Alberta Foothills Cumulative Effects Assessment

Phase 1 Project Report

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May 2021

Prepared for Environment and Climate Change Canada

CENTRE FOR ENVIRONMENTAL ASSESSMENT RESEARCH

Acknowledgements: This report and all associated analysis was funded by and prepared for Environment and Climate Change Canada's Cumulative Effects Coordination Unit. The project was led by staff from the University of British Columbia's Centre for Environmental Assessment Research. The project team wishes to thank the 15 Advisory Committee members who assisted with steering this research.

Suggested citation: Buse CG, Yarmey N, Arnold L, Brubacher J, Hanna K. (2021). Alberta Foothills Cumulative Effects Assessment. Report prepared for Environment and Climate Change Canada. Kelowna, BC: University of British Columbia.

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Executive Summary

Cumulative effects of multiple land uses create legacy challenges for ecosystems, communities and human health. The Alberta Foothills provides a unique case study to understanding these interrelated land use dynamics. The region is home to numerous land uses including, but not limited to: human settlements, ranching, agriculture, mining, oil and gas exploration, renewable energy projects, forestry, and associated infrastructure. When combined, these activities may alter baseline conditions and have negative implications for sustainability in its broadest sense.

Building on existing best-practices in cumulative effects assessment, Phase 1 of this project seeks to build a new regional screening tool to better understand changes to landscape values over time in the Alberta Foothills region. The goals of this study include: [1] identifying cumulative effects of relevance to the Alberta Foothills; [2] surfacing indicators and data sources that can be utilized to develop an understanding of existing regional cumulative effects across the Alberta Foothills; [3] creating a geospatial interface that integrates environmental, community and health impacts of multiple land-uses; and [4] developing an accessible geospatial tool that synthesizes diverse data sources and communicates information about the current state of cumulative effects across the Alberta Foothills.

To address these goals, Environment and Climate Change Canada contracted a research team from the University of British Columbia's Centre for Environmental Assessment Research to undertake an integrated cumulative effects assessment. The research team deployed a combination of reviewing environmental impact assessments related to projects operating within the Alberta Foothills regulated by both provincial and federal authorities, convening an expert advisory group to provide feedback on the research process and development of the screening tool, and deploying a novel assessment methodology to develop an "EnviroScreen" which represents a quantitative depiction of cumulative environmental, socioeconomic and health impacts. This report discusses the existing status of knowledge of cumulative effects in the Foothills region, details the methodology deployed to undertake the assessment and its associated limitations, presents results and suggests future opportunities for research.

In total, 20 project EAs were reviewed for indicators of cumulative effects, and 15 advisory committee members were engaged. This surfaced a total of 34 indicators of cumulative effects that represent four dimensions of the enviroscreen model: environmental exposures, environmental effects, sensitive populations and socioeconomic characteristics. These four sub-indices are composite measures of relevant indicators, which are then scaled to represent a cumulative landscape burden, a cumulative population characteristics score, and ultimately an EnviroScreen score representing an integrated measure of cumulative environmental, community and health impacts. Each indicator and its corresponding indices are displayed spatially at the level of Local Geographic Areas in an online portal which can be accessed here.

Results suggest that with the exception of Edson, Drayton Valley and Rocky Mountain House, the Foothills region has comparatively lower EnviroScreen scores relative to the rest of the province. This gives additional credence to the need for more robust management, conservation, protection and remediation in these three LGAs. Notwithstanding Fox Creek, the study area has a well-defined north-south gradient, with higher scores resembling greater pressures in the northern half of the study region. Southern LGAs tend to perform better than northern LGAs as a result of the lower human footprint and corresponding implications for environmental, social and health impacts. The implications of the model and opportunities for refinement and next research steps are described in detail. The project team's commitment is to continue to work with the funder and relevant stakeholders and rightsholders to prioritize next steps for this research which will be undertaken during the second phase of work between September 2021 – March 2022.

1.0 Introduction

1.1 Study Rationale

The Alberta Foothills region is located between the eastern slopes of the Canadian Rocky Mountains and the prairies. The region has a long history of natural resource development and related land uses and is home to a number of rural areas and small municipalities. Past, present and future proposed land uses include oil and gas infrastructure, mining, forestry operations, electricity transmission projects, and related land-uses. Many major projects that have undergone environmental impact assessment applications and determinations have raised concerns about how a single project may interact with other land uses, which may create synergistic interactions resulting in cumulative effects.

The Impact Assessment Agency of Canada (formerly the Canadian Environmental Assessment Agency) defines cumulative effects as “the effect of the environment which results from effects of a project when combined with those of other past, existing and imminent projects and activities. These may occur over a certain period of time and distance”.[1] While this definition places environmental effects—those implications for environments and/or ecosystems explicitly—the new *Impact Assessment Act, 2019* broadens the purview of conventional approaches to impact assessment to explicitly include socioeconomic, sociocultural and health as valued components of significance for the assessment of cumulative effects within a broader and more holistic view of sustainability. This builds on past legislation such as the *Canadian Environmental Assessment Act, 2012* assessments of cumulative effects could be extended beyond environmental concerns to also include “changes on health and socio-economic conditions, physical and cultural heritage and other matters”.[2] The ‘integration imperative’ of merging environmental, community and health value is therefore increasingly of strategic interest for government agencies that oversee impact assessment, but also for communities in terms of what dictates “social license to operate”.[3]

Thus, in the context of this report, cumulative effects refer to legacy impacts of multiple land uses on environments, communities and health. This makes cumulative effects the responsibility of no single sector, stakeholder or rightsholder, and require consideration of large spatial regions to overcome identified limitations of environmental impact assessments of a singular project. In response to the persistent challenges of identifying, assessing and managing cumulative effects, Environment and Climate Change Canada’s (ECCC) Cumulative Effects Coordination Unit commissioned a cumulative effects assessment of diverse land uses and their impacts on environmental, community and health valued components. The first phase of this study (Phase 1) is strategically oriented towards assessing current conditions for cumulative environmental, community and health impacts of resource extraction and development processes across the Alberta Foothills region.

1.1.1 Research Objectives

Recorded consultation with Indigenous communities and the public during environmental impact assessments of numerous past and on-going projects within the Alberta Foothills identified that the need to better understand and minimize cumulative effects due to potential project interactions with pre-existing land-uses and other forms of past, present and future industrial developments (e.g. not limited to past/present projects assessed under provincial and/or federal regulations, but also logging, agriculture, urbanization and other forms of land use). The combination of the multiple land-use activities within the Alberta Foothills hold potential for significant impacts on sensitive or at-risk species and their habitats (e.g. migratory birds, caribou, etc.), watercourses and watercourse crossings, and sensitive ecosystems (e.g. wetlands, boreal forest, montane, rough fescue). Further, many Indigenous rightsholders have raised concerns that social and cultural well-being are not adequately assessed in assessment processes, which may impact Treaty rights or have negative impacts on certain cultural values (e.g. country foods).

Accordingly, new developments and land uses can present unique challenges and opportunities for ecosystems, communities and human health alike.[3–5] Attending to the cumulative impacts of a project and its interactions with pre-existing and future land uses requires a robust assessment and monitoring framework rooted in empirical observations about changes to environmental, community and health values that are typically altered due to project construction, operation, decommissioning and abandonment. In order to overcome the limitations of existing approaches, a broader regional approach may be required to adequately account for the diversity of pressures on environmental, community and health valued components, as well as the benefits of multiple projects. Drawing from emerging international best practices in impact assessment, and new guidance provided under the *Impact Assessment Act, 2019*, this study is guided by the following research objectives:

1. To identify cumulative effects of relevance to the Alberta Foothills;
2. Identify indicators and data sources that can be utilized to develop an understanding of existing regional cumulative effects across the Alberta Foothills;
3. Create a geospatial interface that integrates environmental, community and health impacts of multiple land-uses
4. Develop a geospatial tool that synthesizes diverse data sources and communicates information about the current state of cumulative effects across the Alberta Foothills.

1.2 Alberta Foothills in Context

The Alberta Foothills region runs from the southwest boundary of the Rocky Mountains to the mid-west portion of the province near Grand Prairie. This region covers about 66 436km^2 (approximately 10% of the province) and includes the Upper Foothills—characterized as a pure conifer dominated ecosystem—and the Lower Foothills which is comprised of conifer-mixed wood-deciduous landscapes.[6] A region comprised of the Foothills and the forested slopes of Alberta's Rocky Mountains are together known as the Eastern Slopes, which plays a critical role in storing, purifying and slowly releasing water that forms the headwaters of a numbers of important watersheds.[7]

The Foothills is a transitional ecosystem between the Boreal Natural Regions to the north and east, and the Rocky Mountain Natural Region to the west and as such, consists of a mixture of these different ecosystems [8]. The Foothills is an ecologically important region holding sensitive habitat areas for threatened fish and wildlife. Based on a Canada-wide assessment to inform conservation planning, this region was also identified as a priority for provincial and/or federal protection due to its importance in providing key ecosystems services in climate regulation, freshwater, and nature-based recreation.[9] The foothills region has a long history of oil and gas infrastructure, mining, forestry operations, electricity transmission projects, and related land-uses.

1.2.1 Socioeconomic Context

Our study area is defined according to 18 Local Geographic Areas (LGAs) that comprise the Alberta Foothills (i.e. the study region, see Table 1). LGAS are boundaries defined by Alberta Health Services in order to provide detailed information for planning, monitoring, and management.[10]

A relatively high proportion of the population in the Foothills region identify as Indigenous. According to the 2016 Canadian Census of Population, in Pincher Creek and Valley View, Indigenous populations approach almost one third of the population. The foothills region is also intersected by Metis Nation of Alberta regions 3,4 and 6 (http://albertametis.com).

The most significant employment industries across the study area are mining, quarrying, and oil and gas extraction, health care and social assistance, and accommodation and food services, although people may be employed in one LGA and live in others. A higher proportion of the population in the Foothills region is employed in mining, quarrying, and oil and gas extraction than the province as a whole. In 4 of the LGAs over 18% of the population is employed in this sector (Fox Creek, Edson, Drayton Valley, and Crowsnest Pass). Past mine closures and fluctuating markets have had significant socioeconomic effects, such as the past closures of the Grande Cache mine.[11] Tourism and recreation are also a key source of employment, with provincial and national parks and recreation sites located within and adjacent to the region.

Table 1. Local Geographic Areas Comprising the Alberta Foothills Study Region, Canadian Census, 2016

LGA	Population 2016	Area (km sq.)	Population Density (people per km sq.)
Black Diamond	9,403	1,240	7.58
Canmore	26,450	9,114	2.90
Cardston-Kainai	15,593	5,444	2.86
City of Grande Prairie	63,166	135	467.90
Claresholm	6,352	1,829	3.47
Cochrane-Springbank	43,334	477	90.85
Crowsnest Pass	5,681	3,001	1.89
Drayton Valley	17,723	4,084	4.34
Edson	15,079	11,392	1.32
Fort Macleod	5,491	1,705	3.22
Fox Creek	2,074	11,479	0.18
Grande Cache	3,759	8,207	0.46
Grande Prairie County	20,093	7,503	2.68
High River	23,396	2,856	8.19
Hinton	11,102	9,197	1.21
Okotoks-Priddis	41,769	765	54.60
Pincher Creek	8,360	3,938	2.12
Rocky Mountain House	20,800	19,013	1.09

1.2.2 Historical and Contemporary Land Uses in the Alberta Foothills

The Alberta Foothills are home to numerous forms of industrial land-uses, including agriculture and ranching, forestry, mining, oil and gas development, and renewables. Importantly, these industries are all regulated to different extents and sometimes by different levels of government, which means some of these industries are subject to environmental assessment legislation—which includes the assessment of cumulative effects—but others are not. Each industry also has its own supporting infrastructure and are not often assessed in relation to one another, potentially giving rise to cumulative effects that manifest from the interaction or accumulation of impacts to ecosystems, communities and human health over time. Key historical and contemporary land uses are described below.

1.2.2.1 Agriculture

The agriculture industry in the foothills, and the province of Alberta, is dominated by livestock and grazing with Alberta representing a third of Canada's beef cattle ranching farms.[12] Alberta is also a large producer of grain and the second largest producer of wheat in Canada behind Saskatchewan.[12] Climate change pressures such as water availability, increasing temperatures, and extreme weather are a concern for the resilience of the agriculture industry.[13] In addition, agriculture producers have raised concerns in response to the increasingly fragmented landscape due to ongoing industrial coal and oil and gas development, and the implications of these operations for grazing operations and water access.[14] Agriculture also plays a role in creating management challenges for cumulative effects through irrigation patterns, agricultural run-off, and broader changes to water drainage patterns over time.

1.2.2.2 Forestry

Forestry in Alberta is a growing industry. The majority of harvest activity occurs in the Upper Athabasca and Upper Peace land use planning areas, which each intersect with the eastern portions of the Foothills region. Clearcutting is the primary harvesting method applied throughout the province, representing 97.57% of the area harvested in 2016.[15] Wildfire risk within forest management areas is a primary concern and threat to ecosystems and harvest potential. The Edson Forest Area, Rocky Mountain Forest Area, and the Rocky Mountain House Forest Areas each have portions which intersect the foothills region, and recent fire seasons have affected areas within and adjacent to the area.[16]

1.2.2.3 Mining

The Foothills Region is home to extensive coal extraction and development. Coal mining and development has a long history in Alberta, originating in the 1800s and providing the primary source of energy until overtaken by oil and gas in the 1960s.[17] Province wide, Alberta averages 25-30 million tonnes of coal production each year.[17] There are significant coal operations and also reserves in the Foothills region making it an area of focus for potential future exploration and development. Active coal extraction in the foothills includes metallurgical coal used for the production of steel, and thermal extraction and production.[18] Significant active metallurgical coal mines include the Grande Cache goal mine and the Teck Resources Cheviot Mine.[18] Active thermal bituminous coal mines in the region include the Vista mine (approved in 2018), and the Coal Valley mine which has been in operation since 1978 and undergone a number of expansions.

There remains significant potential coal reserves in the foothills region, particularly in Crowsnest Pass, where the Benga Mining Grassy Mountain Coal metallurgical open pit mine is currently under regulatory review.[18] The future of coal exploration and development is uncertain and is increasingly part of the political and public conversation. Tight restrictions for coal exploration and development existed in the foothills region which was classified as category 2 and 3 lands under the Alberta 1976 Coal Policy.[19] In 2020, the Alberta government rescinded this policy, which resulted in an influx of coal exploration lease applications and approvals, and concerns from tourism and recreation operators, agricultural producers, environmental groups and organizations, Indigenous groups, and the public.[19,20] The government has since halted granting new exploration leases in order to engage in further consultation.

1.2.2.4 Oil and Gas Exploration, Extraction, Processing and Transportation

Oil and gas development have a long history in the Foothills Region, however, gas development is much more significant. Gas fields and gas processing facilities are particularly dominant in the eastern portions of the region.[21] Marketable gas is expanding and key formations intersecting the foothills include the Montney and Duvernay formations.[21] The NOVA Gas Transmission Limited (NGTL) 2021 System Expansion Project is a significant infrastructure project located within the study region, which was approved by the Governor in Council subject to conditions on October 19, 2020. The completed project will be located between the Grand Prairie area to north of Calgary, occupying the Foothills natural region of Alberta, and will consist of new pipeline and supporting infrastructure running parallel or adjacent to the existing NGTL system. The project is of strategic interest to the Alberta and Canadian economies in order to take advantage of opportunities for natural gas extraction in northwest Alberta and northeast British Columbia, and moving gas for provincial distribution and exportation to other markets.

1.2.2.5 Renewable Energy

Hydroelectric development has been active for over 100 years in Alberta, though only about 2.8% of the province's energy was generating by hydro power in 2016.[22] The majority of the active hydroelectric plants province wide are owned and operated by Trans Alta which first opened a plant in the province in 1911. There is significant hydroelectric potential across the Foothills region and in the broader province, with some companies exploring potential developments. Wind generation currently contributes a large proportion of renewable energy for the province, accounting for just under 7% of all power generated in Alberta.[22] Active wind energy production in Alberta started in the vicinity of Fort Macleod and Pincher Creek within the Foothills region, and about half the current installed generation is produced in that area. Developments in wind and solar power are anticipated to increase over the next 20 years.[22]

1.2.4 State of knowledge on cumulative effects of multiple land uses in the Alberta Foothills

Over the past 20 years, Alberta has increased its attention to the study of cumulative effects, leading to the creation of cumulative effects management frameworks and regional strategic assessment considerations to support land use planning processes.[23] Like many jurisdictions in Canada, major projects typically require an environmental impact assessment under Alberta's *Environmental Protection and Enhancement Act.* This legislation is typically regulated by either the Alberta Energy Regulator—in the case of energy projects—while Alberta Environment and Parks administers the impact assessment process for all other types of industrial activity. Notably, current legislation recommends that the Terms of Reference scope the bounds of the environmental impact assessment report, which may include "the potential positive and negative environmental, health, social, economic and cultural effects of the proposed activity as well as an assessment of cumulative effects".[24] This has led to most cumulative effects assessments primarily being undertaken in Alberta as part of project-based environmental impact assessment.[25]

In 2007, the province developed a proposed regulatory framework for managing environmental cumulative effects, with the goal of prioritizing a healthy environment for all Albertans.[26] The framework and associated cumulative effects management system is guided by four interrelated processes: developing objectives, developing strategies to meet those objectives, delivering on the strategy, and managing performance. A related goal of the framework was to enhance connections between related regulations, and encourage consideration of cumulative effects under the provincial *Water Act, Alberta Land Stewardship Act,* land-use framework and regional planning processes, the Sustainable Resource and Environmental Management Initiative, Climate Change Action Plan, Clean Air Strategy, and Biodiversity Strategy.[25,26] In the wake of these developments, the province has begun to consider regional strategic assessment as an opportunity to consider cumulative effects at an appropriate scale (i.e. beyond the footprint of any single project).[23]

To date, this regulatory and policy attention has led to the accumulation of a body of evidence on cumulative effects in certain watersheds, notably the Athabasca watershed[27,28]—home to the Alberta oil sands. Comparatively limited attention has been given to the Foothills region in its entirety. Research that has been conducted in the Foothills has primarily focused on Alberta's Southern East Slope watersheds using web-based simulators to project future change based on current conditions. The final report of these modeling efforts titled *Cumulative Effects of Land Uses and Conservation Priorities in Alberta's Southern East Slope Watersheds*[29] commissioned by the Alberta Chapter of the

Wildlife Society suggests significant presence of cumulative effects in the southern Foothills region at present. These models are primarily focused on ecological values of strategic importance to highlight the benefits and challenges of land use change over time, with a particular focus on grazing, croplands, forestry, energy, settlements, and recreation. Results suggest that continuing to maintain land use pressures is not favorable for key species (including Westslope Cutthroat Trout, Bull Trout, and Athabasca Rainbow Trout, and Grizzly Bears) that are key indicators of the sustainability of larger watersheds. These dynamics are primarily attributed to climate change, increases in linear development and settlement patterns, and resulting changes to hydrological systems. Nonetheless, the modeling produced through this research suggests that enhancing ecological protections through conservation can not only enhance the functioning of key ecosystems and species, but potentially restore ecosystems as well. Similar regional assessments that fully integrate a suite of ecological, socio-economic and health values are currently lacking in the broader Alberta Foothills region.

1.2.4.1 Ecosystems of Concern

The Alberta Foothills has several ecosystems of concern, many of which face a number of pressures driven by both anthropogenic and natural processes. According to the Alberta Wilderness Association,[30] these include the following areas:

- **Little Smoky**: Located east of Jasper National Park, this area makes up a large portion of the Upper and Lower Foothills and contains a variety of habitats for at-risk species including Woodland Boreal Caribou and Southern Mountain Caribou—both of which have been determined to be significantly impacted by anthropogenic landscape disturbance and wildfires[31]—Arctic grayling, and Grizzly bear;
- **Kakwa:** Located west of the town of Grande Cache, Kakwa's Rocky Mountain and the Foothills contain a variety of habitats for mountain sheep, grizzly bear and Woodland caribou. This region is the winter range for the Redrock/Prairie creek and the Narraway caribou herds (both of which are provincially and nationally threatened species);
- **Goose Wallace**: Located in the Upper Foothills in east-central Alberta, this area is characterized by muskegs and shrubland that follow plateaus with adjoining steep slopes. The area is home to many rare plant species and large mammals;
- **Otauwau**: Located in central Alberta, this area consists of many ecosystem types and a resultantly high level of biodiversity;
- **Marten Mountain:** Located in the eastern-most portion of the Foothills, this region contains a very high level of biodiversity and provides critical habitat for different species of migrant songbirds;
- **North Saskatchewan and Ram Rivers**: This region north of Banff National Park provides migratory corridors for many wildlife species in addition to supplying important sources of water to the North Saskatchewan watershed;
- **The Foothills Parkland Natural Subregion**: Located west of Calgary, this region has >50% of native vegetation, 90% of which lies within the High Value Landscape (defined as large and mainly intact tracts of native grassland), making this a valuable grassland ecosystem.[32]
- **Transition zone between the drier prairie ecosystem and the higher altitude montane ecosystem:** The multiple transition zones along the eastern slopes of the rocky Mountains provide refuge to various species at risk including Long-toed salamanders, Columbia spotted frogs, American badgers, Pygmy owls, Wolverines and cougars.[33]

1.2.4.2 Animal Species at Risk

Due to the unique nature of the Alberta Foothills region, it is range for a wide variety of flora and fauna across different climate zones and biogeophysical regions. The following species within the Foothills region are either endangered, threatened, or of special concern under Canada's Species at Risk Act, and numerous other species are considered 'sensitive':

- Mammals: Grizzly Bear, Woodland Caribou
- Birds: Barred Owl, Trumpeter Swan, Peregrine Falcon, Black-throated Green Warbler, White-winged Scoter
- Fish: Bull Trout, Arctic Grayling, Athabasca Rainbow Trout, Westslope Cutthroat Trout

Across the entire province of Alberta, of the 2015 species listed in the Government of Alberta's Wild Species Status Search, 132 of them are extirpated/extinct, at-risk, or sensitive.[34] Similar species estimates across just the Alberta Foothills region were not available at the time of producing this report. However, previous research has found that cumulative industrial activities has negatively impacted species named above in other parts of Alberta.[35]

1.2.4.3 Climate Change in the Alberta Foothills

Alberta's paleoclimate was drastically different from the present. During geologically 'recent' time periods such as the Hypsithermal (approximately 5000-7000 years before present), Alberta was about 2ºC warmer than present. Conditions were substantially drier, with strong evidence of high forest fire activity in the Foothills and Rocky Mountains, which created an upslope movement of tree species.[36] More recently, Alberta has seen significant climate events in the form of fires and floods, and since the 1900s, the mean provincial average has increased by 1.4ºC, with most warming occurring since the 1970s.[37]

Data from the Canadian Climate Atlas[38] combines 24 climate models to predict a range of future climate-related outcomes for low and high emissions scenarios. Under the current trajectory "high emissions" scenario, annual average temperatures are expected to rise across the study region by approximately 2ºC by 2050, and as much as 4ºC by 2080. Annual average precipitation is expected to increase by as much as 6% by 2050 across the Foothills region, and by as much as 12% by 2080 under the high emissions scenario.

Climate change will impact the range and tenure of different animal and plant species. Climate change is already increasing the proportion of grassland covering the Foothills region, and the Foothills ecosystem is expected to decrease by between 18.7% and 32.2% based on low and high emissions scenarios, respectively.[39] Most of the grassland encroachment is expected in the southern region of the Foothills, and it is expected that most of the northern Foothills will remain forested.[40] Recent research suggests that climate change is altering the distribution and range of vascular plants by 1-5km/year in the Foothills region.[41] It is also projected to impact forest harvest rates through the introduction of invasive species such as the Mountain Pine Beetle. While conifer species are likely to increase across the Foothills, and the productivity of lodgepole pine have increased, it is unclear whether this is due to management practices or climate change influences.[42] Further, research suggests that climate change is already impacting the reliability of surface water flows from Alberta's glaciers with implications for future water supply and quality.[43,44]

1.2.4.4 Human Population Vulnerability

Diverse land-uses also create unique pressures on specific populations that may be more or less vulnerable to changing ecosystem conditions that are impacted by resource extraction and development, and climate change. Past research has found that areas with higher degrees of anthropogenic landscape disturbance. For example, people living near major energy projects have lower self-reported health and may have higher rates of cancer,[4546] children may have elevated risk of exposure to toxic chemicals in soils from industrial processes.[47] Adverse pregnancy and birth outcomes are the most commonly studied and documented endpoint.[48–50] Moreover, climate change is expected to differentially impact children, the elderly, people with chronic conditions, and Indigenous populations.[51] A full articulation of social and health vulnerability is beyond the scope of this report. Demographic information for each LGA that comprise the study area is included in Table 2, which includes the following highlights:

- Cardston-Kinai (8.1%), Grande Prairie City (7.9%) and Grande Prairie County (7.9%) have the highest proportion of young children, with the range across the entire sample being 4.3-8.1%;
- Cardston-Kinai (16.7%), Grande Prairie County (15.4%) and Okotoks-Priddis (14.8%) have the highest proportion of youth over the age of 5, and the entire sample has a range of 9.3-16.7%;
- Claresholm (26.1%), Crowsnest Pass (23.0%) and Pincher Creek (19.8%) have the highest proportion of people aged 65 and older, with sample values ranging from 6.6%-26.1%;
- Cardston-Kinaie (50.4%), Fort Macleod (50.4%) and Pincher Creek (50.1%) have the highest proportion of women, and Grande Cache (44.6%) the lowest;
- The proportion of people with First Nations or Inuit status ranges between 0.5-31.5%. The highest proportion of Indigenous identity is in Cardston-Kinai (31.5%), Pincher Creek (17.7%) and Canmore (13.6%);
- LGAs ranged between 56.4-74.4% of the population reporting good, very good or excellent self-rated health, according to the Canadian Community Health Survey. The regions with the lowest self-rated health include Rocky Mountain House (56.4%), Grande Prairie City (56.6%), and Drayton Valley (56.9%).

Table 2. Demographic Information According to Local Geographic Areas, 2016

LGA	Age 0-4	Age 5-14	Age 65+	Male	Female	First Nations or Inuit Status	Population reporting good, very good or excellent health
Black Diamond	5.5%	12.0%	18.1%	50.1%	49.9%	6.7%	66.7%
Canmore	5.7%	11.5%	10.7%	50.8%	49.2%	13.6%	71.4%
Cardston-Kinai	8.1%	16.7%	14.9%	49.6%	50.4%	31.5%	60.6%
Claresholm	4.3%	9.6%	26.1%	50.5%	49.5%	1.0%	66.3%
Cochrane-Springbank	5.8%	12.7%	13.2%	50.1%	49.9%	0.5%	74.4%
Crowsnest Pass	4.4%	9.3%	23.0%	51.3%	48.7%	1.1%	62.2%
Drayton Valley	6.5%	12.8%	12.0%	51.4%	48.6%	1.3%	56.9%
Edson	6.5%	12.4%	11.2%	52.1%	47.9%	1.7%	57.0%
Fort Macleod	7.3%	12.9%	17.4%	49.6%	50.4%	12.2%	61.5%
Fox Creek	6.3%	13.3%	7.0%	54.3%	45.7%	2.5%	58.3%
Grande Cache	5.0%	13.3%	9.7%	55.4%	44.6%	2.2%	59.2%
Grande Prairie City	7.9%	13.2%	6.6%	51.9%	48.1%	1.7%	56.6%
Grande Prairie County	7.9%	15.4%	7.8%	51.3%	48.7%	1.8%	57.9%
High River	5.4%	12.5%	19.4%	50.2%	49.8%	0.7%	64.2%
Hinton	6.3%	12.5%	10.8%	52.2%	47.8%	2.8%	59.6%
Okotoks-Priddis	5.5%	14.8%	11.8%	50.0%	50.0%	0.6%	66.8%
Pincher Creek	5.5%	11.8%	19.8%	49.9%	50.1%	17.7%	64.5%
Rocky Mountain House	6.2%	13.3%	14.5%	50.4%	49.6%	8.4%	56.4%

2.0 Research Methods

Following leading practices in environmental,[52–54] social,[55,56] and health impact assessment,[57–59] and drawing inspiration from the latest developments in the field of cumulative effects assessment[3,5,60–65] this project utilized an iterative methodology to develop an understanding of existing cumulative effects across the study area. This process generally followed existing practice-based guidelines and recommendations from the Impact Assessment Agency of

Canada for how to assess cumulative effects by scoping the project, identifying relevant valued components, populating values with available data, and reporting results to support future monitoring and evaluation activities.

This cumulative effects assessment utilized three inter-related research methods to scope and assess cumulative effect values of interest:

> [1] reviewing existing and prospective environmental impact assessment reports for major projects located across the study region;
>
> [2] convening an Advisory Committee of individuals who are familiar with cumulative effects assessment, local data/indicators and the context of the Alberta Foothills; and
>
> [3] applying the 'CalEnviroScreen' methodology—a relativist, equity-informed assessment technique that brings together environmental, community and health indicators into a singular assessment framework capable of communicating interactions between multiple cumulative effects at various spatial scales.

The goal of triangulation was to gain insight into possible indicator selection and utilization for this research. Details of each method are described in the sections that follow, with limitations of each phase of analysis noted.

2.1 Environmental Assessment Review

2.1.1 Process

The research team reviewed all publicly available historical and current Environmental Impact Assessments approved by the Canadian Environmental Assessment, the National Energy Board, and the Alberta Energy Regulator/Alberta Provincial Environmental Assessment Office. We specifically extracted documents from projects that either historically operated, are currently operating, or have been proposed to operate in the future, which are located within the study region. All projects were assessed under historical legislation (i.e. none had been included under the new federal Impact Assessment Act). Projects were drawn specifically from Alberta's open data platform[i] and the Canadian Impact Assessment Registry.[ii]

Key word searches for "cumulative", "cumulative effects" and "cumulative impacts" within identified projects and their supporting EIA documents were utilized to:

- Understand the historical context of major industrial development in the study region;
- Consider how historical land uses had been conceptualized in terms of cumulative effects, as per proponents of specific projects and the public's reaction to them; and
- Extract publicly available indicators and data sources that could support a regional cumulative effects assessment of the study area.

Short descriptions of each project were created, and indicators of identified concerns regarding cumulative effects (and their accompanying data sources) were extracted for consideration in subsequent phases of analysis.

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[i] https://www.alberta.ca/environmental-impact-assessments-current-projects.aspx

[ii] https://iaac-aeic.gc.ca/050/evaluations/050?culture=en-CA

2.1.2 Limitations

The review of EAs, while comprehensive in terms of searching for cumulative effects, did not review documents in full. Relying on key word searches was deemed pertinent given the time demands of this project and the need to conceptualize historical concerns surrounding cumulative effects from existing projects. However, it is possible that other types of cumulative effects which were not formally named as such within project documentation were raised through letters from the public, participating government ministries, and/or the proponent. Extracted indicators may therefore not represent the full suite of considerations raised from particular projects as they relate to past, present and future land uses across the Alberta Foothills. While the study team did record all indicators that were identified for cumulative effects consideration, it is notable that many were not fully assessed during environmental impact assessment due to determinations of non-significance and/or not having a clearly established pathway by which a single project may cumulative contribute to changes in any given valued component. Finally, this review is limited to major industrial projects, whereas cumulative effects is a cross-sector challenge that can be affected by a multitude of small changes to valued components over time. Other non-project-based land uses such as forestry and agriculture have different regulations, but are not subject to environmental impact assessment and may also contribute to cumulative effects. More fulsome consideration of these sectors is provided in our modeling efforts through the use of spatial data representing the landscape disturbance caused by these industries.

2.2 Expert Advisory Committee

2.2.1 Process

To support the selection of indicators and their utilization in the analysis, an Expert Advisory Committee (EAC) was created. The EAC is not a decision-making entity, nor a representative group of organizations, but a group of engaged experts with knowledge and expertise of cumulative effects at the local, provincial and national scale. This group met to provide feedback on indicator selection, flag additional indicators and data sources that could be included in subsequent analysis, and to share comments on the project report. The full Terms of Reference that supported the formation and engagement with the Advisory Committee is provided in **Appendix 1**.

2.2.2 Limitations

The EAC was convened to help start the project, but the value of this report and tool would be greatly enhanced with further engagement and enhance representativeness of feedback. Indeed, the EAC is not intended to be a representative group of affected stakeholders and/or Indigenous rightsholders, nor is its membership public in order to protect the anonymity of EAC members. Participation included numerous provincial and national government agencies, watershed boards, members of Indigenous governing bodies, concerned community members, and an industry affiliate. Because of the challenges of 'representing' a specific organization and/or community, the study team opted to rely on the expertise and engagement of EAC membership through a voluntary process which may have limited fulsome participation by some stakeholders/rightsholders. The process was also 'in camera', and recorded consultation with this group does not attribute specific recommendations to individuals, but to the EAC as a whole.

In order to have a group that had expertise which reflected multiple domains of interest for this assessment (e.g. ecological, community, health values), the project team primarily relied on referral sampling on recommendations from the funder (Environment and Climate Change Canada), its pre-existing relationships within the province of Alberta, relationships from other government organizations involved in impact assessment processes, and through

Indigenous engagement. This may have limited the participation of some groups such as a wide array of different industrial players that operate within the study region.

In total, the study team reached out to 25 Indigenous communities whose traditional, ancestral territory overlap with the study area. A short project description was shared and we invited comments and the opportunity to both engage with the Expert Advisory Committee, or to receive a full copy of the report once this research was complete. However, given the on-going challenges of the COVID-19 pandemic, all communications had to be undertaken digitally which may have limited participation of some individuals and/or communities. Moreover, many Indigenous communities may lack capacity to engage with research projects based on other community priorities. Building relationships with these communities should be an on-going process and goal related to the work of assessing cumulative effects.

2.3 Indicator Selection

2.3.1 Process

Indicators were collected through the review of existing and historical environmental impact assessment applications and assessment reports that legislated provincial and/or federal environmental impact assessment, and in conversation with EAC members. Indicator selection followed a more or less iterative process of selection, by:

1. Identifying regional issues of concern;
2. Scoping relevant indicators that represent those issues of concern;
3. Considering data sources that may measure issues of concern; and
4. Revising the list based on available data and their limitations.

Indicators were ultimately selected on the basis of relevance and availability of data at the lowest order geographical level that enabled display of environmental, community and health values (e.g. LGAs). All indicators were evaluated and selected according to best practices in indicator selection,[66] whereby indicators should be:

- **Relevant** and relate directly or indirectly to a valued component identified as significant to the study of cumulative effects in the study region;
- **Practical** and able to be measured through achievable data;
- **Measurable** so as to reflect changes to valued components over time;
- **Responsive** to the effects of a project and related land-uses in the study region;
- **Accurate** in reflecting changes over time; and
- **Predictable** in terms of their response to a project.[66,67]

Indicators were the foundation of the analytic approach deployed for this study, and were utilized to approximate multiple domains of impact across the Foothills region and its interactions with pre-existing and future land uses. Once indicators were selected and appraised for data availability, we matched available data, commenting on data limitations and knowledge gaps where appropriate.

2.3.2 Limitations

The biggest challenge of selecting indicators is the availability of comprehensive data sets that cover the entirety of the study area. Indeed, the bias of indicator utilization in any quantitative assessment leans towards valued components that can be counted, and not necessarily the things that count when conceptualizing cumulative impacts on people and populations (e.g. impacts to treaty rights). Relatedly, indicators are often collected and represented at different regional scales. The lowest order scale of analysis for which environment, community and health data can all be reliably represented in Alberta is at the level of LGAs. This geography, while perhaps more suitable for representing socioeconomic and health values, may lack the granularity to explore interactions between values in specific places within an LGA. Because of the diversity of species ranges, habitats and water courses within the study area, the LGA may not be granular enough to depict changes to specific ecological values, and future modeling should improve the granularity of environmental values to remedy this challenge. Unfortunately, reliable health data were not shared with the project team until after the completion of this phase 1 report, and will be remedied in subsequent phases of research.

Further, many indicators related to Indigenous land-uses simply have no data, or may be collected through cross-sectional data collection processes that are not standardized across the study area. Moreover, because of the regional scale of this analysis, some indicators may not be 'responsive' in a way that can be attributable to a specific project or projects that are located within the study region. Thus, the indicators are not necessarily comprehensive, but represent the best available public data, and other datasets could be explored in the future that represent other strategic values of interest. More comprehensive engagement activities (i.e. beyond the EAC) would help to identify additional potential data sources and their opportunity for integration into the tool.

Perhaps the most significant limitation of utilizing an indicator-based approach is the lack of robust and reliable indicators related to Indigenous culture, traditional ecological knowledge, and impacts to treaty rights. This is currently a significant limitation from a data availability perspective, and the research team makes recommendations on how this and other limitations identified here could be remedied later in the report.

2.4 Depicting Cumulative Environmental, Community and Health Impacts of Multiple Land-uses

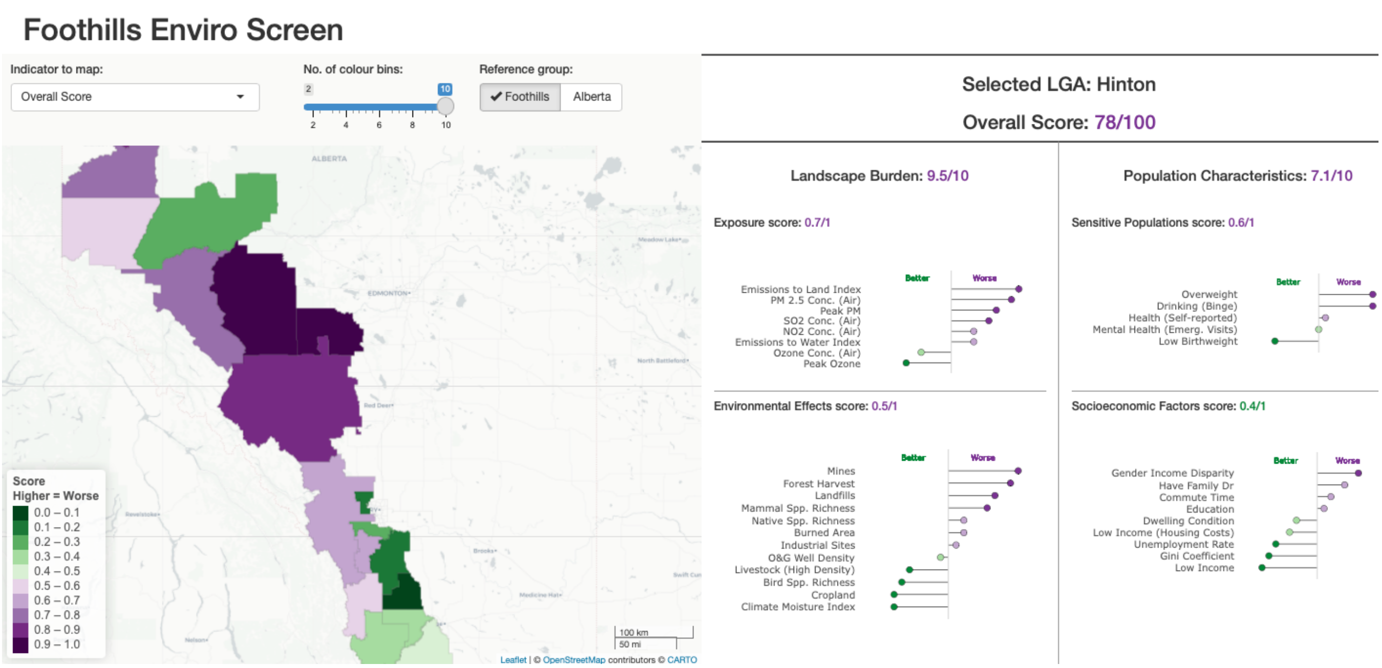
2.4.1 Overview of the "CalEnviroScreen" Analysis Method

This phase of the project assessed the current status of environment, community and health values within the study region identified through engagement with environmental impact assessments and with EAC members. The research team utilized a novel approach to standardizing indicators to create indices that enable the measurement of cumulative effects. Specifically, the project team adapted one of a leading approach for characterizing environmental, community and health values into a singular assessment architecture: the CalEnviroScreen method. The CalEnviroScreen is a relativist assessment tool that produces cumulative effect scores based on the land-use burden of a particular geographic area and its socioeconomic composition.[68,69] It is based on the United States Environmental Protection Agency's Environmental Justice Screening Tool,[70] and has more recently been utilized to model cumulative effects in the City of Chicago,[71] and environmental health disparities in Washington state[72] and in California.[73] Similar tools exist in the Canadian context, such as the BC Oil and Gas Commission's area-based analysis initiative, although the integrative potential of merging multiple environmental, social and health values has yet to be realized, as the tool currently only measures hydro-riparian ecosystems, old forest, wildlife and old growth management areas.[74]

Relativistic spatial assessment tools offer significant potential for quantifying the combined cumulative effects on environmental, community and health values.[69] Relativistic assessment methods have the advantage of comparing values across different locations within the study region to determine a relative sense of where pressures to land use values are greatest. Based on engagement with Environmental Impact Assessment documents surfaced in our review of impact assessment registries, and engagement with the EAC, we identified four possible categories of indicator which are referred to as ‘sub-indices’ (i.e. environmental exposures, environmental effects, sensitive populations, socioeconomic marginalization). These sub-indices are ultimately scaled up into two meta-level indices (i.e. landscape burden and population characteristics), which when combined, represent an “EnviroScreen Score”. Each indexed value and their relationship to higher order variables are defined as follows, and a screenshot of the ShinyApp is depicted as Figure 1, below:

- **EnviroScreen Score**: a quantitative measure of cumulative effects ranging between 0-100 where higher scores indicate greater environmental, socioeconomic and health pressures relative to other geographic units comprising the overall sample;
    - **Landscape Burden**: a composite measure of environmental exposures and effects that characterizes the overall pressure to regional environments/ecosystems;
        - **Environmental exposures**: measurements of different types of pollution that people may come into contact with;
        - **Environmental effects**: locations of toxic chemicals or landscape-level changes to environments;
    - **Population Characteristics:** a composite measure of sensitive populations and socioeconomic factors that may modify human interaction with environments;
        - **Sensitive populations**: the people in communities who may be differentially exposed to or affected by land use changes because of their health status; and
        - **Socioeconomic factors**: conditions of daily life that may increase people’s stress or modify their exposure to the negative impacts of multiple land-uses.

Figure 1. Screenshot of the EnviroScreen Shiny App



2.4.2 "EnviroScreen" Score Calculations

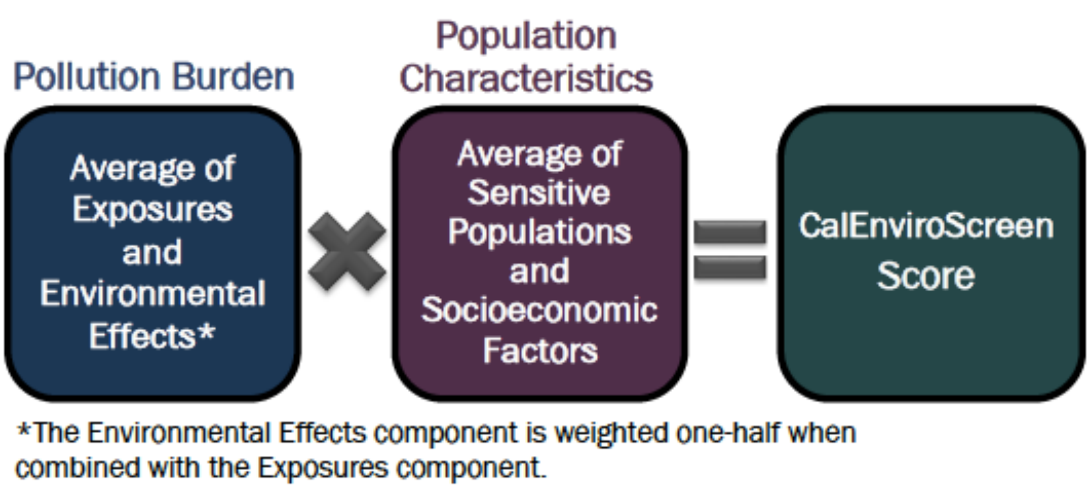
The calculation of EnviroScreen scores follows several discrete steps. First, each individual indicator is transformed via a process of standardization (i.e. the transformation of all indicators to the same scale so that they can be compared directly, irrespective of their value and or unit(s) of measurement), to ensure directionality of every variable is consistent (e.g. more of a given indicator represents a 'worse' score relative to other units in the sample), and then a rank-percentile is calculated. Ensuring consistency of variable directionality is a key component to ensuring no indicator 'cancels out' another. Rank-percentile refer to where a given LGA falls in relation to all other LGAs within the study sample. Ranking is a useful way to deal with the multiple distributions of data for all indicators, but especially for standardizing indicators from fundamentally different data sources enabling the inclusion of a diversity of data sources. In other words, this form of standardization is agnostic towards whether a variable is normally distributed, or follows another distributional pattern (e.g. left or right skewed). Missing or unreliable data are excluded from percentile calculations and not assigned a value, and for LGAs that have a value of zero for any indicator, they are excluded form percentile calculations and manually assigned a value of zero.

Second, indicators representing each sub-index (e.g. environmental exposures, environmental effects, etc.) are averaged to create an indexed value for each of the four sub-indices. Environmental exposures, sensitive populations and socioeconomic factors are all equally weighted in the model. However, Environmental effects is weighted as half due to the challenges of attributing environmental exposures impacts to environmental effects.[68]

Third, landscape burden and population characteristics scores are computed and normalized to represent values between 0-10. To do this, each component sub-index is averaged, and then divided by the maximum LGA value for a given meta-level index. The result is then multiplied by 10 to ensure landscape burden and population characteristics equally contribute to the overall score.

Finally, the EnviroScreen score is calculated by multiplying the landscape burden scores by the population characteristics score to represent a score from 0-100, where higher scores are indicative of a greater degree of cumulative effects (see Figure 2).

Figure 2. Approach for calculating 'CalEnviroScreen' Scores[γ][75]



[γ]Note that CalEnviroScreen refers to the combination of environmental exposures and effects as "pollution burden" where we refer to our meta-level score as "landscape burden".

2.4.3 Limitations

The EnviroScreen is a screening tool that is intended to be a starting point to identify trends in a wide variety of data relative to impact assessment and cumulative effects assessment. Accordingly, the value of the tool is in how it is used to understand relative pressures across a geographic area. Indeed, while the static outputs of sub- and meta-level indices are intended to approximate scores of 'cumulative impacts', the ground-truthing of those scores is made possible through data integration and the ability to determine which indicators might be driving higher scores in particular sub-regions of the study area.

Notwithstanding the EnviroScreen's ability to encourage data diversity and the inclusion of a potentially infinite number of indicators in its model, the approach does have several limitations. First, it should be apparent from the text above that the EnviroScreen methodology is rooted in a 'detriments' understanding of pressures to environments, communities and health, whereby the measurement of factors that are inherently negative across these three domains determines the final score. This is not to say that the same method could not be applied to measuring assets, but the model is ill-equipped to measuring both assets and detriments at the same time given the uncertainty of corresponding pathways between variables and the mitigating or amplifying relationships therein.

Second, because indicators are standardized using a rank/percentile approach, the resulting scores do not communicate actual risks associated with specific indicators, but rather, relative differences between geographic units in the sample. Thus, any of the essential resulting scores for sub-indices, meta-level indices and the EnviroScreen scores themselves are only meaningful when interpreted against the rest of the sample from which it was drawn (e.g. other LGAs). In other words, these values demonstrate where landscape and population pressures are greatest in relation to all other units across Alberta Foothills LGAs. To address this limitation, the study team ran analyses for the entire province of Alberta, and have enabled a provincial comparator toggle in the tool to compare the study region to the rest of the province.

Third, because the model is drawing from secondary data, it relies on assumptions that the data collection methods, and the validity and certainty of measures for those data sources are reliable.

Fourth, this approach may lead specific indicators to become inflated based on their ranking, whereby small differences between units in the sample may be made larger than they are due to the relativistic assessment. The study team has maintained a focus on sharing raw indicator values, as well as transformed values to examine where the inflation (or deflation) of values might occur across the sample.

Fifth, the model assumes that each sub-index (notwithstanding environmental effects which is weighted as one half the contribution of the environmental exposures index) is weighted evenly, and that the pollution burden and population characteristics synergistically interact to become equal to or greater than the sum of their parts (i.e. cumulative effects). As a result, impacts to a given indicator contributing to an index can be diluted indicator scores because they contribute less to the overall model by virtue of being averaged.

Finally, while the relativistic analysis approach is a key strength to this analytic method, it does require that every geographic unit in the sample has commensurate data to perform transformations. Missing data for specific regions may therefore challenge to the deployment and utilization of specific indicators because of their inability to be compared to the remainder of the sample. Thus, the analysis presented here represents a baseline cumulative effects assessment of the Alberta Foothills using publicly accessible data available for every LGA across the study region.

2.5 Description of ShinyApp

Given the complexity and breadth of indicators utilized to inform the assessment of cumulative effects, the research team created an exploratory tool to accompany this report. The “Alberta Foothills CEA ShinyApp” was developed using R Studio and QGIS technology to create an interactive display and dropdown menu to share information for every LGA within the study area. It serves as a supplemental tool for readers of this report to undertake the following:

- Interactively engage with the data utilized in the assessment and its geospatial representation;
- Explore the relationships between variables across the study area; and,
- Formulate hypotheses regarding each indicator and its corresponding indices.

The ShinyApp displays each individual indicator, sub-index, meta-level index, and EnviroScreen score. Selecting an LGA will bring up each component indicator and its relationship to either the provincial median score for the median of all LGAs within the Alberta Foothills. Users may also select how they would like the data to be represented (i.e. the number of bins each LGA could fall into). Accordingly, it is one-part ‘data-synthesis’—merging multiple environmental, community and health datasets into a singular visualization platform—and one-part hypothesis generating, insofar as tool enables its users to create new research questions and analyze unique pressures across corresponding LGAs to inform future planning and action. Its interactive nature allows users to create all manner of static maps. The ShinyApp is currently accessible at the following link: https://nicholas-yarmey.shinyapps.io/Foothills_Enviro_Screen/

3.0 Results

This section reports on the results of the review of existing and prospective projects requiring an environmental impact assessment; measurement of anthropogenic footprint and its change over time across the study region; and the results of applying the EnviroScreen methodology.

3.1 Environmental Assessment Review

Our review of environmental assessments located within the study region surfaced 20 different projects. The name of the project, its status, corresponding registry, lead agency, and type of project are documented in Table 3 with corresponding links to source documentation.

Our review of project documentation surfaced several key issues of concern, which typically reflect those mandated under existing environmental assessment legislation for valued components of specific interest to provincial and federal ministries. However, most issues raised through the commenting phase were flagged by proponents in their response as having a low significance determination and/or limited attribution to the specific project under assessment. Thus, the majority of concerns raised by participating agencies and/or the public had no corresponding indicator, dataset or subsequent assessment.

Across projects reviewed, common values included, but were not limited to:

- Water quantity/quality (including timing, volume and peak flow rates of overground water sources and supply of groundwater)
- Air quality (but specifically sulphur dioxides, nitrogen oxides and particulate matter)
- Fish habitat and aquatic resources
- Sensitive habitats
- Species-at-risk
- Human health
- Indigenous rights (including land access, harvest of traditional foods and medicines, impacts to local culture).

As reported in environmental impact assessment documentation that comprised our review, many stated values for measuring cumulative effects are broad and do not have accompanying recommendations for specific indicators and/or datasets. Similar challenges are present for other values raised as being important for cumulative effects which were less universally considered due to determinations of non-significance, relative to those listed above, including: noise and light pollution; aesthetic connections to landscapes; traffic patterns; access to essential services; demographic changes; housing quality; biodiversity; emissions to soils and waterways; labour patterns; tourism; cultural and heritage; and climate change.

Table 3. List of Projects that Required a Provincial and/or Federal Environmental Assessment Certificate within the Study Region

Name	Year of EIA Submission	Registry Source	Regulating Body	Project type	Status of EA Certificate and/or Project	Link
Baseline Mountain Underground Limestone Project	2003	AB Open Data	AER	Underground limestone quarry	Project on indefinite hold	https://open.alberta.ca/publications/environmental-assessment-barakat-resources-ltd-baseline-mountain-underground-limestone-project
Coal Valley Resources Mercoal West/Yellowhead Tower Mine Expansion	2009	AB Open Data	AER	Coal Mine Expansion	EA complete/In Operation	https://open.alberta.ca/publications/environmental-assessment-mercoal-west-yellowhead-tower-mine-expansion
Maxim Power Corp HR Milner Expansion (power plant)	2010	AB Open Data	AER	Coal fired generating facility	EA complete/In Operation	https://open.alberta.ca/publications/environmental-assessment-maxim-power-corp-hr-milner-expansion-project
Coalspur Mines Ltd Vista Coal Mine	2013	AB Open Data/IAAC	AER/IAAC	Coal Mine	EA complete/In Operation	https://open.alberta.ca/publications/environmental-assessment-coalspur-mines-ltd-vista-coal-mine-project
Coal Valley Robb Trend Project	2014	AB Open Data	AER	Coal Mine	EA complete/In Operation	https://open.alberta.ca/publications/environmental-assessment-coal-valley-resources-inc-robb-trend-project
Pembina Gas - Two Lakes Sour Gas Facility	2019	AB Open Data	AER	Sour gas processing facility	EA under review	https://open.alberta.ca/publications/environmental-assessment-pembina-two-lakes-sour-gas-processing-facility

Benga Mining Grassy Mountain Coal	2020	AB Open Data/IAAC	IAAC/AER	Open pit metallurgical coal mine	EA under review	https://open.alberta.ca/dataset/12ab5b0c-c74d-4936-8fe7-2d550a2fa69e/resource/d30733f1-d0a7-4566-bf69-2d4b66e4d8e0/download/2020-06-25-grassy-letter-to-benga-re-eia-completeness.pdf
AB Transportation Springbank Off-stream reservoir project	2021	AB Open Data	Alberta Environment and Parks	Off-stream flood diversion	EA under review	https://open.alberta.ca/publications/environmental-assessment-alberta-transportation-springbank-off-stream-reservoir-project
Coalspur Mines Ltd Vista Coal Mine phase I and II expansions	2019	IAAC	AER/CER	Expansion of Vista mines	On-going	https://iaac-aeic.gc.ca/050/evaluations/proj/80341
Prairie Lights Power Project	2020	IAAC	IAAC	Natural gas generating station	Does not warrant assessment under IAA	https://iaac-aeic.gc.ca/050/evaluations/proj/80324
Sunchild Gas Distribution Line	2020	IAAC	Indigenous Services Canada	Natural gas distribution line	Does not warrant assessment under IAA	https://iaac-aeic.gc.ca/050/evaluations/proj/80787
Wesley FN Solar Panel Project	2020	IAAC	Indigenous Services Canada	Solar panel installation	Does not warrant assessment under IAA	https://iaac-aeic.gc.ca/050/evaluations/proj/80483
West Path Delivery 2022/23	2020	IAAC	IAAC	Construction and operation of pipeline segments	Does not warrant assessment under IAA	https://iaac-aeic.gc.ca/050/evaluations/proj/80548
Ya Ha tinda Ranch Solar Array	2021	IAAC	Parks Canada	Solar array and microgrid installation	Does not warrant assessment under IAA	https://iaac-aeic.gc.ca/050/evaluations/proj/81227
Springbank Off-stream Reservoir	2021	IAAC	IAAC	Flood mitigation reservoir	EA under review (IAAC)	https://iaac-aeic.gc.ca/050/evaluations/proj/80123

NOVA Gas Transmission 2021 Expansion	2021	IAAC	CER	Pipeline natural gas	EA Complete/Under Construction	https://iaac-aeic.gc.ca/050/evaluations/document/exploration/80153?type=4&culture=en-CA
Pembina Pipeline Class Location Upgrade	On-going	IAAC	Parks Canada	Upgrade existing pipeline	On-going	https://iaac-aeic.gc.ca/050/evaluations/proj/80229
Edson Mainline Expansion	On-going	IAAC	CER	Pipeline natural gas	On-going	https://iaac-aeic.gc.ca/050/evaluations/proj/80173
Pipeline Riser on IR Reserve	On-going	IAAC	Indigenous Services Canada	Pipeline on reserve	On-going	https://iaac-aeic.gc.ca/050/evaluations/proj/80868
Tent Mountain Coal Mine	On-going	IAAC	IAAC	Coal mine	On-going	https://iaac-aeic.gc.ca/050/evaluations/proj/81436

3.2 Measuring Anthropogenic Footprint

Conventional approaches to measuring cumulative effects on the environment often include a spatial measure of changes to natural land cover from anthropogenic impacts on large landscapes.[76,77] Such an approach does not seek to explicitly characterize more nuanced features such as habitat intactness, but is a measure of how landscapes have changed from human development over time.

The Alberta Biodiversity Monitoring Institute created an open dataset depicting "prevalent and accurate delineation of surficial human disturbances in Alberta".[78] The human footprint measure consolidates 21 different human footprint categories (e.g. linear features) based on 115 unique anthropogenic disturbances into a single dataset for the purposes of understanding cumulative effects of human footprint on biodiversity.[76] Table 4 depicts the 2010 and 2018 human footprint index by area for each LGA comprising our study area, and also reports on the percent change across that eight-year period. The information in Table 4 is also able to be displayed spatially. Figure 3 depicts the spatial variation among LGAs in 2010, 2018 and as a percentage change between their 2010 and 2018 values.

Results suggest that between 2010 and 2018, Fox Creek and Grande Cache, two neighbouring LGAs, experienced the largest changes in anthropogenic footprint, increasing 1165% and 1094.9%, respectively. Grande Prairie County and Hinton also saw large increases (788.6% and 622.9%). These four regions Claresholm, High River, Cardston-Kinnai, Fort Macleod, Okotoks-Priddis and Cochrane-Springbank were among LGAs with the lowest percent change between 2010-2018, with a percent change of less than 4%, although many of these LGAs rank among the most disturbed LGAs by area in 2018 (e.g. Claresholm's Human Footprint covers approximately 71.5% of its area).

These results suggest that the LGAs comprising the Alberta Foothills experience a differing degrees and rates of anthropogenic disturbance from multiple land uses at present. LGAs in the north have seen the largest increases in human footprint over the past ten years largely occupy parts of Alberta where oil and gas exploration, extraction and transmission via pipeline infrastructure have seen considerable expansion over the past decade.

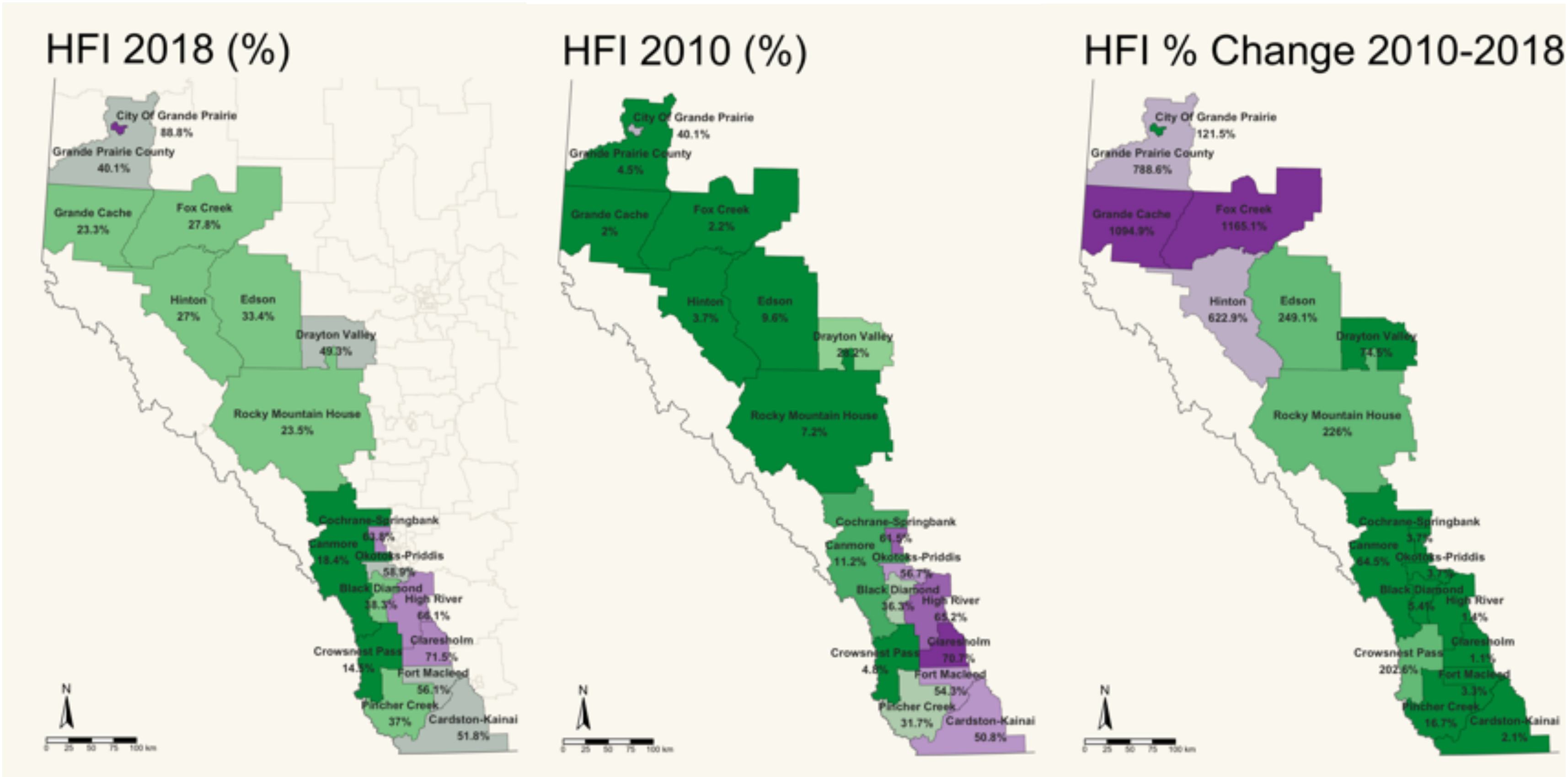
Table 4. Human Footprint Index for Local Geographic Areas Comprising the Alberta Foothills, 2010 and 2018[b]

LGA	Population 2016	Area (km sq.)	HFI 2010 Area (km sq.)	HFI 2010 Area (%)	HFI 2018 Area (km sq.)	HFI 2018 Area (%)	HFI 2010-2018 (% Change)
Black Diamond	9,403	1,240	450.3	36.3	474.7	38.3	5.4
Canmore	26,450	9,114	1022.3	11.2	1681.3	18.4	64.5
Cardston-Kainai	15,593	5,444	2764	50.8	2822.7	51.8	2.1
City of Grande Prairie	63,166	135	54.3	40.1	120.3	88.8	121.5
Claresholm	6,352	1,829	1293.7	70.7	1308	71.5	1.1
Cochrane-Springbank	43,334	477	293.5	61.5	304.3	63.8	3.7
Crowsnest Pass	5,681	3,001	144	4.8	435.8	14.5	202.6

Drayton Valley	17,723	4,084	1153.4	28.2	2013.1	49.3	74.5
Edson	15,079	11,392	1090.6	9.6	3807.5	33.4	249.1
Fort Macleod	5,491	1,705	926	54.3	956.6	56.1	3.3
Fox Creek	2,074	11,479	252.6	2.2	3195.6	27.8	1165.1
Grande Cache	3,759	8,207	159.8	2	1909.4	23.3	1094.9
Grande Prairie County	20,093	7,503	338.8	4.5	3010.5	40.1	788.6
High River	23,396	2,856	1862	65.2	1887.3	66.1	1.4
Hinton	11,102	9,197	343.5	3.7	2483.1	27	622.9
Okotoks-Priddis	41,769	765	434.3	56.7	450.4	58.9	3.7
Pincher Creek	8,360	3,938	1247.2	31.7	1455.6	37	16.7
Rocky Mountain House	20,800	19,013	1372.2	7.2	4472.7	23.5	226

ϕSource: Alberta Biodiversity Monitoring Institute, 2020

Figure 3. Human Footprint Index Comparing Anthropogenic Disturbance in 2010 and 2018[ϕ]



ϕSource: Alberta Biodiversity Monitoring Institute, 2020

3.3 EnviroScreen Indicators

Indicators were selected based on the review of existing and historical EAs, consultation with the Expert Advisory Committee, and from the research team's familiarity with scientific literatures on cumulative environmental, community and health impacts. The included list of indicators for this phase of research and their corresponding categorization for the purpose of calculating enviroscreen indicators is as follows:

- **Environmental Exposures**
  - Peak ozone, peak particulate matter, ozone concentration, particulate matter concentration, nitrogen dioxide concentration, sulphur dioxide concentration, climate moisture index, emissions to water, and emissions to land (each of the latter which include Cadmium, Selenium, Mercury, and Lead)
- **Environmental Effects**
  - Industrial sites; forest harvest; cropland; high-density livestock; landfills; mines; oil and gas well density; area burned by wildfire; bird species richness; native plant richness; and mammal species richness
- **Sensitive Populations**
  - Self-reported health; binge drinking; overweight; low birthweight; and mental health emergency visits
- **Socioeconomic Factors**
  - Unemployment rate; no high-school diploma; have family doctor; low-income after tax; housing insecurity; dwelling condition; commute time; gender income disparity; and Gini coefficient

A full description of the raw values and their corresponding percentile-rank would be burdensome given the sheer breadth of data and information included in the EnviroScreen model. Full definitions, data sources, and additional information on calculating derived variables is included in **Appendix 2,** with associated comments on data limitations. The full list of indicators, their raw values and rank/percentile calculations can be found in **Appendix 3**. Static spatial representations of all indicators have been provided in a supplemental file to the funder and are available upon request. These maps provide static representations of what can be found when selecting a specific indicator in the accompanying Alberta Foothills CEA Shiny App.

Since the focus of this research is on composite indices that measure cumulative effects, the report does not narratively describe all individual indicators in the model. It is worth noting that when comparing specific indicators to the spatial display of human footprint, presented in Section 3.2, those regions with the highest human footprint index scores tend to also have the highest levels of air pollution, lower levels of species richness, high levels of emissions to land, high degrees of forest harvest, high rates of binge drinking, greater gender income inequality, and higher levels of unemployment.

The research team also explored relationships between variables, and a correlation matrix analyzing relationships between raw values is made available in **Appendix 4**. This table highlights cells where statistically significant relationships exist ($P<0.05$) for associations with a Pearson's-R of 0.5 and higher (or -0.5 and lower). For example, forest harvest is strongly negatively correlated with mammal species richness ($R=-0.9$, $p<0.05$) and native species richness ($R=-0.8$, $p<0.05$) confirming past research that suggests forestry can impact habitat diversity and availability.[79] The goal of this approach is not to explore interrelationships in depth, but rather confirm the appropriate directionality of all indicators in the model to ensure each individual variable is contributing appropriately to each sub-index and higher order indices.

Notably, some indicators identified in the review of environmental impact assessment documents within the study area did not have publicly available data sources (e.g. noise and light pollution), and others (such as specific species whose range does not cover every LGA within the study region) had to be approximated by higher-order proxy variables relating to species richness.

3.3.1 Measuring labour sector concentration

In addition to some of the included indicators above, Advisory Committee Members suggested exploring labour concentration in specific sectors may help to determine which LGAs are over-reliant on singular indices. To undertake such an analysis, the research team relied on the Herfindahl-Hirschman Index (HHI)—a measure of the size of firms in relation to an industry to determine the amount of competition among them—which can similarly be used to describe the concentration of economic sectors in relation to the overall economic drivers of a region.

The HHI was calculated by squaring the proportion of each LGA's workforce occupying a given industry sector as defined by Statistics Canada:

$$HHI = s_1^2 + s_2^2 + s_3^2 + \ldots s_n^2 \text{ (where } s_n \text{ equals the market share \% of a sector expressed as a whole number)}$$

The HHI is interpreted on a scale of 1 to 10,000, where a higher score is equivalent to a greater concentration of workers being employed in a single sector. An HHI of less than 1500 is considered to be a dispersed workforce, 1500-2500 is a moderately concentrated workforce, and scores greater than 2500 indicate a highly concentrated workforce.

Results for the study area are depicted in Table 5 and indicate that HHI values range from 705.2 (Cochrane-Springbank) to 1266.4 (Fox Creek), relative to a province wide average across all provincial LGAs of 696.6. Most LGAs in the study region tend to have higher proportions of their populations working aged populations employed in three specific sectors: agriculture, forestry and fishing; mining, quarrying and oil and gas extraction; and health care and social assistance. However, the relatively low HHI values across the entire study area and low range between maximum and minimum values signify the low likelihood of significant employment concentration in any one field. Indeed, even Fox Creek which employs 29% of its working aged population in mining, quarrying and oil and gas extraction, and which resultingly has the highest HHI value in the study region, still has a value representing what would be a dispersed and distributed workforce overall. Because of the limited range and variation in scores between LGAs, the research team opted to leave these results out of the final model.

Table 5. Employment concentration by sector for LGAs located across the Alberta Foothills and corresponding HHI, Canadian Census, 2016

	Crowsnest Pass	Pincher Creek	Fort Macleod	Cardston-Kainai	Okotoks-Priddis	Black Diamond	High River	Claresholm	Didsbury	Cochrane-Springbank	Canmore	Rocky Mountain House	Drayton Valley	Hinton	Edson	Grande Cache	Fox Creek	Valleyview	Grand Prairie County	Alberta
Not applicable	0.5	2.4	0.7	3.5	1.2	3.4	1.3	0.9	1.4	1.5	2.1	1.4	1.0	1.2	1.5	1.0	0.8	2.3	0.9	1.7
All industry categories	99.5	97.6	99.3	96.5	98.8	96.7	98.7	99.0	98.6	98.5	97.9	98.7	99.0	98.8	98.5	99.0	99.2	97.8	99.1	98.3
Agriculture forestry fishing and hunting	1.8	14.6	18.9	10.5	1.8	8.6	8.4	15.3	10.7	1.5	3.7	10.1	6.8	2.1	5.0	8.4	1.2	13.7	5.3	2.8
Mining quarrying and oil and gas extraction	18.6	6.4	1.5	1.9	7.0	5.4	3.6	3.5	6.4	8.8	3.5	13.0	18.9	14.5	18.6	14.2	29.0	12.2	12.7	6.3
Utilities	0.4	0.6	0.4	1.1	1.2	0.5	0.9	0.3	0.5	1.3	0.8	1.1	0.9	0.2	0.8	3.4	0.8	1.9	0.6	1.0
Construction	8.6	8.3	10.7	10.0	12.4	14.7	11.8	7.1	13.0	9.5	9.9	12.2	9.1	7.3	9.0	9.8	7.5	12.2	12.2	10.4
Manufacturing	3.2	3.7	8.1	4.0	5.7	4.7	8.6	5.6	4.7	4.1	3.3	3.8	3.7	11.1	5.8	2.1	5.6	2.6	4.6	5.6
Wholesale trade	1.8	1.8	3.9	2.1	4.0	1.9	3.5	3.0	2.9	2.8	1.7	2.1	2.2	2.0	2.5	0.5	2.0	1.4	5.1	3.6
Retail trade	9.8	9.8	8.6	7.1	10.4	8.2	12.1	8.2	8.6	9.0	8.7	9.9	10.5	13.0	11.4	8.2	6.7	9.5	8.5	11.0
Transportation and warehousing	3.0	1.9	6.2	3.3	3.9	4.4	5.4	6.3	6.4	4.7	3.7	3.7	6.1	5.7	7.1	3.7	9.5	5.8	7.0	5.1
Information and cultural industries	0.0	1.0	1.3	0.7	1.5	1.5	0.8	0.7	1.4	1.3	1.2	0.7	0.6	1.1	0.6	0.5	1.2	0.4	0.8	1.5
Finance and insurance	2.1	1.7	1.9	2.1	3.3	1.8	2.7	3.5	2.8	3.5	1.8	2.1	1.6	1.7	1.6	1.8	0.8	1.1	2.3	3.1
Real estate and rental and leasing	1.8	1.4	1.1	1.0	2.3	1.2	1.5	0.7	1.6	2.2	1.9	1.2	1.8	1.7	1.3	0.8	1.6	0.8	2.8	1.8
Professional scientific and technical services	4.2	5.2	2.1	3.6	9.0	7.9	6.4	4.3	6.3	10.4	9.1	4.0	4.8	3.9	3.6	1.1	2.8	2.3	6.1	7.4
Management of companies and enterprises	0.4	0.0	0.0	0.0	0.4	0.4	0.3	0.0	0.2	0.5	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.2
Administrative and support waste management	4.6	2.9	2.2	3.8	3.9	4.7	4.0	3.6	3.5	3.3	4.4	3.0	3.8	2.9	3.2	1.8	2.8	3.2	2.7	3.9
Educational services	3.9	6.0	5.6	13.0	7.0	5.6	4.1	4.9	5.6	6.8	7.7	6.2	4.9	4.3	4.5	4.7	1.2	5.9	5.7	6.5
Health care and social assistance	12.5	12.6	13.9	17.4	9.6	10.7	10.0	17.2	9.7	11.1	10.5	8.4	7.2	6.4	7.0	5.5	4.4	8.5	7.2	10.9
Arts entertainment and recreation	3.3	3.4	1.1	3.0	2.9	2.8	2.1	2.6	1.8	2.9	6.6	1.7	1.3	1.5	0.9	0.8	2.0	1.0	1.8	2.0
Accommodation and food services	9.3	7.4	5.4	3.5	5.2	4.2	4.9	5.9	3.6	6.5	11.7	6.1	6.4	10.3	6.5	7.7	9.9	6.3	4.6	6.8
Other services (except public administration)	5.8	3.6	4.1	4.4	4.3	5.3	4.5	5.0	5.6	4.4	3.7	5.8	6.2	5.5	6.7	5.8	6.0	4.3	5.9	4.7
Public administration	5.1	7.7	2.8	7.9	4.5	5.7	4.4	2.8	4.6	5.5	6.0	4.7	3.2	5.1	3.9	18.5	4.4	7.0	3.8	5.4
HHI	**914.6**	**815.3**	**961.8**	**902.2**	**706.9**	**752.2**	**735.5**	**880.4**	**730.0**	**705.2**	**736.8**	**790.2**	**863.6**	**848.2**	**871.9**	**962.7**	**1266.4**	**856.1**	**725.0**	**696.6**

3.4 EnviroScreen Sub-indices

EnviroScreen sub-indices are a starting point for screening and measuring unique features of ecological and social systems that can scale up to represent cumulative effects. The results of sub-index calculations are presented in Table 6, and are descriptively characterized in the subsections below.

Table 6. Sub-index scores for EnviroScreen components for all LGAs in the Alberta Foothills

	EnviroScreen Sub-Indices			
LGA	**Environmental Exposures Percentile (0-1)**	**Environmental Effects Percentile (0-1)**	**Sensitive Populations Percentile (0-1)**	**Socioeconomic Factors Percentile (0-1)**
Cochrane-Springbank	0.7	0.4	0.3	0.3
Okotoks-Priddis	0.6	0.5	0.3	0.4
City Of Grande Prairie	0.6	0.5	0.7	0.5
Cardston-Kainai	0.4	0.5	0.5	0.6
Pincher Creek	0.4	0.5	0.5	0.6
Crowsnest Pass	0.5	0.4	0.6	0.5
Fort Macleod	0.4	0.5	0.5	0.5
Claresholm	0.4	0.4	0.3	0.4
High River	0.5	0.5	0.3	0.4
Black Diamond	0.6	0.5	0.4	0.6
Canmore	0.6	0.4	0.5	0.5
Drayton Valley	0.6	0.7	0.6	0.6
Rocky Mountain House	0.6	0.5	0.7	0.8
Edson	0.7	0.6	0.7	0.7
Grande Prairie County	0.5	0.7	0.5	0.5
Fox Creek	0.4	0.6	0.5	0.5
Grande Cache	0.4	0.4	0.7	0.6
Hinton	0.7	0.5	0.6	0.4

3.4.1 Environmental Exposures

The overall scores suggest that Edson, Hinton, and Cochrane-Springbank have the highest degree of environmental exposures conceptualized by the model. Some LGAs such as Cochrane-Springbank and Canmore have high exposure scores which are striking, insofar as they also have the lowest environmental effects score. This is in stark contrast to many LGAs which tend to have correspondingly high environmental exposure and effects scores, and may be explained by the high degree of reliance on air quality measures as environmental exposures within the model. For example, peak $PM_{2.5}$ and particulate matter concentration generally appear to be more significant in northern LGAs (Grande Cache, Fox Creek, Grand Prairie and Edson), whereas SO_2 is more prominent in Edson and Rocky Mountain House. The results for environmental exposure further suggest that regions in the southern Foothills have lower exposure than those in the north. Two spatial bands of higher environmental exposure scores run through the central area of the foothills (Hinton, Edson, Drayton Valley), and among LGAs in closest proximity to the City of Calgary (Canmore, Cochrane-Springbank, Okotoks-Priddis), potentially explained by higher degrees of oil and gas operations in the north and close proximity to higher density traffic near a major city.

3.4.2 Environmental Effects

Results suggest that LGAs in the northern region of Grande Prairie County and the central region of Drayton Valley tend to have higher environmental effects scores, although the spatial variation of scores is less defined relative to other sub-indices. Edson, Drayton Valley and Grand Prairie County have the highest scores of all LGAs suggesting higher environmental exposures to indicators supporting this cumulative effects analysis, and Canmore and Crowsnest Pass have the lowest environmental effects scores. Given that environmental effects scores are primarily comprised of land disturbances, Canmore and Crowsnest Pass's low scores may be due to their proximity to national parks and other protected areas. This gives credence to the benefits of conservation activities and protected areas for positively impacting environmental effects scores in the Foothills region. The EnviroScreen model appears to accurately represent environmental disturbance, where mines become a principle driving factor of higher scores in mining intensive regions such as Crowsnest Pass, Fort Macleod, Hinton and Grande Cache, and oil and gas development seems to drive higher scores in the north.

3.4.3 Sensitive Populations

The EnviroScreen model suggests that most of the northern and/or north central LGAs are home to particularly sensitive populations. Edson, Grand Cache and Rocky Mountain House have the highest scores, and therefore higher proportions of sensitive populations based on included variables relative to all other LGAs in the Alberta Foothills. The LGAs of Okotoks-Priddis, Cochrane-Springbank, High River and Claresholm perform best in this regard, suggesting their populations are healthier with lower proportions of sensitive populations relative to other LGAs in the Alberta Foothills. This may be driven in part by economic opportunities, lifestyle, and service provision in the City of Calgary relative to more rural areas of the study area.

The correlation table in Appendix 4 further suggests that sensitive population scores and socioeconomic marginalization are highly correlated. The City of Grand Prairie is a notable outlier in this regard, which has a higher sensitive population score, but a low socioeconomic factor score, suggesting that irrespective of economic opportunities and services available to residents of the city, the population still has relatively worse health status.

3.4.4 Socioeconomic Factors

Despite their positive correlation, socioeconomic factors do not follow the same spatial variation as the sensitive population scores. Rocky Mountain House has the highest score of all LGAs, and Cochrane-Springbank the lowest. The grouping of LGAs in the central area of the study area (Drayton Valley, Edson and Rocky Mountain House) tend to have higher rates of unemployment, higher gender income disparity, and lower levels of educational attainment relative to other LGAs in the sample. LGAs surrounding the City of Calgary tend to perform better in terms of socioeconomic factor scores, suggesting major metropolitan areas may have a certain degree of 'spill over' in terms of encouraging economic opportunities for surrounding LGAs.

3.4 EnviroScreen Higher-order Indices of Impact

The EnviroScreen methodology culminates by combining lower order indices into two meta-level measures: landscape burden and population characteristics, which are ultimately multiplied to produce an overall EnviroScreen score. Table 7 displays the computational results for these indices, which are elaborated upon in the corresponding sub-sections below.

Table 7. EnviroScreen meta-level indices and overall scores for LGAs within the Alberta Foothills study region

	Meta-Level Indices Score (Range 0-10)		EnviroScreen Score (Range 0-100)
LGA	**Landscape Burden Score**	**Population Characteristics Score**	
Cochrane-Springbank	8.9	4.4	39.7
Okotoks-Priddis	8.6	5.1	43.7
City of Grande Prairie	9.1	7.8	71.2
Cardston-Kainai	6.3	7.6	48.0
Pincher Creek	6.1	7.6	46.6
Crowsnest Pass	6.8	7.2	49.0
Fort Macleod	6.7	7	47.0
Claresholm	6.2	5	31.4
High River	7.4	4.8	35.6
Black Diamond	8.3	7.2	59.9
Canmore	8.2	6.9	57.0
Drayton Valley	10	8.6	86.0
Rocky Mountain House	8.4	10	84.0
Edson	10	9.4	93.8
Grande Prairie County	9.1	7	63.7
Fox Creek	7.2	6.4	46.5
Grande Cache	6.5	8.7	56.3
Hinton	9.5	7.1	67.4

3.4.1 Landscape Burden

The EnviroScreen model projects that LGAs occupying the northern half of the study region tend to have higher landscape burden scores than those in the south, with the exception of Grande Cache which is closer in scoring to southern LGAs. This corresponds to findings related to human footprint index which follows a similar pattern of landscape use. However, there is variation in which key indicators appear to drive scores in different LGAs. For example, Edson, Drayton Valley, and Rocky Mountain House have high oil and gas well density, high SO2 and NO2 concentrations, and high forest harvest areas, while in Grande Cache, peak particulate matter, particulate matter and mine footprint are more significant than other LGAs. Southern LGAs have the lowest scores of all LGAs in terms of landscape burden, potentially due to their proximity to protected areas.

3.4.2 Population Characteristics

There is a high degree of spatial variation in population characteristics scores. The central area of the study region has the greatest concentration of high population characteristics scores (notably Edson, Rocky Mountain House, Grande Cache and Drayton Valley). Rocky Mountain House and Edson have the highest scores among all LGAs in terms of population characteristic scores, relative to High River and Cochrane-Springbank which are the best performers among all LGAs, suggesting that suburban proximity to the City of Calgary may positively impact population characteristics. .

There is some variability between LGAs in terms of indicators that are contributing to lower scores. For example, unemployment and the proportion of the population without a high school degree or diploma are higher in Edson, Drayton Valley and Rocky Mountain house. When considered in relation to the landscape burden scores, this result suggests that areas facing socioeconomic and health marginalization may be disproportionately exposed to landscape burden in these LGAs. These findings are also borne out in the final EnviroScreen score.

3.4.3 EnviroScreen Scores

EnviroScreen scores follow a well-defined north-south gradient, with the exception of Fox Creek, where northern LGAs tend to have higher scores relative to those located in the southern reaches of the Alberta Foothills. Edson, Drayton Valley, Rocky Mountain House and Hinton have the highest EnviroScreen scores, suggesting that the interactions between environmental conditions and communities is greatest in these LGAs. Conversely, Claresholm has the lowest score, suggesting that for this LGA anthropogenically driven environmental changes and its impacts on human populations is lowest among all LGAs in the study region.

EnviroScreen scores are largely clustered (e.g. higher scoring LGAs tend to border other high-scoring LGAs, and lower scoring LGAs tend to be surrounded by other low-scoring LGAs). However, Fox Creek appears to be an outlier in this regard, with a relatively low overall EnviroScreen, yet being surrounded by some of the highest scoring LGas in the sample, despite significant oil and gas exploration and associated land use. This suggests that some of Fox Creek's environmental impacts may be offset by the socioeconomic impacts of rapid industrial development. Similarly, the model projects that the LGAs of Canmore and Black Diamond appear to be geographic transition zones between higher scoring LGAs in the north and central regions of the study area, and the lower scores in the southern reaches of the foothills.

When comparing the sample of 18 LGAs in the Foothills to the entire sample of 132 LGAs across Alberta, it is notable that the Foothills region tends to perform much better on average, with the exception of Edson, Drayton Valley and Rocky Mountain House. This finding suggests that these areas may be the best targets of additional conservation and protection programs, and careful consideration of additional cumulative effects should be given to proposed land uses in these regions.

4.0 Discussion and Implications

The EnviroScreen scores show how cumulative disturbances to ecosystems and ecosystem processes can be contextualized in a broader and more powerful way than simply considering landscape and ecological disturbance alone. The model shows a clear pattern of vulnerability across higher order indices, while also enabling a breakdown of specific indicators to better understand what drives resulting scores in a given LGA, making it a powerful tool for evaluating interventions and mitigative activities in relation to current conditions.

This analysis of cumulative effects across the Alberta Foothills makes several important contributions. This is one of the first integrative analyses of cumulative impacts on environment, community and health of multiple land-uses undertaken in the Canadian context, using a novel assessment architecture that can merge multiple forms of data and display them spatially. The method therefore builds on existing guidance on the conduct of cumulative effects assessment,[80] including the use of geographic information systems in modeling cumulative effects,[81] while doing so at a scale (e.g. LGAs) that is appropriate for understanding multiple impacts across numerous industries using robust sources of data.[82] Indeed, past research has suggested that understanding cumulative effects at a regional scale is more appropriate for modeling their impacts relative to project-specific cumulative effects assessment, precisely because of the synergistic interactions between land-uses.[23] Further, the method explicitly builds several discrete indices of impact, to examine how multiple groupings of indicators become greater than the sum of their parts.[83]

As a result of the integration described above, EnviroScreen scores communicate information about spatial disparities in how communities and individuals are exposed to the negative impacts of multiple land uses.[84] While conventional cumulative effects assessments primarily predict the additive impact on discrete valued ecosystem components,[3] the EnviroScreen method screens the impact of numerous existing pressures across environmental, community and health values, assuming synergistic rather than purely additive relationships among these variables. The results may be used to design future monitoring relative to the existing-condition values established in this report. Historical baselines could also be created, depending on the availability and robustness of historical data. Historical baselines could assist to understand changes to values over time, which changes tend to drive enviroscreen scores higher and lower over time, and to better understand changes in land-use patterns and associated impacts to valued components over time[85] In this regard, EnviroScreen methods encourage consideration of how to set social, economic and ecological objectives in planning processes such as regional and/or strategic environmental assessment, land-use and resource planning, and official plans.[86]

Given that cumulative environmental, community and health effects of resource extraction and development are not the responsibility of any one sector, EnviroScreen scores can also enable more robust cooperation and collaboration between proponents, governments, not-for-profit groups and Indigenous communities. This can result from multiple sectors being able to visualize the interaction between their own jurisdictional priorities in relation to others, and in analyzing where known vulnerabilities or pressures are, engage in dialogue around intersectoral management, data-sharing, and collaborative adaptive management.[5]

4.1 What does this assessment communicate about cumulative effects in the Alberta Foothills and their management?

4.1.1 Cumulative Effects in the Alberta Foothills

The analysis presented above, and when put in direct comparison with Alberta median scores per the ShinyApp, suggests that despite performing better than most LGAs across Alberta. However, the Foothills region is still home to industrial pressures that leave lasting legacies for ecosystems, communities and human health. Regions with a high human footprint index tend to have resultingly high EnviroScreen scores. Indeed, Edson, Drayton Valley and Rocky Mountain House are more heavily impacted by cumulative environmental, community and health impacts than southern LGAs, further signifying that that rapid changes to industrial land uses over the past decade (see Table 4, above) may have driven significant impacts with highly localized implications across diverse ecological, socioeconomic and health values.

There are notable risks associated with the presentation of these findings. First, regions that are heavily impacted by existing land uses could be viewed by some readers as potential 'sacrifice zones' that greenlight certain developments due to already degraded environments. Such an approach should not be encouraged, as research suggests that such zones in other industrial areas differentially impact vulnerable populations and lead to even worse environmental outcomes overall.[87,88] Instead, the EnviroScreen model gives credence to the fact that these areas should be targeted for additional conservation, protection and environmental remediation activities. Alternatively, readers could interpret the relatively lower scores in the southern reaches of the Foothills as opportunities to allow more development. It is important to note that existing research suggests that taking a 'business as usual' approach to development in the southern reaches has already negatively impacted ecosystems and key species of interest. This finding suggests that more should be done across the region, and historical analyses of changes over time could help to quantify the degree of change to inform future land use planning processes in an attempt to alleviate risks associated with negative changes to environments, communities and health. Rather than being 'anti-development', the screening tool instead should be cautiously interpreted against key values of concern, and enables analysts, planners and project proponents to consider how a specific project or land use may magnify or abate existing cumulative effects, rather than adding to them.

4.1.2 Management thresholds

The use of thresholds in managing cumulative effects has been widely panned in the literature due to the inherent complexity associated with attributing a change in any one value to a specific project or industry. Beyond the challenge of attribution, many indicators may have inherent 'tipping points' and non-linear relationships that operate across multiple spatial and temporal scales.[89] These types of phase shifts in a value are largely unpredictable. Further, they become even more complicated in the realm of social and health impact assessment, where beyond toxicological exposures which can in some cases quantify dose-response relationships, social and health values are highly variable within and between communities, potentially requiring an entirely new paradigm for understanding changes over time.[90] Indeed, identifying thresholds after they have been crossed is far easier than identifying threshold exceedances in the future due to empirical observations of negative impacts.[91] The current model is agnostic towards whether one variable precipitates a change in another, but it warrants mentioning that there are numerable categories of thresholds which correspond to specific shifts in ecological, social or health outcomes and their resulting implications for other values (e.g. national standards for releases of toxic pollutants to air, water and soils).[91]

Any discussion of management of strategic values will also necessarily require trade-offs, and past evidence suggests Canadians value both immediate development benefits and conservation.[92] Given that this analysis takes a 'regional' rather than project-specific approach to accounting for existing cumulative effect impacts, a central challenge is in the implementation of solutions by regions that have different political priorities and management objectives. This perhaps indicates a need to continually engage local stakeholders and rightsholders to support the identification objectives for particular values (rather than thresholds) and tracking changes in those values over time. The benefit of a screening tool such as the EnviroScreen is to help shape regulatory requirements and management objectives that meet a goal of sustainability in the broadest sense, and to indicate to decision-makers, stakeholders and rightsholders where opportunities for conservation may be present.

Irrespective of these challenges, a strength of the EnviroScreen method is its quantification and standardization of numerous indicators of interest. Depending on local priorities, historical data on indicators used in this assessment, or other indicators of relevance where data exists, can be incorporated to understand how values have changed over time, and develop hypotheses as to why these changes occurred. Measuring percent historical changes to indicators over time, and ground truthing those changes with local communities to understand whether such changes presented net negatives or positives for a specific value, can help to inform an understanding of the degree of change (e.g. expressed as a percent change from a baseline condition) and the implications of that change at the local and/or regional level. The authors suggest that pending such historical analysis, a change of more than 10% to any indicator between data collection and modeling periods should warrant consideration and discussion of possible risk mitigation activities, and that community consultation should be used to determine an appropriate management objective.

4.2 Future Analytic Opportunities for Model Refinement and Management

This analysis has presented a first-of-its kind articulation of regional cumulative effects in the Alberta Foothills. In order to address some of the limitations identified in the methodology section of this report, and to explore subsequent opportunities from this analysis, the authors suggest several future opportunities for analysis and model refinement to support adaptive management in the Alberta Foothills region.

4.2.1 Improving the spatial granularity of the model

The research team selected LGAs as an appropriate level of analysis given it is the lowest order geography at which robust health reporting occurs in Alberta. However, Advisory Committee members flagged that such large regional scales may be ill-equipped to adequately account for ecological data which is highly dependent upon geography, climate and the unique micro-ecologies of the Alberta Foothills. Thus, improving the granularity of the model should be a priority.

The study team determined that socioeconomic information is available down to the level of census dissemination areas across the study area. Most of the ecological data that were collected would also be able to be fit to the level of census dissemination areas. However, health information is still only publicly available at the level of LGAs, and applying higher-order measures to lower order geographies risks committing an ecological fallacy (i.e. making inferences about individuals from inferences about the group to which those individuals belong). Making such a sacrifice to improve the granularity of the model would not only improve the ability to model ecological data at a more appropriate scale, but it would also increase the total number of observations and the statistical power of the model, drawing out data variabilities while also enabling a more localized understanding of how impacts are distributed within LGAs.

4.2.2 Modeling EnviroScreen scores through the use of historical data

Despite using some measure of change across the study region, this analysis primarily addressed the need to establish a contemporary baseline of cumulative effects across the Alberta Foothills. Thus, key dimensions of temporal change and how some static indicators may have changed over time are notably absent from the current conceptualization of cumulative effects. While this is not necessarily problematic, insofar as contemporary conditions are reflective of accumulation of impacts over time, establishing a historical baseline would provide additional information as to: how indicators behave over time, which geographic areas have seen the largest changes, and how management thresholds might be set based on how these social-ecological systems have evolved. Such an approach also has the added value of encouraging future modeling scenarios based on historical changes to indicators, enabling the modeling of impacts to indicators based on prospective changes across different areas of the study region.

To that end, it is recommended that a future step be to analyze historical data in relation to the established baseline values for indicators and their corresponding indices. Our analysis suggests that socioeconomic and health information are robust and go back at least 20 years. However, some ecological datasets are relatively new, and more recent techniques for assessing air quality from satellite imaging, or measuring toxic releases to land and water lack reliable historical data sources at a regional scale. Scoping historical data availability should therefore be a priority, particularly if it is anticipated that this approach be used to identify management objectives for valued components moving forward (see section 4.1.2, above, for further rationale).

4.2.3 Ground-truthing data with Indigenous and settler communities to source additional indicators and data

While the data explored in this assessment broadly consideration of environmental, community and health information, the EnviroScreen's approach to data diversity could encourage the inclusion of other indicators and data sources, permitting they are available across each geographic unit comprising the study region. Engaging communities in dialogue about which values are more or less important could help to improve the focus of the model, and potentially eliminate or add specific indicators that may better approximate the on-the-ground realities of the Alberta Foothills region.

Moreover, engaging communities in conversation about the quality and availability of data can not only work to surface new, previously underutilized data sources, but may also enable a more fulsome consideration of data quality among existing indicators. These types of dialogues have proven incredibly helpful for assessing the reliability of existing data, and may enable community members to comment on where the analytic method and or corresponding indicators under or over-estimate the degree of impact on the landscape and/or their corresponding populations.[93] They also empower community members to engage with research and planning processes, and to unlock the wisdom of lived experience.[94] For example, a recent cumulative effects assessment in the Lesser Slave region of Alberta worked with Traditional Ecological Knowledge (TEK) holders to understand how historical and present narratives around impacts to land and communities were understood through Indigenous ways of knowing.[95] The fact that Indigenous knowledge systems span generations was found to enhance understandings of cumulative effects, while also speaking to social-ecological limits and thresholds around resource abundance, access and harvesting practices, all key Indigenous rights of significance for cumulative effects analysis for which no universal data currently exists. The direct engagement with Indigenous communities about how to incorporate qualitative information regarding cumulative effects, and directly observable impacts to Indigenous rights would serve as a particularly innovative approach to cumulative effects assessment, and help to establish baselines and engagement processes that could be used to inform other analyses in the Alberta and broader Canadian contexts. Such an approach may also serve to explore creative opportunities for integrating qualitative information into the model.

4.2.4 Exploring alternative weighting regimes of indicators and sub-indices

Ground-truthing data with communities can also be instructive as to how different indicator suites and/or indices ought to be weighted based on local priorities. Currently, the EnviroScreen model assumes each sub-index and meta-level index contributes equally to the resulting cumulative effects score, which can limit or maximize the influence of one or more indicators within a given index. Considering how suites of indicators could be grouped and weighted (e.g. emissions to air, emissions to land, emissions to water) relative to including multiple data points to measure air quality could be considered for the purposes of simplifying the model and its usability.

Further, some communities may already have strategic development priorities and/or conservation goals stated in existing plans. This may cause them to weight specific indicators or sub-indices differently, which may alter how a community understands what is most important to them in terms of depicting cumulative impacts. A potential future application to examine indicator weighting with communities could be to program a weighting feature in the ShinyApp that lets you change the relative contribution of each sub-index, or specific indicators, to the EnviroScreen score. This would enable communities to understand how changing priorities over time may lead to shifts in cumulative effects that they deem are tolerable or which they know they are able to mitigate through particular management practices.

4.2.5 Case study research of the most impacted areas identified by the model

The EnviroScreen method comparatively analyzes the relative pressures to social-ecological systems. Accordingly, this type of screening tool demonstrates which parts of the Alberta Foothills are more or less cumulatively impacted by multiple land-uses, but it is limited in its ability to characterize the pathways by which these impacts accumulate over time. While a robust historical analysis (as recommended above) might serve to remedy some of these issues, it is recommended that future research deploy case study methodologies in heavily impacted areas, or even in outlier regions (such as those identified in section 3 above) which might help understand the underlying processes behind the patterns in the data. Examining case studies of outlier regions could also provide insight into potential interventions that could improve ecological, socioeconomic and health conditions.

Case study research studies could yield additional benefits by identifying effects pathways for key environmental, social and health cumulative effects. The goal of conducting such research would be to confirm the model's analytic findings and develop an understanding of which indicators in the model behave as drivers, modifiers and outcomes when considering social-ecological change over time. Building an understanding of the causal dynamics of these relationships can work to better support the development of management triggers and systems, and work to identify a next generation of regional cumulative effects management actions that stem cumulative effects from having unabated impacts over time. Modeling the feedback loops through the use of systems dynamics modeling could be a beneficial methodological starting point from which to build a predictive model that works to understand the attribution of a specific change and its resulting implications for the rest of the complex system (as depicted by the indicators utilized to conceptualize cumulative effects in this report).

4.2.5 Modeling assets

It is noted above that the EnviroScreen methodology is inherently rooted in a detriments model of cumulative effects. However, it is important to note that cumulative effects can be both positive and negative, and that modeling the benefits of development for particular regions such as population successes (e.g. positive impacts to quality of life) or interventions that successfully remediate environments may shed additional understanding on cumulative effects.

While it could be argued that the inverse scoring of the existing model could be interpreted as assets, the study authors argue that this approach may not necessarily capture the nuanced resources that enable regions to be more or less resilient in the face of ecological change. Creating new indicator suites based on observations of what is working to limit the negative impacts of cumulative effects documented in this report, and to place such an "AssetScreen" in conversation with the EnviroScreen could therefore assist in identifying which management activities are leading to improvements in environmental, social and health conditions over time, and why.

The items listed above appear in no particular order. The project team's commitment is to continue to work with the funder and relevant stakeholders and rightsholders to prioritize next steps for this research which will be undertaken during the second phase of work between September 2021 – March 2022.

5.0 Conclusion

This document reports on a preliminary screening assessment of cumulative environmental, community and health impacts that may be influenced by natural resource extraction and development activities within the Alberta Foothills region. Findings suggest that despite Foothills LGAs typically having lower EnviroScreen scores than the rest of Alberta, there is still significant landscape level disturbances that are impacting the health and functioning of ecosystems, communities and individuals across the study region.

The biggest contribution this report makes to understanding cumulative effects is its attempt to overcome the 'impotence' of cumulative effects assessment when leveled at individual projects.[96] The regional and integrative analysis presented here serves as a first-of-its-kind assessment in the Canadian context. Moreover, the creation of the ShinyApp that accompanies this report provides an interactive platform for data exploration, hypothesis generation and scientific communication to support future research and land-use management in the Foothills region. Ultimately, directly engaging communities with this tool will be helpful in building social license to operate for new projects, supporting conservation activities and environmental remediation spending, and the environmental, socioeconomic and health sustainability of the region into the future.

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Appendix 1. Expert Advisory Committee Terms of Reference

Alberta Foothills Cumulative Effects Assessment
Expert Advisory Committee
Terms of Reference

Project Background
The Alberta Foothills region is home to an array of past, present and future resource development and industrial land uses. Project-specific environmental impact assessments have continued to raise concerns over cumulative environmental, community and health impacts of multiple land-uses throughout this region, highlighting how a cumulative effects assessment could enhance management objectives, support long-term planning processes, and empower local communities to better advocate for sustainable development. To address this need, Environment and Climate Change Canada have contracted a research team led by the University of British Columbia's Centre for Environmental Assessment Research (the "Project Team") to conduct a cumulative effects assessment of the Alberta Foothills region.

Objectives
The goals of the Alberta Foothills Cumulative Effects Assessment (ABF-CEA) project are to:

[1] Characterize cumulative environmental, community and health impacts related to natural resource development in the Foothills Region of Alberta through the development of a geo-spatial Environmental Screening tool; and

[2] Align the screening tool with the best available evidence, indicators and data to represent/depict cumulative impacts in the study region and identify areas of concern to support future management and monitoring activities.

Purpose and Relevance
This document outlines the Terms of Reference for an ABF-CEA Expert Advisory Committee (EAC). The EAC will include diverse perspectives from those with experience on the cumulative effects of natural resource extraction, and will be comprised of people with both technical and lived expertise as it relates to the project's goals. The EAC will be invited to add perspective and provide advice to the project team on the undertaking of the cumulative effects assessment. Issues that will be discussed with the EAC and the project team will include, but not limited to: providing feedback on indicators and data sources; sharing or making linkages to additional data sources (where possible); commenting on iterations of the cumulative effects screening tool; and providing feedback on engagement strategies that will be central to the project.

Expert Advisory Committee Membership and Structure

Membership is voluntary, but all current and future members must agree and adhere to the Terms of Reference. Members will be invited and selected by the Project Team in conjunction with staff from Environment and Climate Change Canada. Membership will be structured around the broad participation of diverse perspectives from relevant national, provincial and local stakeholders and Indigenous rightsholders. Members will not be considered 'representatives' of specific organizations or sectors, but rather will be selected for their familiarity with issues relevant to the study region and willingness to engage with the project. Information shared will be privy only to EAC members, unless with express written permission to share this more publicly.

The EAC will be comprised of ~13-15 people who have experience with or are able to speak to the range of environmental, community and/or health perspectives important to the study area. Several seats will be reserved for participants from federal agencies (e.g. Environment and Climate Change Canada, Health Canada and the Impact Assessment Agency of Canada, Canadian Energy Regular), several will be reserved for participants from provincial agencies (e.g. the Alberta Energy Regulator, Environment and Parks, Agriculture and Forestry), and the remainder

of the seats will be made open to other relevant participants with suitable expertise to assist with guiding the project (e.g. Indigenous community members, watershed or conservation staff, academics, etc.). The EAC will strive for equal gender representation among members, and privilege Indigenous participation wherever possible.
Roles and Responsibilities of the Expert Advisory Committee

Roles and Responsibilities of EAC Members
The EAC is not a decision-making body. The primary role of the EAC is to ensure that project processes and outcomes are aligned with multiple interests and priorities of relevant stakeholders and rights-holders. In order to meet this need, the EAC is expected to:

- Provide advice, guidance, and recommendations to the Project Team to help achieve project goals;
- Reflect and share insights on lessons and implications of research and outreach activities in relation to the project.
- Individual EAC members have the following responsibilities:
- Understand the goals, objectives, and desired outcomes of the project;
- Provide guidance on project scope and direction by identifying how the needs of different perspectives can be addressed through on-going and future research (pending funding);
- Respond to occasional emails from the Project Team with time sensitive requests;
- Participate in committee meetings through attendance, discussion, and review of minutes and other relevant documents (as necessary);
- Act on opportunities to share information about the project with interested parties;
- Support open discussion and debate, and encourage fellow EAC members to share their insights.
-

Responsibilities of Project Team in Convening the Expert Advisory Committee
The Project Team is responsible for chairing the EAC. In addition to the responsibilities of individual members, the Project Team is expected to:

- Uphold the values and rules of engagement that EAC members agree upon;
- Ensure that agendas and supporting materials are delivered to members in advance of meetings;
- Oversee and facilitate meeting discussions;
- Clarify and summarize what is happening throughout each meeting;
- Encourage broad participation from and on-going communication between EAC members;
- End each meeting with a summary of relevant action items.

Advisory Committee Rules of Engagement
Members will be respectful of one another even on matters where they have differing opinions. Discussion and debate is welcome and encouraged when undertaken in good faith that focuses on information, ideas, and potential solutions/opportunities, and not the people who might carry those ideas. It is the responsibility of all EAC members and the Project Team to ensure the committee environment is respectful, and to recognize and stop any behavior that is counter to these rules of engagement. It is understood by EAC members that all information shared in relation to the project are strictly confidential but may be utilized to strengthen the research, and any ideas shared will not be attributable to individuals in meeting minutes. However, meeting minutes may share information and be part of the project record. In instances where EAC members wish content to be ‘struck by the record’, this will be discussed with the Project Team. All committee members agree not to share sensitive or confidential information related to the project, and it is understood that this confidentiality agreement survives the completion of the project.

Tenure, Succession and Transition
Appointments to the EAC will be made by the Project Team, and will last until either (a) the project is complete, or (b) a member voluntarily removes themselves from the committee. Participation is completely voluntary and members of the Advisory Committee are free to resign at any point in time. If members are unable to continue and wish to resign, they must provide notice to the Project Team and the Project Team may ask for support in finding a replacement member. Regular attendance is expected of all members. In the event that the absenteeism of a member becomes a matter of concern, the Project Team may request that the EAC nominate a replacement member.

Frequency of Meetings

The EAC will meet bi-monthly, or as needed. The Project Team will be present at these meetings. These meetings will be scheduled well in advance and will be held by videoconference/teleconference to minimize travel and environmental impacts. As indicted above in Section 2.2, EAC members may be called upon for advice by email in between regularly scheduled meetings.

Meeting agenda and minutes
The agenda and minutes will be recorded and distributed by the Project Team and approved by committee members.

Reporting Structure
The EAC will provide advice to the Project Team, with the primary point of contact being Chris Buse (see contact information, below). EAC members will receive drafts and final materials of all deliverables related to the project as they become available. Any questions or concerns should be directed to:

Chris Buse, PhD
Email: chris.buse@ubc.ca
Phone: +1.778.349.4242

Appendix 2. List of Indicators, Definitions and Data Sources

	Indicator Name	Indicator Definition	Data Source
Landscape Burden (Environmental Exposures)	Peak Ozone	ppb. Peak ozone measured at air monitoring stations. National Air Pollution Surveillance (NAPS) Program	National Air Pollution Surveillance
	Peak PM	µg/cubic m. Peak fine particulate matter measured at air monitoring stations. National Air Pollution Surveillance (NAPS) Program	National Air Pollution Surveillance
	Ozone concentration (air)	3 year average concentration of ozone in air ppb	CANUE
	PM concentration (air)	3 year average concentration of particulate matter 2.5 in air ug/m3	CANUE
	NO2 concentration (air)	3 year average concentration of NO2 in air ppb	CANUE
	SO2 concentration (air)	3 year average concentration of SO2 in air ppb	CANUE
	Climate moisture index	Projected climate moisture index under RCP 8.5 (2071-2100). More negative values indicate a drier climate	Open Canada *Derived variable*[2]
	Emissions to Water Index	Index calculated using National Pollutant Release Inventory. Pollutants included: Cadmium, Selenium, Mercury, and Lead	National Pollutant Release Inventory *Derived variable*[3]
	Emissions to Land Index	Index calculated using National Pollutant Release Inventory. Pollutants included: Cadmium, Selenium, Mercury, and Lead	National Pollutant Release Inventory *Derived variable*[3]
Landscape Burden (Environmental Effects)	Industrial Sites	percent land cover. Includes well pads, batteries, compressor stations, refineries, pulp and paper mills, tank farms, power generators, urban industrial, employee camps, and associated clearings.	Human Footprint Inventory

	Forest Harvest	percent land cover. Includes areas where forestry operations have occurred (cut blocks, clear cut, selective harvest, salvage logging).	Human Footprint Inventory
	Cropland	percent land cover. Cultivated cropland or crop rotation, including grains, oilseed, lentils, row crops.	Human Footprint Inventory
	Livestock (High Density)	percent land cover. Confined feedlot operations and high density livestock, interpreted as the presence of large buildings and fenced pens appearing to be used for the purpose of feeding and confining pigs, chickens, or cows.	Human Footprint Inventory
	Landfills	percent land cover. Includes landfills and transfer stations.	Human Footprint Inventory
	Mines	percent land cover. Includes coal, gravel pit, oil sands, peat and associated waste, overburden, and tailings, waste and drainage sites.	Human Footprint Inventory
	Oil &Gas Well Density	calculated wells/sq km based on list of all wells reported to Alberta Energy Regulator	Alberta Energy Regulator
	Area burned by wildfire	percent of area (cumulative) burned by wildfire	Alberta wildfire. Historical wildfire perimeter. *Derived variable1*
	Bird Species Richness	measure of species richness	Alberta Biodiversity Monitoring Institute
	Native Plant Richness	measure of species richness	Alberta Biodiversity Monitoring Institute
	Mammal Species Richness	measure of species richness	Alberta Biodiversity Monitoring Institute
Population characteristics (sensitive populations)	Drinking (Binge)	percent of population reporting 5 or more drinks more than once per month	Canadian Census 2016
	Overweight	percent of population with BMI 25-30	Canadian Census 2016

	Health (Self-reported)	Percent of population self-reporting health as "very good" or "excellent"	Canadian Census 2016
	Low Birthweight	Percent low birth weights (of live births), less than 2500 g	Canadian Census 2016
	Mental Health (Emergency Visits)	Frequency of emergency visits for mental health reasons over a year - all variables combined into percentile rank. Rates are for 11 different hospital codes: behavioural and emotional disorder with onset child and adolescence, dementia, depressive disorders, disorders of adult personality and behaviour, mental and behavioural disorders, mental/ behavioural disorder, psychoactive substance use, mood affective disorders, neurotic/ stress related/ somatoform disorders, organic including symptomatic mental disorders, schizophrenia schizotypal and delusional disorders, and substance related disorders.	Alberta Health Services
Population characteristics (socioeconomic factors)	Unemployment Rate	percent unemployed	Canadian Census 2016
	Education (no higher education)	percent without certificate, diploma, or degree	Canadian Census 2016
	Have Family Dr	percent of population with a regular family doctor	Canadian Census 2016
	Low Income	percent of population considered low income based on low income cut off after tax	Canadian Census 2016
	Low Income (Housing Costs)	percent of owner households spending 30% or more of its income on shelter costs	Canadian Census 2016
	Dwelling Condition	percent of dwellings needing major repairs	Canadian Census 2016
	Commute Time	percent who commute more than 45 minutes	Canadian Census 2016
	Owned Dwelling	percent living in owned dwelling	Canadian Census 2016
	Gender Income Disparity	ratio of female : male average income	Canadian Census 2016 (ratio calculated)

	Gini coefficient	Measure of income inequality calculated based on average value (midpoint) for each 10k income bracket	Canadian Census 2016. *Derived variable*[4]

[1] Data from 2010 to 2018 was subsetted and the 'intersect' tool was applied to combine the wildfire data with the LGA dataset. The 'dissolve' tool was then applied using the LGA unique identifier as the dissolve field. The areas of the resulting polygons were calculated using the 'calculate geometry' tool, which were then divided by the original areas of each LGA to calculate a wildfire percent coverage per LGA.

[2] This variable was derived using the 'zonal statistics as table' tool in ArcGIS to calculate the mean CMI value for each LGA. Missing data were ignored in the calculation

[3] All monitoring sites from Alberta were included, in addition to all sites in BC that were within 100km of the Alberta-BC border. Land and water releases were processed separately using the same methods. In R statistical software, releases of cadmium, selenium, mercury, and lead from 2010 to 2019 were subsetted and pollutant quantities were converted into deciles for each of the four pollutants separately. In Arc, the 'kernel density' tool was applied to the resulting point data with the pollutant deciles as the weight function, a cell size of 1km and a search radius of 100km. The 'zonal statistics' tool was then applied to the resulting raster surface to calculate a mean pollutant value for each LGA. These methods combined all four pollutants into a single measure and gave each one an equal weighting by first standardizing their quantities into deciles.

[4] Gini coefficient calculated using midpoint for each income bracket: under 10k; 10-20k; 20-30k; 30-40k; 40-50k; 50-60k; 60-70k; 70-80k; 80-90k; 90- 100k; 100k +. For 100k + 115k was used as the midpoint.

Appendix 2. List of Indicators, Values and Rank/Percentile Scores

Table A2: Indicator Raw Values and Percentile-rank

LGA	Environmental Effects							
	Industrial Sites		Forest Harvest		Cropland		Livestock (High Density)	
	Value (% of total area)	Percentile rank	Value (% of total area)	Percentile rank	Value (% of total area)	Percentile rank	Value (% of total area)	Percentile rank
Cochrane-Springbank	0.82%	0.94	0%	0.08	36.86%	0.67	0%	0.22
Okotoks-Priddis	0.64%	0.83	0.67%	0.39	40.27%	0.72	0%	0.22
City Of Grande Prairie	8.15%	1.00	0%	0.08	52.27%	0.89	0.73%	1.00
Cardston-Kainai	0.18%	0.50	0.49%	0.28	46.77%	0.78	0.24%	0.83
Pincher Creek	0.18%	0.39	4.45%	0.50	27.45%	0.50	0.15%	0.78
Crowsnest Pass	0.03%	0.06	8.84%	0.67	2.28%	0.22	0%	0.22
Fort Macleod	0.18%	0.33	1.05%	0.44	49.47%	0.83	0.53%	0.94
Claresholm	0.11%	0.11	0.11%	0.22	66.52%	1.00	0.11%	0.72
High River	0.35%	0.72	0.07%	0.17	59.34%	0.94	0.28%	0.89
Black Diamond	0.16%	0.28	0.56%	0.33	31.07%	0.56	0.08%	0.67
Canmore	0.13%	0.17	6.30%	0.56	8.46%	0.39	0.01%	0.50
Drayton Valley	0.69%	0.89	6.60%	0.61	33%	0.61	0.02%	0.61
Rocky Mountain House	0.15%	0.22	11.45%	0.72	8.38%	0.33	0.01%	0.44
Edson	0.27%	0.61	21.56%	0.89	5.73%	0.28	0%	0.22
Grande Prairie County	0.49%	0.78	15.68%	0.78	18.89%	0.44	0.01%	0.56
Fox Creek	0.31%	0.67	22.74%	1.00	0.23%	0.17	0%	0.22
Grande Cache	0.18%	0.44	20.80%	0.83	0.01%	0.06	0%	0.22
Hinton	0.22%	0.56	22.14%	0.94	0.07%	0.11	0%	0.22

Table A2 continued

	Environmental Effects			
LGA	Landfills	Mines	Oil &Gas Well Density	Area burned by wildfire

	Value (% of total area)	Percentile rank	Value (% of total area)	Percentile rank	Value (% of total area)	Percentile rank	Value (% of total area)	Percentile rank
Cochrane-Springbank	0%	0.39	0%	0.08	0.22 wells/sq. km	0.39	0%	0.17
Okotoks-Priddis	0%	0.39	0.13%	0.39	0.13 wells/sq. km	0.28	0%	0.47
City Of Grande Prairie	0%	0.39	0%	0.08	0.36 wells/sq. km	0.50	0%	0.17
Cardston-Kainai	0%	0.39	0.18%	0.50	0.15 wells/sq. km	0.33	4.80%	1.00
Pincher Creek	0.03%	0.89	0.15%	0.44	0.07 wells/sq. km	0.11	0.50%	0.75
Crowsnest Pass	0%	0.39	0.37%	0.83	0.05 wells/sq. km	0.06	0.60%	0.89
Fort Macleod	0%	0.39	0.59%	0.94	0.1 wells/sq. km	0.17	0%	0.17
Claresholm	0%	0.39	0.06%	0.33	0.47 wells/sq. km	0.67	0%	0.17
High River	0%	0.39	0.21%	0.56	0.45 wells/sq. km	0.61	0%	0.17
Black Diamond	0%	0.39	0.32%	0.78	0.69 wells/sq. km	0.78	0%	0.39
Canmore	0%	0.39	0.03%	0.17	0.11 wells/sq. km	0.22	0%	0.47
Drayton Valley	0.05%	1.00	0.25%	0.61	2.87 wells/sq. km	1.00	0.40%	0.67
Rocky Mountain House	0.01%	0.78	0.05%	0.28	0.59 wells/sq. km	0.72	0.60%	0.83
Edson	0%	0.39	0.25%	0.72	0.98 wells/sq. km	0.94	0.10%	0.56
Grande Prairie County	0.03%	0.94	0.25%	0.67	0.73 wells/sq. km	0.83	0.60%	0.94
Fox Creek	0%	0.39	0.04%	0.22	0.77 wells/sq. km	0.89	0.50%	0.75
Grande Cache	0%	0.39	0.38%	0.89	0.41 wells/sq. km	0.56	0%	0.33
Hinton	0.01%	0.83	1.25%	1.00	0.34 wells/sq. km	0.44	0.20%	0.61

Table A2 continued

	Environmental Effects									
LGA	**Area burned by wildfire**		**Climate moisture index**		**Bird Species Richness**		**Native Plant Richness**		**Mammal Species Richness**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**
Cochrane-Springbank	0%	0.17	-43.2	0.72	38.4	0.72	62.2	0.39	47.1	0.44
Okotoks-Priddis	0%	0.47	-42	0.67	39	0.67	65.4	0.28	47.8	0.39
City Of Grande Prairie	0%	0.17	-23.3	0.56	37.8	0.78	62.6	0.33	52.2	0.17
Cardston-Kainai	4.80%	1.00	-44.8	0.78	47.2	0.33	70	0.17	50.4	0.28
Pincher Creek	0.50%	0.75	-9.4	0.33	49.9	0.28	66.6	0.22	51.2	0.22

Crowsnest Pass	0.60%	0.89	0.7	0.06	55.4	0.11	45.5	0.50	44.3	0.50
Fort Macleod	0%	0.17	-52.8	0.89	40.9	0.56	73.7	0.11	52.7	0.06
Claresholm	0%	0.17	-57	0.94	42.7	0.50	79.5	0.00	53.2	0.00
High River	0%	0.17	-51.5	0.83	43.7	0.39	76.1	0.06	52.6	0.11
Black Diamond	0%	0.39	-32.8	0.61	40.6	0.61	56.2	0.44	47.9	0.33
Canmore	0%	0.47	-5.8	0.22	58.9	0.06	44.2	0.56	35.8	0.56
Drayton Valley	0.40%	0.67	-23.3	0.50	23.1	0.94	36.6	0.72	22.7	0.72
Rocky Mountain House	0.60%	0.83	-5.6	0.17	52.7	0.22	32.5	0.94	24.2	0.61
Edson	0.10%	0.56	-19.3	0.44	36.4	0.83	34.1	0.83	20.3	0.83
Grande Prairie County	0.60%	0.94	-18.5	0.39	30.7	0.89	36.3	0.78	24.1	0.67
Fox Creek	0.50%	0.75	-7.2	0.28	43.3	0.44	33.3	0.89	17	0.94
Grande Cache	0%	0.33	4.7	0.00	61.4	0.00	37.8	0.67	17.3	0.89
Hinton	0.20%	0.61	-5.5	0.11	54.2	0.17	38.4	0.61	21.2	0.78

Table A2 continued

	Environmental Exposure							
LGA	**Peak Ozone**		**Peak PM**		**Ozone concentration (air)**		**PM concentration (air)**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**
Cochrane-Springbank	58.5 ppb	0.94	14.2 µg/cubic m	0.06	38 ppb (3 yr. average)	0.78	6.1 ug/m3 (3 yr. average)	0.50
Okotoks-Priddis	58.7 ppb	1.00	15 µg/cubic m	0.11	38.2 ppb (3 yr. average)	0.89	6.1 ug/m3 (3 yr. average)	0.44
City Of Grande Prairie	55.7 ppb	0.56	18.3 µg/cubic m	0.89	32.3 ppb (3 yr. average)	0.06	6.7 ug/m3 (3 yr. average)	0.83
Cardston-Kainai	54.9 ppb	0.28	16 µg/cubic m	0.33	36.1 ppb (3 yr. average)	0.44	5.1 ug/m3 (3 yr. average)	0.17
Pincher Creek	54.1 ppb	0.11	16.7 µg/cubic m	0.56	35.7 ppb (3 yr. average)	0.39	6.1 ug/m3 (3 yr. average)	0.39
Crowsnest Pass	54.6 ppb	0.22	16.7 µg/cubic m	0.61	35.6 ppb (3 yr. average)	0.33	6.2 ug/m3 (3 yr. average)	0.56
Fort Macleod	55.4 ppb	0.50	15.9 µg/cubic m	0.28	36.8 ppb (3 yr. average)	0.67	5.5 ug/m3 (3 yr. average)	0.22
Claresholm	55.7 ppb	0.61	16.3 µg/cubic m	0.50	36.3 ppb (3 yr. average)	0.56	5 ug/m3 (3 yr. average)	0.11
High River	57 ppb	0.83	16.1 µg/cubic m	0.44	38.1 ppb (3 yr. average)	0.83	6.3 ug/m3 (3 yr. average)	0.67
Black Diamond	57.3 ppb	0.89	15.8 µg/cubic m	0.22	38.4 ppb (3 yr. average)	0.94	5.6 ug/m3 (3 yr. average)	0.28
Canmore	56.4 ppb	0.78	16.1 µg/cubic m	0.39	38.5 ppb (3 yr. average)	1.00	7.4 ug/m3 (3 yr. average)	1.00
Drayton Valley	55.1 ppb	0.39	17.1 µg/cubic m	0.67	36.7 ppb (3 yr. average)	0.61	6.6 ug/m3 (3 yr. average)	0.78

Rocky Mountain House	55.1 ppb	0.44	17.4 µg/cubic m	0.72	37.2 ppb (3 yr. average)	0.72	6.3 ug/m3 (3 yr. average)	0.61
Edson	55.9 ppb	0.72	15.5 µg/cubic m	0.17	36.1 ppb (3 yr. average)	0.50	6.6 ug/m3 (3 yr. average)	0.72
Grande Prairie County	55.7 ppb	0.67	18 µg/cubic m	0.78	32.5 ppb (3 yr. average)	0.11	4.5 ug/m3 (3 yr. average)	0.06
Fox Creek	55 ppb	0.33	19.5 µg/cubic m	1.00	34.1 ppb (3 yr. average)	0.22	5.9 ug/m3 (3 yr. average)	0.33
Grande Cache	53.9 ppb	0.06	18.8 µg/cubic m	0.94	33.5 ppb (3 yr. average)	0.17	7.1 ug/m3 (3 yr. average)	0.89
Hinton	54.2 ppb	0.17	18.1 µg/cubic m	0.83	35.6 ppb (3 yr. average)	0.28	7.2 ug/m3 (3 yr. average)	0.94

Table A2 continued

	Environmental Exposure							
LGA	**NO2 Concentration (air)**		**SO2 Concentration (air)**		**Emissions to Water Index**		**Emissions to Land Index**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**
Cochrane-Springbank	6.3 ppb (3 yr. average)	0.89	0.32 ppb (3 yr. average)	0.67	0.51 (higher = more emissions)	0.83	0.09 (higher = more emissions)	0.61
Okotoks-Priddis	5.6 ppb (3 yr. average)	0.61	0.21 ppb (3 yr. average)	0.50	0.61 (higher = more emissions)	0.89	0.04 (higher = more emissions)	0.44
City Of Grande Prairie	7.4 ppb (3 yr. average)	1.00	0.2 ppb (3 yr. average)	0.44	0.12 (higher = more emissions)	0.56	0.17 (higher = more emissions)	0.83
Cardston-Kainai	5.6 ppb (3 yr. average)	0.56	0.09 ppb (3 yr. average)	0.17	0.01 (higher = more emissions)	0.06	0.18 (higher = more emissions)	0.89
Pincher Creek	4.4 ppb (3 yr. average)	0.06	0.32 ppb (3 yr. average)	0.72	0.26 (higher = more emissions)	0.61	0.01 (higher = more emissions)	0.17
Crowsnest Pass	4.7 ppb (3 yr. average)	0.17	0.35 ppb (3 yr. average)	0.89	0.69 (higher = more emissions)	1.00	0 (higher = more emissions)	0.06
Fort Macleod	5.4 ppb (3 yr. average)	0.50	0.14 ppb (3 yr. average)	0.33	0.06 (higher = more emissions)	0.28	0.08 (higher = more emissions)	0.56
Claresholm	5.2 ppb (3 yr. average)	0.44	0.14 ppb (3 yr. average)	0.39	0.08 (higher = more emissions)	0.39	0.01 (higher = more emissions)	0.22
High River	4.6 ppb (3 yr. average)	0.11	0.02 ppb (3 yr. average)	0.06	0.4 (higher = more emissions)	0.78	0 (higher = more emissions)	0.11
Black Diamond	5 ppb (3 yr. average)	0.28	0.25 ppb (3 yr. average)	0.56	0.61 (higher = more emissions)	0.94	0.02 (higher = more emissions)	0.39
Canmore	4.8 ppb (3 yr. average)	0.22	0.12 ppb (3 yr. average)	0.22	0.28 (higher = more emissions)	0.72	0.12 (higher = more emissions)	0.72
Drayton Valley	6.3 ppb (3 yr. average)	0.94	0.35 ppb (3 yr. average)	0.83	0.07 (higher = more emissions)	0.33	0.02 (higher = more emissions)	0.33
Rocky Mountain House	5 ppb (3 yr. average)	0.39	0.38 ppb (3 yr. average)	1.00	0.01 (higher = more emissions)	0.11	0.05 (higher = more emissions)	0.50
Edson	6.2 ppb (3 yr. average)	0.83	0.37 ppb (3 yr. average)	0.94	0.09 (higher = more emissions)	0.50	0.47 (higher = more emissions)	0.94

Grande Prairie County	5.9 ppb (3 yr. average)	0.78	0.31 ppb (3 yr. average)	0.61	0.08 (higher = more emissions)	0.44	0.12 (higher = more emissions)	0.78
Fox Creek	5 ppb (3 yr. average)	0.33	0.13 ppb (3 yr. average)	0.28	0.03 (higher = more emissions)	0.22	0.11 (higher = more emissions)	0.67
Grande Cache	5.8 ppb (3 yr. average)	0.72	0.06 ppb (3 yr. average)	0.11	0.02 (higher = more emissions)	0.17	0.01 (higher = more emissions)	0.28
Hinton	5.6 ppb (3 yr. average)	0.67	0.33 ppb (3 yr. average)	0.78	0.26 (higher = more emissions)	0.67	0.57 (higher = more emissions)	1.00

Table A2 continued

	Population Characteristics (sensitive populations)									
LGA	**Drinking (Binge)**		**Overweight**		**Health (Self-reported)**		**Low Birthweight**		**Mental Health (Emergency Visits)**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**
Cochrane-Springbank	11.70%	0.11	51.90%	0.17	74.40%	0.00	7.90%	0.89	0.33	0.33
Okotoks-Priddis	13.10%	0.50	55.80%	0.28	66.80%	0.11	6%	0.44	0.36	0.36
City Of Grande Prairie	13.20%	0.61	66.30%	1.00	56.60%	0.89	5.50%	0.33	0.58	0.58
Cardston-Kainai	10.50%	0.06	60.30%	0.56	60.60%	0.50	6.60%	0.75	0.71	0.71
Pincher Creek	14.30%	0.89	59.50%	0.50	64.50%	0.28	5.10%	0.25	0.71	0.71
Crowsnest Pass	13.10%	0.44	60.50%	0.61	62.20%	0.39	6.10%	0.53	0.78	0.78
Fort Macleod	12.70%	0.33	62.80%	0.72	61.50%	0.44	6.60%	0.75	0.42	0.42
Claresholm	12.20%	0.28	53.90%	0.22	66.30%	0.22	4.70%	0.14	0.69	0.69
High River	12%	0.17	56%	0.33	64.20%	0.33	5.10%	0.25	0.52	0.52
Black Diamond	14%	0.78	51.50%	0.11	66.70%	0.17	6.20%	0.61	0.54	0.54
Canmore	14.30%	0.83	43.20%	0.06	71.40%	0.06	8.60%	1.00	0.37	0.37
Drayton Valley	13.10%	0.56	57.20%	0.39	56.90%	0.83	8.20%	0.94	0.35	0.35
Rocky Mountain House	15.80%	1.00	57.50%	0.44	56.40%	0.94	5.80%	0.39	0.67	0.67
Edson	13.30%	0.67	64.10%	0.83	57%	0.78	6.70%	0.83	0.45	0.45
Grande Prairie County	12.10%	0.22	65.40%	0.89	57.90%	0.72	6.50%	0.67	0.22	0.22
Fox Creek	13%	0.39	62.30%	0.67	58.30%	0.67	4.10%	0.06	0.51	0.51
Grande Cache	13.60%	0.72	63.40%	0.78	59.20%	0.61	6.10%	0.53	0.79	0.79
Hinton	15.10%	0.94	65.70%	0.94	59.60%	0.56	4.70%	0.14	0.5	0.50

Table A2 continued

	Population characteristics (socioeconomic factors)							
LGA	**Unemployment Rate**		**Education (no certificate, degree, or diploma)**		**Have Family Dr**		**Low Income**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**
Cochrane-Springbank	7.60%	0.33	4.40%	0.06	87.10%	0.06	2.80%	0.11
Okotoks-Priddis	7.50%	0.28	6.20%	0.11	86.50%	0.11	2.90%	0.17
City Of Grande Prairie	9.60%	0.61	13.80%	0.33	74.70%	0.83	5.10%	0.94
Cardston-Kainai	9.70%	0.67	15.70%	0.61	87.50%	0.00	5.50%	1.00
Pincher Creek	10%	0.75	15.90%	0.67	82.30%	0.44	3.90%	0.58
Crowsnest Pass	8.90%	0.47	14%	0.39	84.50%	0.28	3.20%	0.33
Fort Macleod	5.40%	0.06	16.70%	0.78	79%	0.50	4.20%	0.69
Claresholm	5.80%	0.11	14.70%	0.50	83.90%	0.33	3.60%	0.44
High River	7.40%	0.22	11.40%	0.22	85.80%	0.17	3.10%	0.28
Black Diamond	10%	0.75	14.60%	0.44	84.90%	0.22	3.70%	0.50
Canmore	8.30%	0.39	10.40%	0.17	83.80%	0.39	4.50%	0.81
Drayton Valley	11.70%	0.89	18%	0.83	76.50%	0.61	4.50%	0.81
Rocky Mountain House	12.80%	0.94	18.50%	0.89	65.70%	0.89	4.20%	0.69
Edson	10.10%	0.83	18.90%	0.94	64.70%	0.94	3.90%	0.58
Grande Prairie County	8.90%	0.47	16.20%	0.72	75%	0.78	3.40%	0.39
Fox Creek	9.50%	0.56	19.90%	1.00	75.40%	0.67	3%	0.22
Grande Cache	13.10%	1.00	13.30%	0.28	77.40%	0.56	5%	0.89
Hinton	7.30%	0.17	15.30%	0.56	75%	0.72	2.10%	0.06

Table A2 continued

	Population characteristics (socioeconomic factors)					
LGA	**Low Income (Housing Costs)**		**Dwelling Condition**		**Commute Time**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**

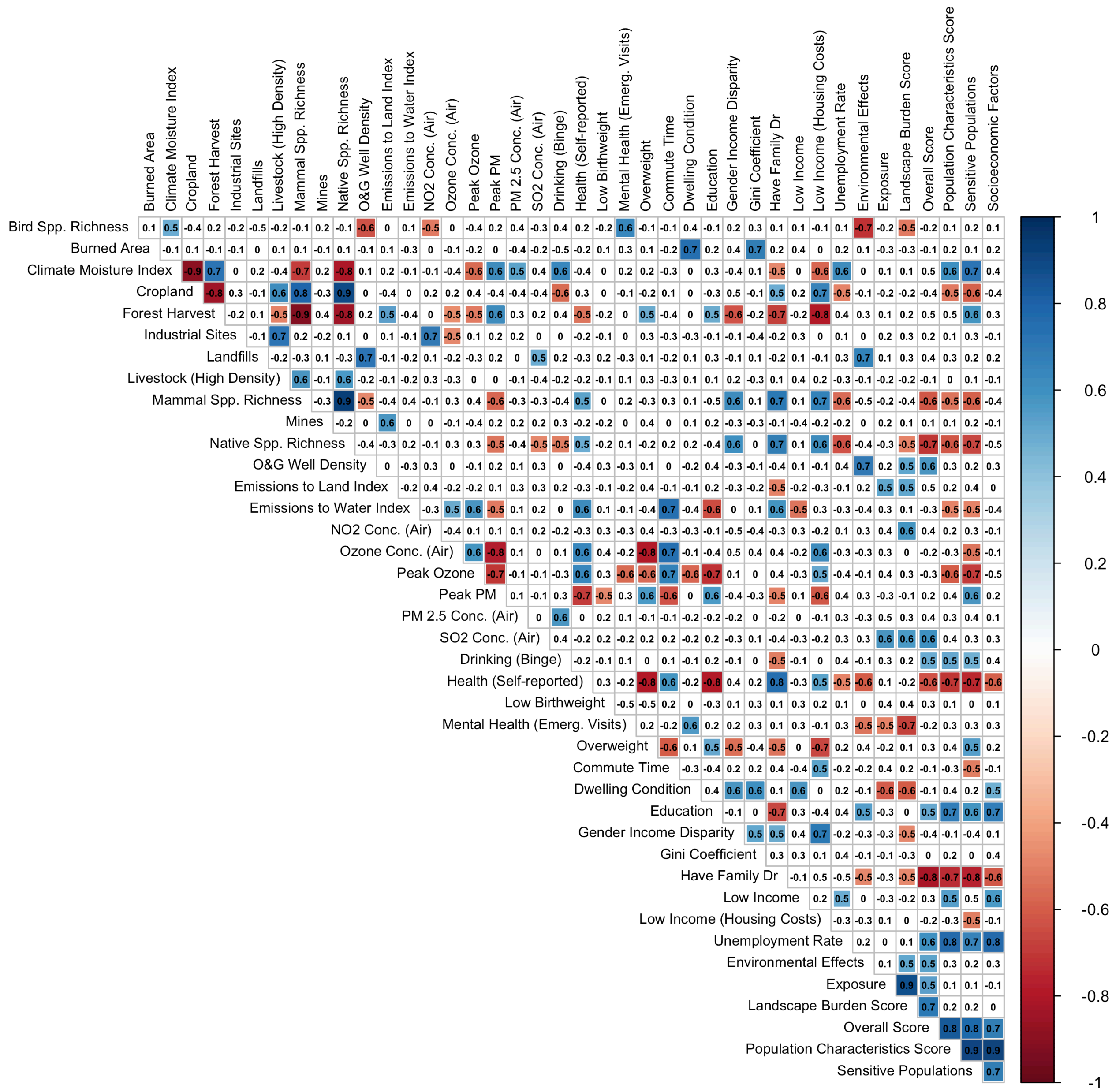
Cochrane-Springbank	13.10%	0.44	2.70%	0.06	24.70%	0.94
Okotoks-Priddis	15.60%	0.78	2.80%	0.11	23.40%	0.89
City Of Grande Prairie	13.90%	0.58	4.50%	0.17	6.90%	0.06
Cardston-Kainai	14.10%	0.67	20.80%	1.00	12.70%	0.33
Pincher Creek	13.40%	0.50	15%	0.94	11.70%	0.28
Crowsnest Pass	10.60%	0.17	8.80%	0.72	17.90%	0.72
Fort Macleod	13.90%	0.58	11.30%	0.83	13.60%	0.39
Claresholm	17.20%	0.94	8.60%	0.67	14.50%	0.44
High River	16.70%	0.83	6.10%	0.22	19.80%	0.83
Black Diamond	17.80%	1.00	8.50%	0.56	39%	1.00
Canmore	17.10%	0.89	8.60%	0.61	18.40%	0.78
Drayton Valley	12.90%	0.39	7.20%	0.44	14.60%	0.50
Rocky Mountain House	14.20%	0.72	9%	0.78	16.10%	0.67
Edson	10.90%	0.22	7.90%	0.50	16%	0.56
Grande Prairie County	11.80%	0.33	7.20%	0.39	11.60%	0.22
Fox Creek	5.90%	0.06	6.10%	0.28	9.50%	0.17
Grande Cache	9.70%	0.11	11.50%	0.89	9.20%	0.11
Hinton	11%	0.28	7%	0.33	16.10%	0.61

Table A2 continued

	Population characteristics (socioeconomic factors)					
LGA	**Owned Dwelling**		**Gender Income Disparity**		**Gini coefficient**	
	Value (% of total area)	**Percentile rank**	**Value (% of total area)**	**Percentile rank**	**Value (% of total area)**	**Percentile rank**
Cochrane-Springbank	88.80%	1.00	0.53	0.56	0.403	0.56
Okotoks-Priddis	86.50%	0.89	0.58	0.44	0.407	0.67
City Of Grande Prairie	65.10%	0.06	0.56	0.50	0.373	0.06
Cardston-Kainai	77.80%	0.44	0.83	0.06	0.452	1.00
Pincher Creek	78.20%	0.50	0.81	0.11	0.425	0.94
Crowsnest Pass	81.80%	0.72	0.53	0.61	0.414	0.78
Fort Macleod	80.30%	0.61	0.67	0.28	0.38	0.22

Claresholm	77.80%	0.39	0.72	0.17	0.38	0.17
High River	80.90%	0.67	0.67	0.33	0.388	0.33
Black Diamond	82.50%	0.78	0.69	0.22	0.41	0.72
Canmore	69.40%	0.11	0.84	0.00	0.417	0.83
Drayton Valley	83.80%	0.83	0.52	0.67	0.406	0.61
Rocky Mountain House	79.70%	0.56	0.6	0.39	0.419	0.89
Edson	76.70%	0.33	0.51	0.78	0.396	0.50
Grande Prairie County	87.90%	0.94	0.52	0.72	0.382	0.28
Fox Creek	73.60%	0.17	0.46	0.89	0.396	0.44
Grande Cache	76%	0.28	0.46	0.94	0.393	0.39
Hinton	74.80%	0.22	0.49	0.83	0.378	0.11

Appendix 3. Correlation plot between all included indicators*



*Significant relationships between indicators appear in highlighted cells, where Pearson's R is 0.5 or higher and where p<0.05