure selected indicators are not ideal; however, the selected approach to modeling indicators was largely dictated by the data available at the time of modeling. In addition, the scale of the assessment itself imposed a major constraint on what data could be included. Given that the objective of this assessment is to compare indicators across the Athabasca Watershed, the existing information used to create each indicator model had to be available and comparable for every subwatershed. Consequently, if reliable data for a given indicator was only available for eight of the ten subwatersheds, the data would have been excluded from the analysis because the missing data would not allow for direct comparisons across all subwatersheds. This approach to modeling, which required spatial data coverage for a very large geographical extent, meant that much of the data utilized came from provincial or national monitoring programs. At these scales, the datasets tend to have relatively coarse resolution, and thus, results are only applicable at broad spatial scales. Data from low-resolution satellite imagery were also used to derive information about land use, and as a result, these data only distinguished broad cover classes at course scales.

The project objective of modeling and comparing indicators at the subwatershed scale necessitated the exclusion of many small-scale studies with very detailed chemical, physiological, and biological data. While these studies are very valuable and contribute important information on the current state of the watershed, these data could not be included in this assessment because of the variation in research methodologies across studies. Differences in data collection methods, including the timing and/or intensity of sampling, makes standardizing results from individual small scale studies very difficult, and in many cases, makes direct comparisons of the data impossible. In addition, much of the raw data from these very focused studies were not available, either because of limitations associated with the project timeline, or because of proprietary concerns over data ownership. For these reasons, much of the research conducted under the North Rivers Basin Study (NRBS) and Northern Rivers Ecosystem Initiative (NREI), as well as many of the very detailed scientific studies that have been completed or are on-going in the Lower Athabasca subwatershed, were not included in this assessment. In addition, the data used in this modeling work had to exist in a readily usable format (i.e. GIS shapefile or geodatabase, or existing digital database). Data for some indicators (i.e. effluent water quality) only exist in paper (PDF) format, and thus, would have had to be converted into a digital format before the data could be used. The time and effort required for such a task was not included in the scope of this project.

In an effort to be transparent and explicit about what data were used in the development of indicators models, versus what data exist but were not available or were considered unsuitable for the purposes of this assessment, the following is a discussion of the knowledge and data gaps specific to each criterion that were encountered during this project. It is important to emphasize that the Athabasca State of the Watershed report is a living document which will be improved and updated as new information becomes available to address existing data limitations and gaps.

CRITERION 1: CONSERVATION OF BIOLOGICAL DIVERSITY

Biotic (Species) Indicators

Over the last several decades, extensive research and monitoring has been conducted on flora and fauna throughout the Athabasca Watershed; however, this information is typically conducted at relatively small spatial scales, with each project having different objectives, research methodologies, and sampling efforts. Much of this information exists as Master's or PhD theses, and as government or consulting reports, and extensive effort would be required to compile and organize this information into a standardized and comparable format. Further, much of this data is considered proprietary and getting permission to use the raw data from many of these studies is difficult and time consuming. Consequently, obtaining data from these smaller scale and geographically focused projects and studies was not the focus of this work. However, information from these studies would be invaluable if future state of the watershed assessments take a more focused approach, and assess watershed condition at the subwatershed scale.

Given the large-scale approach that was used to model watershed indicators, efforts were focused on obtaining species information at the provincial scale from Alberta Sustainable Resource Development, the Alberta Biodiversity Monitoring Institute, and the Federation of Alberta Naturalists. Alberta Sustainable Resources and Development maintains the Fisheries and Wildlife Management Information System (FWMIS), a centralized database that contains occurrence records for fish and wildlife species. Records in this database come from sightings that are reported primarily by government employees and consultants who conduct wildlife research and monitoring in the province. While the reporting of fish occurrence data to FWMIS has been a long-standing requirement of fish research licenses, the reporting of other wildlife occurrence data has only recently become a mandatory requirement of wildlife research permits. Further, the government does not require rigorous collection and reporting of habitat information to FWIMS, and as a result, there is very little information available on the location of critical habitat, such as fish spawning areas (L. Makowecki, 2012, Personal Communication). Given the nature of the data reported to FWMIS, this information is not appropriate for assessing the condition of fish of populations in State of the Watershed assessments. In order to assess watershed condition or "health", standardized population or abundance data is needed across the watershed. Occurrence data simply reports on where species were observed, with no standardized information on sampling effort and critical water parameters, including trap-hours, sampling methods, water temperature, and water conductivity. As a result, occurrence data provides no basis for assessing the relative condition of species populations or habitat in a given area relative to another. Moreover, the reporting of fish and wildlife occurrences tends to be biased towards areas with higher human activity (i.e. roads and settlements), making it difficult to evaluate whether a reported species absence is genuinely an absence, or whether it is instead an artifact of under sampling or a lack of sampling. Given these limitations, FWMIS records could not be used to assess the condition of aquatic species or species guilds in the watershed.

The Alberta Biodiversity Monitoring Institute (ABMI) was created in large part to address the lack of standardized population data identified above. The ABMI is a provincial program designed to track the status and changes of biodiversity at regional scales, and the data collected through the program is publically available. While the ABMI is an excellent source of biodiversity data, the program was not fully launched until 2006, and the early focus of the data collection program has been on terrestrial biodiversity. ABMI does have an aquatic sampling program, where the primary focus is on wetland sampling. In association with the Alberta Conservation Authority (ACA), ABMI is also conducting a smaller lake monitoring program, which included fish sampling. However, at present the number of wetland and lake sites that have been sampled in the Athabasca Watershed is currently limited. Within two to five years, however, coverage of ABMI sites in the Athabasca Watershed is expected to be much better, and this data will be important for use in future State of the Watershed assessments.

The Regional Aquatic Monitoring Program (RAMP) is a multi-stakeholder organization funded by industry with the goal of monitoring the state of the aquatic environment and any changes that may result from cumulative resource development within the Regional Municipality of Wood Buffalo. While this program has collected monitoring data on fish populations since 1987, and on benthic invertebrates since 2000, the sampling is restricted to the Lower Athabasca subwatershed, and there is no equivalent monitoring program in other regions of the Athabasca Watershed that would allow for comparisons across subwatersheds.

MAINTENANCE OF SURFACE WATER QUALITY

Surface Water Quality

Monitoring chemicals in large river systems such as the Athabasca River is a complex task because water quality is subject to high variability (Tate et la. 1999, Kelly et al. 2009). Concentrations can vary substantially over time (season, flow rate) and over space within the system (Water Monitoring Data Review Committee 2011), making it difficult to use a few measurements of concentrations of contaminants in river water to assess environmental impacts. In particular, high water events (i.e. spring snow-melt, and heavy rainstorms) act as high-intensity pulses, where high volumes of runoff or melt-water can export large loads of non-point contaminants into the Athabasca and its tributaries (Timoney and Lee 2009; Tate et al. 1999). Thus, having a network of water quality stations across the watershed, on both major rivers and smaller tributaries, that are frequently sampled, is an important requirement for assessing water quality at the scale of large river basins.

At present, the majority of water quality data collected in the Athabasca Watershed is focused on sampling stations located along the main stem of the Athabasca River. As part of the Long-Term River Network (LTRN) and Medium-Term River Network (MTRN) Alberta Environment maintains four stations located upstream of Hinton (Station AB07AD0100), downstream of the town of Athabasca (AB07BE0010), upstream of Fort McMurray (AB07CC0030), and at Old Fort near the Peace-Athabasca Delta (AB07DD0010). The Federal Government (Environment Canada; EC) maintains a long-term monitoring station on the Athabasca in Jasper National Park, near the Snaring River, in addition to administering the Environmental Effect Monitoring (EEM) program. Under the federal Pulp and Paper Effluent Regulations, all mills are required to submit EEM data on water quality electronically to Environmental Effects Monitoring data housed by Environment Canada at least once every 3-years. In addition, the Environment Effects Monitoring (EEM) program maintains water quality samples on the Athabasca River at locations both upstream and downstream of the four pulp mills located in Hinton (West Fraser), Whitecourt (Millar Western and Alberta Newsprint), and Athabasca (Alberta Pacific).

Beyond the main stem of the Athabasca River, Alberta Environment has water quality stations along the major tributary rivers (i.e. McLeod, Pembina, Berland, Calling, Lesser Slave, and House rivers); however, most of these stations have not been sampled since 2000. In the Lower Athabasca subwatershed, the Regional Aquatics Monitoring Program has been collecting water quality data since 1997, and under the Muskeg River Watershed

Management and Monitoring Framework, Alberta Environment has been collecting water quality data for the Muskeg River. Finally, individual company-specific water quality data also exists.

Each of these existing monitoring programs has been designed to achieve different objectives, complicating attempts to standardize and merge water quality data into a single data source. The Alberta Environment LTRN and Environment Canada stations were designed to track trends in nutrients, metals, and other contaminants (primarily focused on pesticides). The EEM water quality data is reported under federal legislation for enforcement purposes to investigate site-specific impacts at industrial sites, with no considerations of the sampling design needed for assessing broad-scale water quality status. Finally, the design of the RAMP program has been previously critiqued, with concerns being raised over the potential limitations of the program to assess water quality concerns (Kelly et al. 2009, Water Monitoring Data Review Committee 2011). At present, the design of the RAMP program is being reviewed, and may be included as part of the new Federal Oil Sands Monitoring plan.

A review of the compiled water quality for the above sources reveals several data gaps and limitations. Several of these limitations have been noted by the Water Monitoring Data Review Committee (2011), as follows:

1. Insufficient Sampling Intensity: Since 2006, the majority of 153 water quality stations in the watershed report data only once per year. This is insufficient because of high variability due to storm events, snow-melt, and low and high flow periods (Tate et al. 1999). Average annual sampling intensity for each data source is reported in Table 20.

Table 20. Average sampling intensity for active water quality stations in the Athabasca Basin. Those stations that have not reported water quality data since 2006 have been excluded.

DATA SOURCE	AVERAGE # OF SAMPLES PER ANNUM	# OF STATIONS
EC	4	1
EEM	1	70
AENV-LTRN	12	3
AENV-MTRN	6	2
RAMP	1.5	53

2. Inconsistent Reporting of Water Quality Variables: The number of water quality variables tested in each sample is highly variable. Some samples only report on 4 to 6 variables (typically phosphorous, nitrogen, dissolved oxygen and lead), while other report a complete suite of over 200 nutrients, dissolved metals, total metals, and pesticides. Given water testing costs, this variability in the number of tests is not surprising; typically, water quality testing is only performed on the variables of interest for each monitoring program.

3. Incomplete Reporting of Water Quality Variables: Basic water chemistry variables (including total dissolved solids, conductivity pH, temperature, and water hardness) are not always reported. This information is important to include because it is needed to determine if some metals and nutrients exceed established thresholds limits. The threshold concentrations of several of the metals and nutrients tracked by Alberta Environment (i.e. Aluminum, Cadmium, Lead, Nickel, and Ammonia) are dependent on other water chemistry variables such as pH, temperature, and water hardness.

4. Inadequate Data Reporting: Some water quality variables, particularly pesticides, and polycyclic aromatic hydrocarbons (PAHs), and other polycyclic aromatic compounds are generally reported qualitatively rather than quantitatively. For example, the pesticide Atrazine is reported as <0.005ug/L (the established Alberta Environment and CCME thresholds), rather than as an actual concentration. This qualitative reporting makes both temporal trend analysis and spatial comparisons of Atrazine concentrations impossible.

5. Regional Differences in Water Quality Variable Reporting: Given the diverse land-uses and geology in the Athabasca basin, and the differing goals of the organizations collecting water quality data, tracking of specific chemical groups only occurs in some areas. Pesticides are tracked in the Upper and Central Athabasca regions, but not in the Lower Athabasca. In contrast, polycyclic aromatic compounds are only tracked in the Lower Athabasca region. Due to the diverse land-uses occurring within the Watershed, water quality monitoring programs may require regionally-set objectives, goals, and targets to understand the impacts of site-specific point and non-point contaminant releases.

6. Insufficient Spatial Sampling: AENV only maintains 4 long term monitoring stations in the Athabasca Watershed. This is insufficient to track to the increasing development pressure occurring throughout the watershed.

Lake Trophic Status

Alberta Environment has specified Lake Trophic Status as an indicator for provincial watershed assessments (AENV 2008); however, very few lakes have been sampled. In the Athabasca Watershed, data on trophic status is only available for 43 lakes. In addition, many northern boreal lakes are naturally eutrophic or hypereutrophic, confounding attempts to separate and assess the impacts of land-use.

CRITERION 3: MAINTENANCE OF ECOLOGICALLY SIGNIFICANT WATER LEVELS AND FLOW

Good spatial and long-term information on surface water flow exists within the Athabasca Basin. Alberta Environment maintains flow gauges on along the Athabasca River, and many of the major tributaries. The long-term flow database is maintained by the Water Survey of Canada (WSC), and easily accessible via the Internet. At present, daily average flow information is currently being collected at 69 stations in the watershed (the establishment data of each station ranges from 1913 – 2000). Of these stations, however, only 14 stations report data for the full year (12-months), with the remainder either reporting only seasonally for one of three periods (either March to October, April to September, or May to August). This seasonal limitation on flow information at some stations restricts the capacity of the information to be used in calculating the River Flow Quantity Index. Information on the full year (12-months) is needed for determining both the Summer and Fall/Winter RFQI. The Fall/Winter RFQI is important to calculate because winter low flows are considered a limiting factor in many aquatic systems.

CRITERION 4: MAINTENANCE OF GROUNDWATER QUALITY AND QUANTITY

While there has recently been extensive work done on groundwater quality and quantity in the northern portion of the Athabasca Watershed (see LAR-GWF 2011 for full details), there is very little information available on groundwater quantity in other regions of the watershed. Consequently, this State of the Watershed assessment could not adequately address groundwater quality or quantity. As provincial programs and initiatives progress, the availability to data on groundwater in the Athabasca Watershed should increase; however, many of these initiatives focus on groundwater resources in the north eastern portion of the watershed. A better understanding of groundwater quality and quantity is also required for other regions of the Watershed where domestic and agricultural pressures on groundwater resources are high.

CRITERION 5: MAINTENANCE OF WATERSHED INTEGRITY

Human Land Use and Land Conversion

The land use/land cover layers that have been created as part of the deliverables of this project provide invaluable information on current and historical land use in the Athabasca Watershed; however, at present, these layers have some limitations. The classification of forest types (deciduous and conifer), lakes and large permanent wetlands, agricultural lands, and built-up areas are considered to be robust. The classification of other vegetation types, including wetlands, low shrub cover and recently burnt areas, is less consistent and requires additional processing and ground truthing to make the classification of these land covers more accurate. Additional classification work should also extract information on the extent and boundaries of recent (<30 years) forest harvesting activity. While very good spatial information on forestry activity exists, it is proprietary data and is very difficult to access.

Point Source Contaminants

All direct releases of waste water to surface water bodies are regulated under the Water Act. These include municipal effluent releases from sewage treatment plants, and industrial releases for pulp mills and some mining operations. Water quality sampling is conducted for all of these releases; however, much of this information only exists in hard copy and digital (.pdf) reports, and compiling this information into a digital database would require substantial effort. In addition, municipal stormwater discharges are an additional point source of contaminants, but accessing data on the volumes of these releases is difficult, as each individual municipality holds this information.

Non-point Source Contamination

There are two major sources of non-point contaminants in the Athabasca Watershed: agriculture inputs and industrial releases. Air pollution makes up a large proportion of the non-point source containments released into the Athabasca Watershed. Contaminants collect on the surface vegetation or snow through deposition, and then have the potential to flow into aquatic features through runoff and snowmelt (Kelly et al. 2009). Modeling air pollution and deposition is a complex task, but industrial facilities act as point sources, with High levels of contaminants surrounding facilities (Kelly et al. 2009). This source of non-point contamination is not well documented because of insufficient sampling intensity and methodologies. While the WBEA operates air quality monitoring stations, additional water quality testing needs to be conducted on snow samples to examine the extent and concentration of deposition relative to point sources (Kelly et al. 2009, Water Monitoring Data Review Committee 2011). In addition, to determine the impact of deposition on surround aquatic features, water quality testing needs to be conducted more frequently, and at the appropriate times of the year (i.e. during snowmelt, rainfall events and baseflow) to capture peak input/runoff events.

6.0 Conclusions

This report provides a preliminary large-scale overview of the various factors (pressure indicators) that may be impacting the ecological condition of the watershed. In addition, the report documents the data and knowledge gaps limiting a more detailed assessment of the current condition of the watershed. The data modeling indicates that many human development pressures (i.e. roads, urban development, agriculture, forestry and industrial extraction) may potentially have strong cumulative impacts on biodiversity and ecological integrity throughout the majority of the Athabasca Watershed. Many tertiary watersheds are subject to multiple land uses, making it important to understand if and how human land uses are interacting, and the impacts on biotic condition.

Within the time constraints of this project, data modeling was finalized for 7 indicators, and substantial progress was completed for an additional 7 indicators. Finalizing analyses and data modeling of these 7 additional indicators should be a priority for future work. The steps needed to complete the work for each indicator is outlined above in the indicator section write-up. Additionally, further classification, refinement, and field-truthing of the land use/land cover layer is critical because this information will be the basis of any future cumulative effects assessment, and scenario model of future development alternatives.

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