Alberta Tomorrow Indicator Equations

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Introduction

This document provides formulae for the indicators included in Alberta Tomorrow. The formulae relate indicators to the following variables tracked by Alberta Tomorrow:

- Total study area size in hectares (T)
- Hectares of forest (F), wetlands (W), prairie (P), agricultural land (A), and settlement (S)
- Hectares of settlement today (S_0)
- Natural (i.e., predisturbance) hectares of forest (F_{init}), wetlands (W_{init}), and prairie (P_{init})
- Future area of forest ($F_{projected}$), wetlands ($W_{projected}$), prairie ($P_{projected}$), and agricultural land ($A_{projected}$), as projected in land use assessment mode
- Proportion of natural land with development (D)[1]
- Future proportion of natural land with development, as projected in land use assessment mode ($D_{projected}$)[2]
- User-defined (i.e., future) proportion of natural land with development (D)
- A binary variable indicating whether best practices are turned on (B)
- Today's human population (Pop_0), energy production ($Energy_0$), and timber production ($Timber_0$)
- Future energy production, as projected in land use assessment mode ($Energy_{projected}$)
- Human population (Pop), energy production (Energy), and timber production (Timber). These values are calculated by Alberta Tomorrow and then used in formulae for other indicators.

1 Environmental Indicators

Environmental indicators are reported as a % of the estimated natural level of the indicator. An indicator's natural level is its value in the absence of land use. This value depends on the assumed composition of the natural landscape (i.e., the relative abundance of F_{init}, W_{init}, and P_{init}). The assumed composition of the natural

[1] Proportion of natural land with development is calculated using ALCES Online as the proportion of natural cells (i.e., >% natural land cover) that have greater than 2% coverage by industrial footprint including roads, seismic lines, pipelines, and wells.
[2] Projected value for D is calculated using the business as usual scenario in ALCES Online.

landscape varies across natural regions, and is based on the proportion of the natural region that is forest (F_{init}), wetland (W_{init}), and prairie (P_{init}). Values of these variables are provided in table 1 below for each natural region, based on appendix 4 of Natural Regions Committee (2006) which specifies the proportion of each natural region that is upland vs wetland/water landscape elements. For the grassland natural region, upland landscape elements are assumed to be prairie. For the boreal, foothills, and Canadian shield natural regions, upland landscape elements are assumed to be forest. Upland landscape elements in the Parkland are a natural region are a mix of forest and prairie. The relative abundance of forest and prairie was estimated based on the abundance of soil types in the parkland natural region. Black Chernozems were historically the dominant soils under grasslands in the Foothills Parkland and Central Parkland natural subregions, whereas in the Peace River Parkland natural subregion grasslands were historically associated with Solonetzic soils (Natural Regions Committee 2006). These two soil types account 75% of the Parkland natural region (Appendix 5, Natural Regions Committee 2006). Therefore, 75% of upland landscape elements in the Parkland natural region are assumed to be grassland in the following table.

Table 1. Pre-settlement composition of Alberta's natural regions assumed by Alberta Tomorrow.

Natural region	F_{init}	W_{init}	P_{init}
Grassland	0	0.06	0.94
Boreal	0.6	0.4	0
Foothills	0.84	0.16	0
Parkland	0.225	0.1	0.675
Canadian Shield	0.7	0.3	0

1.1 Natural Landscapes

1.1.1 Unit

Percent of natural.

1.1.2 Formula

$$\%natural = 100 * \frac{(1 - D * (1 - B * 0.2)) * (F + W + P)}{T}$$

1.1.3 Rationale

Natural landscape is assessed as the % of the landscape that has natural landcover (i.e., F, W, or P) and is without development (i.e., occurs in a 1000 m cell without footprint).

Best practices can reduce the area of footprint associated with industrial development through strategies that minimize the size and lifespan of industrial features. Based on a scenario analysis completed for caribou ranges in northeastern Alberta, best practices may be able to reduce the area of anthropogenic footprint by approximately 20% (Athabasca Landscape Team 2009). Therefore, the effect of development (D) on natural landscapes is reduced by 20% when best practices are turned on.

1.2 Caribou (Mammal habitat for boreal study areas)

1.2.1 Unit

Percent of natural.

1.2.2 Formula

Calculating probability of persistence requires two steps. First, range disturbance is calculated from the composition of the landscape, the level of development, and whether best practices are turned on. Second, probability of persistence is calculated based on range disturbance.

Step 1

$$\%range\ disturbance = 100 * \frac{((A + S) + D * (1 - 0.2 * B) * (F + W + P))}{T}$$

Step 2

Probability of persistence is categorical rather than continuous, and is related to % of a range that is disturbed by anthropogenic footprint. The relationship between range disturbance and probability of persistent is provided in the table below.

Table 2

% Range Disturbance	Probability of persistence
0	100
10	90
20	78
30	66
40	50
50	35
60	25
70	15
80	8
90	4
100	0

1.2.3 Rationale

The recovery strategy for woodland caribou (Environment Canada 2012) presents a relationship between range disturbance and probability of woodland caribou herd persistence based on a meta-analysis of woodland caribou range and population data, and a population viability analysis. The relationship, as presented in Table E-1 of the report, was used here to derive the relationship between range disturbance and probability of persistence present in table 2. In the recovery strategy (Environment Canada 2012), range disturbance is assessed as the percent of a range disturbed by fire or within 500 metres of anthropogenic disturbance. The relationship between range disturbance and probability of herd persistence is used in Alberta Tomorrow to estimate the probability of caribou persistence. When calculating the range disturbance, range disturbance is calculated as agricultural area, settlement area, and natural area that is developed (i.e., within a 1000 m cell with footprint). Fire was not incorporated.

Best practices can reduce the area of footprint associated with industrial development through strategies that minimize the size and lifespan of industrial features. Based on a scenario analysis completed for caribou ranges in northeastern Alberta, best practices may be able to reduce the area of anthropogenic footprint by approximately 20% (Athabasca Landscape Team 2009). Therefore, the effect of development (D) on range disturbance is reduced by 20% when best practices are turned on.

1.3 Grizzly Bear (Mammal habitat for prairie, foothill, and mountain study areas)

1.3.1 Unit

Percent of natural.

1.3.2 Formula

For clarity, calculation of the grizzly bear indicator is presented as two steps. First, the grizzly bear exposure index is calculated. Second, the exposure index is converted to a value that ranges from 0 to 100%, where 100% indicates pristine grizzly bear habitat.

Step 1: calculate grizzly bear exposure index

$$exposure\ index = 1.0598 + \frac{100 * A}{T} * (0.0057 - B * 0.0020) + \frac{100 * D * (F + W + P)}{T} * (0.0055 - B * 0.0026) + \frac{100 * S}{T} * (0.0688 - B * 0.0322)$$

Step 2: convert exposure index to an indicator ranging from 0 to 100%

$$grizzly\ bear = 100 * \frac{\max(0, 1.5 - exposure\ index)}{0.4402}$$

1.3.3 Rationale

The response of grizzly bear to land use is based on a factorial simulation experiment that assessed the effect of land use amount and best practices on grizzly bears in the southern east slopes of Alberta (Stelfox et al. 2008). Relevant best practices included minimizing the size of industrial footprint (i.e., reclamation of wells and roads, locating multiple wells per well pad) and managing human access. Grizzly bear response was assessed using an exposure index that conveys the exposure of grizzly bears to mortality risk; higher values indicate increasing risk to grizzly bears. A regression equation that summarizes the outcomes of the simulation experiment was used here to estimate the increase in the exposure index associated with each 1% of the landscape allocated to each land use (agriculture, energy/forestry/transporation, and settlements), and how much the increase is mediated by implementing best practices. Exposure index increases associated with each 1% of the landscape allocated to a land use are as follows: agriculture=0.005721 (0.003732 with best practices); industrial development (energy/forestry/transporation)=0.005518 (0.002892 with best practices); and settlements=0.068786 (0.036588 with best practices).

To create a grizzly bear index ranging from 0% (worst value) to 100% (best value), we compare a simulated landscape's grizzly exposure index to the range of 1.0598 to 1.5. 1.0598 is the index's value in the absence of land use and is therefore consistent with 100%. Stelfox et al. (2008) state that an exposure index value of 1.25 is high and suggests that grizzly population persistence is at risk; we assume that an exposure index value of 1.5 is very high and is consistent with 0%.

1.4 Fish Habitat

1.4.1 Unit

Percent of natural.

1.4.2 Formula

$$Fish = 100 * \frac{\left(\frac{(0.2 * (A + S) + (F + W + P) * (D * 0.2 + B * 0.5) + (1 - D) * 0.9))}{0.9}\right)}{T}$$

1.4.3 Rationale

The status of the fish community was assessed using the index of native fish integrity (INFI), a measure that conveys changes in abundance and composition of fish species with a value ranging from 1 (undisturbed community) to 0 (highly disturbed community). As part of an assessment of the future effects of land use to ecosystems in northeastern Alberta, the simulation tool ALCES was applied to evaluate the potential response of INFI to expected rates of development (Wilson and Stelfox 2008). The results from that scenario analysis are used here to parameterize the INFI relationship for Alberta Tomorrow. The INFI value at year 30 of the simulations was used because 30 years if the length of the Alberta Tomorrow simulations. At year 30 of the base case simulation, INFI equaled approximately 0.2. When access was strictly controlled (i.e., access management), INFI increased to approximately 0.7 at year 30. In the absence of land use (RNV), the mean INFI was approximately 0.9. When calculating INFI for Alberta Tomorrow, the INFI value associated with no land use (i.e., 0.9) applies to natural landcover (F, W, P) that is not allocated to development. The INFI value associated with access management (i.e., 0.7) applies to natural landcover (F, W, P) that is allocated to development but where best practices are applied. The INFI value without access management (0.2) applies to agricultural or settlement areas and natural landcover that is allocated to development without best practices. The INFI values are then scaled to a maximum value of 1 (i.e., 100%) by dividing the INFI values by the INFI value associated with no land use (0.9).

1.5 Water Quality

1.5.1 Unit

Percent of natural.

1.5.2 Formula

$$Water\ quality = 100 * \frac{(0.228 * F_{init} + 0.050 * P_{init})}{(0.228 * F + 0.05 * P + \frac{0.603 * A}{(1 + B)} + 0.831 * S)}$$

1.5.3 Rationale

Phosphorus runoff associated with land cover types is based on phosphorus export coefficients provided by Donahue (2013) for various natural and anthropogenic land cover types. Phosphorus export coefficients were derived from Donahue (2013) as follows: forest equaled the average of coefficients for conifer dominated forest, deciduous dominated forest, and wooded (0.228 kg/ha/year); prairie equaled the coefficient for native grassland (0.050 kg/ha/year); wetlands equaled 0 kg/ha/year because wetlands act as a nutrient sink as opposed to a source; agriculture equaled the average of coefficients for general agriculture in flat, rolling, and hilly landscapes (0.603 kg/ha/year); and settlement equaled the average of coefficients for city core and suburban (0.831 kg/ha/year). Donahue (2013) provides coefficients by natural region; the coefficients described above are area weighted averages of the coefficients for the natural regions. Best practices are assumed to reduce phosphorus runoff from agricultural land by 50%. Devlin et al. (2002) suggest switching from broadcast to injection application of fertilizer to reduce phorphorous runoff by 50%. Tabbara (2003) found that incorporation reduced losses of phosphorous from crops by as much as 30 to 60% depending on source and application rate. Olson (2004) estimated that the use of nitrogen-based manure application rates instead of phosphorus-based manure application rates resulted in twice as much manure being applied to crops than is necessary to achieve phosphorus requirements for crops.

1.6 Water Use

1.6.1 Units

Units of the raw indicator (as opposed to the index) are m3. Energy production in the equation is in GJ.

1.6.2 Formula

$$Water\ use = (175.78 * A + 31.23 * Pop + 0.03544 * Energy) * (1 - B * 0.3)$$

$$Water\ use(index) = \min(100, 100 * \frac{(175.78 * A + 31.23 * Pop + 0.03544 * Energy) * (1 - B * 0.3)}{2 * (175.78 * A_0 + 31.23 * Pop_0 + 0.03544 * Energy_0)})$$

1.6.3 Rationale

Agricultural water use

In 2005, stockwatering and irrigation in Alberta used 102,718 dam3 and 2,110,017 dam^3, respectively (Alberta Environment 2007). Total agriculture area in Alberta as calculated using ALCES Online is 12,587,744 ha, so crop and livestock water use per ha is estimated to equal 175.8 m^3/ha.

Settlement water use

In 2005, municipal water use in Alberta was 130,865 dam^3 (Alberta Environment 2007). Total population in Alberta as calculated using ALCES Online is 4,189,943. Average municipal water use per person is therefore estimated to equal 31.2 m^3.

Energy sector water use

In 2005, the petroleum sector used 261,243 dam^3 of water (Alberta Environment 2007). Total energy production in Alberta as calculated using ALCES Online is 7,372,286,626 GJ. Average energy sector water use is therefore estimated to equal 0.035436 m3/GJ.

Best practices

Best practices reduce water use by 30%, based on the target in the provincial water strategy of increasing water use efficiency by 30% (Alberta Environment 2003).

1.7 Biotic Carbon

1.7.1 Units
Percent of natural.

1.7.2 Formula

$$Biotic\ carbon = 100 * \frac{(200 * W + 137 * P + 171 * (1 - D * 0.09) * F + 97 * A)}{(200 * W_{init} + 137 * P_{init} + 171 * F_{init})}$$

1.7.3 Rationale

Storage of biotic carbon in vegetation and soil is calculated using the following biotic carbon densities:

- 200 tonnes/ha for wetlands based on the mineral wetland value from Tarnocai (2006);
- 170.7 tonnes/ha for forest (Kurz and Apps 1999);
- Converting natural forest to managed forest (i.e., for timber production) reduces the amount of carbon storage due a reduction in the average age of the forest, even when the storage of carbon by forest products is taken into account. The reduction in carbon storage is estimated to equal 9% for Canadian boreal forest (Kurz et al. 1998). Therefore, carbon storage by forests is reduced by 9% in Alberta Tomorrow for forests that are allocated to development.
- 137 tonne/ha for prairie based on the mid-point of carbon densities of Alberta rangelands provided by Bremer (2008);
- Averaged across soil types, converting native rangeland to cropland reduces soil organic carbon by 29% (Bremer 2008). Therefore, the carbon density of agricultural land was assumed to be 97 tonne/ha (i.e., 29% lower than the carbon density of prairie);

1.8 Greenhouse Gases

1.8.1 Units
Units of the raw indicator (as opposed to the index) are tonnes of CO2 equivalent. Energy and timber production in the equation is in GJ and m3, respectively.

1.8.2 Formula

$$\boldsymbol{GHG\ emissions = (1.708 * A + 23.903 * Pop + 0.018 * Energy + 0.039 * Timber) * (1 - B * 0.5)}$$

$$\boldsymbol{GHG\ emissions(index) = \min\left(100, 100 * \frac{(1.708 * A + 23.903 * Pop + 0.018 * Energy + 0.039 * Timber) * (1 - B * 0.5)}{2 * (1.708 * A_0 + 23.903 * Pop_0 + 0.018 * Energy_0 + 0.039 * Timber_0)}\right)}$$

1.8.3 Rationale

Canada's Greenhouse Gas Inventory by economic sector for the year 2015 (http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1) was used to estimate the amount of greenhouse gas emitted per unit of oil and gas, agricultural and forestry production and per person (table 2). Sectors whose emissions were associated with human population included transportation, electricity, buildings, and waste.

Agricultural GHG emissions

In 2015, agriculture GHG emissions of the agriculture sector were 21.5 MtCO2eq. Total agriculture area in Alberta as calculated using ALCES Online is 12,587,744 ha, so GHG emissions per ha is estimated to equal 1.71 tonne/ha.

Settlement GHG emissions

In 2015, GHG emissions by transportation, buildings, electricity, and waste sectors equaled 100.2 MtCO2eq. Total population in Alberta as calculated using ALCES Online is 4,189,943. Average GHG emissions per person are therefore estimated to equal 23.9 tonne.

Energy GHG emissions

In 2015, GHG emissions by the oil and gas sector equaled 132.3 MtCO2eq. Total energy production in Alberta as calculated using ALCES Online is 7,372,286,626 GJ. Average GHG emissions from energy production are therefore estimated to equal 0.018 tonne/GJ.

Forestry GHG emissions

In 2015, GHG emissions by the forestry sector was 0.82 MtCO2eq. Total timber production in Alberta as calculated using ALCES Online is 721,218,569 m3. Average GHG emissions from timber production are therefore estimated to equal 0.039 tonne/m3.

Best practices

Best practices have the effect of reducing GHG emissions by 50%. This is based on the Alberta Government's goal of reducing GHG emission intensity by 50% below the business as usual level by 2050 (Alberta Government 2008).

2 Socio-economic Indicators

Socio-economic indicators are reported as % of the estimated maximum level for the indicator, where maximum is defined as double the current amount. For each indicator, two equations are provided: 1) raw indicator value (e.g., people, $, GJ, etc.); and 2) an index. For each indicator, the index equals 50 for the current value of the indicator and increases to 100 if the raw indicator value doubles relative to current. Raw indicator units for each indicator are identified below.

2.1 Human population

2.1.1 Unit

People.

2.1.2 Formula

Note: the best practice should only apply to the forecast.

$$Pop = Pop_0 * \frac{S}{S_0} * (1 + B * 0.25)/1$$

$$Human\ population\ (index) = \min(100{,}100 * \frac{S}{2 * S_0})$$

2.1.3 Rationale

Current population was calculated using ALCES Online, a land-use planning decision support tool. ALCES Online calculates population based on census data and the location of residential footprint. If best practices are applied, forecasted human population density increases by 35%. Scenario analyses that explored the consequences of high density urban development strategies proposed by the Calgary and Edmonton metropolitan plans identified that high density greenfield developments and densification of existing neighborhoods has the potential to increase population density by 35% (Calgary; Carlson et al. 2014) and 38% (Edmonton; Advisory Panel on Metro Edmonton's Future 2016) relative to low density urban development.

2.2 Gross Domestic Product

2.2.1 Unit

$. Energy and timber production in the equation is in GJ and m3, respectively.

2.2.2 Formula

$$GDP = 292.82 * A + 27.50 * Timber + 11.29 * Energy$$

$$GDP(index) = 100 * \frac{(292.82 * A + 27.50 * Timber + 11.29 * Energy)}{2 * (292.82 * A_0 + 27.50 * Timber_0 + 11.29 * Energy_0)}$$

2.2.3 Rationale

GDP contributions by the agriculture, forestry, and energy sectors were based on Statistics Canada table 379-0030 for the year 2016. Units are chained 2007 dollars. Industries included in the calculation of agriculture GDP were crop and animal production and support activities for crop and animal production. Industries included in the calculation of forestry GDP were forestry and logging and support activities for forestry. Industries included in the calculation of oil and Gas GDP were oil and gas extraction and support activities for oil and gas extraction.

2.3 Hydrocarbon production

2.3.1 Unit

Barrels of oil per year

2.3.2 Formula

The formula is only needed when calculating future production in land use planning mode. The maximum growth in energy production is set at twice current production.

$$\boldsymbol{Energy} = \boldsymbol{Energy_{projected}} * \frac{\boldsymbol{D} * (\boldsymbol{A} + \boldsymbol{F} + \boldsymbol{W} + \boldsymbol{P})}{\boldsymbol{D_{projected}} * (A_{projected} + F_{projected} + W_{projected} + P_{projected})}$$

$$\boldsymbol{Energy}(\boldsymbol{index}) = \mathbf{min}(\mathbf{100}, \mathbf{100} * \frac{\boldsymbol{Energy}}{\mathbf{2} * \boldsymbol{Energy_0}})$$

2.3.3 Rationale

Past, current, and projected future energy production within each school division was calculated using ALCES Online, a land-use planning decision support tool. ALCES Online calculates the production (m3) of oil, gas, and bitumen based on the location of wells and mines, and sub-regional production data from the Alberta Energy Regulator. Oil, gas, and bitumen production was first converted from m3 to GJ using the following conversion factors used by the National Energy Board: oil=38.51 GJ/m3; bitumen=40.9 GJ/m3; natural gas=0.037066 GJ/m3. GJ was then converted to barrels of oil using the conversion factor 0.171 barrel of oil equivalent/GJ (https://www.unitjuggler.com/convert-energy-from-GJ-to-boe.html).

2.4 Agricultural production

2.4.1 Unit

People fed per year.

2.4.2 Formula

$$Agricultural\ production = 3.3 * A$$

$$Agricultural\ production\ (index) = \min(100, 100 * \frac{A}{2 * A_0})$$

2.4.3 Rationale

Total agricultural production in Alberta was estimated by converting 2003 production values for crop types (all types except corn for grain, mixed grains, and tame hay) and animal products (beef, pork, milk, cream, chicken, turkey, eggs, honey) consumed by humans (Alberta Agriculture, Food and Rural Development 2003) into calories using conversion values provided by the USDA National Nutrient Database for Standard Reference (USDA 2004). The total caloric production (approximately 60 trillion kcal) was then divided by the area of converted agricultural land in Alberta from the 2001 Census of Agriculture (14,388,588 ha; Statistics Canada 2001) to estimate an caloric production rate of 4,250,842 kcal/ha. Caloric production was then converted to number of people fed based on the average caloric consumption per person per year in Canada (1,288,450 kcal; https://en.wikipedia.org/wiki/List_of_countries_by_food_energy_intake), resulting in a rate of 3.3 people fed per ha.

2.5 Timber production

2.5.1 Unit

Logging truck loads per year.

2.5.2 Formula

The formula is only needed when calculating future production in land use planning mode.

$$\boldsymbol{Timber\ production = Timber_0 * \frac{D * F}{D_{projected} * F_0}}$$

$$\boldsymbol{Timber\ production(index) = \min(100, 100 * \frac{Timber}{2 * Timber_0})}$$

2.5.3 Rationale

Current timber production within each school division was calculated using ALCES Online, a land-use planning decision support tool. ALCES Online calculates the production (m3) of timber based on the location of cutblocks and provincial timber production data. Timber production in other years was assumed to be proportional to the area of forest available for forestry. Timber production was converted from m3 to number of logging truck loads using the conversion factor of 48.57 m3/load, based on data from British Columbia (BC Forest Safety Council).

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