Alberta Foothills Cumulative Effects Assessment

Phase 2 Project Report

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Abstract

This report shares key findings from an assessment of cumulative environmental, community and health effects across the Alberta Foothills. Specifically, it reports on methodological innovations undertaken in the creation of the Alberta Foothills Cumulative Effects Screening Tool, or the ABFoothillsEnviroScreen. This report is part of a multi-year study of cumulative effects in the Alberta Foothills. More information on the project rationale and key findings from Phase 1 research, which specified indicator selection processes and the analytics procedure for computing cumulative effects scores can be found here. This report shares insights from Phase 2, which was oriented towards engaging potential knowledge users to beta test the tool, statistically validate the model by reducing available indicators to more appropriately fit the data, and a number of innovations to the tool, including the addition of a historical analysis feature, a sub-watershed unit of analysis toggle, and a indicator selection tool that allows users to explore data by creating their own version of an EnviroScreen model. Core results are shared from the Phase 2 assessment and put in conversation with initial findings from Phase 1. Implications for future research are discussed. Appended to this report are a user guide and walk-through scenarios to demonstrate the potential use cases for the tool.

To explore the tool as you read this report, see:

https://planetaryhealth.shinyapps.io/Foothills_Enviro_Screen/

1.0 Introduction

1.1 Study Overview

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 including oil and gas exploration, development and transportation (i.e. pipelines), mining, forestry operations, electricity transmission projects, industrial agriculture, ranching and related supporting land-uses. Increasingly, there is recognition that multiple land-uses and land-use interactions between various industries can leave lasting legacy impacts for environments, communities and human health.

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] In 2019, the new *Impact Assessment Act* broadened the purview of conventional approaches to impact assessment beyond the narrow focus on environmental conditions identified in the above quotation 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 is what is referred to as the 'integration imperative'—the necessary merging of environmental, community and health values into a more comprehensive understanding of 'impact'.[2]

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 all sectors, and requires consideration of large spatial regions to overcome identified limitations of environmental impact assessments of a singular project.[3] This is why many researchers and impact assessment practitioners increasingly assert that cumulative impacts are best addressed through regional assessment processes, rather than in single project environmental impact assessments which are typically scoped only in terms of impact from the physical footprint of a particular project or land-use. 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, with a specific focus on the Alberta Foothills.

1.1.1 Phase 1 Overview

Phase 1 initiated the assessment of cumulative impacts and drew from emerging international best practices in impact assessment to develop a geospatial tool capable of quantifying cumulative environmental, community and health impacts, in keeping with the broad strategic goals of the *Impact Assessment Act, 2019.* Specifically, Phase 1 involved:

- Reviewing environmental assessment reports under the old Canadian Environmental Assessment Act of 2012 from designated projects within the study area to understand past conceptualizations of cumulative impacts relevant to the Alberta Foothills, and to identify relevant indicators;
- Source data to populate those indicators;

- Create a geospatial interface (e.g. a ShinyApp) capable of merging environmental, community and health impacts of multiple land-uses, while also enabling the synthesis of that information to communicate the state of cumulative effects across the Alberta Foothills. The result was the creation of the Alberta Foothills EnviroScreen Cumulative Effects Screening Tool.

Phase 1 ran from September 2020 – March 2021. The Phase 1 project report[4] shares key findings from this research, including known sensitive areas, species at risk, past research on cumulative effects,[5–9] results from the review of Environmental Impact Assessment documents, and findings from this first of its kind integrative assessment of cumulative effects for the Alberta Foothills. It also clearly outlines the methodological orientation to calculating indexed cumulative effects values based on the CalEnviroScreen method developed by the California Environmental Protection Agency.[10]

1.1.2 Phase 2 Objectives

The Phase 1 research process identified several important potential future opportunities to refine the newly created measurement model and cumulative effects screening tool. These included, but were not limited to:

1. Improving the spatial granularity of the model where possible;
2. Assessing change to included indicators through the creation of a historical baseline;
3. Ground-truthing the tool and associated data with Indigenous and settler communities to source additional data and explore future use cases for the tool;
4. Conducting case study research on the most impacted areas identified by the screening tool; and
5. Aspirationally, modeling potential assets through original data collection in partnership with impacted communities, stakeholders and rightsholders to move beyond a 'detriments' framing of impact.

2.0 Research Methods

An array of research methods were deployed to engage communities, statistically validate the model developed in Phase 1, and to source and display additional data and information imputed into the ABFoothillsEnviroScreen tool. The Phase 1 report outlines the process and rationale for calculating EnviroScreen scores (and additional sub-indices referenced within this report). Readers who are interested in the mechanics of the model should consult the Phase 1 report for further information.

2.1 Public Engagement Process

Recognizing some of the engagement challenges that were posed in Phase 1, particularly due to the COVID-19 pandemic, a core thrust of the Phase 2 workplan was to undertake a series of engagement activities to ground-truth the model from Phase 1, explore the use case for the tool, and hear recommendations for strengthening the tool.

2.1.1 Engagement with Indigenous Communities

Numerous Indigenous communities have both present and traditional/ancestral connections to the Alberta Foothills. Following the engagement protocols established in Phase 1, the study team conducted three waves of engagement between November 2021 and March 2022, reaching out to Indigenous, First Nations and Métis organizations and communities located across the study area. In total 23 communities were contacted via email or telephone. The first contact point was initiated in November 2021 to brief communities and nations on the continuation of this project, share findings to date, and invite interested community members to engage with the project team. The second contact point was in December 2021 to invite community members to two in-person workshops to learn about the tool. An option was also given to connect one-on-one to discuss this work, and the study team participated in several in-person meetings with interested communities to learn more about their interests in the tool, possible uses moving forward, and opportunities to enhance the tool. A third contact point was initiated in March 2022 to invite community members to participate in two public and freely accessible training workshops (described below). Contacts were also given the option to meet with the study team one-on-one.

2.1.2 Engagement with the Public

Four free-to-attend and publicly accessible workshops were held with the intention of 1) sharing key insights from the project to date; 2) sharing the tool and receiving feedback on potential future improvements; and 3) exploring the use case for the tool to inform decision-making. The first two workshops were held on December 14th and 16th, primarily with goal of ground-truthing data and indicators, exploring findings, and receiving feedback from interested stakeholders and rightsholders located across the study region. Two additional workshops were held on March 29th and 31st to share the findings from Phase 2, and provide a training opportunity on how to use the tool to examine cumulative effects across the Foothills. Invitations were circulated among the Phase 1 Advisory Committee, and via referral methods through municipalities, Indigenous organizations and communities, local economic development agencies, environmental organizations, municipalities, and watershed organizations. Invited participants were encouraged to share the invitation with their members and anyone else they thought may be interested in attending, resulting in nearly 200 unique registrations across all workshops (see Table 1). The study team also met one-on-one with a variety of interested individuals and organizations to share the tool, project results, and learn about opportunities to which the tool could be utilized in practice.

Table 1. Registration and Attendance at Community-Engaged Workshops

Workshop Date	Registered	Attended
December 14, 2022	55	39
December 16, 2022	51	42
March 29, 2022	48	33
March 31, 2022	42	31

2.1.3 Limitations

While significant efforts were made to engage relevant potential knowledge users of the tool, public engagement is always an incomplete and on-going process. The largest limitation of the study team's engagement was the COVID-19 pandemic. The study team made intentional decisions not to run in-person sessions for the safety of participants and researchers alike. Challenges of 'zoom fatigue' (i.e. a sense of exhaustion experienced from participating in numerous virtual/digital calls) may have limited the reach of the public sessions hosted during this project. Nonetheless, the study team took efforts to share this work with multiple interested parties when opportunities were presented.

2.2 Model Validation Procedures

2.2.1 Process

Model validation utilized a series of dimension reduction procedures to (e.g. principal components analysis, factor analysis) to understand how the suite of available indicators represented latent concepts present in the data. The process of validating the model started with exploratory principal components analysis, whereby each of the environmental, community (i.e. socioeconomic) and health indicator data were analyzed and interpreted together. Using existing best-practices, the study team set Eigenvalue cut-offs to 1.0, and factor extraction scores to greater than 0.7 to determine which variables to include, and then explored model structure and factor loadings. This resulted in a potential 6-factor solution that required additional data reduction.

Given the shear breadth of available data, the team opted to increase the cut-offs of Eigenvalues to 2.0, keeping factor extraction scores to greater than 0.7. This resulted in a much simpler four-factor solution to enhance the legibility and usability of the data. Confirmatory factor analysis was then conducted on each latent concept of interest to further validate the composition of indicators. Once confirmed, the study team moved forward with a four-factor solution that differed from the original conceptualization put forward by the CalEnviroScreen—the methodology that served as the basis for Phase 1's analysis and measured four latent concepts including environmental exposures, environmental effects, socioeconomic marginalization and sensitive populations. The four factors measured by the data in the ABFoothills were found to measure the following components based on how they fit the data:

- **Pollution**: multiple types of anthropogenic emissions to land, air and water
    - *Measures*:
        - Peak ozone; lead in air; nitrogen dioxide annual average concentration; annual average particulate matter concentration; pollutant releases to land; pollutant releases to water

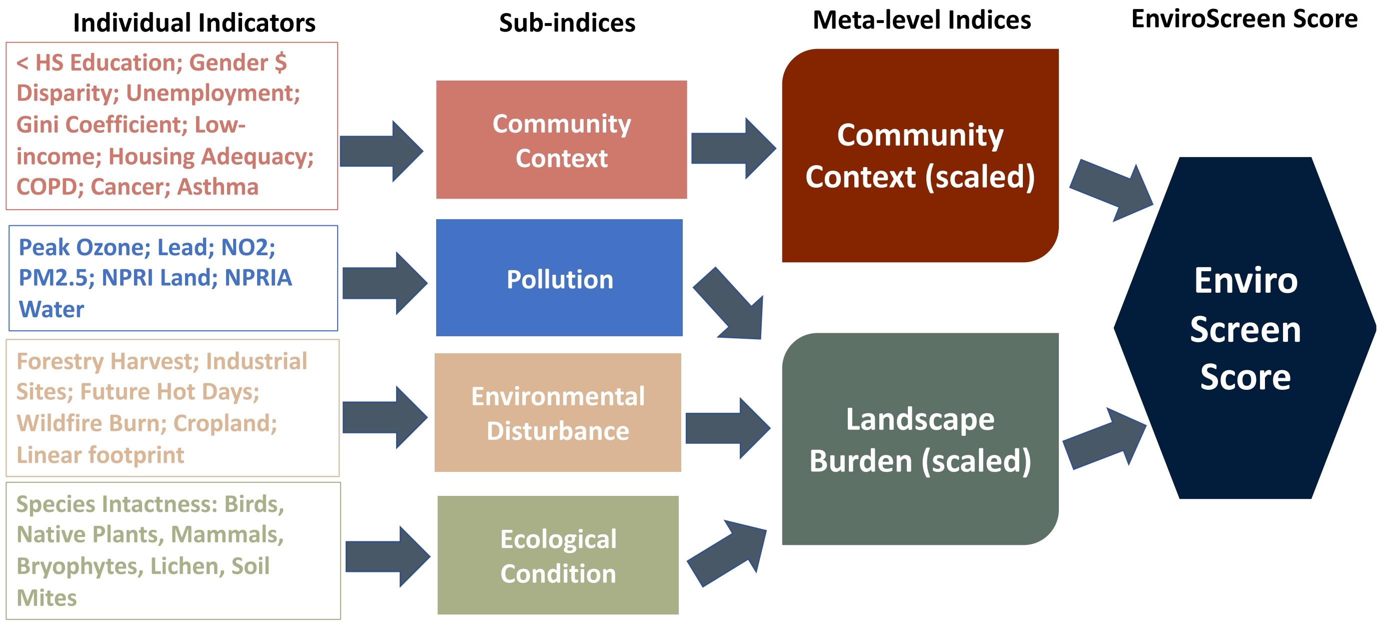
- **Environmental change**: physical changes or alterations to the landscape from various land uses and climate change indicators
    - *Measures*:
        - Forestry harvest; industrial sites; future hot days; wildfire burn area; cropland; linear footprint.

- **Ecological context**: a composite measure of the species richness of plants, mammals, birds, lichen, moss and soil mites
    - *Measures*:
        - Bird species intactness, native plant species intactness, mammal species intactness, bryophyte species intactness, lichen species intactness, soil mites species intactness

- **Community context**: a composite measure of socioeconomic and health data
    - *Measures*:
        - Proportion of population with less than high school education; gender income disparity; unemployment rate; gini coefficient; housing adequacy; chronic obstructive pulmonary disorder prevalence; all-cause cancer mortality; asthma incidence rate

Figure 1 depicts how individual indicators are scaled into their respective indices. The phase 1 report should be consulted for all associated calculations and descriptions of limitations associated with the computational methods, and the meta-data for specific indicators, including data links has been made available in Appendix 1. All indicators and indices are equally weighted.

Figure 1. Graphical depiction of the relationships between individual indicators, computed sub-indices and meta-level indices, and resulting EnviroScreen scores



2.3 Re-design of the ABFoothills EnviroScreen ShinyApp (Version 2)

2.3.1 Process

Based on the research objectives listed above, and feedback provided by participants engaged over the 2 years of implementing this project, Phase 2 included several changes to the graphical interface (i.e. the ShinyApp) that acts as the data portal for the ABFoothillsEnviroScreen tool. Four specific changes were made to the tool in Phase 2:

1) Creation of a geospatial toggle that allows users to change from viewing measured indicators and indices at the level of local geographic areas (N=18) to that of sub-watersheds (N=34). This resulted in a more granular depiction of ecological variables. The within province comparison compares only rural and remote Local Geographic Areas (LGAs) across Alberta (i.e. it omits urban LGAs comprising Lethbridge, Calgary, Red Deer and Edmonton given that urban land uses differ considerably and are associated with different relationships to environmental change, pollution and ecological condition). LGAs serve as the unit of analysis for this study. They are a geographic classifier similar to municipalities, and are the lowest level of analysis for which health information is made publicly available.

2) Creation of a historical baseline toggle that allows users to toggle information from the most current data, to an established historical baseline for all available data in 2010. Users are also able to display any indicator

or calculated index as a value of percent change relative to the historical baseline to determine how values vary across time.

3) Creation of a raw value toggle that allows users to toggle information to see the raw values for all indicators relative to the percentile rank standardization feature which all indicators undergo to compute each respective index. This enables users to further analyze indicators to overcome the limitation named in the Phase 1 report where the percentile rank transformation can unnecessarily inflate relatively small differences in the data for indicators with a low range of overall values. The raw value tool enables users to explore individual indicators based on raw values to understand if and how values are being artificially inflated through transformation.

4) A ‘select indicators’ tool was created that enables users to select from the broader suite of data embedded in the tool to create their own version of an EnviroScreen model and explore data therein. This feature will not necessarily produce statistically validated results and so should be used with caution, but the tool was identified by knowledge users as a helpful way to model different relationships between variables that serve different knowledge needs from diverse organizations and users. A warning is embedded above the tool to communicate to users that enabling this functionality will create a model that has not been statistically validated (i.e. the base or default model which is automatically projected upon loading the tool).

2.3.2 Limitations

A full articulation of the limitations of the tool are articulated in the Phase 1 report. In relation to the changes referenced above, there are several limitations that require mention. First, the sub-watershed toggle is only available for ecological indicators measuring the three sub-indices measuring different aspects of the environment (i.e. the landscape burden meta-level index, as well as the pollution, environmental change, and ecological context sub-indices). The lowest level of analysis that health data is publicly reported is that of local geographic areas, and for that reason, the tool is unable to compute a community context score or display health and census data at the sub-watershed level.

Second, the historical analysis feature only goes back as far as 2010. This is primarily related to the data sets being utilized and the relatively recent move towards open data that has enabled the development of the tool. Many datasets that are publicly available (notwithstanding the Canadian census) only go back several years. The study team compared available collection years for datasets that are regularly updated and deemed 2010 to be one of the only years where the entire suite of data were available to be modeled using this method. The ability of the tool to make historical comparisons will improve if additional years of data become available and are input into the tool. However, it should be noted that 2010 is not a pre-disturbance baseline, but rather a ‘degraded baseline’, meaning there are already cumulative impacts present across the study region. Future modeling work could attempt to understand change relative to pre-industrial or undisturbed landscapes for ecological variables, although the idea of ‘pristine’ landscapes is not applicable to socioeconomic or health values. Thus, historical comparisons should be interpreted with caution, as the 2010 analysis includes the cumulative effects that occurred prior to 2010.

Third, the ‘select indicators’ tool, as referenced above, will not produce statistically validated models, as the default model is the only version that fit the data currently embedded in the tool. Thus, results should be interpreted with caution when using this feature. Moreover, in order to calculate an EnviroScreen score, at least one indicator from each sub-index will need to be selected.

3.0 Results

This section reports on the results of the newly created ABFoothills EnviroScreen tool. The results are displayed according to key findings from public engagement before sharing results from the newly created sub-indices, meta-level indices and overall EnviroScreen scores. Results are also presented at the sub-watershed level and from the historical analysis to add a temporal dimension of understanding to cumulative impacts present across the Alberta Foothills. Results are primarily communicated at a general level of analysis for findings across the Foothills and we encourage readers to actively utilize the tool to explore specific data points of interest using the features embedded within the tool.

3.1 Public engagement: What we heard

Our engagement sessions illuminated the significant and on-going interest and attention dedicated to environmental, socioeconomic and health issues for people who live, work and play across the Alberta Foothills. The initial public engagement relied on sharing the model developed in Phase 1, and workshop participants were keen to see other valued components more adequately integrated into the data portal. Specific interests included water licensing, impacts on diverse species, fish species, and linear density--a composite measure of any linear feature constructed on a landscape (e.g. power lines, roads, railways, pipelines).

To attend to these indicators, the study team reviewed additional data leads. We found that some water licensing information is available for only a limited portion of the southern reaches of the study area through Alberta's Water License Viewer. Given the limited data and lack of comprehensive data collection, this indicator was not included and once the License Viewer data displays comprehensive information for the entire province, it could provide act as a highly informative variable to include in the screening tool.

We worked with staff from the Alberta Biomonitoring Institute (ABMI) to source additional information on diverse species, and included several additional measures to more adequately portray the ecological context of the Alberta Foothills. These indicators included bird, mammal and native plant species intactness, as well as metrics for bryophytes, lichens, mosses and soil mites. We were unable to find comprehensive data sets for the health and availability of fish species across the study area. ABMI also shared linear features data, which was flagged as a highly useful variable for land use planning and conservation perspectives, and a proxy for habitat continuity and connectivity. The study team incorporated several features of linear density: roads, transmission lines, railways and pipelines, as well as a comprehensive measure that was the sum total of each individual linear measure. The composite measure was retained in the statistically validated model.

Participants flagged other limitations associated with the tool, including the need for a temporal element (now included), interest in thinking through multiple weighting regimes for specific indicators which is beyond the scope of this project in its current iteration, and the need to explore different geographies. Geographic tensions about data availability and granularity of data also featured prominently, and despite numerous experts indicating that the nature of cumulative effects is such that they best lend to being assessed at regional or large landscape levels, participants were still interested in high resolution location data such as specific stream crossings or wetlands. To reconcile these tensions, the study team has created opportunities for data to be linked and downloaded so that users can utilize point and more granular rastor data to answer specific questions, and also created a sub-watershed scale of analysis for ecological variables as a compromise in wanting to depict more granular data at a more meaningful, discrete and bounded bio-geophysical unit of analysis. We also explore these possibilities in the discussion section, below.

In general, participants saw multiple uses for the tool, and recognized the challenge of trying to have a tool that represents a whole spectrum of land-use interests. Potential uses were particularly related to the governance of natural resources through processes such as environmental impact assessment, but also for land-use planning processes, the designation of protected areas, public education and engagement processes, and the comprehensive assessment of watershed health. Overall, feedback was generally positive about the degree of integration and usability of the tool as an initial step in screening cumulative effects.

3.2 EnviroScreen Sub-indices

EnviroScreen sub-indices are the lowest order indices of composite measures for ecological and social indicators that can scale up to represent cumulative effects. The results of sub-index calculations are presented in Table 2 and are descriptively characterized in corresponding subsections below. Table 2 color codes the resulting scores according to terciles:

- Red: Highest tercile, suggests the highest overall impact
- Yellow: Middle tercile, suggests moderate overall impact
- Green: Lowest tercile, suggests lowest overall impact

Table 2. Sub-index scores for EnviroScreen components for all Local Geographic Areas in the Alberta Foothills Organized North to South

Local Geographic Areas (North to South)	Sub-Indices			
	Community Context	Pollution	Environmental Disturbance	Ecological Condition
City of Grande Prairie	0.47	0.43	0.46	0.94
Grande Prairie County	0.53	0.61	0.66	0.44
Grande Cache	0.72	0.33	0.30	0.10
Fox Creek	0.70	0.56	0.54	0.16
Hinton	0.40	0.50	0.45	0.20
Edson	0.63	0.49	0.48	0.33
Drayton Valley	0.68	0.97	0.62	0.67
Rocky Mountain House	0.72	0.55	0.44	0.28
Canmore	0.34	0.58	0.31	0.16
Cochrane-Springbank	0.25	0.45	0.44	0.85
Okotoks-Priddis	0.30	0.65	0.55	0.73
Black Diamond	0.53	0.48	0.39	0.56
High River	0.30	0.38	0.52	0.73
Crowsnest Pass	0.66	0.33	0.46	0.00
Claresholm	0.41	0.41	0.41	0.81
Pincher Creek	0.67	0.22	0.55	0.40
Fort Macleod	0.48	0.49	0.51	0.62
Cardston-Kainai	0.61	0.41	0.68	0.52

3.2.1 Community Context

Community context scores are a composite measure of socioeconomic marginalization and human health. While each of these two components was separated in the Phase 1 analysis, the dimension reduction analysis identified that the included variables in the model were best grouped together in that they all collectively measure the underlying latent concept of community context. The results in Table 2 illustrate that LGAs bordering the city of Calgary were among the lowest scoring regions, suggesting that proximity to major urban areas tends to result in better access to services, better overall health outcomes and more economic opportunities relative to rural areas. Rocky Mountain House and Grande Cache are projected to be among the highest scoring LGAs, followed closely by Fox Creek Drayton Valley, Pincher Creek and Crowsnest Pass, suggesting these LGAs have higher degrees of socioeconomic marginalization and ill-health outcomes.

3.2.2 Pollution

Pollution is a composite measure of emissions to land, air and water. Drayton Valley was found to have the highest pollution score of all LGAs. This is potentially reflective of the long tenure of oil and gas, and other forms of industrial land use present in that LGA. Only three LGAs fell into the lowest tercile of pollution score: Grande Cache, Crowsnest Pass and Pincher Creek, suggesting the lowest levels of human emissions to land, air and water in these LGAs. Most LGAs fell into the second tercile of impact from pollution when compared to all other LGAs, although within provincial comparison reveals lower overall scores compared to the rest of LGAs across the province.

3.2.3 Environmental Change

Environmental change is a composite measure of anthropogenic disturbance to the landscape and future climate change. Environmental disturbance scores resulted in Grande Prairie County and Cardston-Kainai as having the highest scores, and Canmore as having the lowest. Environmental change had the smallest overall range of all sub-indices, where the difference between the smallest and highest score was 0.36. Most LGAs fell in the middle tercile of impact.

3.2.4 Ecological Condition

Ecological condition is a composite measure of the intactness of multiple types of species (i.e. mammals, birds, native plants, lichens, bryophytes, mosses and soil mites). This indicator is the clearest indicator of the robustness of local environments in the face of the disturbance types listed above, and signals the relative health of natural systems and processes as being relatively high across the Alberta Foothills. Urban and peri-urban LGAs that include the City of Grande Prairie, Cochrane-Springbank, and Okotoks-Pridis, in addition to High River and Claresholm, had the highest scores, suggesting that the high degree of landscape alteration in these areas results in lower overall levels of native species. However, seven LGAs fell in the lowest tercile of impact for this indicator.

3.3 EnviroScreen Meta-level 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 3 displays the computational results for these indices as compared to all LGAs within the sample, and also the meta-level index scores relative to the rest of the province, which are elaborated upon in the corresponding sub-sections below. Results are also discussed in terms of the changes in meta-level index scores relative to the Phase 1 groupings of indicators.

3.3.1 Landscape Burden

Landscape burden is a composite measure of the three environmental sub-indices described above. It can be thought of as an overall measure of landscape health in relation to all other LGAs or sub-watersheds. Drayton Valley had the highest landscape burden score at the LGA level, corresponding with findings from the Phase 1 analysis. Notwithstanding Drayton Valley, Fort Macleod and Cardston-Kainai, urban and peri-urban LGAs tended to have higher landscape burden scores which is reflective of larger processes of urbanization and their impacts on local environments. Crowsnest Pass had the lowest overall landscape burden score, although it is worth nothing that most LGAs bordering the eastern slopes of the Rocky Mountains tended to have lower overall landscape burden scores, likely as a product of their overlap with and proximity to protected areas that limit development.

Table 3. EnviroScreen meta-level indices and overall scores for LGAs within the Alberta Foothills study region and compared provincially

Local Geographic Areas (North to South)	Meta-Level Indices Score (Range 0-10)		EnviroScreen Score (Within Foothills Comparison) (Range 0-100)	EnviroScreen Score (Within Provincial Comparison) (Range 0-100
	Landscape Burden Score	Population Characteristics Score		
City of Grande Prairie	9.5	6.5	62.3	46.5
Grande Prairie County	8.6	7.3	63	33.6
Grande Cache	3.6	10.0	36.1	22.2
Fox Creek	5.6	9.8	54.9	32.7
Hinton	5.9	5.5	32.7	24.8
Edson	6.9	8.7	60.2	36.7
Drayton Valley	10.0	9.4	94	55.9
Rocky Mountain House	6.4	10.0	64.1	34.9
Canmore	4.2	4.8	20	13.3
Cochrane-Springbank	9.0	3.5	31.7	20.1
Okotoks-Priddis	8.8	4.2	36.9	21.0
Black Diamond	6.4	7.4	47.7	25.1
High River	8.1	4.1	33.5	18.8
Crowsnest Pass	2.9	9.1	26.5	18.2
Claresholm	7.4	5.7	42.2	20.0
Pincher Creek	5.3	9.3	49.3	26.7
Fort Macleod	6.7	6.7	46.9	22.1
Cardston-Kainai	6.9	8.5	58.4	29.0

Table 4 outlines the percent change in scores from version 1 of the screening tool to version 2. Results show that Canmore, Crowsnest Pass, and Grande Cache saw the largest percent decrease in landscape burden scores across all Foothills LGAs. In general, the reformatting of the impact indices lowered scores across the study region, with the exception of a 19.4% increase for Claresholm, and modest increases for High River, Cardston-Kainai, the City of Grande Prairie, and Okotoks-Priddis. In general, these findings align with stakeholder feedback on the perception of impact, and also correlate with overall findings that when compared to the rest of the Alberta, the LGAs in the ABFoothills (with the exception of Drayton Valley) are among the lowest scoring LGAs for landscape burden. These results do not necessarily mean that there is no presence of cumulative impacts or effects of specific projects, but rather, as a screening tool, the results can be put in context with the broader foothills and the province to demonstrate lower levels of impact. Importantly, the percent changes in values reflect the incorporation of more ecological data into the model, and the creation of three sub-indices instead of two in the original Phase 1 tool and results. In general, stakeholders communicated that the data are more representative of ecological variables of interest than the Phase 1 model.

3.3.2 Population Characteristics

Population characteristics scores are a scaled version of the community context score (e.g. each value is divided by the highest overall value in the entire sample and multiplied by ten—for more information see the Phase 1 report). Accordingly, there are few differences in terms of the population characteristics scores and the results described above for the community context sub-index. However, the new composition of this index resulted in changes relative to the phase 1 analysis, with only six LGAs falling within +/- 10% of their score in version 1 (see Table 5).

Canmore, Hinton and Cochrane-Springbank saw the largest decreases in population characteristics scores in the newest version, whereas Fox Creek, Crowsnest Pass and Pincher Creek all saw the largest increases in values. These changes are attributable to the fact that health and socioeconomic indicators are now dually measured by a single index relative to two, based on the statistical validation procedure undertaken to verify the composition of each latent sub-index.

Table 4. Percent change in landscape burden scores from version 1 to version 2 of the ABFoothills EnviroScreen Tool

Local Geographic Area (North to South)	% Change in Score from V1 to V2
City of Grande Prairie	4.4%
Grande Prairie County	-5.5%
Grande Cache	-44.6%
Fox Creek	-22.2%
Hinton	-37.9%
Edson	-31.0%
Drayton Valley	0.0%
Rocky Mountain House	-23.8%
Canmore	-48.8%
Cochrane-Springbank	1.1%
Okotoks-Priddis	2.3%
Black Diamond	-22.9%
High River	9.5%
Crowsnest Pass	-57.4%
Claresholm	19.4%
Pincher Creek	-13.1%
Fort Macleod	0.0%
Cardston-Kainai	9.5%

Table 5. Percent change in population characteristics scores from version 1 to version 2 of the ABFoothills EnviroScreen Tool

Local Geographic Area (North to South)	% Change in Score from V1 to V2
City of Grande Prairie	-16.7%
Grande Prairie County	4.3%
Grande Cache	14.9%
Fox Creek	53.1%
Hinton	-22.5%
Edson	-7.4%
Drayton Valley	9.3%
Rocky Mountain House	0.0%
Canmore	-30.4%
Cochrane-Springbank	-20.5%
Okotoks-Priddis	-17.6%
Black Diamond	2.8%
High River	-14.6%
Crowsnest Pass	26.4%
Claresholm	14.0%
Pincher Creek	22.4%
Fort Macleod	-4.3%
Cardston-Kainai	11.8%

3.3.3 EnviroScreen Scores

EnviroScreen scores from the validated model show that Drayton Valley had the highest overall score for the entire study region. In general, higher scoring LGAs tend to fall in the northern half of the study area (with the exception of Grande Cache and Hinton). This coincides with findings from the Phase 1 analysis. The majority of LGAs fell into the middle tercile of overall impact, with Hinton, Canmore, Cochrane-Springbank and Crowsnest Pass falling among the lowest scoring LGAs when compared to the rest of the Alberta Foothills LGAs. However, when compared to all other scores across the complete sample of 95 LGAs that comprise the entire province of Alberta (excluding urban areas), we find that overall, most LGAs in the Foothills fall in the lowest tercile of overall impact. This suggests that the overall presence of cumulative effects is lesser than what is present across the rest of the province of Alberta, and is suggestive of lower levels of cumulative environmental, socioeconomic and health pressures in general. These findings also mirror what was found in the Phase 1 analysis, although they can be more reliably interpreted based on the validation of indicator groupings undertaken as part of this analysis.

Relative to EnviroScreen scores in Phase 1 (see Table 6), 13 of the 18 LGAs in the Foothills actually had a lower score projected from the validated model. Canmore, Crowsnest Pass and Hinton saw the largest decreases overall. Fox Creek, Claresholm and Cardston-Kainai all saw increases in their scores relative to Phase 1. It is important to note that this is reflective of the now validated sub-indices contributing to the overall EnviroScreen score. Further, these should not be thought of as absolute decreases, given Phase 1 and 2 EnviroScreen scores are measuring different indicators and features of impact, and express relative rather than absolute measures of cumulative effects.

Table 6. Percent change in EnviroScreen scores from version 1 to version 2 of the ABFoothills EnviroScreen Tool

Local Geographic Area (North to South)	% Change in Score from V1 to V2
City of Grande Prairie	-12.5%
Grande Prairie County	-1.1%
Grande Cache	-35.9%
Fox Creek	18.1%
Hinton	-51.5%
Edson	-35.8%
Drayton Valley	9.3%
Rocky Mountain House	-23.7%
Canmore	-64.9%
Cochrane-Springbank	-20.2%
Okotoks-Priddis	-15.6%
Black Diamond	-20.4%
High River	-5.9%
Crowsnest Pass	-45.9%
Claresholm	34.4%
Pincher Creek	5.8%
Fort Macleod	-0.2%
Cardston-Kainai	21.7%

3.4 Changes in cumulative effects over time, 2010-2018

An innovative feature for the new version of the ABFoothillsEnviroScreen Tool is the ability to map indicators against pre-existing historical data. While the limitations of the relatively recent historical baseline are described above, the tool does enable users to track changes in specific indices of impact, as well as specific indicators relative to a historical measure. Here, we present high level results according to the meta-level scores, and we encourage readers to consult the tool for more information.

3.4.1 Changes to population characteristics scores relative to 2010

Population characteristics scores had a change in range from -3.10 to +3.40. Fox Creek and Grande Cache saw the largest absolute increase in raw values of population characteristics scores relative to other regions in the Alberta Foothills, followed by Rocky Mountain House, Cardston-Kainai and Pincher Creek. Hinton shows the largest decrease in cumulative socioeconomic and health pressures over time (-3.1), followed by Claresholm (-2.2) and Black Diamond (-1.9). These are relatively small changes, suggesting only small increases and decreases in cumulative socioeconomic and health pressures across the Foothills, with most LGAs experiencing little to no change.

3.4.2 Changes to landscape burden scores relative to 2010

Absolute values of change to landscape burden scores ranged from -1.9 to +1.6, signifiying that landscape burden was not significantly altered across the Foothills LGAs. Drayton Valley, Grande Prairie County, Rocky Mountain House and Pincher creek all saw the largest proportionate increase, whereas Hinton saw the largest proportionate decrease.

3.4.3 Changes to EnviroScreen scores relative to 2010

EnviroScreen scores had an absolute change of -33.9 to +17.7 for raw values relative to the 2010 measures. Fox Creek and Rocky Mountain House saw the largest increases in change over time, and Hinton the greatest decrease in change over time. This suggests that the increasing pressures of socioeconomic and landscape burden conditions have become greater in Fox Creek and Rocky Mountain House over time, raising concerns about future development prospects that may continue to alter these impacts in negative ways in the future.

3.5 Analysis of Cumulative Effects at the Sub-watershed Scale

The inclusion of a watershed scale provides a unique unit of analysis that is perhaps more relevant to quantifying environmental impacts over large regions.[11] This is because watersheds are geographically and physically bounded in ways that social jurisdictions are not (e.g. by defined and delimited elevation limits). This makes them a discrete bio-geophysical unit that may be ideal for the assessment of cumulative effects.[12]

3.5.1 EnviroScreen Sub-indices: Measuring pollution, environmental change, and ecological context

It was not possible to model community context scores due to the fact that the lowest level of analysis for health information that is publicly available in Alberta is at the level Local Geographic Areas. The study team encourages users to explore this data at the higher order level of analysis if it is of interest. Extrapolating health data to this level of analysis would result in committing an ecological fallacy—attributing larger group phenomenon to a smaller level of analysis—and would result in the intention introduction of uncertainty and error in measurement. However, due to the finer resolution of ecological data, the study team was able to model the other three sub-indices (see Table 7).

Table 7. Landscape burden and component sub-index scores at the level of sub-watersheds across the Alberta Foothills, 2018

Sub-watershed	Environmental Change Score (/1)	Pollution Score (/1)	Ecological Context Score (/1)	Landscape Burden Score (/10)
Berland	0.4	0.2	0.2	3.7
Brazeau	0.2	0.3	0.2	2.9
Cascade	0.0	0.3	0.0	1.5
Central Bow - Jumpingpond	0.6	0.4	0.9	7.8
Central Oldman - Belly	0.7	0.4	0.5	6.4
Central Oldman - Willow	0.5	0.2	0.2	3.6
Clearwater	0.5	0.4	0.6	6.4
Elbow	0.5	0.4	0.7	6.6
Fish (Alta.)	0.7	0.4	0.8	7.7
Ghost	0.4	0.3	0.2	3.6
Headwaters North Saskatchewan	0.2	0.2	0.0	1.9
Headwaters Red Deer	0.3	0.4	0.5	5.3
Headwaters Smoky	0.3	0.3	0.1	2.7
Highwood	0.3	0.3	0.6	5.5
Kananaskis	0.2	0.2	0.1	2.0
Little Bow a	0.4	0.2	0.8	5.7
Lower McLeod	0.6	0.5	0.7	7.4
Lower Smoky	0.5	0.2	0.9	6.9
Lower Wapiti	0.7	0.6	0.8	8.7
Simonette	0.5	0.3	0.5	5.8
Spray	0.1	0.2	0.1	1.3
St. Mary	0.4	0.3	0.6	5.7
Upper Athabasca - Oldman	0.7	0.5	0.5	6.8
Upper Athabasca - Windfall	0.7	0.3	0.6	6.3
Upper Bow - Policeman	0.5	0.3	0.5	5.8
Upper Little Smoky	0.6	0.3	0.5	5.9
Upper McLeod	0.5	0.4	0.4	5.7
Upper N. Saskatchewan - Ram	0.5	0.5	0.4	5.7
Upper N. Saskatchewan - Wabamun	0.7	0.7	0.9	9.4
Upper Oldman	0.5	0.1	0.3	3.9
Upper Pembina (Alta.)	0.7	0.4	0.4	6.5
Upper Red Deer - Blindman	0.5	0.9	1.0	10.0
Upper Red Deer - Little Red Deer	0.6	0.4	0.9	8.3
Upper Smoky	0.4	0.1	0.3	3.4
Upper Wapiti	0.5	0.2	0.3	4.2

Each of the pollution, environmental change and ecological context scores results in similar spatial clustering, insofar as scores tend to be much lower in both within Foothills and within Province comparisons for sub-watersheds closer to the Eastern Slopes of the Rocky Mountains, reflecting the potential benefits of proximity to protected areas. Environmental change values were generally low across all sub-watersheds, with higher levels of impact occurring in the northwestern reaches of the study area. Pollution scores were similarly low, with the exception of those in the central and western reaches of the study area abutting Edmonton, where pollution pressures were the highest in the entire sample. Ecological conditions scores were lowest in the western reaches of the study area, but particularly in sub-watersheds that were closer to urban areas of Grande Prairie, Edmonton, Red Deer, Calgary and Lethbridge, suggesting that urbanization has an inverse relationship to the presence of native plants and animals.

When aggregated, the three sub-indices represent the landscape burden score—a composite measure of environmental pressure. When comparing sub-watersheds against each of the 34 other sub-watersheds in the sample, findings demonstrate that sub-watersheds abutting Grande Prairie, Edmonton and Calgary have the highest scores, and that sub-watersheds near the headwaters of the Rocky Mountains tend to have lower cumulative ecological pressures (see Figures 2 and 3).

While the within provincial comparison of landscape burden scores at the level of LGAs showed that LGAs in the Foothills tend to score much lower than the other 95 rural LGAs across Alberta, the more granular depiction of landscape burden shows a different story. When comparing Foothills sub-watersheds against all other provincial sub-watersheds, findings illustrate that pressures are still greater for sub-watersheds adjacent to larger urban centres, but that that relative environmental pressures tend to be higher than reported at the LGA level, particularly for sub-watersheds in the north, central and southwestern areas of the study region. In other words, calculating cumulative environmental pressures at the sub-watershed pressure is perhaps more revealing of where pressures exist when compared provincially, relative to the larger and coarser level of analysis presented at the level of LGAs. Future work that seeks to source downscaled health

Figure 2. Sub-watershed landscape burden score, within Foothills comparison

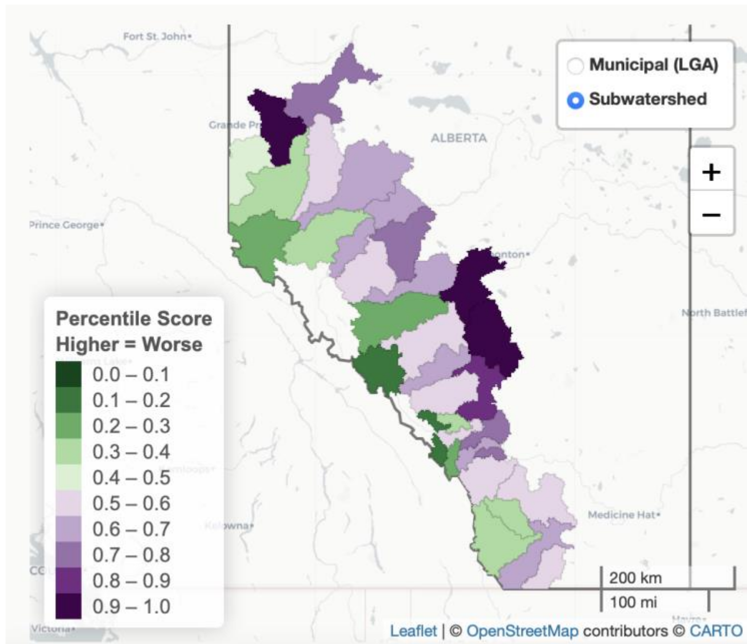
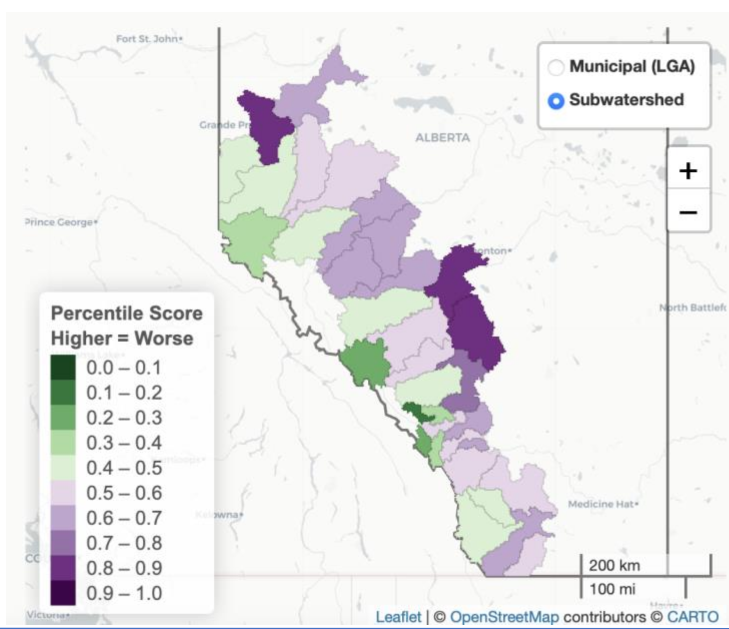


Figure 3. Sub-watershed landscape burden score, within Province comparison



information may also tell a different story of cumulative impact on community and health values, and should be a priority for future research.

4.0 Implications for Future Research and Tool Development

4.1 New insights from the second iteration of the ABFoothills EnviroScreen Cumulative Effects Screening Tool

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, cumulative effects are an important consideration for landscape planning and resource governance throughout the Foothills. Indeed, the Foothills region is home to numerous socioeconomic and 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.

Importantly, just because the screening tool displays a low score does not mean there are low risks for any type of development, and similarly, just because there are high scores does not mean that region should be viewed as a so-called ‘sacrifice zone’.[13–15] Rather, the potential of the tool is in its ability to rapidly explore and compare data, and to offer an initial step to screen cumulative effects at a regional level and direct users attention to the other types of informations that project proponents, planners and other decision-makers may need to collect to adequately account for cumulative effects.

The novelty and innovation developed in this second phase of research was threefold. First, the tool has been updated to include historical data. This resolves limitations identified with the Phase 1 screening tool regarding the lack of baseline values to measure change over time—a key aspect of cumulative effects assessment. While the historical baseline available based on publicly available datasets that are imputed into the model are do not go back particularly far in history, future research may seek to model ecological data as undisturbed or pristine areas to compute percentage changes. Such an approach, however, would require innovation in order to be applied to human values (e.g. economic and health), as ‘undisturbed states’ such as the complete absence of low-income or complete absence of cancer are unrealistic to model as a relevant historical baseline. Irrespective, continuing to incorporate data into the tool will strengthen its utility in the future.

Second, this analysis and the corresponding tool are able to quantify measures of cumulative effects at the level of sub-watersheds for ecological variables. Given the availability of rastor data, future research could apply a smaller size grid cell to increase the granularity even further, but this was beyond the scope of work of this project and merits exploration in the future.

Third, the ABFoothillsEnviroScreen tool enables pan-provincial and within-Foothills comparisons of impact. This makes the tool an effective screening tool in the context of environmental, socioeconomic and health impacts at multiple comparative levels. Future work could further enhance the comparability of the tool by fully modeling data for all available LGAs and sub-watersheds so that the tool becomes relevant to the entirety of the province of Alberta, beyond just this proof of concept directed at the Foothills.

4.2 Other research opportunities

There are several other potential areas of future research that would continue to strengthen the tool in its present form. These could include specific approaches leveled at downscaling socioeconomic and health information, or sourcing information through alternative mediums at appropriate levels of analysis. For example, census data is available at the level of census-subdivisions which are much more granular than LGAs. Through the use of GIS software, centroids of census sub-divisions could be captured, and their metadata re-appropriated and applied to specific grid cells, or sub-watersheds. This would necessarily introduce conditional errors and uncertainty into the reporting of health and socio-economic information at the level of sub-watersheds or specific grid cells, but given the main thrust of this tool is an exploratory analysis of cumulative effects, such an approach could be warranted, and could still be ground-truthed by programming original source data at an appropriate level of analysis.

Health data presents other challenges, primarily related to sharing sensitive health information that risks identifying patients in smaller landscape units. Accessing health information at lower levels of analysis is possible, but would require clearance through a Statistics Canada Research Data Centre, and even then, there may be limitations on what data can be displayed publicly. Irrespective of these challenges, a key direction moving forward based on stakeholder input was that the ability to map cumulative impacts at even finer grain spatial scales. Using this methodology holds significant potential to screen and assess the *intensity of land uses* with greater certainty, which could significantly enhance the utility of the tool in shaping siting decisions for specific projects.

As a screening tool, the value of the EnviroScreen scores and related sub-indices is to explore and screen for potential cumulative effects, and analyze specific indicators of pressure that can be further explored through targeted case studies, risk mitigation activities, conservation initiatives or related programs. Case study research on impacted areas and with impacted communities could be a powerful way to further validate the findings of the EnviroScreen tool in localized and nuanced ways. We begin to identify potential opportunities to use the tool through the appended "User Guide" and through the development of two scenarios to walk users through how to use the tool (see Appendix 2).

Finally, the analysis above provides support to trial the tool in other provincial contexts, each of which have unique circumstances for data collection and availability. Creating local teams of researchers that can bring together multi-stakeholder working groups of actors to develop associated tools could lay not only the foundation for future provincial pilots, but also the generation of a Canada-wide cumulative effects screening tool.

5.0 Conclusion

This document reports on a second phase of analysis and engagement on the cumulative environmental, community and health impacts that develop through the interaction of multiple projects and landuses across the Alberta Foothills. The newly validated model and accompanying tool presents unique opportunities to screen for potential impacts, assess cumulative effects at a regional level (i.e. Local Geographic Areas), assess cumulative environmental effects at the level of sub-watersheds, and quantify changes to cumulative effects over time. Findings from the Phase 2 analysis are largely supportive of those described in the Phase 1 report, whereby Foothills LGAs typically having lower EnviroScreen scores than the rest of Alberta.

While our engagement found that there is still interest from multiple local stakeholders on the importance of assessing fine resolution cumulative impacts (e.g. on a specific species, or a discrete location), this screening tool presents a significant step forward in assessing cumulative impacts at a regional level to consider multiple potential forcings and their legacies for environmental, community and health values. The ShinyApp that accompanies this report provides an interactive platform to [1] store multiple forms of data that are typically used in landuse and resource planning exercises, and [2] quantify and screen where cumulative effects are more and less of a concern across the Alberta Foothills to help make future land use decisions. Given the significant interest in the potential tool, the study team sees it as a significant innovation in the cumulative impacts field which could be trialed in multiple other contexts of Canada and internationally to enhance the knowledge base and provide a tool that can integratively screen cumulative impacts and ground-truth screening scores through the analysis of specific indicators.

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Appendix 1. Metadata for indicators included in the validated ABFoothillsEnviroScreen tool, and associated data sources

component	label	variable	units	round_digits	round_scale	baseline_year	present_year	data_source	var_description
Environmental Change	all_linear_density	Total linear density	km/sq. km	2	1	2014	2018	Alberta Biodiversity Monitoring Institute (ABMI)	Total length of linear development divided by total land area. Includes railways, transmission lines, roads, and seismic lines. Higher values indicate a greater relative length of linear development per square kilometer.
Community Context	asthma_ed_rate	Asthma emergency department visit rate	per 100,000 pop.	1	1	2010	2017	Alberta Health (by request)	Age-adjusted emergency department visit rate for asthma (per 100,000 population). Higher values indicate a greater relative rate of healthcare utilization for asthma.
Community Context	binge_drink_2014_p	High alcohol consumption	% who drink 5+ drinks at least	1	100	2010	2014	Canadian Community Health Survey (CCHS)	Proportion of the population reporting 5 or more drinks more than once per month (age-standardized).

			once per month					http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Higher values indicate a greater relative proportion of the population reporting higher consumption of alcohol.
Ecological Condition	bird_intactness	Bird species intactness	% intact*	0	1	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://www.abmi.ca/home/data-analytics/da-top/da-product-overview/GIS-Biodiversity-Data/Intactness.html	The predicted abundance of birds relative to the predicted abundance for bird species if there were zero human footprint in the same region. This measure reflects how modifications to habitat as a result of human activities result in changes to species abundance. Higher values indicate a low relative abundance of bird species. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of species intactness actually reflect higher levels of impact.

Environmental Change	cfo_prop_p	Livestock (high density)	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://abmi.ca/home/data-analytics/da-top/da-product-overview/Human-Footprint-Products/HF-inventory.html	Proportion of land cover used for confined feeding operations (CFOs) 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. Higher values indicate a greater relative proportion of land cover used for CFOs.
Community Context	commute_45_plus_p	Commute time	% who commute >45 minutes	1	100	Not available	2016	Statistics Canada Census: http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	Proportion of population commuting >45 minutes to work. Higher values indicate a greater relative proportion of the population with long commute times.
Community Context	copd_2017	COPD prevalence	%	1	1	2010	2017	Alberta Health (by request)	Age-adjusted population prevalence of chronic obstructive pulmonary disease (COPD) expressed as a percentage of the total population. Higher

									values indicate a greater relative population prevalence of COPD.
Environmental Change	cultivation_prop_p	Cropland	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://abmi.ca/home/data-analytics/da-top/da-product-overview/Human-Footprint-Products/HF-inventory.html	Proportion of land cover used for agricultural cultivation. Higher values indicate a greater relative proportion of land cover used for agricultural cultivation.
Environmental Change	dry_days	Future consecutive dry days	maximum consecutive dry days per year	1	1	1976-2005	2051-2080 (projection)	ClimateAtlas.ca	Projected change in the maximum consecutive number of days in a year with <1mm of rain/snow by 2080, relative to 1981-2010 baseline under 'business as usual emissions scenario' (RCP8.5). Higher values indicate a

									greater relative change in the projected number of consecutive dry days in a year.
Community Context	dwelling_repairs_p	Dwelling needs major repairs	% of dwellings needing major repairs	1	100	2011	2016	Statistics Canada Census http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	Proportion of the population living in dwellings in need of major repairs. Higher values indicate a greater relative proportion of the population living in dwellings in need of major repairs.
Community Context	ed_visits_mental_health	Mental health emergency department visit rate	per 100,000 pop.	1	1	2010	2017	Alberta Health (by request)	Age-adjusted emergency department visit rate for substance use-related mental health (per 100,000 population). Higher values indicate a greater relative rate of healthcare utilization for substance use-related mental health.
Environmental Change	fire_p	Area burned by wildfire	% (cumulative) area burned	1	1	2001-2010	2011-2020	Alberta Agriculture and Forestry	Cumulative proportion of land area burned by wildfire divided by total land area. Higher

			by wildfire					http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	values indicate a greater relative proportion of land area impacted by wild fires.
Environmental Change	forestry_prop_p	Forest harvest	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://abmi.ca/home/data-analytics/da-top/da-product-overview/Human-Footprint-Products/HF-inventory.html	Proportion of land cover used for forestry operations (clearcut, selective harvest, salvage logging, etc.). Higher values indicate a greater relative proportion of land cover used for forestry operations.
Ecological Condition	greenspace_prop_p	Greenspace	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://abmi.ca/home/data-	Proportion of land cover that is greenspace (for recreational use). Higher values indicate a low relative abundance of greenspace. For the

								analytics/da-top/da-product-overview/Human-Footprint-Products/HF-inventory.html	purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of greenspace actually reflect higher levels of impact.
Pollution	ground_water_quality_risk_p	Groundwater quality risk	(range: 0-1, higher = greater risk)	2	1	Not available	2005	Alberta Agriculture and Forestry https://open.alberta.ca/opendata/gda-537cda97-718b-4530-b0f3-0d7571e149d4	An assessment of groundwater quality risk for the agricultural area of Alberta, which incorporates activities that may impact groundwater quality (e.g., crop production, agrochemical use) and physical characteristics representing an aquifer's vulnerability, and moisture availability. Values range from 0 (lowest risk) to 1 (highest risk). Higher values indicate a greater relative risk to qround water quality from agricultural areas.

Community Context	have_regular_family_doctor_2014_p	Has regular family doctor	% who have a family Dr.*	1	100	2010	2014	Canadian Community Health Survey (CCHS) http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Proportion of the population who self-report having a regular family doctor (age-standardized). Higher values indicate a greater relative proportion of the population with access to a regular family doctor. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower access to family doctors actually reflect higher levels of impact.
Environmental Change	hot_days	Future very hot days	days per year >30C	1	1	1976-2005	2051-2080 (projection)	ClimateAtlas.ca	Projected change in the number of days in a year measuring >30 degrees Celsius by 2080, relative to 1981-2010 baseline under 'business as usual emissions scenario' (RCP8.5). Higher values indicate a greater relative change in the projected number

									of very hot days in a year.
Community Context	hypertension_prev_2018_p	Hypertension prevalence	%	1	100	2010	2018	Alberta Health http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Age-adjusted population prevalence of hypertension expressed as a percentage of the total population. Higher values indicate a greater relative prevalence of hypertension.
Environmental Change	industrial_prop_p	Industrial sites	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://abmi.ca/home/data-analytics/da-top/da-product-overview/Human-Footprint-Products/HF-inventory.html	Proportion of land cover used for industrial purposes (oil and gas facilities, buildings used for temporary residence of industrial employees, areas disturbed for power generation, etc.). Higher values indicate a greater relative proportion of land cover used for industrial purposes.

Environmental Change	landfill_prop_p	Landfills	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI)	Proportion of land cover used for landfills or waste transfer stations. Higher values indicate a greater relative proportion of land cover used for landfills or waste transfer stations.
Pollution	lead_air_p	Lead emissions to air	kg	1	1	2010	2019	National Pollutant Release Inventory (NPRI) https://open.canada.ca/data/en/dataset/1fb7d8d4-7713-4ec6-b957-4a882a84fed3	The sum total of lead released to air by facilities, averaged across total land area. Higher values indicate a greater relative amount of lead emissions to air.
Ecological Condition	lichen_intactness	Lichen species intactness	% intact*	0	1	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://www.abmi.ca/home/data-analytics/da-top/da-product-	The predicted abundance of lichens relative to the predicted abundance for lichen species if there were zero human footprint in the same region. This measure reflects how modifications to habitat as a result of human activities result in changes to species

								overview/GIS-Biodiversity-Data/Intactness.html	abundance. Higher values indicate a low relative abundance of lichen species. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of species intactness actually reflect higher levels of impact.
Community Context	low_bw_prop_2012_p	Low Birthweight	% of live births considered low birthweight	1	100	2010	2018	Alberta Health https://open.alberta.ca/opendata/local-geographic-area-lga-maternal-and-child-health-indicators	Low-birth weight (less than 2500gm), as a proportion of all live births. Higher values indicate a greater relative proportion of low-birth weights.
Community Context	low_income_cutoff_at_p	Low-income after tax	% with income below the low-income cut-off	1	100	2011	2016	Statistics Canada Census http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	Prevalence of low-income individuals (after-tax, adjusted for household size). Higher values indicate a greater relative proportion of people whose after-tax incomes are lower than the Statistics Canada

									low-income cut-off threshold.
Ecological Condition	mammal_intactness	Mammal species intactness	% intact*	0	1	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://www.abmi.ca/home/data-analytics/da-top/da-product-overview/GIS-Biodiversity-Data/Intactness.html	The predicted abundance of mammals relative to the predicted abundance for mammal species if there were zero human footprint in the same region. This measure reflects how modifications to habitat as a result of human activities result in changes to species abundance. Higher values indicate a low relative abundance of mammal species. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of species intactness actually reflect higher levels of impact.

Community Context	mean_gender_income_disparity	Gender income equality	(ratio of female to male income)*	2	1	2011	2016	Statistics Canada Census http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	Median income for men divided by median income for women. Higher values indicate greater incomes for women relative to men (values <1 indicate women make less than men, values >1 indicate women make more than men). For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of pay for women actually reflect higher levels of impact.
Environmental Change	mine_prop_p	Mines	% of landcover	2	100	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://abmi.ca/home/data-analytics/da-top/da-product-overview/Human-	Proportion of land cover used for mines (oil sands, gravel pits, peat, coal, open-pit mines, overburden, etc.). Does not include reclaimed sites. Higher values indicate a greater relative proportion of land cover used for mines.

								Footprint-Products/HF-inventory.html	
Ecological Condition	mite_intactness	Soil mite species intactness	% intact*	0	1	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://www.abmi.ca/home/data-analytics/da-top/da-product-overview/GIS-Biodiversity-Data/Intactness.html	The predicted abundance of soil mites relative to the predicted abundance for soil mite species if there were zero human footprint in the same region. This measure reflects how modifications to habitat as a result of human activities result in changes to species abundance. Higher values indicate a low relative abundance of soil mite species. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of species intactness actually reflect higher levels of impact.

Community Context	mortality_rate_injury_2018	Injury mortality rate	per 100,000 pop.	1	1	2010	2018	Alberta Health (by request)	Age-adjusted mortality rate for external causes (i.e., injuries) (per 100,000 population). Higher values indicate a greater relative number of deaths due to injuries.
Community Context	mortality_rate_neoplasms_2018	Cancer mortality rate (all-cause)	per 100,000 pop.	1	1	2010	2018	Alberta Health (by request)	Age-adjusted mortality rate for all-causes of cancer (per 100,000 population). Higher values indicate a greater relative number of deaths due to cancer.
Ecological Condition	moss_intactness	Bryophytes species intactness	% intact*	0	1	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://www.abmi.ca/home/data-analytics/da-top/da-product-overview/GIS-Biodiversity-	The predicted abundance of bryophytes relative to the predicted abundance for bryophyte species if there were zero human footprint in the same region. This measure reflects how modifications to habitat as a result of human activities result in changes to species abundance. Higher values indicate a low

								Data/Intactness.html	relative abundance of bryophyte species. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of species intactness actually reflect higher levels of impact.
Community Context	no_cert_prop_p	Less than high school education	% without high school certificate, diploma, or degree	1	100	2011	2016	Statistics Canada http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	Proportion of the population with no high school certificate, diploma or degree. Higher values indicate a greater relative proportion of people without a certificate, diploma or degree.
Pollution	no2_p	Nitrogen dioxide conc. (air)	ppb (3 yr. average)	1	1	2008-2010	2014-2016	Canadian Urban Environmental Health Research Consortium (CANUE) https://www.canuedata.ca/canue/metadata.php	Estimate of nitrogen dioxide (NO2) concentration modeled using satellite imagery and air monitoring data at the postal code level. Data represents a 3-year average. Higher values indicate a greater relative NO2 concentration.

Pollution	npri_land_pollution_index	Emissions to land index	(higher = more pollutant emissions)	2	1	2010-2014	2015-2019	National Pollutant Release Inventory (NPRI) https://open.canada.ca/data/en/dataset/1fb7d8d4-7713-4ec6-b957-4a882a84fed3	The sum total of releases of toxic substances to land, averaged across total land area. Includes ammonia, lead, cadmium, phosphorus, arsenic, selenium, cobalt, mercury, nitrate ion, and zinc emitted from facilities (aggregated over 5 years). Higher values indicate a greater relative amount of toxic substances released to land.
Pollution	npri_water_pollution_index	Emissions to water index	(higher = more pollutant emissions)	2	1	2010-2014	2015-2019	National Pollutant Release Inventory (NPRI) https://open.canada.ca/data/en/dataset/1fb7d8d4-7713-4ec6-b957-4a882a84fed3	The sum total of releases of toxic substances to water, averaged across total land area. Includes ammonia, lead, cadmium, phosphorus, arsenic, selenium, cobalt, mercury, nitrate ion, and zinc emitted from facilities (aggregated over 5 years). Higher values indicate a greater relative amount of toxic

									substances released to water.
Pollution	o3_p	Ozone concentration (annual average)	ppb	1	1	2010	2019	National Air Pollution Surveillance (NAPS) program https://indicators-map.canada.ca/App/CESI_ICDE?keys=AirAmbient_PeakO3&GoCTemplateCulture=en-CA	Annual mean 8-hour ozone concentration measured at monitoring stations. Higher values indicate a greater relative annual average ozone concentration.
Community Context	overweight_2014_p	Overweight	% with body mass index 25-30	1	100	2010	2014	Canadian Community Health Survey (CCHS) http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Proportion of the population with a body mass index (BMI) of 25-30 (age-standardized). Higher values indicate a greater relative proportion of the population with high BMI.

Pollution	peak_ozone_p	Peak ozone concentration	ppb (annual peak)	1	1	2010	2019	National Air Pollution Surveillance (NAPS) program https://indicators-map.canada.ca/App/CESI_ICDE?keys=AirAmbient_PeakO3&GoCTemplateCulture=en-CA	Annual measure of 4th highest of the daily maximumum 8-hour average concentrations (ppb), measured using air quality monitoring station. Higher values indicate a greater relative level of peak ozone concentration.
Pollution	peak_particulate_matter_p	Peak particulate matter concentration	micrograms per cubic metre (annual peak)	1	1	2010	2019	National Air Pollution Surveillance (NAPS) program https://indicators-map.canada.ca/App/CESI_ICDE?keys=AirAmbient_PeakO3&GoCTemplateCulture=en-CA	Annual measure of 98th percentile value of the daily 24-hour average concentration of particulate matter (<2.5 micrograms per cubic metre), measured by air quality monitoring stations. Higher values indicate a greater relative level of annual peak particulate matter concentration.

Community Context	percent_who_do_not_speak_english_or_french_2016	No official language	% who do not speak English or French	1	100	2011	2016	Statistics Canada Census http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=323&subCat=1002	Proportion of the population who do not speak English or French. Higher values indicate a greater relative proportion of the population that do not speak English or French.
Ecological Condition	plant_intactness	Native plant species intactness	% intact*	0	1	2010	2018	Alberta Biodiversity Monitoring Institute (ABMI) https://www.abmi.ca/home/data-analytics/da-top/da-product-overview/GIS-Biodiversity-Data/Intactness.html	The predicted abundance of native plant species relative to the predicted abundance for native plant species if there were zero human footprint in the same region. This measure reflects how modifications to habitat as a result of human activities result in changes to species abundance. Higher values indicate a low relative abundance of native plant species. For the purposes of calculation, the tool reverses the directionality of this variable so that regions with lower levels of

									species intactness actually reflect higher levels of impact.
Pollution	pm2.5_p	Particulate matter concentration (annual average)	micrograms per cubic metre	1	1	2010	2019	National Air Pollution Surveillance (NAPS) program https://indicators-map.canada.ca/App/CESI_ICDE?keys=AirAmbient_PeakO3&GoCTemplateCulture=en-CA	Annual mean 24-hour particulate matter (micrograms per cubic metre) concentration measured at monitoring stations. Higher values indicate a greater relative level of mean annual particulate matter concentration.
Community Context	seniors_65_plus_living_alone_2016	Seniors living alone	% of seniors who live alone	1	100	2011	2016	Statistics Canada Census http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToU	Proportion of seniors (aged 65+) living alone. Higher values indicate a greater relative proportion of seniors living alone.

								RL.do?cat=101&subCat=467	
Community Context	shelter_costs_p	Housing burdened population	% of owners spending 30% or more of household income on shelter costs	1	100	2011	2016	Statistics Canada Census http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Proportion of owners spending 30% or more of household income on shelter costs. Higher values indicate a greater relative proportion of financially housing burdened populations.
Community Context	stroke_ed_rate	Stroke emergency department visit rate	per 100,000 pop.	1	1	2010	2017	Alberta Health (by request)	Age-adjusted emergency department visit rate for stroke (per 100,000 population). Higher values indicate a greater relative rate of healthcare utilization for stroke.
Community Context	three_plus_chronic_diseases_percent_2018	Multiple chronic disease prevalence	%	1	1	2016	2018	Alberta Health http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Age-adjusted population prevalence of three or more chronic diseases expressed as a percentage of the total population. Higher values indicate a greater relative

									prevalence of three or more chronic diseases.
Community Context	total_gini	Gini coefficient of income inequality	(range: 0-1, higher = greater income inequality)	3	1	2011	2016	Statistics Canada http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Single derived measure of the distribution of income across a population. Higher values indicate a greater degree of inequality where most income is concentrated among the highest income earners (e.g. more inequality).
Community Context	unemployment_rate_p	Unemployment rate	%	1	100	2011	2016	Statistics Canada http://www.ahw.gov.ab.ca/IHDA_Retrieval/redirectToURL.do?cat=101&subCat=467	Unemployment rate (aged 15+). Higher values indicate a greater relative proportion of the population who are unemployed.
Environmental Change	well_density_p	O&G well density	wells/sq. km	2	1	2010	2020	Alberta Energy Regulator (AER) https://www.aer.ca/providing-	Number of oil and gas wells per square kilometre reported to the Alberta Energy Regulator (AER), based on surface hole location. Higher values

								information/data-and-reports/maps-mapviewers-and-shapefiles	indicate a greater relative number of oil and gas wells per square kilometre.
Environmental Change	wet_days	Future very wet days	days per year >20mm precipitation	1	1	1976-2005	2051-2080 (projection)	ClimateAtlas.ca	Projected change in the number of days in a year with >20mm precipitation by 2080, relative to 1981-2010 baseline under 'business as usual emissions scenario' (RCP8.5). Higher values indicate a greater relative change in the projected number of very wet days in a year.

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