Appendix D: REP Tool Methods

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D.1.0 METHODOLOGY

The following description of the methodology that underpins the REP Tool approach to quantifying relative environmental pressure is an abridged version of the detailed methods, including data sources, presented in Nasr and Orwin (2024). All figures are reproduced unmodified from Nasr and Orwin (2024) under a CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

The REP Tool uses a three-tiered conceptual framework to identify key environmental pressures on ecosystem integrity (Figure D1). This framework was developed using a systematic review of over 500 peer-reviewed articles related to ecosystem integrity analysis and geospatial-based watershed classification models and approaches. The first tier is an ecosystem integrity framework that identifies five key elements that determine ecosystem function based on their relation to, and influence on, the natural state of an ecosystem, and the services it offers. These five elements include: Air Quality, Sediment/Soil Quality, Habitat Health, Hydrologic Regulation, and Social Control.

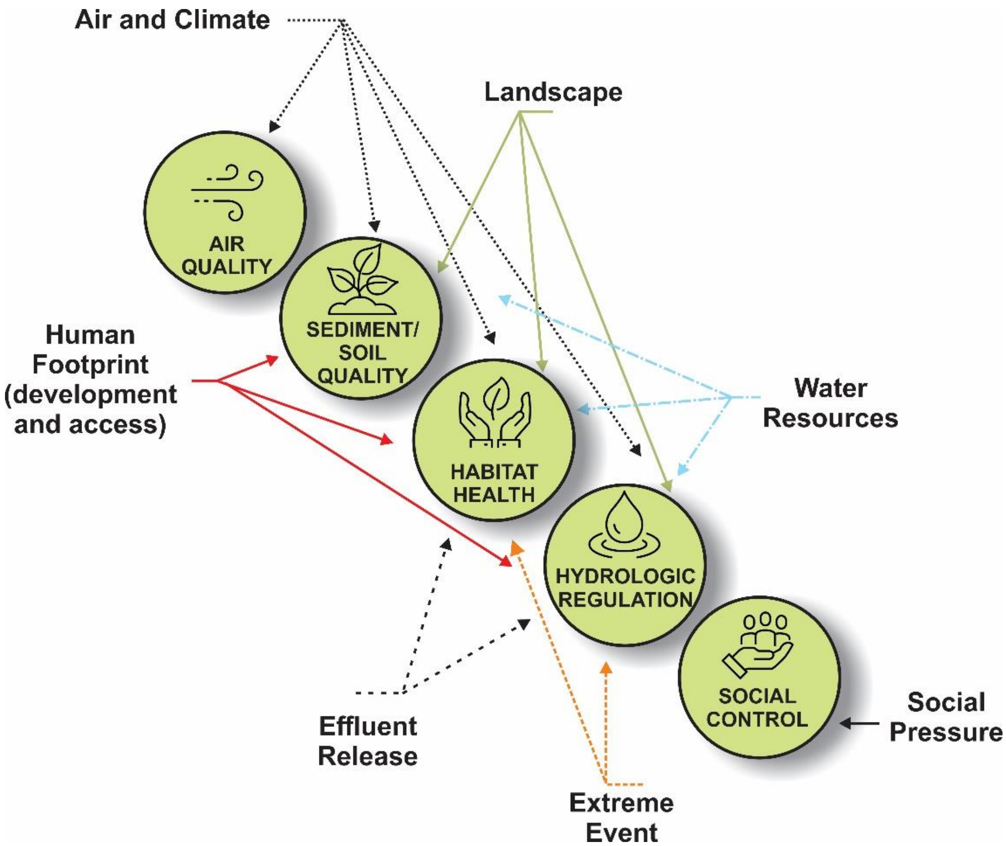

Figure D1: Conceptual framework that underpins the Relative Environmental Pressure (REP) Tool. Tiers 1 and 2 are shown. Reproduced from Nasr and Orwin (2024) under CC BY-NC-ND license.

The second tier in the conceptual framework identifies seven broad groups that individually, or cumulatively, interact to apply environmental pressure to the state of the Tier 1 ecosystem integrity components (Figure D1). These Tier 2 groups are characterized as Air and Climate, Landscape, Water Resources, Social Pressure, Extreme Event, Effluent Release, and Human Footprint (development and access). The cross-linkages between the Tier 2 groups are captured in the REP Tool under the Tier 3 groups that comprise five Environmental Pressure Groups (EPGs) (Figure D2). The individual EPGs are: Atmospheric Alteration; Sedimentation; Habitat Alteration; Hydrologic Alteration; and Social Pressure. These EPGs can affect aspects of ecosystem integrity either individually or cumulatively and are used to identify specific indicators that inform the EPGs (Figure D2). These indicators drive the geospatial data that is then used to quantify and rank relative environmental pressure within the REP Tool at the scale of interest.

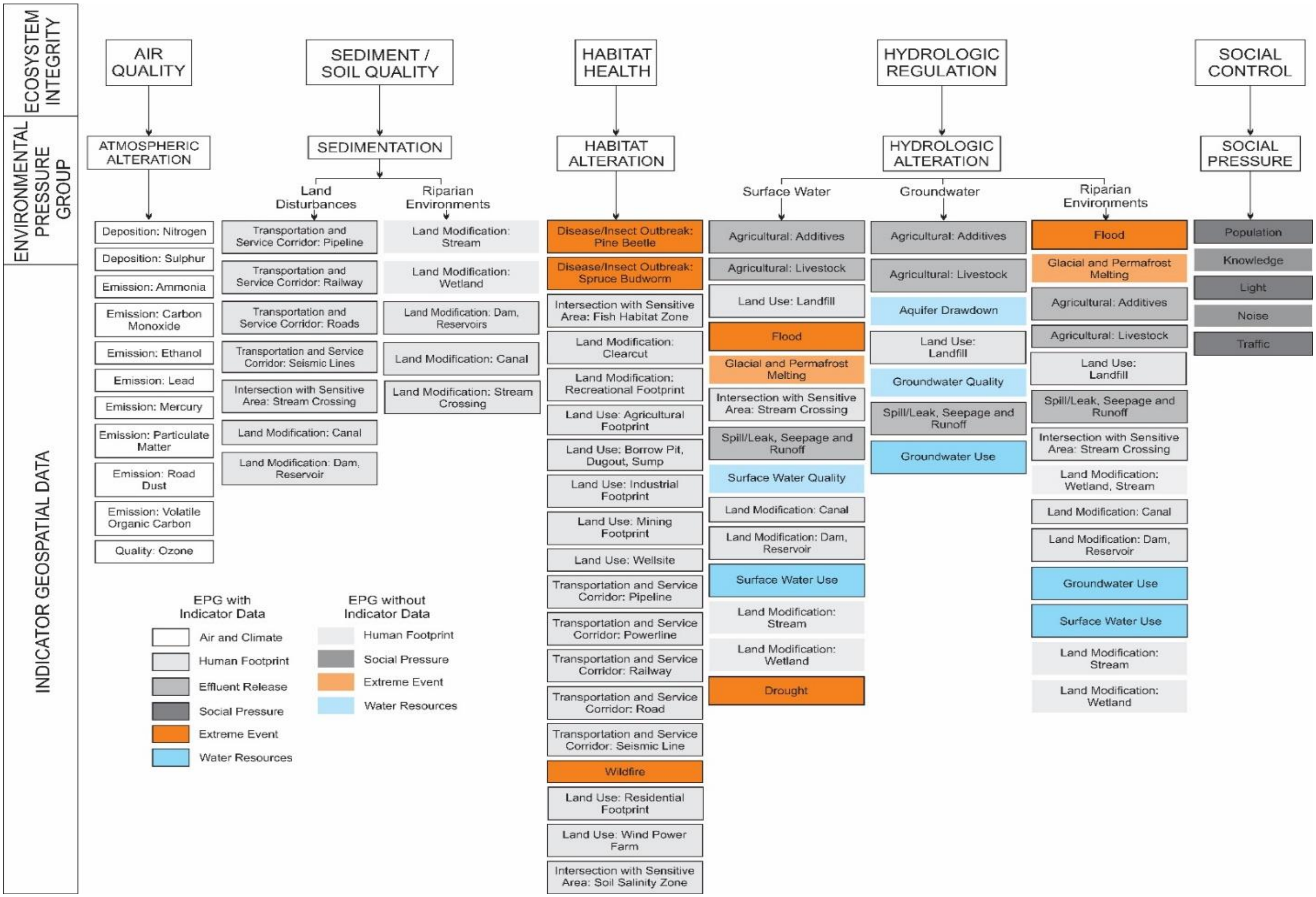

Figure D2: Tier 3 Environmental Pressure Groups (EPGs) of the ecosystem integrity framework used in the Relative Environmental Pressure (REP) Tool. The geospatial data used in running the REP Tool is shown as specific indicators. Reproduced from Nasr and Orwin (2024) under CC BY-NC-ND license.

D.1.1 Generation of relative environmental pressure values

The REP Tool was developed as an automated Python-based model in a PyCharm (2024) working environment using ArcGIS Pro Arcpy scripting (ESRI, 2022). Implementation of the REP Tool to quantify relative environmental pressure at multiple scales leverages nine analytical steps (Figure D3). The steps are organized under four main process categories to allow flexibility in applying the tool. As per Nasr and Orwin (2024), the REP Tool is typically applied using watersheds at a user defined scale. Watersheds provide a natural scale that is often used to assess how internal connectivity between different features (e.g., vegetation, land use, hydrology) combine as physio-geochemical, ecological, and hydrological interactions and processes interact with, and affect ecosystem integrity.

For the SOE, the REP Tool was implemented at a Hydrologic Unit Code at Level 10 (HUC10). This scale provides a sufficient spatial resolution for characterizing land use/land cover in larger areas, such as the OSR. The HUC10s are typically aligned with the contributing areas of tributaries and rivers within the provincial boundary and are classified based on an internationally recognized HUC standard of Strahler Order of 5 and higher. In total, there are 837 HUC10s watersheds in the OSR.

It is important to note that the comparability of relative environmental pressure as a function of where either surface water quantity or quality is measured is critical from a physio-chemical perspective. This criticality derives from the fact that the measured values at each site do not represent that point but are an integrated signal of all physio-chemical process and other influences within the contributing watershed upstream of the measurement point.

The analytical method and processing steps associated with the REP Tool are shown in Figure D3.

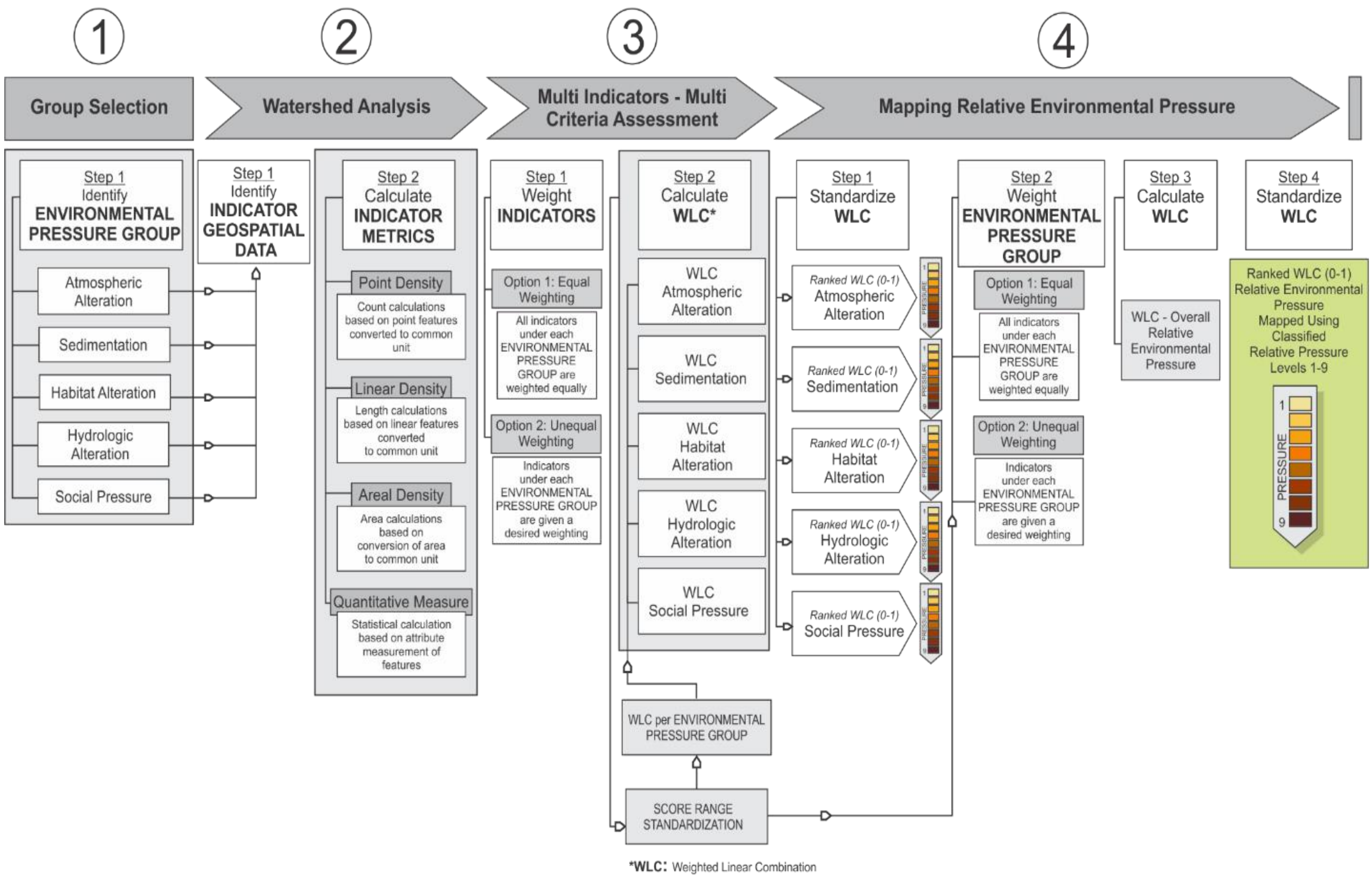

Figure D3: Key analytical steps used to generate relative environmental pressure values within the Relative Environmental Pressure (REP) Tool. Reproduced from Nasr and Orwin (2024) under CC BY-NC-ND license.

Process Category 1: For this category, the end user selects either one EPG or multiple EPGs, depending on desired needs. For this SOE, all EPGs were used to provide an assessment of cumulative environmental pressure.

Process Category 2: This category is divided into two steps, data compilation and generation of indicator summary metrics. In this SOE, all data were assessed for completeness and only those without spatial gaps or missing information were used. The final dataset provided geographically continuous data coverage for the oil sands region and includes the 2021 HFI data produced for this region of Alberta by the Alberta Biodiversity Monitoring Institute (2023).

Within each watershed, summary metrics for each indicator are then calculated based on their specific attribute values. For example, linear density of length per watershed area was calculated for linear features such as roads and seismic lines and the areal coverage of features per sub-watershed area was calculated for non-linear areal features. Additionally, non-linear point features were used for calculating counts per watershed area and point or raster data were used for quantitative measures (e.g., water use, air deposition) based on arithmetic statistical summaries (sum, mean, or maximum value) of an indicator per sub-watershed area. These calculations were done using ArcGIS Pro's statistical 'Summary Within' tool, tailored to suit vector data model analysis. For analytical consistency, all gridded data were converted to point features. Other measurements such as qualitative/categorical measures and distance to features were not included.

Process Category 3: The steps in this category quantify the EPGs by utilizing the indicators calculated under Process Category 2. The REP Tool employs a Weighted Linear Combination (WLC) approach to calculate the relative environmental pressure as the method highlights areas with considerable range differences compared to other methods such as z-score or weighted average approaches that may skew the data range based on statistical values. Additionally, the WLC method provides a more universally applicable approach, making it adaptable to various scenarios. A WLC approach also allows the assessment of multiple indicators cumulatively for each EPG within the REP Tool.

To achieve a cumulative value of pressure level for watershed, the REP Tool initially uses global associations. In this process, the weighting and ranking of each indicator are independently calculated without considering the spatial dependencies of watersheds. The REP Tool's WLC calculations are based on a score range standardization method, using minimum and maximum values of the calculated indicators to normalize the data into a numeric range between zero and one. Normalization is applied to each indicator individually. Using this method, a rank of zero means there is no pressure effect and a rank of one means the pressure effect is at its maximum, based on the distribution within the data being used.

The REP Tool also allows the end user to define weightings for each indicator or EPG where all indicators can be weighted equally or some weighted higher or lower. The application of weightings will depend on the end use or if a specific activity is known to have a disproportionate effect on environmental pressure. For the SOE, all indicators and EPGs were weighted equally. The WLCs of the EPGs are then calculated using the sum of the weighted ranks of indicators for each watershed and per individual EPG.

Process Category 4: In this final step, maps are a product of the cumulative relative pressure, where values are developed by weighting and combining the WLCs from the five EPGs. The cumulative relative pressure level map is produced by standardizing this result between zero and one. The final relative environmental pressure values for each watershed are then classified into nine pressure levels using Jenks natural breaks through goodness of variance fit optimization. The choice of nine levels to represent the range between low to high relative environmental pressure is arbitrary but represents a balance of providing enough detail on relative pressure levels without obscuring broader spatial patterns.

Within the REP Tool, a relative environmental pressure level of one indicates little or no relative environmental pressure compared to a level of nine which indicates maximum relative environmental pressure for the spatial scale being used. As the tool recalculates relative pressure when scales change, the relative pressure level range of these nine pressure levels also changes. It is important to note that sub-watersheds classed into higher-pressure levels (7-9) do not necessarily indicate adverse outcomes but do indicate where they may be occurring.

D.2.0 REFERENCES

Alberta Biodiversity Monitoring Institute. (2023). Wall-to-Wall Human Footprint Inventory - Year 2021. Last modified Aug 16, 2023. (https://abmi.ca/data-portal/46.html)

ESRI. (2022). ArcGIS Pro. Copyright © 1995-2022 Esri. https://www.esri.com/en-us/legal/requirements/open-source-acknowledgements

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