

Cumulative Effects Assessment of the North Saskatchewan River Watershed using ALCES



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The North Saskatchewan Watershed Alliance (NSWA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. The organization is guided by a Board of Directors composed of member organizations from within the watershed. It is the designated Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River under the Government of Alberta's *Water for Life Strategy*.

Report prepared under contract to NSWA by Dr. Michael G. Sullivan, ALCES Group.

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EXECUTIVE SUMMARY

The North Saskatchewan Watershed Alliance (NSWA) was designated in 2005 as the Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River basin, under *Water for Life: Alberta's Strategy for Sustainability*. Part of its mandate as a WPAC is to prepare an Integrated Watershed Management Plan (IWMP) for the North Saskatchewan River Basin (NSRB). This plan will include advice to the government of Alberta regarding the watershed values and trade-offs that are acceptable to a broad spectrum of stakeholders.

The North Saskatchewan River Basin is one of the largest and most populated major watersheds in Alberta. As such, it is at the core of providing valued services to Albertans. The importance of providing water for drinking and industrial purposes is understood by all, but the full range of services and values of this river go well beyond utilitarian values. The North Saskatchewan River Basin (NSRB) has historical, recreational and spiritual values, supports Alberta's natural capital of biological diversity, and provides ecosystem services such as water purification, sewage disposal, flood control, and climate amelioration.

The value of these important services, however, can be substantially diminished through incremental, gradual encroachment of human development and related impacts on watershed function. As part of their work towards the IWMP, the NSWA desired to gain a better understanding of long-term, cumulative impacts of development on the watershed, and to highlight potential conflicts between development and sustainability. The NSWA engaged the ALCES[®] Group to undertake a high-level, strategic and exploratory cumulative effects modeling for the NSRB.

Specifically, the NSWA-ALCES[®] cumulative effects assessment project is intended to simulate the effects of major land uses in the watershed (agriculture, forestry, urban, and petrochemical industry) on specific watershed "values" (i.e., biodiversity, landscape integrity, water quality, and water quantity) over a 100 year time span. The assessment evaluated four scenarios of potential development:

1. Business-as-usual: population growth and development rates characteristic of the last 10 years.
2. Business-as-expected: lower rates of population growth and development.
3. *Best Practices* and Green Cities: lower rates of growth, reduced sprawl and reduced run-off of stormwater and pollutants as a result of best practices.
4. Best Practices, Green Cities, and Climate Change: including effects of predicted changes in temperature and precipitation from climate models.

This assessment found that the NSRB is, and will continue to be, heavily influenced by human development. Currently, the main footprints affecting watershed values are urban and residential development, and agricultural use. *The cumulative effects from these and*

other activities have had significant detrimental effects on biodiversity, landscapes and water quality. Effects on the quantity of water, however, are at this point comparatively minor.

Modeled scenarios show that urban and residential expansion will be very significant, and will largely occur at the expense of natural and agricultural lands. Based on this assessment, if society continues with “Business-as-usual” develop, urban and rural residential development would completely consume a surface area equivalent to the North Saskatchewan River watershed (aside from protected areas) in 46 years. However, the future cumulative effects of the transition towards urban land use are likely to result in relatively minor additional effects on biodiversity, landscape and water quality compared to the cumulative effects that have already occurred.

The results suggested by these simulations can be used to highlight potential areas of mitigation and restoration, and priorities for policy changes. Although the establishment of Water Conservation Objectives (under the *Water Act*) for water quantity appears worthy, they should be considered carefully if they take precedence over water quality and aquatic ecosystem objectives. However, over the longer term, the potential effects of climate change on water use could have substantial impacts on river flow, biodiversity and water quality. *Therefore, strategies should be favoured that emphasize reductions in point- and non-point pollution as well as protection and restoration of the aquatic ecosystem, including lakes, wetlands and riparian areas, and that have the potential to increase resilience and mitigate potential effects of climate change on these systems.*

Considerable weight should be given to issues of urban and residential sprawl in light of the potential large losses of native and agricultural land and effects on environmental quality. Restoring the watershed to more acceptable levels of biodiversity, landscape and water quality would likely involve considerable mitigation of existing effects of urbanization and agriculture, such as the restoration of riparian areas and reductions in non-point source pollution. *In the future, controlling residential sprawl appears to be one of the most powerful means of limiting further degradation of this watershed.*

This strategic cumulative effects assessment evaluated potential broad-scale implications of future watershed scenarios on biodiversity, landscape integrity, water quality, and water quantity. It is not intended to offer fine-scale, predictive trends or relationships, and the findings should be complemented with more detailed assessment and modeling of hydrology, water quality, and the aquatic ecosystem as required. Further scenario development and analysis may be needed to refine understanding about trade-offs within regions or sub-basins of the NSRB and to evaluate specific strategies for watershed management.

This model should be seen as an important, educational, first step towards integrating watershed planning (*Water for Life*), cumulative effects management (*Cumulative Effects Management Framework*) and land use planning (*Land Use Framework*) in the NSRB.

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1.0 INTRODUCTION

The North Saskatchewan Watershed Alliance (NSWA) was designated in 2005 as the Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River basin, under *Water for Life: Alberta's Strategy for Sustainability*. Part of its mandate as a WPAC is to prepare an Integrated Watershed Management Plan (IWMP) for the North Saskatchewan River Basin (NSRB). This plan will include advice to the government of Alberta regarding the watershed values and trade-offs that are acceptable to a broad spectrum of stakeholders.

The North Saskatchewan River Basin is one of the largest and most populated major watersheds in Alberta. As such, it is at the core of providing valued services to Albertans. The importance of providing water for drinking and industrial purposes is understood by all, but the full range of services and values of this river go well beyond utilitarian values. The North Saskatchewan River Basin (NSRB) has historical, recreational and spiritual values, supports Alberta's natural capital of biological diversity, and provides ecosystem services such as water purification, sewage disposal, flood control, and climate amelioration.

The value of these important services, however, can be substantially diminished through incremental, gradual encroachment of human development and related impacts on watershed function. The emerging Alberta *Land Use Framework* (LUF; Government of Alberta, 2008) proposes to address the issue that "all land uses cannot occur at all locations and at all times." It is likely that Regional Plans prepared under the LUF will reinforce the importance of the health and integrity of major watersheds, similar to the goals of *The Policy for Resource Management of the Eastern Slopes*, introduced by the Government of Alberta in 1977, and *Water for Life*, introduced in 2003. Society must recognize the explicit trade-offs that occur between land use benefits (jobs, royalties, rents, etc.) and ecological integrity when decisions are made about future land use trajectories.¹

As part of their work towards the IWMP, the NSWA desired to gain a better understanding of long-term, cumulative impacts of development on the watershed, and to highlight potential conflicts between development and sustainability. Initial discussions about modeling approaches revealed a variety of perspectives regarding the most appropriate way to meet this objective. Available approaches include: scenario analysis and map visualization; spatially-explicit modeling; and geographic strata / land use footprint modeling (Holroyd, 2008; Hudson, 2002). The type of model chosen depends on need and planning context; watershed planning may make use of several

¹ Major patterns of land use change over time (e.g. urbanization, deforestation)

different types of models in combination, including hydrological, water quality, and land-use models.

NSWA determined that the high-level, strategic and exploratory approach to modeling was initially most suited to their needs, and engaged the ALCES[®] Group (www.foremtech.com) to undertake the cumulative effects modeling for the NSRB. ALCES[®] (A Landscape Cumulative Effects Simulator) is a model that provides a comprehensive approach to simulating and evaluating a broad range of effects from a wide variety of land uses over time. It has been extensively tested and validated in Alberta and other areas for resource management, land use planning, and cumulative effects evaluation (Hudson, 2002). It has been determined to be valuable for strategic, regional-scale evaluations of water quality issues, hydrology, and fish community integrity (Jones, 2008; Lagimodiere and Eaton, 2009; Schindler and Donahue, 2006).

Specifically, the NSWA-ALCES[®] cumulative effects assessment project is intended to simulate the long-term (over 100 years) effects of major land uses in the watershed (agriculture, forestry, urban, and petrochemical industry) on specific watershed “values” (i.e., biodiversity, landscape integrity, water quality, and water quantity). It is not intended to offer fine-scale, predictive trends or relationships, and the findings should be complemented with more detailed assessment and modeling of hydrology, water quality, and the aquatic ecosystem as required.

2.0 METHODS

2.1 Overview

The project used ALCES[®] (Version III) to simulate changes to the existing landscape composition within the North Saskatchewan River watershed, and related those changes to four valued watershed components which were determined by the NSWA. These valued components and their associated indicators are:

1) *Biodiversity*

- Index of native fish integrity

2) *Landscape Integrity*

- Percent of basin defined as “human-disturbed”
- Road density
- Percent wetland cover

3) *Water Quality*

- Indices of landscape-level run-off of phosphorus, nitrogen, and sediment

4) *Water Quantity*

- Index of main stem river flow
- Indices of proportion of river water borrowed and consumed

Twenty main landscape types and 15 primary human development footprints were identified for the North Saskatchewan River watershed (Table 1). The total amounts of each landscape type and footprint type were calculated from GIS data obtained from several sources: Alberta Sustainable Resource Development (ASRD); Parks Canada; Alberta Agriculture and Rural Development (AARD); and Agriculture and Agri-Food Canada (AAFC). GIS data sources and processing steps are described in Appendix B-1. These GIS data have inherent limitations due to scale and date of origin, but the author holds the assumption that the model results are broadly indicative of current watershed conditions and trends.

Potential future trajectories for development of major industries, activities and municipalities were obtained from industrial and agricultural business plans, forestry annual allowable cut (AAC) plans, and municipal development forecasts. These assumptions are presented in Appendices B-2 through B-7. A detailed review of the general ALCES[®] model, process, and indicators is presented as a series of publication abstracts in Appendix C.

Table 1: Landscape and footprint types (and GIS-derived areas) simulated in ALCES[®] model used for NSWA cumulative effects assessment.

LANDSCAPE TYPES	Area (ha, or km)
Hardwood	465,512
Mixedwood	42,048
White Spruce/Pine	1,144,998
Black Spruce	520,904
Wetland (bog/fen, includes treed wetlands)	157,819
Forest Grass and Shrub	179,100
Grass and Shrub	77,517
Ditch	192
Canals	1,922
Municipal Sewage lagoons	976
Dugouts, Quarries, and Reservoirs	5,669
Small Lentic	73,169
Large Lentic	66,506
Large Lotic	46,063
Medium lotic	11,403
Small Lotic	14,620
Rock and Ice	420,607
Annual Crops (cereal, oilseed, pulse)	1,085,844
Forage crops	332,335
Pasture / tame grassland	648,508
Totals	5,295,714
FOOTPRINT TYPES	
Major roads	9,083 km
Minor roads	39,350 km
Railroads	1,115 km
In-block roads / truck trails	(calculated during runs)
Mines (coal mines, sand/gravel and borrow pits)	8,120 ha
Feedlots	334 ha
Power lines	2,397 km
Golf Courses, resorts	1,225 ha
Cities and towns	133,288 ha
Rural residential (acreages)	192,189 ha
Industrial	11,015 ha
Seismic	40,665 km
Well sites	22,959 ha
Pipelines	20,237 km

2.2 Primary Indicators and Land Use Factors

2.2.1 Biodiversity

Indicator: Index of Native Fish Integrity

This index relates the expected structure and composition of a typical community of fish to various levels of development pressure. This index incorporates five land use factors: stream fragmentation; human access; human population density; water quality; and water quantity. A detailed description of the Index of Native Fish Integrity (INFI) is referenced in Appendix C-1.

In brief, a high numerical value of this index (e.g., approximately between 0.8 and 1.0) indicates that the fish community will be composed of sensitive fish species, rare fish, top predators and long-lived individuals. These species may include Bull Trout, Walleye, and Lake Sturgeon in a river like the North Saskatchewan. Most people would interpret this condition as providing “good fishing”.

As the numeric index declines, these sensitive types of fish species will also decline and be replaced by a fish community composed of less sensitive species including omnivores, generalists, and short-lived, small-bodied species. Many people would interpret these changes as a loss of valued species, a decline in fishing quality, and an increase in “trash” fish. A very low value of this index (e.g., values below 0.2) would reflect a simple fish community composed of a one to a few highly tolerant species such as White Suckers, Brook Sticklebacks and Fathead Minnows. These species would typically not support any sport, commercial or food fisheries. Even though fish numbers may actually be quite high, most people would interpret this condition as essentially “fishless”, simply based on the absence of fish species of any traditional value.

FACTORS IN THE INFI

- **Stream fragmentation** was modelled using the dynamic relationships between changes in road density and existing stream density, which resulted in a simulated number of road-stream crossings. These simulated crossings were subjected to simulated flood events, derived from the ALCES[®] meteorology sub-model. Relationships between flood events (frequency and magnitude) and probability of a crossing becoming a fish barrier were used to derive the frequency distribution of probable road-stream crossing barriers to fish. This relationship was used to derive the proportion of the watershed streams that may be lost to use by fish each year (i.e., stream fragmentation).
- **Human population density** was modelled as the number of people (per square kilometre) simulated to reside in the watershed.

- **Human access** was modelled as the density of roads, trails and other linear features (e.g., seismic lines) that could provide vehicle access to streams and lakes. Current density of linear features is displayed in Figure 1.
- An index of **water quality** (as it pertains to the integrity of the simulated fish community) incorporated the combined landscape nutrient run-off indices of phosphorus, nitrogen, and sediment. These indices relate the cumulative totals of nutrient runoff (derived from export coefficients) from simulated changes in landscape composition.
- An index of **water quantity** (as it pertains to the integrity of the simulated fish community) was treated in a similar manner. Each landscape and footprint type was assigned a surface water run-off yield (from values provided by Alberta Environment in Appendix C-3). Changes in the landscape composition would therefore result in a cumulative change in surface water yield and therefore run-off. The meteorology sub-model provided annual simulated values for precipitation (as rain or snow as rain-equivalents) as input to the water quantity run-off sub-model.

Relationships between each of the five land use factors and the index of native fish integrity were all negative (e.g., more stream fragmentation resulted in a decline in the INFI). Specific relationships between each land use factor and the INFI were derived from literature values, local studies and consultations with local experts. Rates of decline based on the influence of each factor were modelled separately. The combined effects of the five factors were modelled as a single unweighted average.

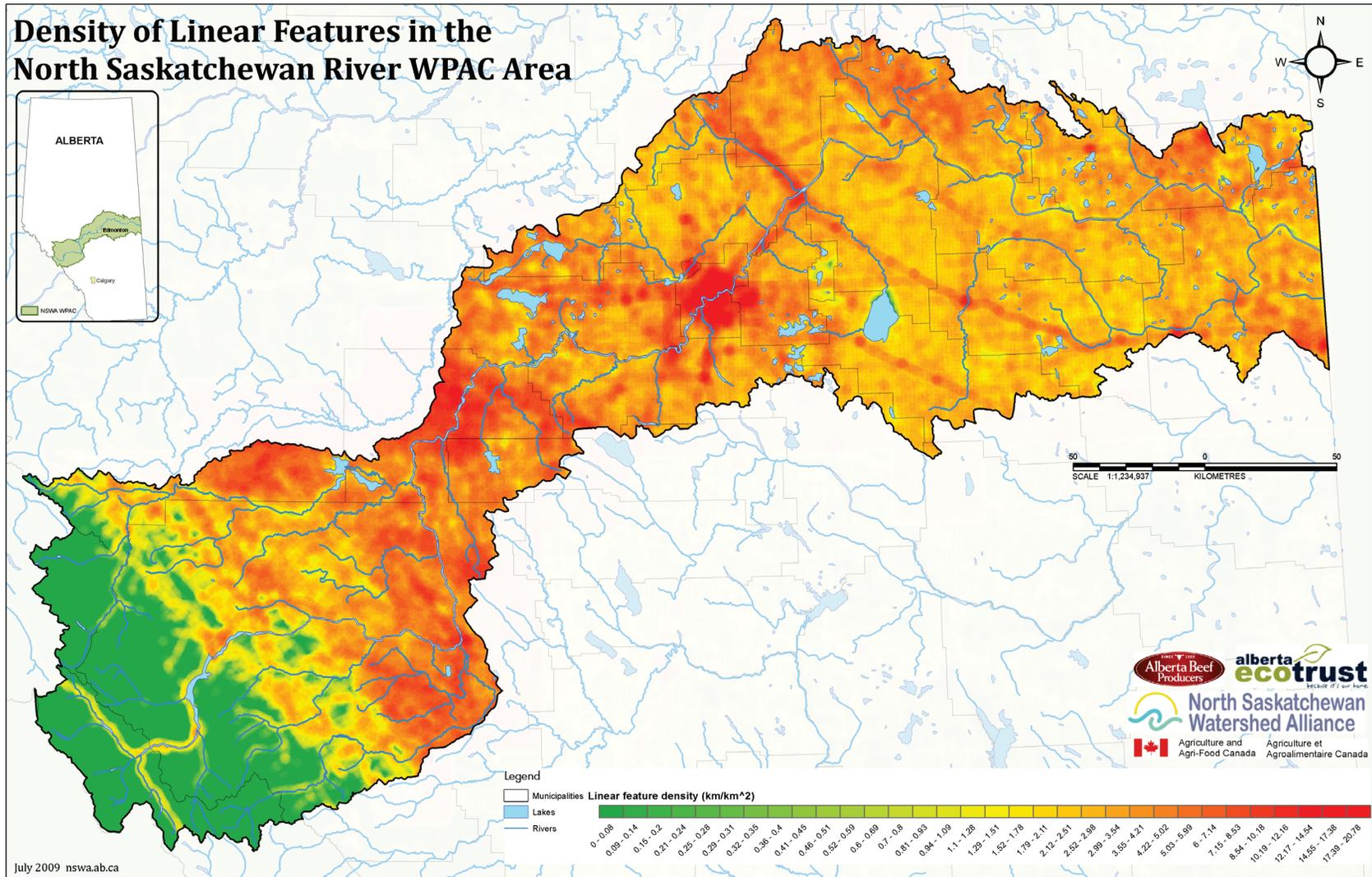


Figure 1. Density of Linear Features (km/km²) in the North Saskatchewan River watershed. Linear features include roads, highways, pipelines, seismic lines, and power lines. Base features data courtesy Alberta Sustainable Resource Development.

2.2.2 Landscape Integrity

Indicator: Percent of Basin defined as “Human-Disturbed”

The percentage of the North Saskatchewan River watershed that was in a “human-disturbed state” was determined by accounting for simulated change over time in each landscape and footprint type. The definition of human-disturbed landscapes encompasses anthropogenic footprints and landscape types, including areas of cities, industries, agriculture, road, etc. These types of disturbance can be easily defined as “human-disturbed”.

Other types of disturbance are less easily defined, such as disturbances initially caused by natural forces (i.e., fire, insects, avalanches and wind throw), but subsequently influenced by human activities. For example, partially human-disturbed landscapes included all forestry land areas that had been harvested at least once in the simulation run (e.g., a 100-year-old cut block was still considered as human-disturbed). All land area affected by wildfire was not considered as “human-disturbed” unless the fire occurred on an existing “human-disturbed” footprint (e.g., a wildfire burning over a 70-year-old cut block was considered “human-disturbed”, but a wildfire burning on a natural forest was not considered “human-disturbed”). Fires influenced by human activity (e.g. through climate change or prescribed fire) were not considered to create “human-disturbed” landscapes.

Other natural disturbance events modelled in ALCES[®] included insect outbreaks, wind throw events and avalanches. These events may be modelled with components of human-causation. For example, a proportion of all avalanches (represented by frequency and magnitude factors) were simulated to represent existing avalanche control programs. However, for the simulations in this study all natural disturbance events are considered fully natural and do not contribute to the “human-disturbed” landscape category.

Growth in area of each footprint type could consume a natural landscape type and result in an increase in the proportion of the basin that is “human-disturbed”. Reclamation rates, reforestation rates, and expected life spans of all relevant footprints were also included in these cumulative changes, each of which would result in a decrease in this index. The overall cumulative effect of these simulated expansions (positive relationships) and reclamations (negative relationships) determined the annual value for the index “*Percent of Basin defined as Human-Disturbed*”.

Indicator: Road Density

Roads include all highways, secondary roads, maintained roads, urban and suburban roads, rural acreage roads and driveways, forestry roads, and roads built for oil and gas development. For the road density index, the length of the road (in kilometres) was considered, rather than the actual surface area (i.e., length x width). All roads, except

for forestry in-block roads, are considered to be permanent. In-block roads were reclaimed at rates provided by ASRD.

Indicator: Percent Wetland Cover

Wetland surface area was determined from existing GIS data layers (Appendix B-2). In the ALCES model application wetlands were “consumed” by the growth of footprint types in direct proportion to their distribution on the landscape (e.g., if 20% of wetlands were in forest-shrub lands, and forest-shrub lands were consumed at 2% per year by urban sprawl, then wetlands in that landscape were also consumed at a rate of 2% per year).

No scenarios were simulated where wetlands received special protection above any other landscape type or above any existing protection status (e.g., wetlands in Parks were protected). Also, the direct restoration of wetlands was not simulated in any scenario. The effects of wetland restoration were simulated indirectly, however, through a reduction on basin yield (water run-off coefficients)

The indicator “Percent Wetland Cover” was therefore the simple proportion of the surviving hectares of wetlands in each year, after a simulated footprint growth.

2.2.3 Water Quality

Indicators: Landscape-Level Indices of Phosphorus, Nitrogen, and Sediment

These indicators simply reflect the changes in export coefficients from one landscape type as it is changed into a footprint type or another landscape type. For example, one hectare of mixed wood forest landscape type may have an annual export of 0.0002 tonnes of phosphorus. If half of this hectare were converted to forage crop landscape-type, the annual export of phosphorus from the developed segment would be simulated to increase to 0.00033 tonnes/ha/year. The cumulative effect would therefore be an increase in potential export from that partially developed hectare to 0.000265 tonnes/ha/year.

In these simulations, all conversions and reclamations of landscape types and footprints types were accounted for annually. The cumulative indices of overall export potential, based on the corresponding changes in export coefficients, were therefore also calculated annually.

The indices of nutrient and sediment export were then scaled to reflect the change from that export expected from an undisturbed landscape. The simulations were conducted in the absence of human development and the total sum of nutrients and sediment are calculated and set as the baseline index value. Simulations with human development are conducted and the new total export is calculated. This value is scaled as the inverse proportion of the original export to reflect that the water quality decreased (i.e., if export has doubled, the scaled value is 1/2 or 0.5; if the export is tripled, the scaled value is 1/3 or 0.33).

The indices of landscape nutrient export as simulated in ALCES[®] are not directly correlated to the actual loading into receiving water bodies, or to actual measurements of nutrient concentrations in the receiving waters. It is simply an index of the potential for the changing landscape to generate more (or less) nutrient for movement across the landscape. Large changes in the cumulative export of landscape nutrients, however, would be reasonably expected to result in changes in similar concentrations of nutrients in receiving waters. In one component of this analysis the Index of Landscape Phosphorous Export was scaled to the Index of Main Stem River Flow to infer changes in assimilative capacity caused by water withdrawals simulated in the “Best Practices, Green Cities, and Climate Change” scenario. A review of concepts of the ALCES[®] Index of Landscape Nutrient Run-off is referenced in Appendix C-2 (Schindler and Donahue, 2006).

The export coefficients used in this project were provided by Alberta Environment. They are considered reasonable (rather than exact) and are based on existing scientific literature, local studies, and expert opinion regarding Alberta landscapes. The specific values for each export coefficient, specifying values for each landscape and footprint type are referenced in Appendix C-3. The effects of simulated increases in human

population on amounts of sewage effluent or other point source discharges were not modeled.

2.2.4 Water Quantity

Indicator: Index of Main Stem River Flow

The index of flow in the simulated scenarios relates to the outflow of surface run-off from the study area. This index therefore corresponds to the outflow in the main stem of the North Saskatchewan River at the Alberta-Saskatchewan border. This index is derived from a hydrology sub-model in ALCES®. A detailed description of this sub-model is given in Appendix C-4. In brief, the model is a simple accounting of water balance between precipitation, evaporation, surface run-off, and groundwater infiltration. Each landscape and footprint type has specific meteorological values and water balance coefficients.

The ALCES® index of river flow is expressed in units of cubic meters of water. However, because of the coarse scale of the ALCES® hydrology sub-model and the general values of the water balance coefficients, the index of flow must be considered only roughly indicative of trends, rather than a predictive model of actual river flow. The meteorology values are described in detail in Appendix C-3. The surface run-off coefficients (yield) for landscape and footprint types are also described in detail in Appendix C-3.

Indicators: Proportion of River Water Borrowed and Consumed

The index of “borrowed” water refers to water volumes used by various sectors, but returned directly to the river. The index of water consumption (“consumed”) refers to water that is not returned to the river and is presumably lost to evaporation or other processes. Water consumption and return values were assigned to all human activities modelled in the North Saskatchewan River watershed. These values are described in Appendices B-2, B-3, and C-3.

The cumulative changes in the overall water balance reflect the consequences of changes in precipitation and changes in land uses in the basin. The water input (i.e., precipitation as rain or snow as rain-equivalents) is modelled on an annual basis for each landscape and footprint type. At the same time, consumption and return of water to the surface flow is modelled for each landscape and footprint type. The proportions of these values are used to derive the indices of river flow.

2.3 Simulated Scenarios

Four potential development scenarios were simulated for the North Saskatchewan River watershed: Business-as-usual; Business-as-expected; Best Practices and Green Cities; and Best Practices, Green Cities and Climate Change.

2.3.1 Scenario: Business-as-Usual

This scenario is a simple projection of the urban and municipal growth rates observed in the North Saskatchewan River watershed during a recent 10-year period (1996 to 2006). Annual growth in the surface areas of cities and towns was simulated as 3.1%, and rural residential surface area growth as 7.1%. Human populations were simulated as growing at 2.5%. These growth rates were observed in various municipalities in the watershed during a period of unusually high economic growth and development. This scenario was modelled to confirm (or refute) the widespread view that such high growth rates are unsustainable and unrealistic in the long-term.

In this scenario, urban and rural residential development completely consumed a surface area equivalent to the North Saskatchewan River watershed (aside from protected areas) in 46 years. This is believed to be unrealistic (e.g., municipal growth would likely expand in a north-south axis into other watersheds, rather than east-west, or society would not continue to tolerate urban expansion). Therefore this scenario was not modelled beyond the initial run which demonstrated that it is clearly unsustainable.

2.3.2 Scenario: Business-as-Expected

This scenario simulated conditions of slightly reduced growth, followed within a few decades by considerable reductions in growth. Annual growth in the surface areas of cities and towns was simulated as 2.5% for 40 years, and then reduced to 1%. Annual growth in rural residential surface area was simulated as 3.5% for 40 years, then reduced to 2.5%. Human populations were still simulated as growing at 2.5%. This scenario was modelled to simulate anticipated changes in social tolerances for the negative consequences of development.

2.3.3 Scenario: Best Practices and Green Cities

This scenario simulated a society where tolerance for watershed degradation had been exceeded, and strong restoration and land use measures were being implemented. City growth was continued at the Business-as-Expected rates, but rural / suburban growth was reduced to 2% for the next 40 years, then further reduced to 1%. Additionally, landscape mitigation measures were simulated to reduce the effects of land disturbance on water quality by reducing export coefficients by 50% for all footprint types.

This reduction in nutrient export was meant to simulate a large-scale program of watershed rehabilitation such as restoration of effective riparian areas, reductions in nutrient applications, wetland restoration and prevention of non-point-source nutrient pollution. In these simulations, changes to areas of wetland and riparian landscape were not modelled directly, but instead the theoretical effects of these changes on

nutrient export were simulated. Water yield from urban footprint types was also reduced by 50% to simulate effective restoration of wetland water capture and drainage within highly developed systems.

2.3.4 Scenario: Best Practices, Green Cities, and Climate Change

This scenario simulated conditions where the people in the watershed have implemented a variety of landscape-level restoration and sustainable practices, but climate change affects the water balance in the watershed. The average temperature and precipitation changes as proposed from three climate change models were used to simulate these conditions. Two major changes in water consumption were also simulated in conjunction with climate change. Large-scale (30%) increases in irrigation of cropland increased diversions from the river. Large increases in air-conditioning (12% increase per degree warming) increased demand for electrical power therefore increasing river withdrawals for coal mining and cooling of thermal power plants.

It should be noted that actual increases in irrigation will depend on market conditions, land suitability for irrigated agriculture and the development of irrigation infrastructure. Similarly, technological changes in thermal power generation may alter rates of projected water use. Meteorological and climate change assumptions are detailed in Appendix B-6.

3.0 RESULTS

3.1 Biodiversity

In all scenarios, the index of native fish integrity declined from its current low value of 0.65-0.6 to below 0.5 (Figure 3). The current condition roughly corresponds to a watershed with an altered fish community, supporting relatively poor fishing with a few high-risk and rare species like Bull Trout, Lake Sturgeon and Walleye being in danger of extirpation. All modelled scenarios failed to recover the fish community, and the modelled decline suggests that the future of the North Saskatchewan River fish community will be similar to the current Battle River fish community. Recent studies in the Battle River watershed show that this highly altered community supports very little fishing, several species have been lost, and several others are at a high risk of loss (Stevens and Council, 2008).

The primary causes of the low and declining INFI are high levels of road development, human access, and landscapes with high levels of potential nutrient and sediment runoff (Figure 2). Water quantity, however, was not identified as a significant issue in predicted changes in native fish integrity except under the climate change scenario. These predictions are shown for the Business-as-Expected scenario (Figure 3), although similar predictions are observed as model outputs from each scenario.



Figure 2. Riparian conditions along a reach of the Battle River (photograph courtesy M.G. Sullivan).

3.2 Landscape Integrity

The current level of human disturbance in the North Saskatchewan River watershed is approximately 45 % (Figure 5). In the Business-as-Expected scenario, this increased to over 90% within 100 years, while in the two restricted development scenarios, this increased to over 60% (Figure 5). This change was a result of urban and rural residential expansion, primarily at the cost of an overall loss of agricultural land. The contributing factors to these changes in the overall landscape are shown for the Business-as-Expected scenario in Figure 6.

Road density, a surrogate for many biodiversity concerns, rose to levels of 2.5 km / km² in reduced development scenarios and nearly 4 km / km² in the Business-as-Expected scenario (Figure 7).

Wetland loss resulted in values well below the NSWA thresholds identified in the NSWA's State of the North Saskatchewan Watershed Report (2005) and continued to be a serious concern in all scenarios (Figure 8).

3.3 Water Quality

The indicators chosen to address issues of potential water quality were the relative indices of potential run-off of nitrogen, phosphorus, and sediment from different landscape types. As these indices change, it is expected that the quality of receiving water bodies may also change in similar directions. For instance, if the phosphorus run-off potential from a landscape-type increases because of development, it is likely that water quality in the area could also eventually show the consequences of increased phosphorus loading.

In the Business-as-Expected scenario, the current run-off quality was already poor, but was unlikely to decline much more (Figure 9). The primary causes for the low and declining run-off quality are agriculture (initially), with a major shift of contributing sources towards roads and residential run-off as these developments expand over and replace agricultural lands (Figure 10). Of the alternate scenarios, Best Practices initially improved the run-off quality considerably, although it declined with continued development. The Climate Change Scenario was similar, although a steeper decline in run-off quality resulted from increased concentration of run-off in a declining volume of surface water (Figure 11).

3.4 Water Quantity

Although the human use of water in the watershed increased in all scenarios, this was countered by the increase in surface run-off and river flow caused by increased impervious surface associated with urban, rural residential, and municipal development (Figure 12).

The Climate Change Scenario showed an initial drop in flow (as a result of irrigation initially expanding in the basin and using large quantities of water), but the flow

eventually returned as this agricultural land was lost to residential expansion. The high human use (but eventual return to the river) of water in this scenario resulted in 50% to 100% of the river water being “borrowed” (Figure 13), but with a lower level of actual consumption (Figure 14).

Conservation efforts and setting of instream flow needs objectives may further reduce the projected withdrawal and consumption of water, although this was not modelled in the best practices scenarios.

4.0 CONCLUSIONS AND RECOMMENDATIONS

In brief, the North Saskatchewan River watershed is, and will continue to be, heavily influenced by human development. Currently, the main footprints affecting watershed values are residential and agricultural developments. The cumulative effects from these and other activities have had significant detrimental effects on biodiversity, landscapes and water quality. *Effects on the quantity of water, however, are at present comparatively minor for the basin as a whole.*

Modeled scenarios show that urban and rural residential expansion will be very significant, and will largely occur at the expense of natural and agricultural lands. However, the future cumulative effects of the transition towards urban land use are likely to result in relatively minor additional effects on biodiversity, landscape and water quality compared to the cumulative effects that have already occurred.

The results suggested by these simulations can be used to highlight potential areas of mitigation and restoration, and priorities for policy changes. Although the establishment of Water Conservation Objectives (under the *Water Act*) for water quantity appears worthy, they should be considered carefully if they take precedence over water quality and aquatic ecosystem objectives. However, over the longer term, the potential effects of climate change on water use could have substantial impacts on river flow, biodiversity and water quality. *Therefore, strategies should be favoured that emphasize reductions in point- and non-point pollution as well as protection and restoration of the aquatic ecosystem, including lakes, wetlands and riparian areas, and that have the potential to mitigate potential effects of climate change on these systems.*

In the future, considerable weight should be given to issues of urban and rural residential sprawl in light of the potential large effects on loss of native vegetation and agricultural land and effects on environmental quality. Based on this assessment, urban and rural residential development would completely consume a surface area equivalent to the North Saskatchewan River watershed (aside from protected areas) in 46 years if growth continued at recent rates.

Restoring the current watershed to more acceptable levels of biodiversity, landscape and water quality would likely involve considerable mitigation of existing effects of urbanization and agriculture, such as the restoration of riparian areas and widespread reductions in non-point source pollution. *In the future, controlling urban and rural residential sprawl appears to be one of the most powerful means of limiting further degradation of this watershed.*

This strategic-level cumulative effects assessment evaluated potential implications of future watershed scenarios on biodiversity, landscape integrity, water quality, and water quantity. It should be seen as an educational tool to help stakeholders understand watershed issues during planning. As such, the accompanying presentation

materials (Appendix A) should be incorporated in NSWA's presentations to stakeholders, and discussions about scenarios and results would be useful additions to workshops with stakeholders about watershed issues.

This model should also be seen as an important first step towards integrating watershed planning, cumulative effects management, and land use planning in the NSRB. A substantial GIS database was established to support this project and may be used to support further efforts.

Further scenario development and analysis may be needed to refine understanding about trade-offs within regions or sub-basins of the NSRB and to evaluate more specific strategies for watershed management. For instance, the model could be configured to assess source water protection issues and solutions in resource industry and agricultural areas upstream of Edmonton, or examine biodiversity impacts of land clearing, wetland loss and restoration. ALCES[®] model scenarios and results may also need to be integrated with other tools such as the EFDC water quality model developed by NSWA and Alberta Environment.

A detailed presentation of this project is referenced in Appendix A.

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ADDITIONAL FIGURES

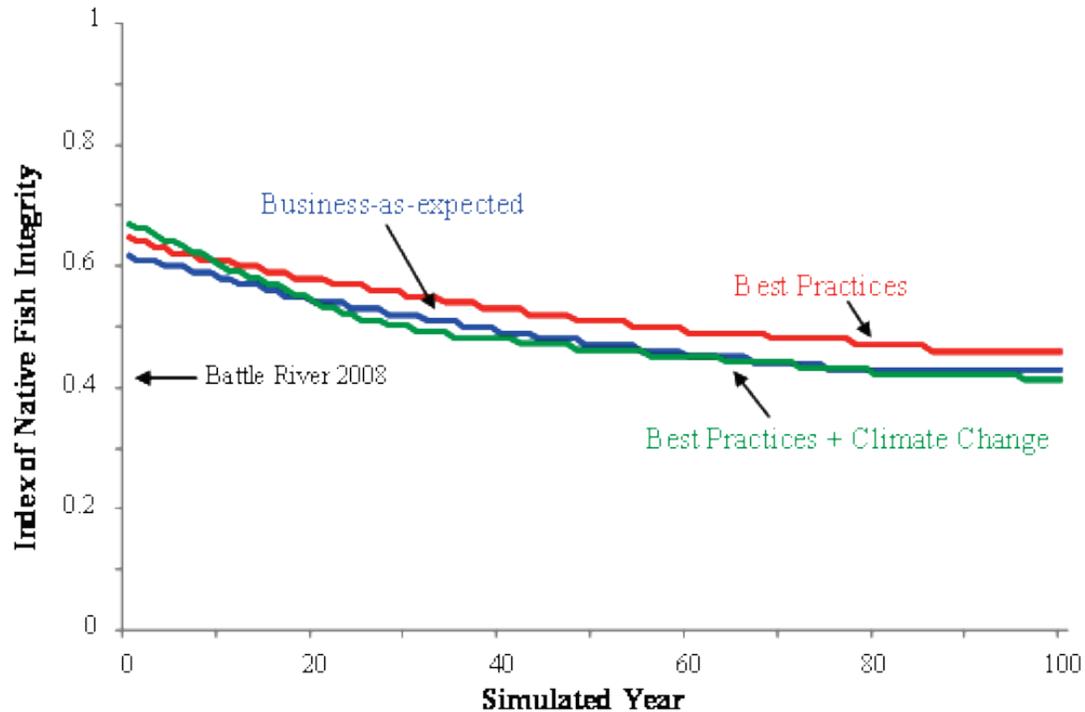


Figure 3. Simulated changes in the Index of Native Fish Integrity in the North Saskatchewan River watershed. The changes in the INFI were simulated under three potential development scenarios using initial data describing current (2006-2009) levels of development, and projecting changes 100 years into the future. The INFI value for the Battle River is an actual measurement, not simulated, and is presented to provide context for simulations.

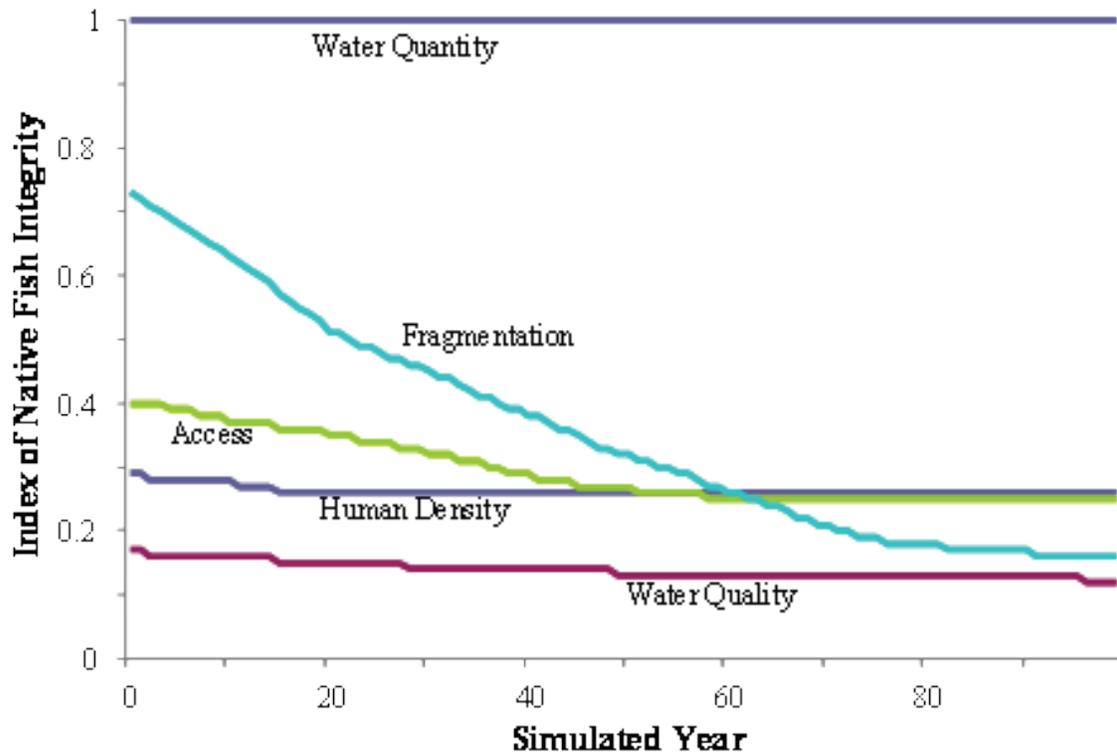


Figure 4. Simulated changes in the Index of Native Fish Integrity as derived for each of five contributing factors, under the “Business-as-expected” development scenario.

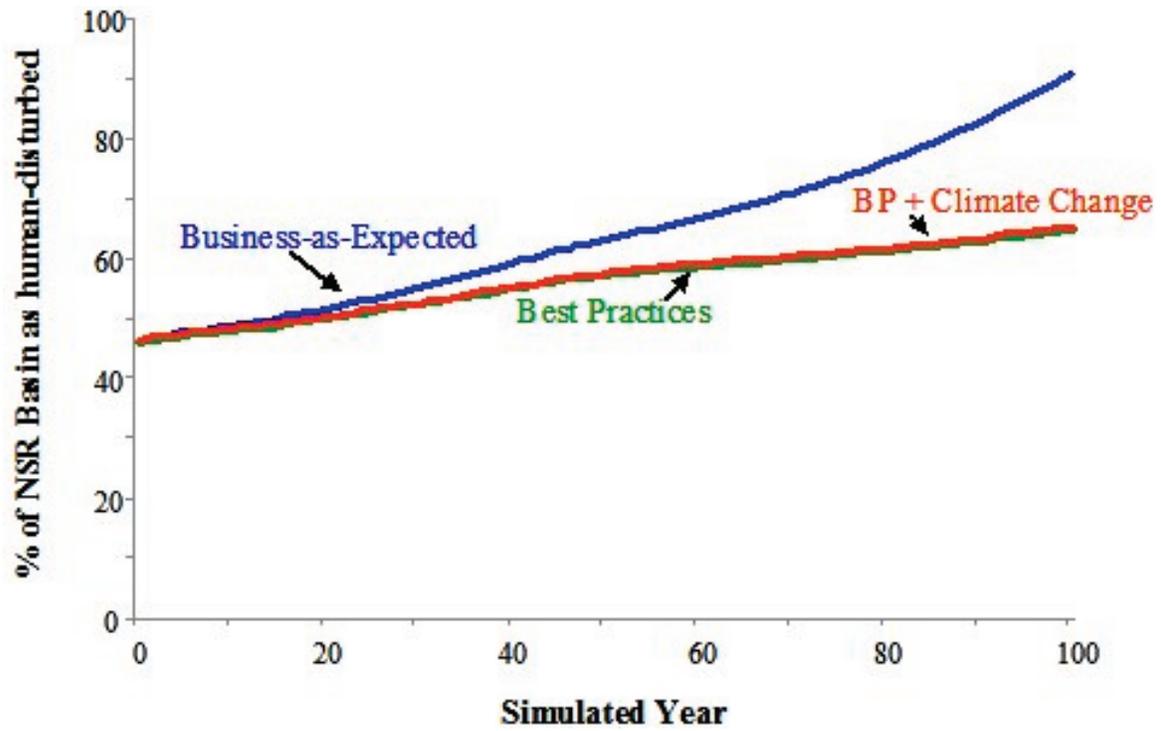


Figure 5. Simulated changes in the index of Percent of North Saskatchewan River watershed defined as “human-disturbed” under three different development scenarios.

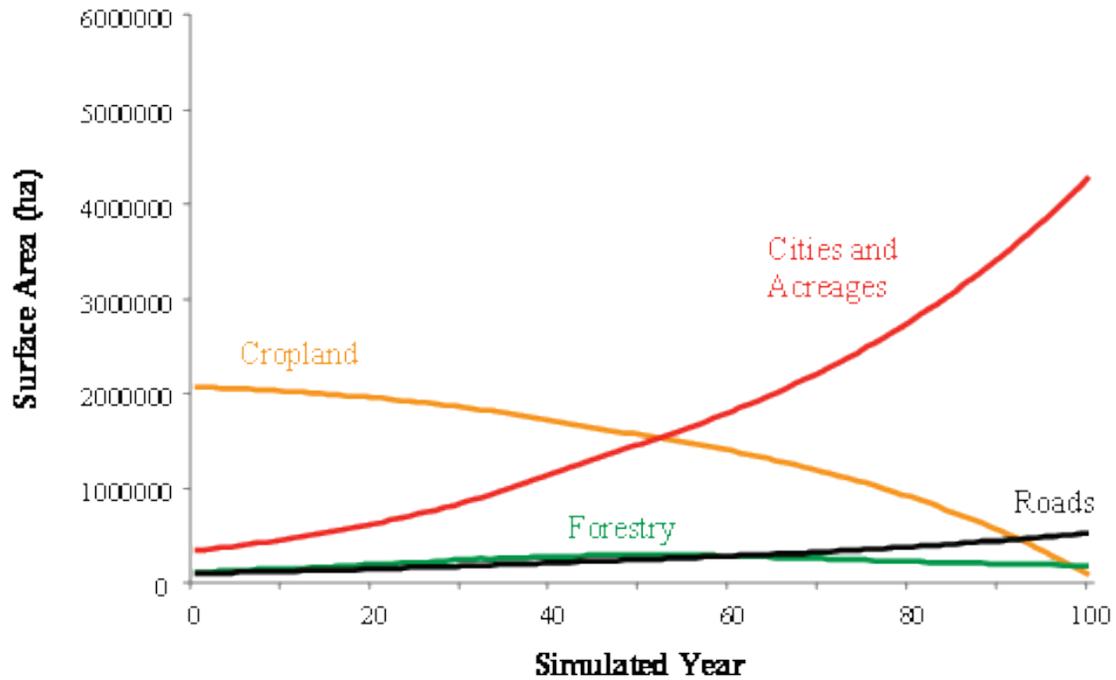


Figure 6. Simulated changes in surface areas of categories of human development in the North Saskatchewan River watershed under the “Business-as-expected” development scenario.

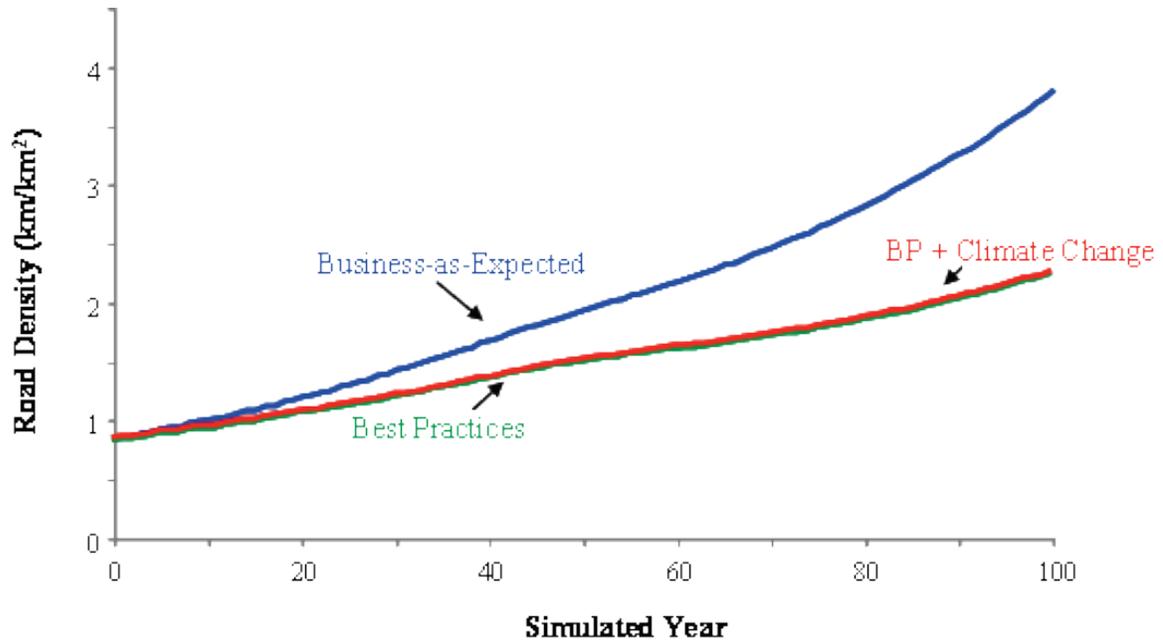


Figure 7. Simulated changes in road density in the North Saskatchewan River watershed under three different development scenarios.

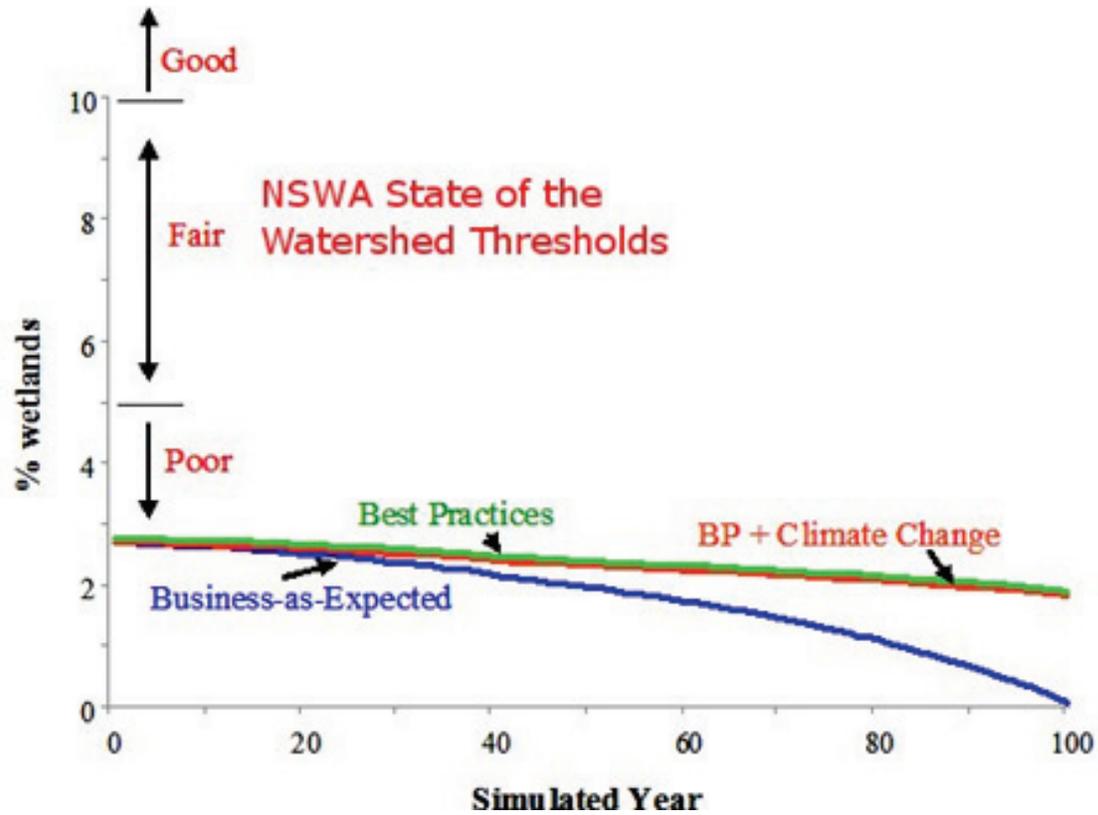


Figure 8. Simulated changes in percentage of wetlands in the North Saskatchewan River watershed, under three different development scenarios. Threshold values for this index were developed for the State of the North Saskatchewan River Watershed Report (2005).

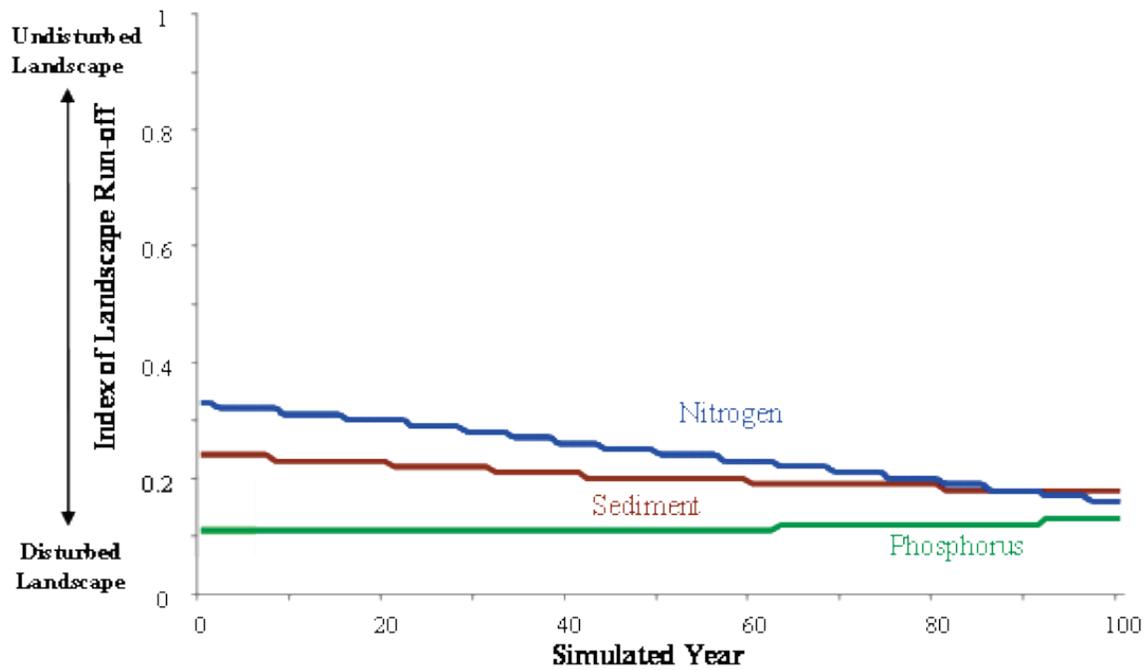


Figure 9. Simulated changes in the index of landscape nutrient run-off in the North Saskatchewan River watershed under the “Business-as-expected” scenario.

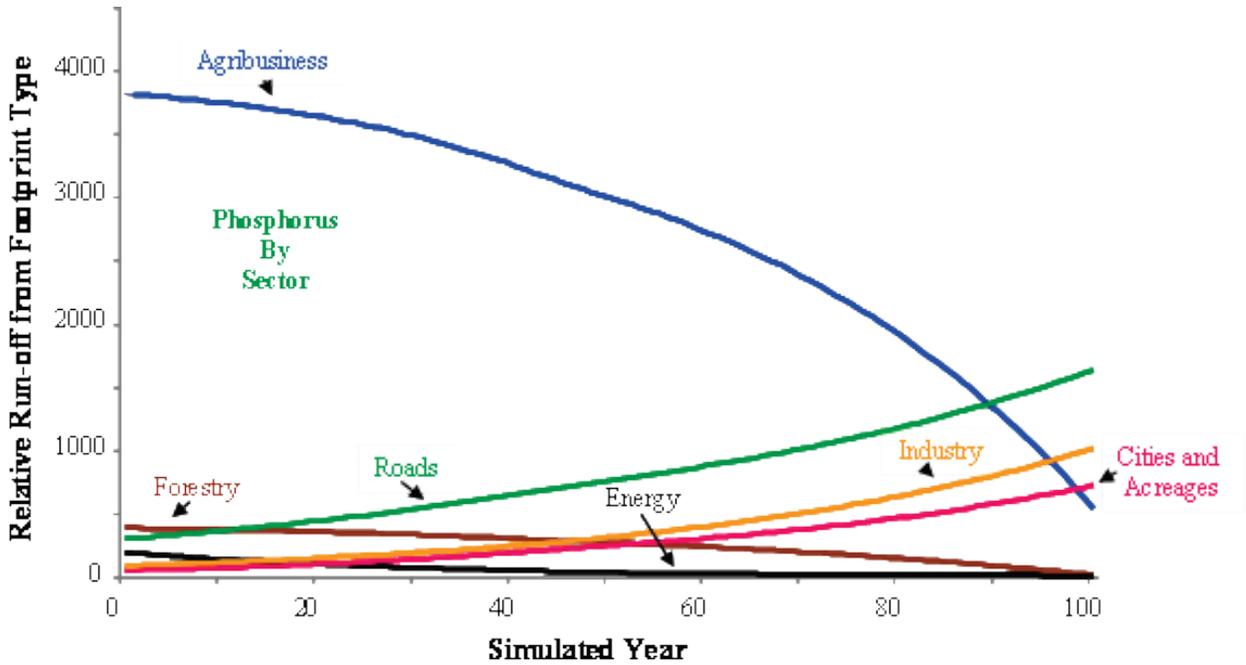


Figure 10. Simulated changes in the relative export of phosphorus by category of human development under the “Business-as-expected” scenario.

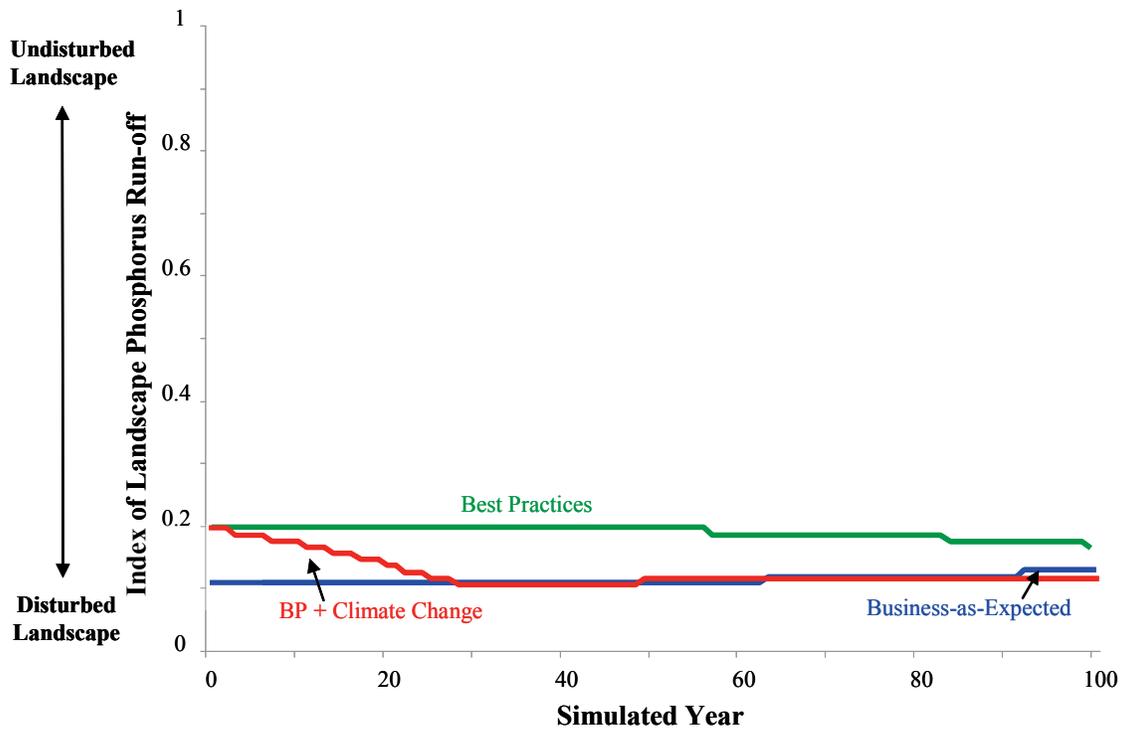


Figure 11. Simulated changes in the index of landscape phosphorous run-off under three potential development scenarios.

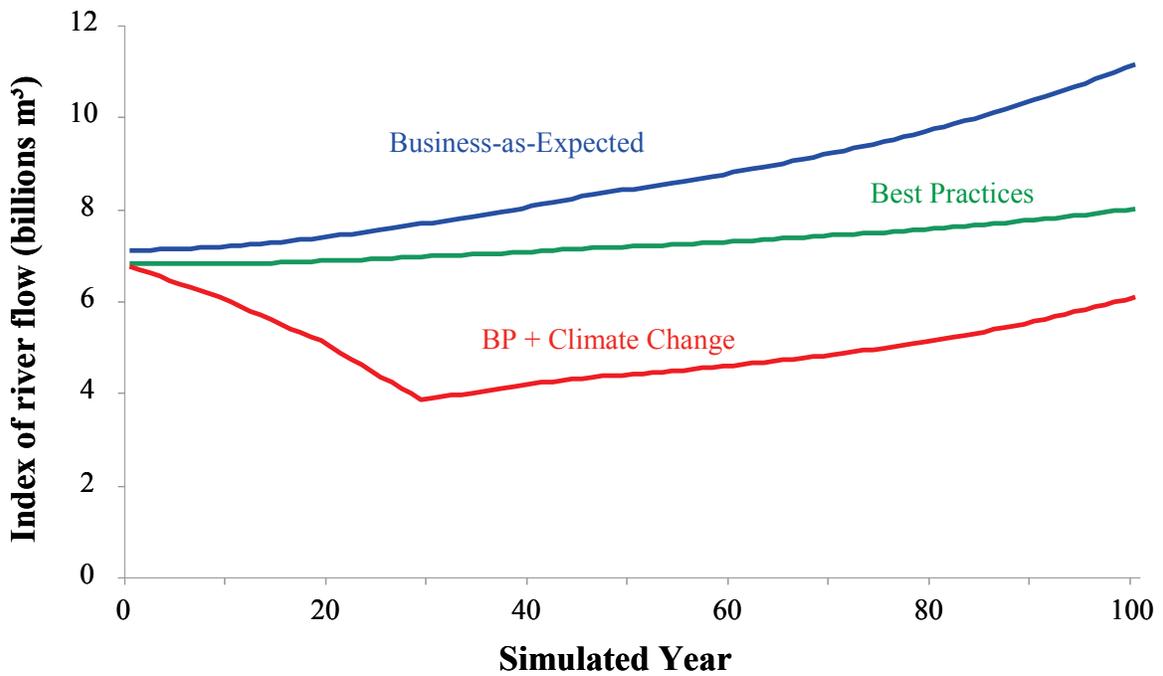


Figure 12. Simulated changes in the index of river flow in the North Saskatchewan River watershed, under three different development scenarios.

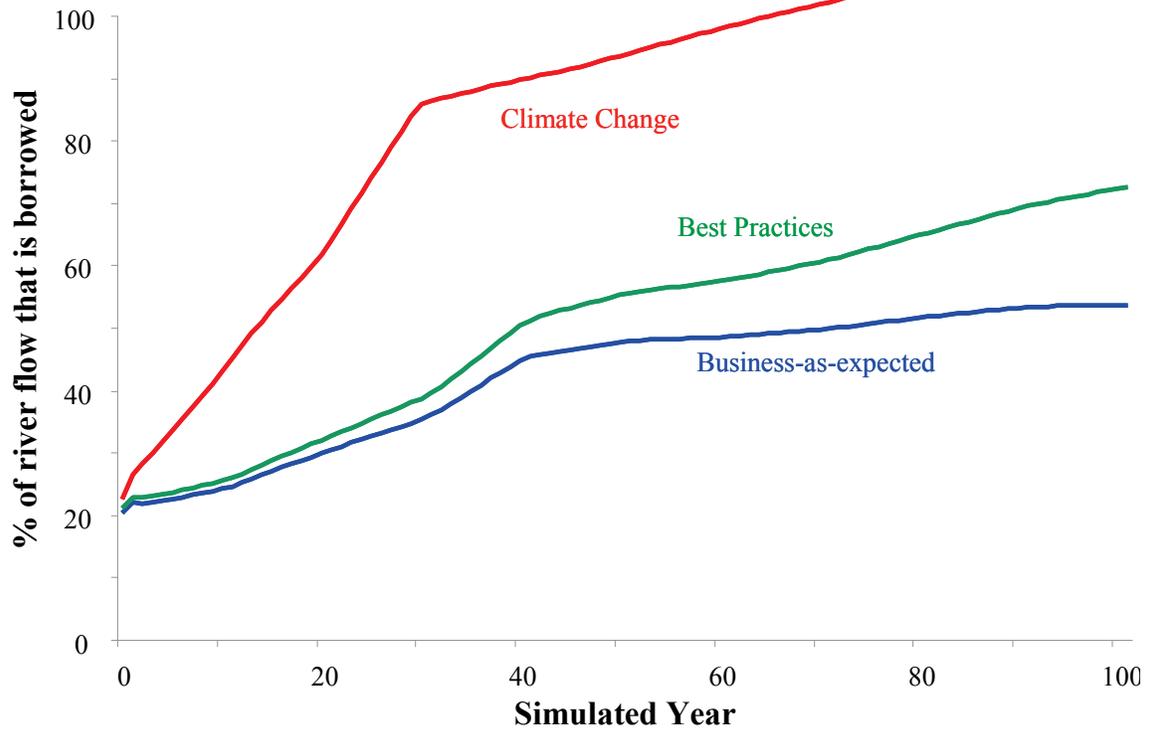


Figure 13. Simulated changes in the borrowed proportion of the simulated river flow in the North Saskatchewan River that was borrowed (i.e. withdrawn and partially returned) under three potential development scenarios. Portion of river flow that is borrowed extends above 100% under the Climate Change scenario because of increased use (and return flow) of water for thermal power generation and irrigation.

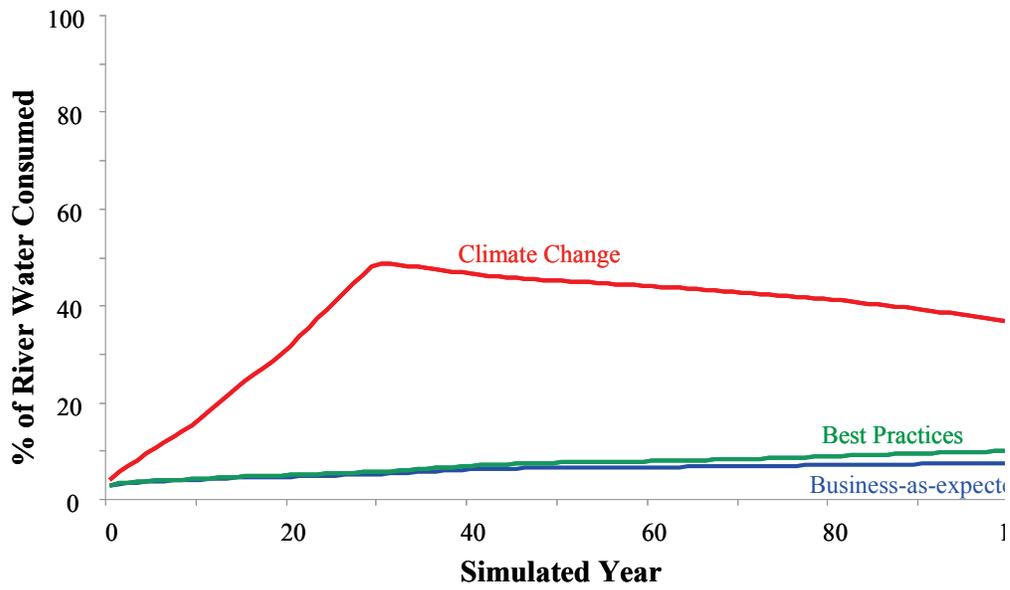


Figure 14. Simulated changes in the percent of NSR river flow that was “consumed” (i.e., withdrawn and not returned) under three development scenarios.

APPENDICES FOR NSWA – ALCES[®] CUMULATIVE EFFECTS ASSESSMENT

Appendix A: Project Overview Presentation

A-1: Presentation to NSWA of results of NSWA-ALCES[®] Cumulative Effects Assessment.

Full presentation available as Power Point Presentation (pps) file at

http://nswa.ab.ca/cumulative_effects

The Last Goldeye?

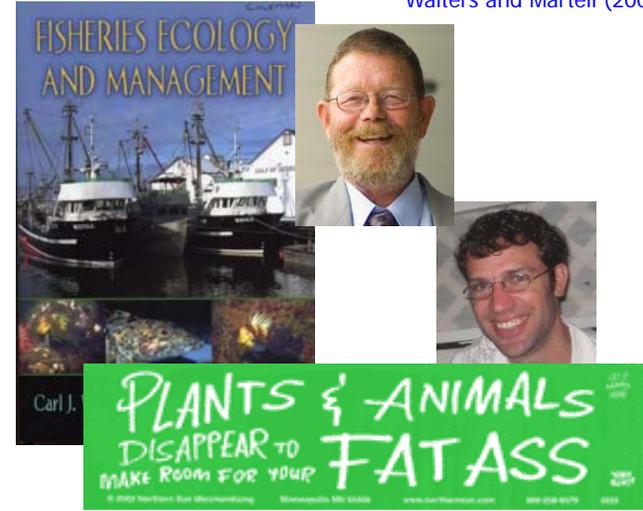
Understanding and managing cumulative effects on the North Saskatchewan River

Presented for North Saskatchewan Watershed Alliance

Prepared by Dr. Michael Sullivan
ALCES Group

One of the biggest mistakes in the development of fisheries science has been the broad assumption that this science is about fish.

Walters and Martell (2004)



Watershed Issues are Social Issues

Very Different World View

Engineers / natural scientists

"Water flows downhill, as a function of topography"



Social scientists



"Water flows uphill, towards money"



Dr. Naomi Krogman

Congratulations, NSWA !

Goldeye



Classic Alberta Prairie / Parkland River fish

Once abundant in North Saskatchewan River's prairie tributary, the Battle River



Goldeye

"1977 was one of my best times as a fisheries biologist. I canoed right across Alberta on the Battle River, catching fish, talking to people, and getting to learn how a whole ecosystem worked."



Dave Christensen
1978, Lacombe Lake

"Locals told me how the big runs of goldeye were almost gone and how you could only catch decent numbers below Forestburg."

"It was really evident that things were going downhill, with big kills of pike in Driedmeat Lake, low oxygen levels in big chunks of the river, and listening to stories about the sad state of the river."

Dave Christensen
Alberta Fish and Wildlife

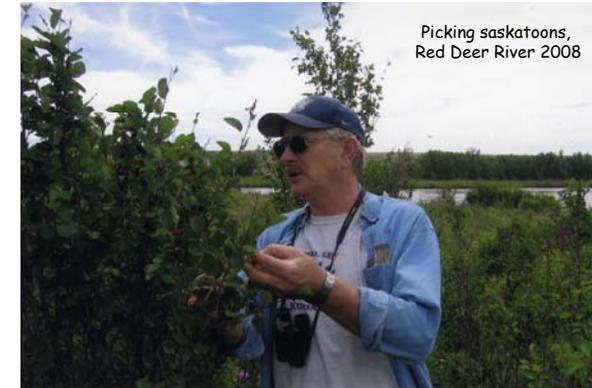
Pike

"There was this one big wetland beside the Battle River right near the Highway 2 Crossing. It was a pike factory, with fantastic spawning and nursery habitat."

"Now, it's gone, completely gone. Drained."

"Every time I drive over that bridge, I look and think how most people wouldn't even know what we've lost."

Dave Christensen
Alberta Fish and Wildlife



Picking saskatoons,
Red Deer River 2008

Battle River fish biodiversity study 2005-07



Big fish = happy people!

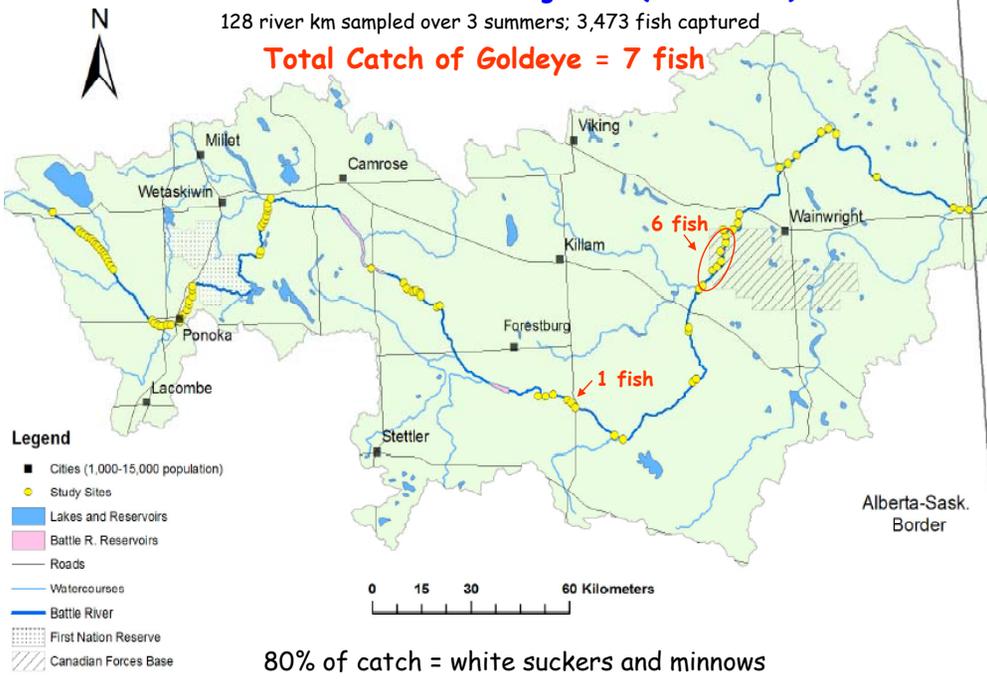


Battle River fish biodiversity study 2006-07

Battle River - Electrofishing Sites (2005-2007)

128 river km sampled over 3 summers; 3,473 fish captured

Total Catch of Goldeye = 7 fish



Goldeye almost gone from Battle River

Fish Biodiversity Study (2005-07)

- Walleye (<20 fish above Wainwright)
- Spottail Shiners (8 caught)
- Iowa Darters (2 caught)
- Mooneye (2 caught)
- Longnose Sucker (1 caught)
- Silver Redhorse Sucker (none)
- Quillback (none)
- Lake whitefish (none)
- Yellow perch (none)
- Sauger (none)

Of the 19 fish species known to have lived in the Battle River up to the 1980s, only 14 still exist, with only 6 in abundance

What Happened ! ?



Shorelines Developed
Natural filters, springs, and habitats gone...

Forests became Fields

Nutrient & sediment run-off,
loss of groundwater...



Urban development
Overfishing, run-off from pavement, sewage...



Road-Stream crossings
Block fish movements, erosion...

Poor Water Quality
Growths, tumours, lesions...



Water disappearing
Low spring flows, loss of floods, winterkill...

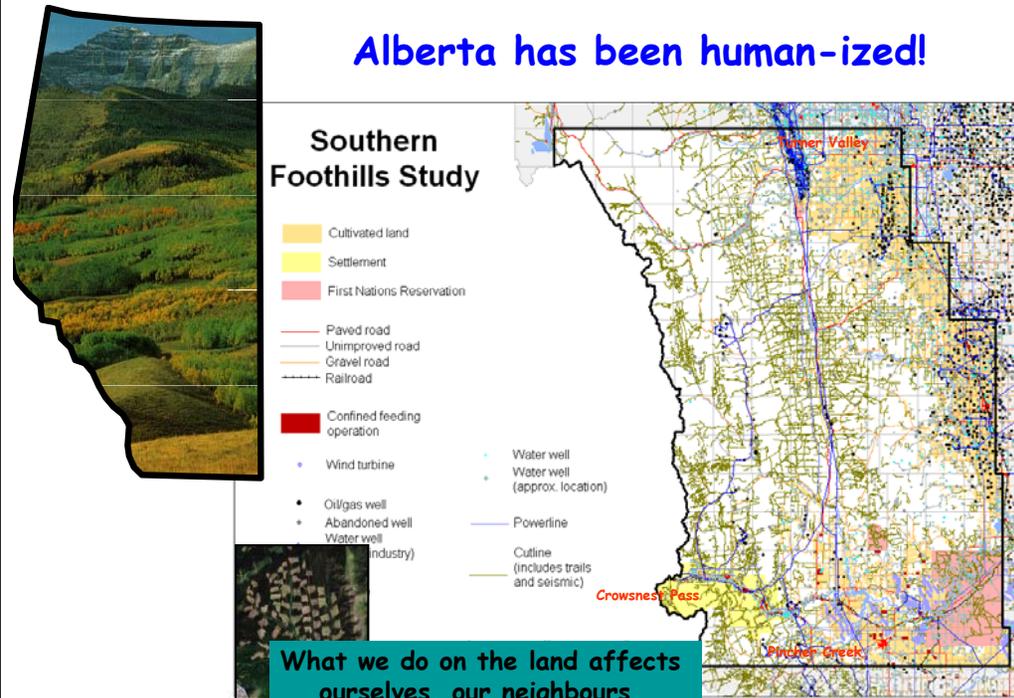


Livestock on streambanks and in river
Erosion and excessive nutrient input...

Is the Battle River a glimpse of the future for the rest of Alberta?



Alberta has been human-ized!



What we do on the land affects ourselves, our neighbours, and all our children

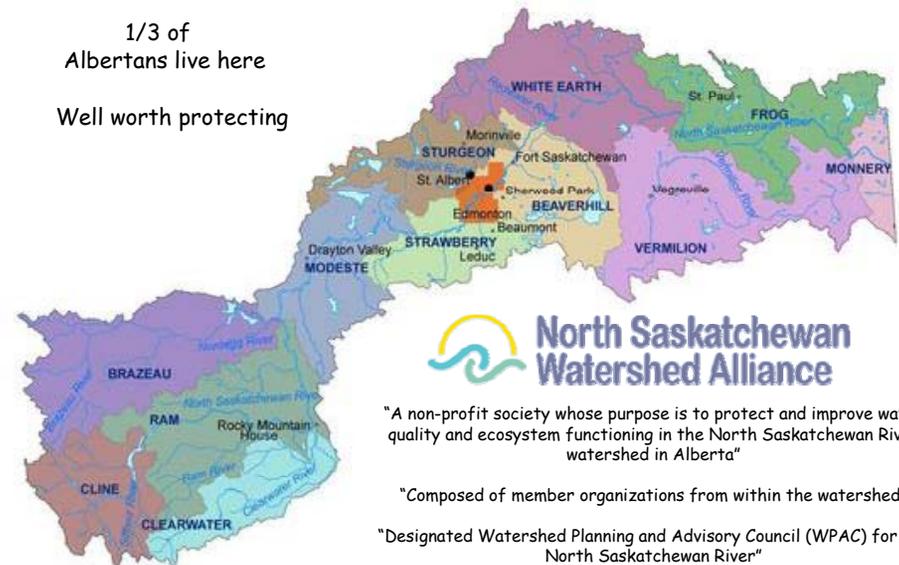
We live in Western Canada's most important watershed



What we do on the land affects ourselves, our neighbours, and all our children

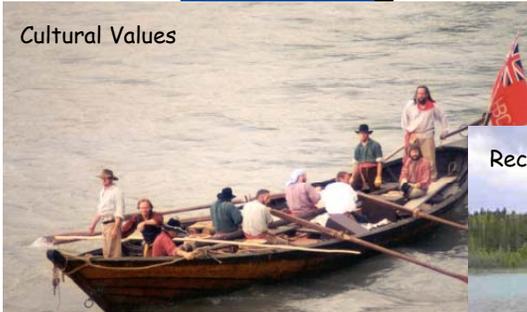
North Saskatchewan River is one of Alberta's most important watersheds

1/3 of Albertans live here
Well worth protecting



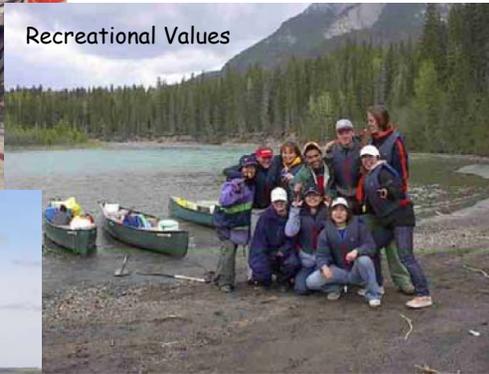
North Saskatchewan River Watershed

Cultural Values



Nominated for Canadian Heritage Rivers status

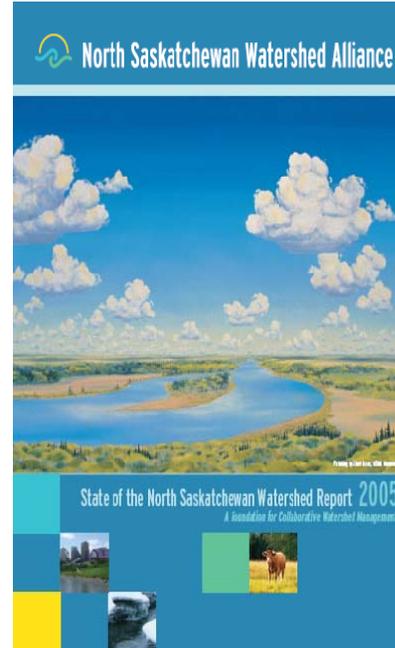
Recreational Values



Natural Values



North Saskatchewan River Watershed



Conclusions

"The overall health of the entire North Saskatchewan Watershed is generally fair, and includes some subwatersheds where ecosystem function is significantly impaired by human activity."

"Watershed health tends to decrease as you move towards the Modeste, Sturgeon and Strawberry subwatersheds, where livestock density, human activity and populations are greatest"

"The impacts of high agricultural intensity in the Bigstone, Iron, Ribstone, Blackfoot, and Paintearth subwatersheds may be reflected in higher phosphorus and lowered riparian health scores and wetland densities."

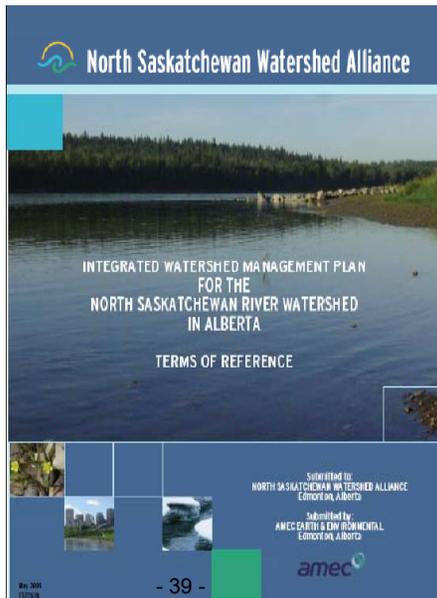
In these Battle River subwatersheds, water quantity will continue to be an issue, as will water quality".

Is Battle River a glimpse of North Saskatchewan's future?

Plan now to avoid further losses

ALCES Modelling Project

- assisting NSWA: 2010 Integrated Watershed Management Plan

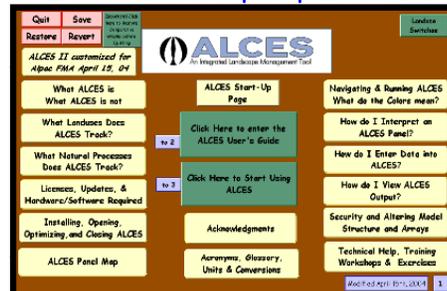


Goals:

- 1) Develop strategies will support sustainable use and management of land and water resources;
- 2) Identify land uses that could adversely affect the future sustainability of the watershed, and;
- 3) Collaborate with watershed communities and the public so that the IWMP meets local and regional needs.

What might a future watershed look like?

ALCES model used to explore possible "futures"



North Saskatchewan Watershed Alliance Goal

"A watershed where ecological integrity is the foundation for environmental, cultural, social and economic decision-making"

Achievable by realizing 4 main objectives:

- Biodiversity
- Natural Landscapes
- Water Quality
- Water Quantity



Personal Level:
Can I go fishing, at a wild, natural spot, and have my kids play in the shallows, of a clear, flowing river?



Plan now to avoid loss of these valuable features in future

North Saskatchewan River Watershed ALCES Scenarios

Suppose for a moment that the future unfolds like THIS (=scenario).

Can I take my kids fishing (= biodiversity indicators),
in a nice place (= landscape indicators),
and play in the shallows (= water quality indicators)
of a flowing river (= water quantity indicators)?

Business-as-usual Scenario (mad-growth)

City growth 3.1%

Rural residential growth 7.5%

Unsustainable. Entire watershed is urban/acreage in 46 years

Business-as-expected Scenario (considerable growth)

Urban sprawl >80% of watershed by 2110 (6% in 2008, 28% in 2060)

Unsustainable for biodiversity, native landscape, and water quality; fine for water quantity

Best Practices and Green Cities Scenario (control urban sprawl and run-off)

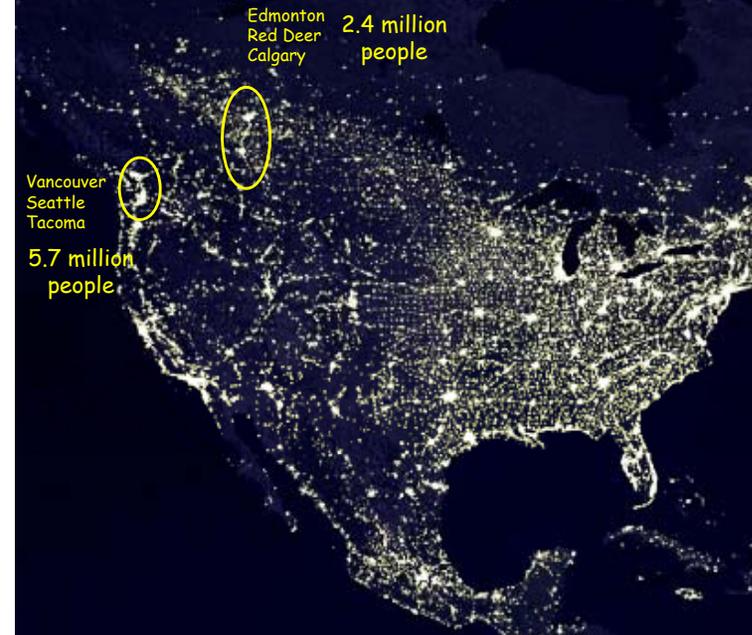
Urban sprawl = 30% of watershed by 2110 (6% in 2008, 20% in 2060)

Partly sustainable (with effort) for biodiversity, native landscape and water quality; fine for quantity

Best Practices, Green Cities, and Climate Change Scenario

Partly sustainable for all indicators (water quantity now an issue)

Satellite image of North America at night



With growth of 2.5%,
QE2 Corridor
will equal
Vancouver-Seattle
in 2041
(32 years)

What happens
to the things
we value?

Biodiversity

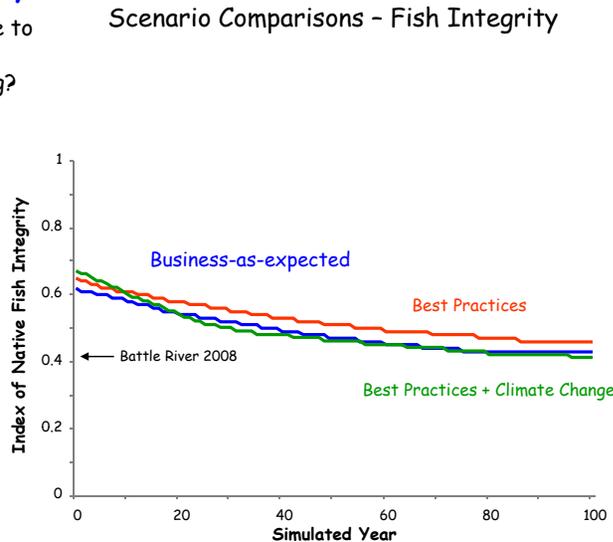
Will I be able to
take my
kids fishing?

No.

Good
fishing!

Poor
fishing

Species
Lost



Conclusions

Not good,
maybe recoverable
with serious effort

Contributing Factors:

Water quantity is fine

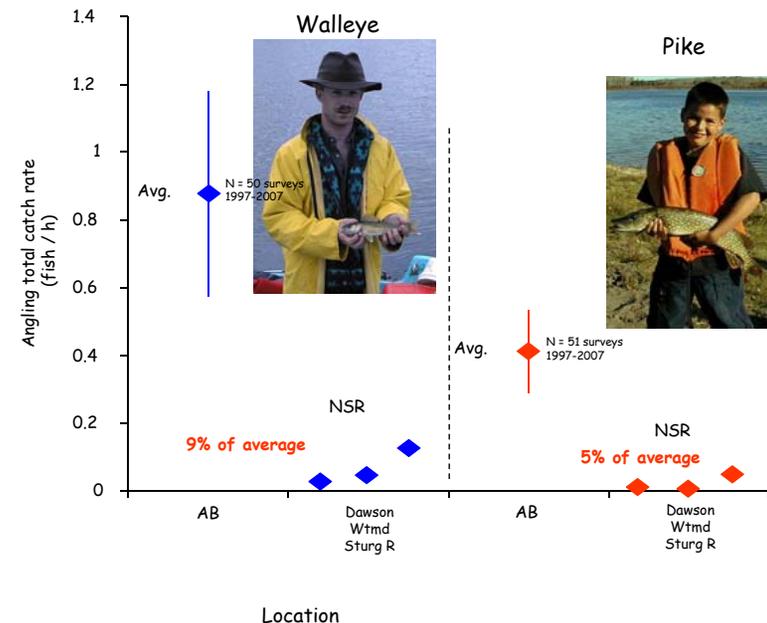
Water quality is poor

Too many people

Too many roads

Status of North Saskatchewan River Fish

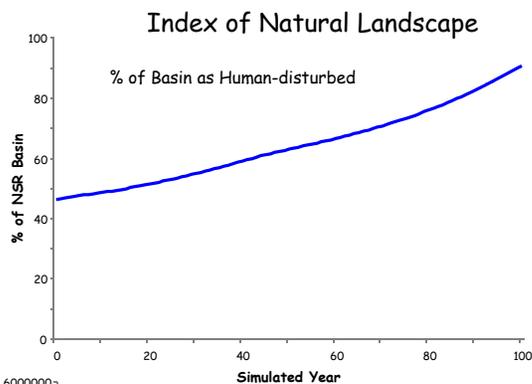
90% to 95% lower than provincial averages



Landscape

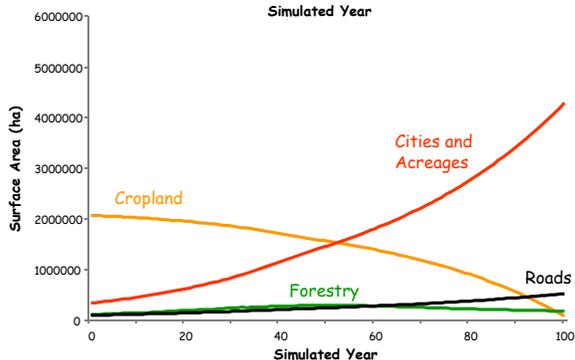
Will I be able to take my kids fishing at a wild, natural location?

No.



Conclusion:
Completely anthropogenic, outside of Parks

Why?



Contributing Factors:
Urban and Acreage Sprawl

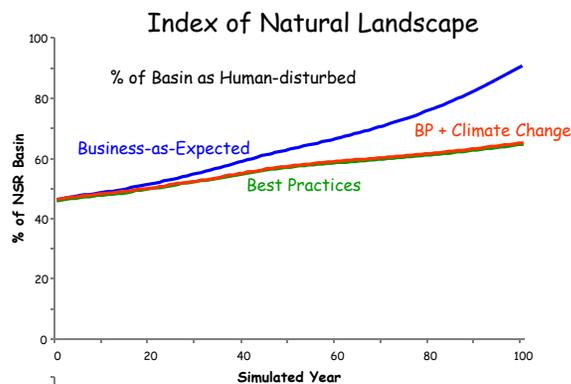
BAE

Landscape

Will I be able to take my kids fishing at a wild, natural location?

If I look hard...

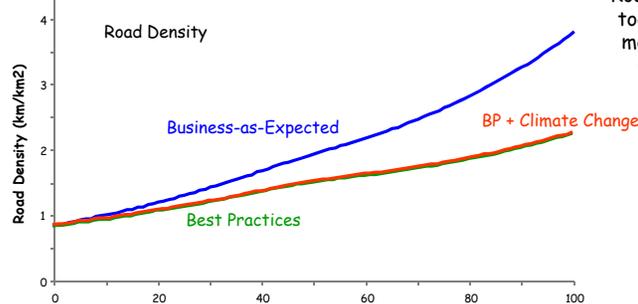
But it isn't "wild"



Conclusion:
Mostly anthropogenic, outside of Parks

Indicator

Road density too high for most "wild" wildlife

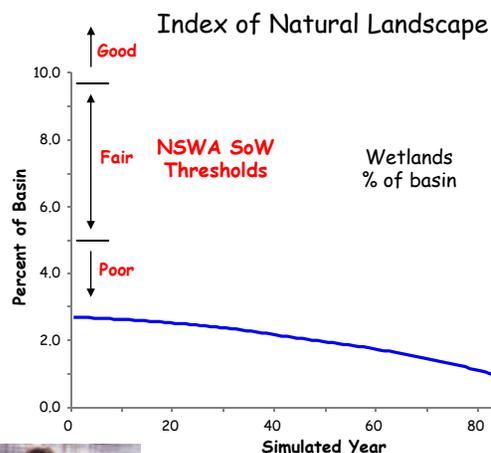


Landscape

Will I be able to take my kids fishing or duck hunting, or to a swamp?

No.

No swamps



Indicator
Wetlands mostly drained

Gone from approx. 8% (natural) to 3% (today) to <1% (next century)



BAE

Water Quality

Will I be able to take my kids to play in clean water?

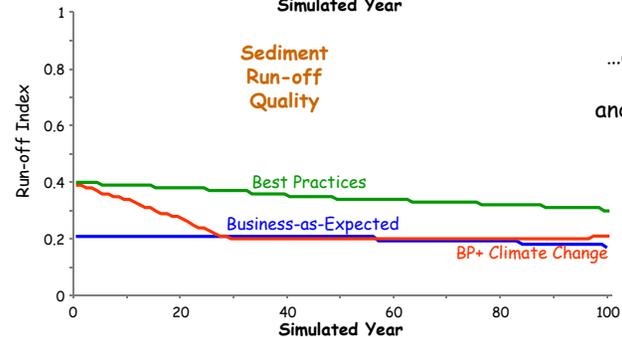
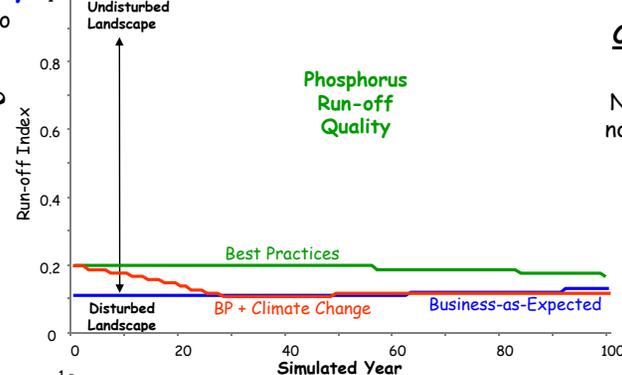
No.

Water's too green and scummy

Index of Landscape Nutrient Run-Off

Conclusions

Not good now, no improvement



...and too silty for trout and real \$\$\$ to treat

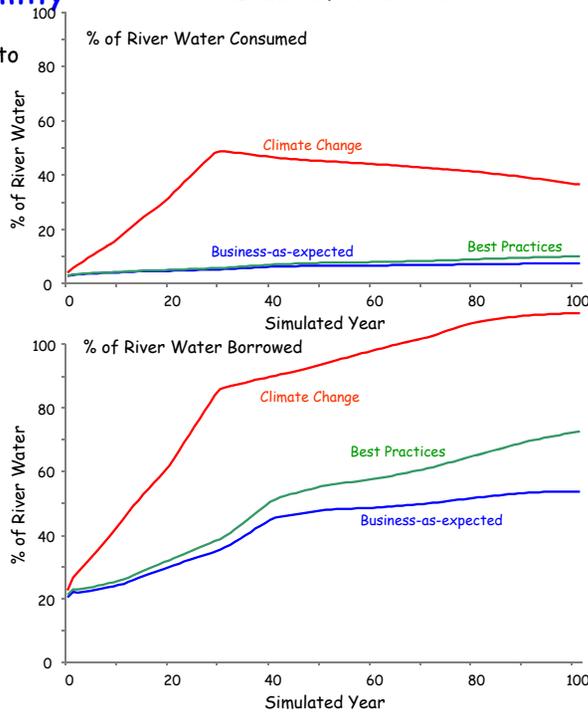
Water Quantity

Index of River Flow

Will I be able to take my kids to a flowing river?

Yes.

But don't tell them where it's been.



Conclusion:
Flows increase (impermeable landscape)
Adequate water quantity, assuming good treatment

Conclusion:
Rental over 50%
Consumption under 50%

North Saskatchewan River Watershed ALCES Scenarios

Suppose for a moment that the future unfolds like **THIS** (=scenario).

Can I take my kids fishing (= biodiversity indicators), in a nice place (= landscape indicators), and play in the shallows (= water quality indicators) of a flowing river (= water quantity indicators)?

Business-as-usual Scenario (mad-growth)

City growth 3.1%
Rural residential growth 7.5%
Unustainable. Entire watershed is urban/acreage in 46 years

Business-as-expected Scenario (considerable growth)

Urban sprawl >80% of watershed by 2110 (6% in 2008, 28% in 2060)
Unustainable for biodiversity, native landscape, and water quality; fine for water quantity

Best Practices and Green Cities Scenario (control urban sprawl and run-off)

Urban sprawl = 30% of watershed by 2110 (6% in 2008, 20% in 2060)
Partly sustainable (with effort) for biodiversity, native landscape and water quality; fine for quantity

Best Practices, Green Cities, and Climate Change Scenario

Partly sustainable for all indicators (water quantity now an issue)

What are potential options worth exploring?

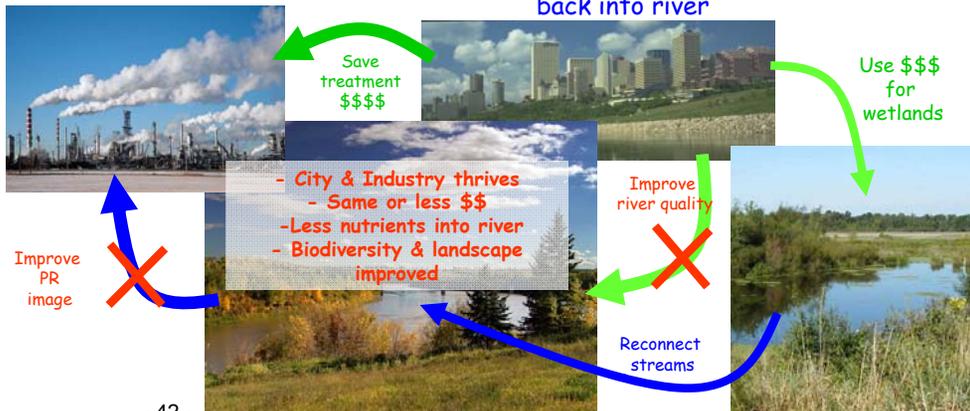
Adequate water quantity

Less-than-adequate
Quality
Biodiversity
Landscape

Trade-offs to consider...

Industry needs water

City pumps (nutrient-rich) water back into river



What can you do to prevent this from being the LAST Goldeye?

County Councilor

- Set watershed goals (and limits) and only approve plans that achieve the goals
- Strategy working elsewhere (Spokane County)

Environmental Agency Employees

- Public Lands: enforce PLA
- DFO: enforce FFA
- F&W: acknowledge responsibility for species decline and loss
- AEnv: CE goals, thresholds and enforce to meet them



What can you do to prevent this from being the LAST Goldeye?



What can you do to prevent this from being the LAST Goldeye?

Policy People

- full-value accounting (Calgary water example)

Business / Developers

- get ahead of curve (sell green before green becomes law)
- demand hard \$ for being green (tax breaks, carbon credits, water credits)

Citizens

- go fishing, canoeing, picnicking
- get royally pissed when you see bad stuff
- give your councilor/public servant/developer an well-deserved earful

Because we don't think about future generations, they will never forget us.
Henrik Tikkanen

"Our children may save us if they are taught to care properly for the planet; but if not, it may be back to the Ice Age or the caves from where we first emerged. Then we'll have to view the universe above from a cold, dark place. No more jet skis, nuclear weapons, plastic crap, broken pay phones, drugs, cars, waffle irons, or television.

Come to think of it, that might not be a bad idea."

Jimmy Buffet, Mother Earth News, March-April 1990

Thank you

Appendix B: Modelling assumptions

B-1: GIS Data Processing Steps

Intent of GIS Work: To create one polygon layer for the study area where every hectare is assigned an ALCES[®] Landscape or a Footprint Type (there is no overlap between polygons). The layer must have a defined set of attributes that are used in generating inputs for the ALCES[®] model.

The following steps provide an overview of the process required to generate the required final polygon data. References are made to data contained in a series of worksheet tabs in this workbook, available at available for download on the project page at <http://nswa.ab.ca/cumulative-effects>

Step 1	<p>Define study area boundary to be used for all GIS work.</p> <p>a) In some cases if the study area is quite large, the study area will have to be split up into sub-units, to expedite data processing.</p> <p>b) Future project needs, such as mapping or modeling requirements, may help in determining sub-units.</p> <p>NSWA: The study area for the North Saskatchewan River basin is defined in the shapefile <i>nsrbasin.shp</i>. The North Saskatchewan River basin is comprised of 12 sub-basins; for data processing purposes, the sub-basins have been combined and the study area split into 4 groups (i.e., NE, SE, NW, and SW groups). Refer to the Sub basin tab for a list of which sub basins belong to each group.</p>
Step 2	<p>Outline ALCES[®] Landscape and Footprint Types (LT and FT).</p> <p>This is based on:</p> <p>a) scope of project (e.g., hydrological project may require more river, lake, wetland classes).</p> <p>b) data availability (ability to canister GIS data classes into defined ALCES[®] classes).</p> <p>c) study area (e.g., study area that crosses many landscapes may require broader definitions, than one in one type of landscape).</p> <p>It is critical at this stage to get project manager input and approval, as all ALCES[®] modeling relates back to these specific FTs and LTs. For example, if there are specific / required runoff coefficients that apply to different LTs, then we must ensure that those specific LTs are in the input dataset.</p> <p>NSWA: Refer to the ALCES[®] Classes and Data tab</p>
Step 3	<p>Determine which GIS datasets are to be used for each ALCES[®] class.</p> <p>Determining which GIS datasets to use is often a work in progress as more data becomes, or does not become available.</p> <p>NSWA: Refer to the ALCES[®] Classes and Data tab</p>
Step 4	<p>Create the combined FT layer.</p>

FT Step 1

Create one polygon layer for each FT class with defined set of attributes.
(Feedlot_final; Industrial_final; Pipeline_final; etc)

GIS data processing requirements and other notes:

- a) may need to extract data from different GIS datasets
- b) may need to convert line and point files to polygon files by buffering or digitizing
- c) may need to combine different datasets to create one polygon layer
- d) overlap may need to be addressed by dissolving features of the same type
- d) source data such as Base Features info or AVI criteria may not be required in the final layer for each footprint but should be maintained in preliminary layers in case future reference is required
- e) any assumptions or steps required to process the data must be documented
- f) for the final individual FT layers, only a field called ALCES[®] is required (text format) - for inclusion of the ALCES[®] name, or code

NSWA: Refer to the following tabs: ALCES[®] FT - AVI; ALCES[®] LT, FT - BF; ALCES[®] LT, FT - misc, for information on how each dataset was used to create the various FTs. In addition, the following general notes for processing some of the layers is provided

Linear FTs (roads, pipelines, seismic lines, powerlines, railroads): Base Features (BF) e00 files were converted to coverages and the various features as identified in the ALCES[®] LT, FT - BF were extracted into separate LT layers. The linear features were buffered as indicated and boundaries were dissolved to remove overlap. A field for ALCES[®] class name was added and populated for each LT layer.

Well data: Used the ERCB well file as it included RecCertified as an attribute (License_St field). So certified wells were removed as were those with the status 'Cancelled' and those 'Issued' wells with no spud date/finish drill date, from the well record. There are RecExempt wells in the dataset, clarification was requested from ERCB as to what this meant, but a clear definition was not available. Well points located within facility sites were also removed. All remaining points were buffered, 100m x 100m, to create 1 ha polygons, 'dissolved' data to get rid of overlap, added "ALCES[®]" field and defined class as Well.

Communities data: BF polygon layers for towns, cities, villages, summer villages, settlements and urban service areas (i.e., Sherwood Park) were merged together. The BF 'uculpt' pt layer has locations of hamlets and localities - little groups of houses. Hamlets are recognizable communities so determined size of about 15 different hamlets from SPOT5 2007 imagery, average size was 21 ha - assigned each hamlet point in the 'uculpt' file a rectangular size of 21 ha. Settlement areas were also available in the AVI data, refer to the ALCES[®] FT - AVI tab. These settlement areas from the AVI data were merged with the buffered hamlet file and the merged communities file, clipped to NSR basin, and dissolved polygons. Final layer has the ALCES[®] field, populated with Town_City.

Facilities: BF facilities polygon layer was used as the base layer (removed pits, mines, tailing piles). ERCB facility points layer included points for BT (battery), CS (compressor station), CT (custom treating), GP (gas plant), and IF (injection facility). A review of 2007 SPOT imagery was undertaken to determine the average size of the ERCB facility pts (BT, CS, CT, GP, IF), then these pts were buffered with these sizes, refer to ALCES[®] LT, FT - misc tab. The BF pts layer were buffered by standard sizes, refer to ALCES[®] LT, FT - BF tab. The three polygon files (BF polygon and buffered point file, ERCB buffered point file) were merged, and overlap dissolved, and ALCES[®] field added.

Mines and Pits: extracted mines and pits from BF access polygon layer, refer to ALCES[®] LT, FT - BF tab. Borrow pit data was obtained from the AVI data, refer to the ALCES[®] FT - AVI tab. The BF and AVI data were merged together, overlap dissolved and ALCES[®] field added.

Feedlots: A list of authorized and registered confined feeding operations and manure storage sites was obtained from the Natural Resources Conservation Board. Each of these sites was located on SPOT5 imagery (2007) and the site was digitized based on the apparent footprint.

Rural residential: Limited data were available for farm residences and rural acreages. BF facility point layer contained lookout towers and cabins - these features were buffered to a 2 ha size. AVI contained some farm and rural ribbon development polygon data, refer to the ALCES[®] FT - AVI tab. CanVec data has a building and structures theme - while this is older data, it does provide point features for buildings on the landscape. The CanVec point features were buffered to a 3 ha size. The three data source layers were merged (BF facility, AVI, and Canvec), the overlap dissolved and ALCES[®] field added.

Golf courses/resorts: Again limited data were available for golf courses and resorts. Canvec data were used, specifically data in the places of interest theme including golf courses, sports fields, theme parks, fairgrounds, and zoos.

FT Step 2 Combine FT layers into one final FT shapefile. (NSRW_FT_Stacked_Final)

To address the overlap that will occur, a hierarchy has been established which assigns an order of precedence for each footprint type which is based on the estimated level of activity or use of each footprint. The hierarchy is as follows:

ALCES[®] FT Classes in Order of Precedence

Cities and towns
Major roads
Mines and Pits
Industrial
Feedlots
Minor roads
Railroads
Wellsites
In-block roads / truck trails
Rural residential
Resorts / golf courses
Seismic
Powerlines
Pipelines

Step 5 Create the combined LT layer.

LT Step 1 The base layer to be used for the LTs must be determined, and processed, then other datasets supplying remaining LT data added in.

The base layer essentially is the dataset with the most landscape data available (e.g., AVI for the forested area)

Some notes for creating this base LT layer:

- a) reclassification of land cover data may be required to translate it into to ALCES[®] LTs.
- b) extracting features, buffering, merging layers may be required to create the LT layer.
- c) attributes required for LTs includes stand age, clear cut and burn information - if available. Some datasets such as AVI include this type of data, others do not (Ag Canada and Central Parkland Native Vegetation data).
- d) some broad classes existed in the datasets used for this project, including 'Water' in both the AG Canada and Central Parkland datasets, and 'Agriculture' and 'Perennial crops and Pasture' in the Ag Canada dataset. While these classes are too broad to split into specific ALCES[®] LTs, they were carried through to the final ALCES[®] file and were split mathematically into the specific ALCES[®] classes.

NSWA: Refer to the following tabs: ALCES[®] LT -Ag Cda land cover; ALCES[®] LT -pnv; ALCES[®] LT, FT - BF; ALCES[®] LT, FT - misc, for information on how each dataset was used to create the various LTs. In addition, the following general notes for processing some of the layers is provided:

AVI data: AVI data requires considerable processing; it was not received in time for use in the NSWA project for landscape mapping though was used for some footprints (refer to ALCES[®] FT - AVI). In general AVI shape files and corresponding attribute tables must be joined and then the data reviewed to ensure consistency and completeness. Scripts are available which can translate AVI data into ALCES[®] LTs, though the scripts may require modification to result in the required LT classes.

BF hydrology data: BF hydrography data, specifically the ssln layer has stream order, this is used to separate stream features into the three river classes. Canals and ditches are identified in the slnet layer. These five linear hydrology features are extracted into separate files and buffered, as indicated in the ALCES[®] LT, FT - BF tab. Each layer is dissolved, and an ALCES[®] field is added. The hypopoly layer contains a number of different ALCES[®] LTs, also identified in the ALCES[®] LT, FT - BF tab. An ALCES[®] field is added to the hypopoly layer and the features identified appropriately. Refer to LT Step 2 for further processing requirements for the hydrology layers.

National Park data: reviewed ecological land classification information (Ecological (Biophysical) Land Classification of Banff and Jasper National Parks, Volume I and II, by W.D. Holland and G.M Coen, published by Environment Canada, Agriculture Canada and the Alberta Institute of Pedology, 1983) in order to canister into ALCES[®] classes.

Central Parkland data (pnv) - where available the native land classifications in this dataset were used as the primary dataset. The ALCES[®] LT - pnv tab indicates how the pnv classes were translated into ALCES[®] classes.

Ag Canada data - The AG Canada dataset was a primary dataset in areas where there were no pnv data, i.e., primarily the forested area. As the AG Canada data covered the entire study area, it was used to fill in data gaps in the non-forested areas. The ALCES[®] LT -Ag Cda land cover tab indicates how Ag Canada landscape classes were translated into ALCES[®] classes.

Wetland - wetland data were available from a number of sources: BF hydrography, pnv, National Park data, and Ag Canada data. The tabs for each of these datasets will indicate which classes from the source datasets were used to create the wetland layer.

LT Step 2

The Individual hydrology layers are combined to create a combined hydro layer.

In a similar process to creating the combined FT layer, the combined hydro layer is also created, the hierarchy is as follows:

1. BF hydro poly layer is the base layer - it includes lakes, rivers, canals, dugouts, lagoons etc.
2. Wetland layer
3. Large rivers
4. Medium rivers
5. Small streams
6. Canals
7. Ditches

LT Step 3 The combined LT layer is created.

This is a stacking process where landcover layers are stacked based on the most accurate dataset, i.e., pnv or AVI data, then Ag Canada data to fill in data gaps.

The combined hydrology layer takes precedence over all other LTs, so is stacked on top.

LT Step 4 Gaps within combined LT/hydro layer are eliminated, or re-populated with an ALCES[®] class creating a final LT/hydro layer (e.g., NSRW_NW_Predisturbance)

This process generates a final LT/hydro layer that is considered close to a predisturbance landscape.

This data is used in the final stacking process of the the FT layer on the LT/hydro layer to create the final ALCES[®] layer (see Step 5). It is also required for a specific ALCES[®] model input - the LT x FT table, which essentially provides proportions of each FT on each LT (see Step 6).

Some notes on this process:

a) gaps can be due to the presence of anthropogenic features in the base data set, or a lack of data.

b) some gaps are difficult to fill or eliminate, such as those left by large communities.

c) the integrate function (in ArcView) was carried out on a copy of the combined LT_hydro layer (using 85 m tolerance - this was used in the ALCES[®] modeling carried out by the Athabasca caribou and West Central caribou landscape planning teams). This process collapses most data gaps by making lines within the set tolerance identical or coincident. However, it significantly and permanently alters the input data, so the integrate function is carried out on a copy of the LT_hydro layer and the integrated copy is used to fill gaps in the LT layer.

d) Any remaining gaps in the data are filled with polygons attributed as "Unclassified" in the ALCES[®] field.

Step 5	<p>Create the final landscape files by overlaying the final footprint file over the final LT/hydro file (e.g., NSRW_NW_Final_ALCES[®]).</p> <p>ALCES[®] class, and stand age/clearcut (if available) data must be carried over into the final landscape file.</p>
Step 6	<p>Determine the proportions of each FT located in each LT.</p> <p>One of the input tables for the ALCES[®] model requires the proportion of each footprint located in each landscape type. This is determined by cross-referencing the final stacked footprint file with the predisturbance files. Either the identity tool or the union tool can be used to obtain this data.</p>
Step 7	<p>Create the riparian buffer file and determine the proportions of each forest cover LT located in the riparian buffer.</p> <p>The proportion of each forest cover LT located in the riparian buffer is required ALCES[®] model input, and is used to calculate the available forest land base for forest harvesting.</p> <p>a) The riparian buffer file is created by buffering hydrology features with a defined buffer width based on previous ALCES[®] modeling projects (i.e., carried out by the Athabasca caribou and West Central caribou landscape planning teams). Refer to the Riparian Buffer data tab for information on buffer widths.</p> <p>b) The final ALCES[®] files were cross-referenced with the riparian buffer file using either the identity or union tool.</p>
Step 8	<p>Create the protected areas file and determine the proportions of each LT located in protected areas.</p> <p>A protected area layer is required in order to determine the amount of each LT located in a protected area, which is a required ALCES[®] model input.</p> <p>Protected areas were identified using provincial shapefiles (available from the AltaLIS website) for Ecological Reserves, Forest Recreation Areas, National Parks, Natural Areas, Provincial Recreational Areas, Provincial Parks, Wilderness Areas, Wilderness Parks, and Wildland Parks. These were all combined into one shapefile. This protected area file was cross-referenced with the final ALCES[®] files in a similar manner to that carried out with the riparian buffer (Step 7).</p>
Step 9	<p>A series of data outputs are required for input into the ALCES[®] model.</p> <p>The following is a list of outputs required, additional processing with the GIS program or Access database will be required to generate this data.</p> <p>(1) ALCES[®] Class (area): total area (ha) of each ALCES[®] class. See the note below re addressing the broad landscape classes carried through the GIS data processing.</p>

(2) ALCES[®] Class (edge): total edge (km) of each FT. Edge of polygon FTs (i.e., mines, feedlots, golf/resorts, rural residential, towns/cities, industrial, and wellsites) is the perimeter of each polygon. Edge of linear FTs is calculated as length = (Perimeter-2*width)/2.

(3) ALCES[®] forest class x seral stage: area (ha) of each forest type by seral stage. For the NSWA this data was not available.

(4) FT x LT: area (ha) of each footprint type within each landscape type (The output is the decimal fraction of each FT in each LT) - refer to Step 6).

(5) ALCES[®] x Clear cut data. For the NSWA this data was not available.

(6) ALCES[®] x Protected area: area of each ALCES[®] class that is protected (refer to Step 8).

(7) ALCES[®] x Rip Buf area: area (ha) of forest cover LTs located within the riparian buffer (refer to Step 7).

NOTE: As identified in LT Step 1, some of the datasets, i.e., AG Canada or Central Parkland Native Vegetation Inventory, contained broad landscape classes called 'Water', 'Agriculture' and 'Perennial Crops and Pasture'. In this last step of determining the hectares of each ALCES[®] LT present in the study area for input into the model, these broad classes need to be split into the actual ALCES[®] LTs.

a) The Agriculture class encompassed all agricultural ALCES[®] LTs, and Perennial Crops and Pasture includes both Forage Crops, and Pasture. AG Census data was available which provided areas (ha) of different kinds of crops and pasture for a number of census years including 2001. 2001 data for the North Saskatchewan sub-watersheds was compiled and the percentage of annual crop, forage crop, and pasture in each sub-watershed was determined. These percentages were applied to the total area of 'Agriculture' and 'Perennial Crops and Pasture', to determine the resulting areas of ALCES[®] classes (i.e., Annual Crop, Forage and Pasture).

b) The Water class encompassed all the hydrology ALCES[®] LTs. The area included in the water class was evenly split between all hydro features.

B-2: Modelling Assumptions for Commercial and Industrial Use of Water

- Modelled as “Commercial Water Consumption” in the ALCES[®] Version III inputs, under “Temporal Trend in Commercial Water Demand” in Sector 8.13.
- Four primary commercial users of water were considered in this input parameter:
 - the proposed Dodds-Roundhill Coal Gasification project,
 - the combined Heavy Oil Upgraders known as the Industrial Heartland Project,
 - the current petrochemical plants in the County of Strathcona (termed “Refineries”), and
 - all other current existing commercial uses of the river (termed “Other Commercial Use”).
- Most water (97%) is with-drawn from surface sources (mainstem river), with the remainder drawn from aquifers. Water withdrawal from reservoirs was not included in the modelling. A return rate of 25% was assumed for all commercial users (AMEC 2007), except for Dodds-Roundhill where all water is consumed (Sherritt 2007). This resulted in a weighted average consumption of 81%.

Scenarios

- The conventional oil refineries were simulated to decline in production and consumption by 2% annually (based on CAPP and EUB projections).
- Dodds-Roundhill and the Heartland Project were projected to increase to their published capacities (according to their proposals: Alberta Environment 2007, AMEC 2007, Sherritt 2007), with full capacity achieved by 2020.
- Other commercial users were projected to increase at an annual rate of 1.5%, simulating a compromise between growth and increases in efficient use of water.
- The consequences of each of these growth trajectories results in a Commercial Water Demand curve as shown in Figure 15. This was used in the ALCES[®] model in Sector 8.13.

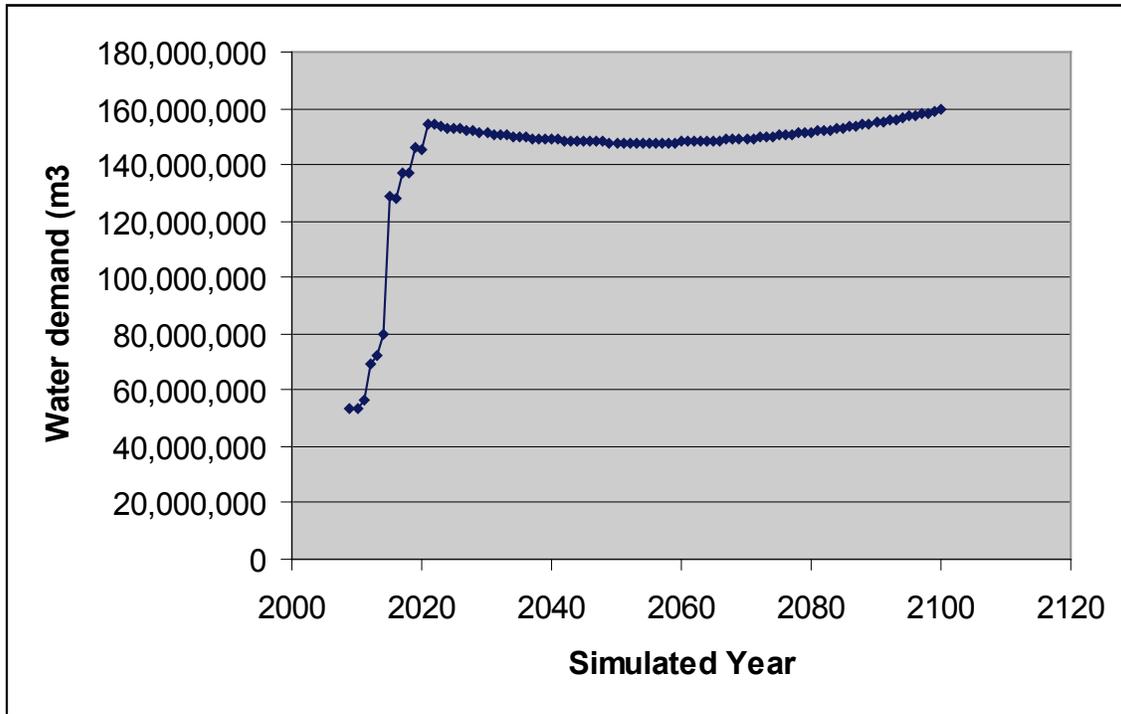


Figure B-2-1. Total water demand projected for all commercial users (including current refineries, proposed upgraders, coal gasification and other commercial users). Data used in Sector 8.13 of ALCES© - NSRB (May 2009).

B-3: Modeling Assumptions for Electrical Generation and Coal Mining in NSRB

- Modelled as “Mining” in the ALCES© III inputs
- All water (100%) is drawn from surface water (mainstem river). A return rate of 90% was used (AMEC 2007). Production from four coal-powered generation plants in the North Saskatchewan River basin (Genesee 3, Keephills, Sundance, and Wabamun) was 3568 MW in 2005 (Transalta Utilities 2009). A small additional amount of electricity was generated from the two reservoirs, but is not included in the electrical-generation-from-coal calculations (i.e., Bighorn Dam produced 120 MW and Brazeau Dam produced 355 MW, Transalta Utilities 2009).
- The generation of electricity from the coal plants diverted 649,980 dam³ of surface water annually for cooling, of which 64,980 dam³ were consumed (AMEC 2007). Therefore, 182 dam³ of surface water were required for cooling per MW of generation, and 18.2 dam³ were consumed per MW of generation.
- The land use area of active coal mines in the North Saskatchewan River basin was 7751 ha. The total area leased for coal mining for electrical generation (all in the Wabamun-Genesee area) is 22,195 ha. Annual production from these mines was 19.9 million tonnes of coal. The values for annual surface area actually mined each year is not available, but using the total area of each mine and the age of each mine results in an estimated annual mined area of 233 ha. Mine yields are therefore 19.9 million tonnes / 233 ha or 0.0854 million tonnes / ha.
- This yield of coal produced 3568 MW of power over one year. Coal mining for electrical generation therefore has a surface footprint of 3568 MW / 233 ha or 15.3 MW / ha / yr. (Interesting expression i.e., footprint = energy per unit area)
- Water demand was 182 dam³ per MW / yr, or 0.182 m³ per Watt / yr. Water use was 10% of this, or 0.0182 m³ per Watt / yr.
- One metric tonne of coal has a volume of 0.8899 m³. Therefore, the generation plants in the Wabamun/Genesee area had an annual requirement of 22.36 million m³ of coal, to produce the electrical power required in 2005. This required 649,980 dam³ of water or 29.067 m³ of water / m³ of coal for electrical generation. Water consumption (e.g., loss of water, primarily through evaporation) is 10% of this total amount.
- Reclamation rates of the mines was derived from information on the EPCOR, TransAlta Utilities, and Sherritt websites (April 2009, Table 1). Of the 7761 ha listed as mined over the life of the mines, a total of 3280 ha have been labelled as reclaimed, with a total of 1163 ha being certified by Alberta Environment as reclaimed.

- The proposed coal mines for coal gasification in the Dodds-Roundhill area are not considered in this sector. The proposed coal gasification project is dealt with in the industrial sector.
- Increases in electrical generation in the NSRB were assumed to be steam-powered using coal or other combustible-fuel and will require similar amounts of water for electrical generation.

Scenarios

- AMEC (2006) describes the projected change in electrical generation in Alberta to be a 2.6% annual increase. The observed growth in electrical generation from 2000 to 2008 was 29%, or a 3.2% annual increase (AESO 2009).
- The scenarios modelled for the change in electrical generation in the North Saskatchewan watershed are a 2.6% increase for 40 years. The growth scenario is modelled in Sector 8.2.1 as a graph in trajectory of surface area of coal mines.
- The growth in mine surface area is based on the active mine area (e.g., 233 ha in 2005) growing by 2.6%

B-4: Modelling Assumptions for Forest Landscape Run-off, River Inputs and Glacial Metrics in the NSRB

Modelled in Sector 5.3 in the ALCES[®] III inputs.

Forest Age

- The effect of forest age on surface water run-off and nutrient run-off were derived from a literature search on Canadian forest hydrology and discussions with Dr. Uldis Silins (Forest Hydrologist, Department of Renewable Resources, University of Alberta) and his graduate students.
- The general conclusion was that recently clearcut forests have higher water yields and nutrient run-off than mature forests. This effect declines during re-growth and is generally undetectable after 40 years. The responses modelled in ALCES[®] were a 2x increase in water yield and nutrient run-off in a 0 year old forest, declining to a background level by in a 40-year-old forest.

Glacial Metrics

- Most of the glacier contribution to flow in the North Saskatchewan River is from the Cline River sub-basin. From all sources, the Cline River contributes about 40% of the total flow to the North Saskatchewan River.
- Between 1948 and 1966, approximately 1000 Mm³ of glacier ice was lost in the Cline drainage (Hench 1971). The total volume of glaciers in the upper Cline River Basin was 21,540 Mm³ in 1998 (Demuth et al 2008). A time model was developed to back-cast the rate of loss calculated as an exponential decay function of the 1948-1966 period. This decay function was applied between 1900 (maximum rate of loss of 165 Mm³/year) and forecast to 2080 (104 Mm³/year).
- The flow in the Cline River is now approximately 3,000 Mm³ per year (Golder 2008), and glacier ablation adds approximately 5.5% to the flow. The added contribution to the total North Saskatchewan River flow is estimated to be 2.2% of annual flow (i.e., 165Mm³ of glacier deficit flow / 7510 Mm³ of total flow).
- If the rate of glacier ablation continues at 0.77% annually, the glacier ice in the North Saskatchewan Basin will be 50% gone in 70 years. This was modelled in the "Future Glacier Melt Water entering Mainstem River" GID as an exponential decay function.

B-5: Modelling Assumptions for Human Population Growth in the NSRB

The Alberta Finance census divisions in the North Saskatchewan River Watershed include most of Census Division 9 (Rocky Mountain House), 10 (Lloydminster), 11 (Edmonton) and 12 (St. Paul). For modelling purposes, the populations in each census division were summed to estimate the human population in the North Saskatchewan River Basin. This estimate of 1.3 million people (2006 census) is slightly higher than the NSWA State of the Watershed report estimate of 1.1 million people. The discrepancy is because some Alberta Finance census divisions (especially Division 12) encompass parts of other watersheds. Using Alberta Finance's high and medium projections of population growth (AB Finance and Enterprise 2008) results in considerably lower projections than extrapolated from trends observed during the past 100 years in Alberta.

Assumptions

- Population growth in the North Saskatchewan River Watershed will follow the Alberta Finance projected trends of 2.0% growth.
- No specific spikes or troughs in population growth rates will be modelled to simulate sector-specific changes (e.g., no sudden change in population will be modelled to simulate upgrader construction or petrochemical decline).
- The projected change in the human population of the North Saskatchewan River Basin is therefore from approximately 1.27 million people in 2006 to 3.04 million people by 2050, and 8.18 million people by 2100.

B-6: Modelling Assumptions for Meteorology and Climate Change in the NSRB

Introduction

- In order to model aspects of cumulative effects associated with hydrology and forest dynamics, the ALCES[®] model requires temperature and precipitation data for the simulated landscape types. Although numerous meteorological stations have operated at various times and locations in the North Saskatchewan River Basin (NSRB) study area, these stations have not consistently recorded meteorological data for each landscape type. In addition, long-term temporal records are not consistent from the various individual stations in study area.
- To resolve this problem, a meteorological modelling exercise was conducted on the study area. Data from local meteorological stations was interpolated over study landscape types using the Parameter-Elevation Regressions on Independent Slopes Model (PRISM), with the specific modifications for Alberta developed by Wang et al. (2006) in their model ClimateWNA_v4.33 (updated to 2008). This allows a fine-scale grid of meteorological data to be superimposed on the study area, and interpolated data for a representative landscape type may be derived.

Methods

- Each of the 20 landscape types used in the ALCES[®] –NSRB simulation project was assigned to a representative geographical location within the study area. This assignment was based on forest cover data from Lee (2008) and consultation with local experts. In addition, to investigate larger scale trends in climate variables, three locations were selected to represent the overall study area. Each location was used as an input parameter in ClimateWNA_v4.33. Derived climate variables were mean annual temperature and precipitation for the period 1901 to 2002. Trends in the means and variances of these parameters were determined using linear regression analysis.
- Three climate change scenarios were also simulated. The Hadley Climate Centre model HADC_M3 (scenario A2) was chosen to represent a median climate change scenario. The United States military/government model PCM (scenario A1FI) was chosen to simulate a minor change scenario, and the Environment Canada model CGM (scenario M2 A2) was selected to represent a major change scenario. These results were interpolated onto the three overall study area locations using ClimateWNA_v4.33, for the time periods 2020, 2050, and 2080.

Results

- The locations chosen to represent the landscape types and overall study area are listed in Table 1. The mean annual climate parameters for each landscape type location are grouped into 30-y climate normal periods (Table 2 and 3). The locations of these representative landscape types are shown in Figure 1.
- The major trend in climate for the study area has been an increase in temperature (Figure 2). Precipitation (Figure 3) has increased in the headwaters area (Saskatchewan Crossing), but not in the central or eastern sections of the study area. Scenarios of climate change suggest that annual mean temperature will continue to increase (Figures 2 and 3), with a minor increase in precipitation.

Table B-6-1. Locations of representative landscape types used for interpolation of climate parameters in ClimateWNA_v4.33 (Wang et al. 2006, updated to 2008).

ALCES [®] LT Class	Representative Location	Latitude	Longitude	Elevation (m)
Hardwood	Drayton Valley	53.22	114.97	864
Mixedwood	Rocky Mountain House	52.38	114.91	1000
White Spruce, Pine	Nordegg	52.47	116.09	1380
Blk Spruce	NW Brazeau Reservoir	53.02	115.80	1068
Wetland	Smoky Lake	54.18	112.44	617
Forested Grassland	W of Two Hills	53.70	111.82	613
Grass Shrubland	NE of Marwayne	53.56	110.15	596
All lentic/lotic	Central NSRB (NW of Devon)	53.42	113.79	698
Rock and Ice	W of Saskatchewan Crossing	51.95	116.85	2478
Annual, Forage Crops	W of Two Hills	53.70	111.82	613
Pasture Crops	NE of Marwayne	53.56	110.15	596
Overall Study Area				
West	W of Saskatchewan Crossing	51.95	116.85	2478
Central	Central NSRB (NW of Devon)	53.42	113.79	698
East	W of Two Hills	53.70	111.82	613

Table B-6-2. Climate normal data (mean annual temperature (MAT) in °C and standard deviation, SD) for ALCES® landscape types and 3 representative study area sites simulated in ALCES® -NSRB, derived from ClimateWNA_v4.33 (Wang, et al. 2006, updated to 2008).

ALCES® LT	MAT, SD		MAT, SD		MAT, SD	
	Period: 1911-1940		Period:1941-1970		Period: 1971-2000	
Hardwood	2.5	1.1	2.3	1.0	2.9	1.1
Mixedwood	2.3	1.1	2.3	0.9	2.8	1.1
White Spruce, Pine	0.9	1.0	0.9	0.9	1.4	1.1
Blk Spruce	2.0	1.1	2.0	0.9	2.4	1.1
Wetland	1.5	1.0	1.4	1.0	2.1	1.1
Forested Grassland	1.4	1.0	1.3	1.0	2.0	1.2
Grass Shrubland	1.2	0.9	1.2	1.0	1.8	1.2
All lentic/lotic	2.2	1.0	2.0	1.0	2.7	1.2
Rock and Ice	-3.0	1.0	-2.9	0.9	-2.5	1.0
Annual, Forage Crops	1.4	1.0	1.3	1.0	2.0	1.2
Pasture Crops	1.2	0.9	1.2	1.0	1.8	1.2
Overall Study Area						
West	-3.0	1.0	-2.9	0.9	-2.5	1.0
Central	2.2	1.0	2.0	1.0	2.7	1.2
East	1.4	1.0	1.3	1.0	2.0	1.2

Table B-6-3. Climate normal data (mean annual precipitation in mm (MAP) and standard deviation, SD) for ALCES® landscape types and 3 representative study area sites simulated in ALCES® -NSRB, derived from ClimateWNA_v4.33 (Wang, et al. 2006, updated to 2008).

ALCES® LT	MAP, SD		MAP, SD		MAP, SD	
	Period: 1911-1940		Period: 1941-1970		Period: 1971-2000	
Hardwood	526	79	533	83	553	77
Mixedwood	525	75	553	81	560	72
White Spruce, Pine	511	77	566	83	605	88
Blk Spruce	518	84	566	95	605	100
Wetland	410	76	408	76	447	81
Forested Grassland	388	70	393	66	416	76
Grass Shrubland	424	83	426	73	418	58
All lentic/lotic	500	73	504	79	522	80
Rock and Ice	806	121	895	115	922	143
Annual, Forage Crops	388	70	393	66	416	76
Pasture Crops	424	83	426	73	418	58
Overall Study Area						
West	806	121	895	115	922	143
Central	500	73	504	79	522	80
East	388	70	393	66	416	76

Table B-6-4. Mean annual temperatures (MAT - °C) at three representative sites in the North Saskatchewan River Basin as simulated under three climate change scenarios.

Climate Model	Year	MAT - Sask. Crossing	MAT - Devon	MAT - Two Hills
HADCM3	2020	1.3	3.8	3.1
	2050	3.1	5.8	5.1
	2080	5.1	8	7.4
PCM	2020	0.9	3.2	2.6
	2050	2.1	4.4	3.8
	2080	3.5	5.8	5.2
CGM	2020	1.2	3.8	3.2
	2050	2.4	5.4	4.8
	2080	4.1	7.5	7.1

Table B-6-5. Mean annual precipitation (MAP - mm) at three representative sites in the North Saskatchewan River Basin as simulated under three climate change scenarios.

Climate Model	Year	MAP - Sask. Crossing	MAP - Devon	MAP - Two Hills
HADCM3	2020	786	521	426
	2050	812	521	426
	2080	839	520	428
PCM	2020	770	539	441
	2050	773	561	461
	2080	775	588	485
CGM	2020	787	538	436
	2050	805	552	447
	2080	831	575	463

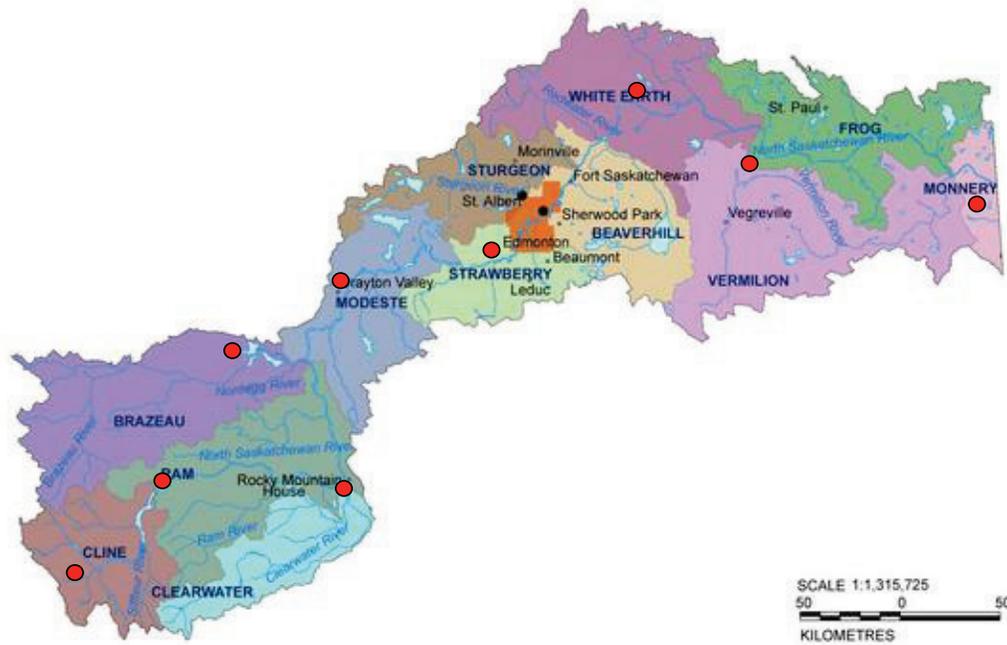


Figure B-6-1. Map of ALCES[®] -NSRB study area, showing locations of representative landscape types (red dots) used for interpolation of climate data.

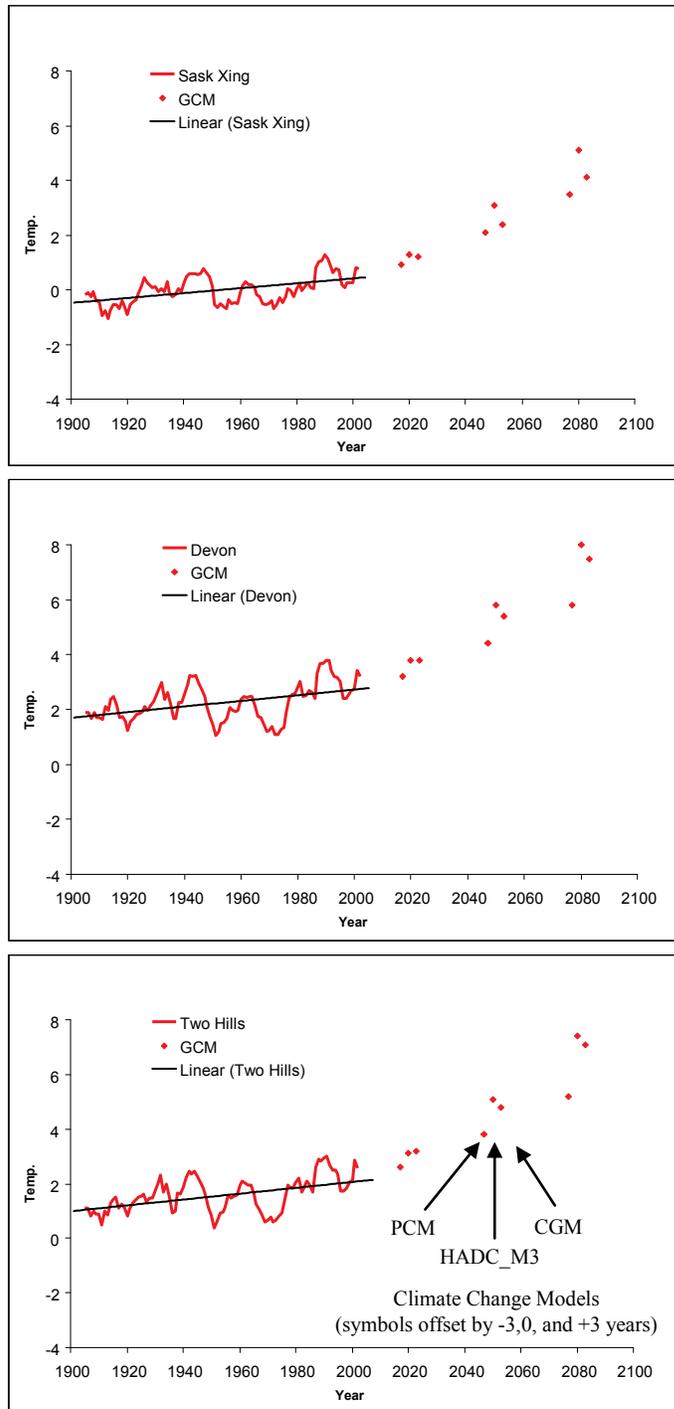


Figure B-6-2. Mean annual temperature (MAT) data for three representative sites in the ALCES[®] – NSRB study area. Data interpolated from meteorological stations and climate models using model ClimateWNA_v4.33 (Wang et al. 2006, updated to 2008).

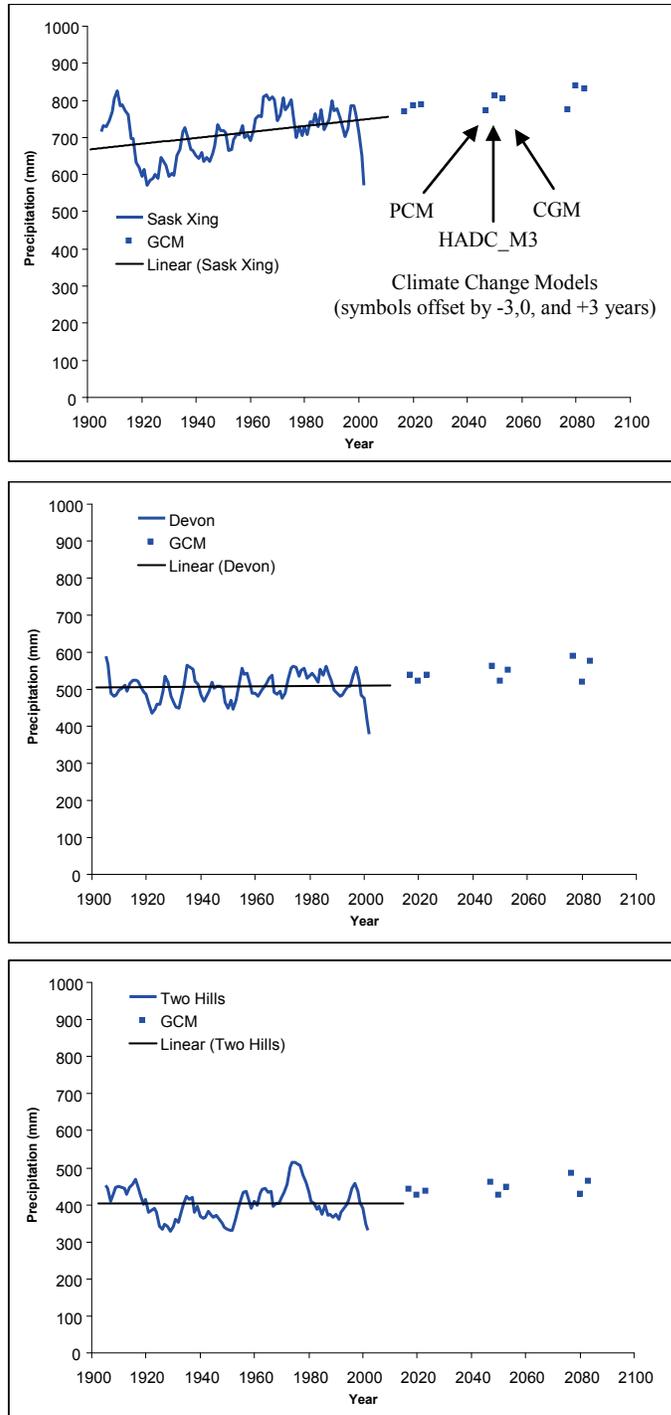


Figure B-6-3. Mean annual precipitation (MAP) data for three representative sites in the ALCES[®] – NSRB study area. Data interpolated from meteorological stations and climate models using model ClimateWNA_v4.33 (Wang et al. 2006, updated to 2008).

B-7: Modelling Assumptions for Pre-industrial Landscapes

- Removed 3 crop-types from LT (annual, forage and pasture) and distributed across 3 native LT (Hardwood, ForGrShrub, GrassShrub). (Based on the 2005 distribution of agriculture (Robertson, Adams), it was assumed that 20% was carved out of aspen forest (Hw) in the north of the watershed, 30% was carved out of aspen parkland (ForGrShr) along the north side of the river, and 50% was carved out of native northern prairie (grass-shrub)).
- It was assumed that ditches were converted from small rivers. Therefore 192 km of Initial ditches were added to pre-industrial small rivers ($192+14620 = 14,813$ km). Similar calculation for canals and med rivers ($1922+11403 = 13325$ km).
- Dugouts (reservoirs) were carved out of mixed wood. It was estimated that 5669 ha of reservoirs were carved out of Mixed Wood (therefore an estimate of pre-industrial Mixed Wood was $42048+5669 = 47717$ ha. Lagoons were also carved out of Mixed Wood, adding another 976 ha to Pre-Industrial mixed wood = 48693 ha.
- Wetlands: if the 2009 value is 157,819 ha of wetlands, and DU believes this represents 65% loss, then the pre-industrial estimate was taken as 450,912 ha of wetlands (i.e., $157,819/0.35 = 450,912$). Therefore 293,093 ha of wetlands were lost. All were assumed to be in the native grass / shrub landscape and thereafter converted to annual and forage crop. Therefore the pre-industrial grass shrub were corrected to $(1,110,861 \text{ ha} - 293,093 \text{ ha}) = 817,768$ ha.
- Riparian area was simply modelled as an area of 100m on each linear feature of lotic water.

Appendix C: ALCES[®] Review and Assumptions

C-1: ALCES[®] Index of Native Fish Integrity

A detailed review of the Index of Native Fish Integrity as modelled in ALCES[®] is presented in Lagimodiere and Eaton (2009). This report is available from the NSWA in electronic format:

<http://nswa.ab.ca/sites/default/files/ALCES%20fish%20indicators%20and%20coefficients%20Lagimodiere%20and%20Eaton%202009.doc>

Executive Summary

This report is one of a number of technical reports prepared to support the development of the Lower Athabasca Regional Plan (LARP) of the Land Use Framework. It describes the indicator selection rationale for proposed fish and fish habitat indicators and provides response curves and coefficients for conducting landscape modelling to evaluate land-use and management scenarios. Model response curves and coefficients are compatible with the use of the ALCES[®] model.

The Index of Native Fish Integrity is a fish community indicator developed through a Delphi (expert opinion) workshop. As well, relevant literature regarding the relationship of land-use activities on fish species and communities was reviewed. Response curves for four key land-use parameters and INFI are described (water use, linear density, human population and watershed fragmentation due to hanging culverts).

Fish habitat indicators include aquatic habitat loss, aquatic habitat fragmentation and water quality index. Aquatic habitat loss measures change in area of watercourses and water bodies. Aquatic habitat fragmentation is represented by: stream crossing density, watershed fragmentation due to hanging culverts and average stream continuity length. The water quality index provides runoff and delivery coefficients for sediment, nitrogen and phosphorous.

Context, caveats and assumptions are provided to aid in the interpretation of these indicators, response curves and coefficients in modelling and plan development. Recommendations on follow-up are provided.

C-2: ALCES[®] Nutrient and Sediment Model

A detailed review of the concepts of the indices relating to nutrient and sediment run-off as used in the ALCES[®] model is presented in Schindler and Donahue (2006). This report is available from the NSWA in electronic format:

<http://nswa.ab.ca/sites/default/files/ALCES%20Hydrology%20Review%20by%20Dr.%20David%20Schindler.doc>

Interpretation of Freshwater and Landuse Issues in Southern Alberta Using Forem Technologies' ALCES[®] Landscape Model

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Our assessment of the applicability of ALCES[®] to freshwater issues in southern Alberta is limited to topics that were discussed in a meeting with representatives from the Southern Alberta Sustainability Strategy (SASS), including from Alberta Environment, Alberta Agriculture, and Forem Technologies.

We feel ALCES[®] is suitable for use in identifying, at a strategic level, potential general freshwater problems associated with existing and projected land use change in Southern Alberta. That is, it is a valuable assessment tool when applied on regional spatial scales and multi-decadal time scales. Thus, use of this model and interpretation of its outputs should be limited to the large scale; investigations into site-specific issues or time-limited dynamics would be better suited to other more detailed mechanistic models.

C-3: Input Parameters

The input parameters used in this assessment are available in spreadsheet format from NSWA on the internet:

http://nswa.ab.ca/sites/default/files/ALCES_Input_parameters_NSWA.xls

Spreadsheet tabs include:

- Initial LT Composition: initial composition of watershed by landscape type.
- river lengths
- Pre-Industrial LT Composition: area of landscape types before industrial footprints and human land uses added
- Initial Footprint Composition: area and length of footprint types
- Initial Footprint X LT %: initial proportion of footprints by landscape type
- Natural Disturbance Regimes: natural disturbance regime metrics and seral stage eligibility by landscape type
- Forest Growth and Yield: post-harvest and post-fire growth and yield by forested landscape type
- Meteorology: precipitation, temperature, and fraction of precipitation to lotic runoff, aquifer recharge and potential evapotranspiration by landscape type.
- Humans and Residences: average # people per residence, average settlement size (ha), and initial human population
- Protected Areas: Proportion of each landscape type in a protected area
- Air Emission References: Average emissions of sulphur dioxide, NO_x, particulate matter, and volatile organic compounds by industrial facility type
- Water Emissions References: run-off (nutrient export and water yield) export coefficients)

C-4: Review of the ALCES[®] Hydrology Sub-Model

A detailed review of the hydrology model used in the NSWA-ALCES[®] cumulative effects assessment is presented in Jones (2008). This report is available at <http://nswa.ab.ca/sites/default/files/ALCES%20Hydrology%20Review%20by%20JP%20Jones%20Sept%2013%202008%20v2.pdf>

Excerpt

The ALCES[®] model is an Integrated Resource Management tool which allows the user to examine various economic, ecological and social consequences of proposed or existing land uses on an existing landscape. Various aspects of air, land and water processes and the interactions between those processes are integrated into the framework of the model. By their very nature, these processes and their interactions are highly complex and ALCES[®] compensates for this complexity by making certain spatial and temporal simplifying assumptions in order to calculate a computationally tractable solution. ALCES[®] generates strategic level, as opposed to operational level, output. This distinction between output types is important and addresses the manner in which the ALCES[®] conceptual framework was developed. Within the context of ALCES[®], strategic level output means that the model produces broad, regional trends for user-defined indicators or parameters. This is different from operational output that is geared towards generating unique values at a point in space and time. With respect to hydrological processes, an example of a strategic level result would be that overall streamflow volumes are projected to decrease in a watershed over the next several years. Conversely, an operational result would determine streamflow rates at specific locations within that watershed at specific times. Both approaches have their respective applications as well as advantages and drawbacks. Strategic level modeling is a tool that is best applied at the policy or high level planning stage while operational modeling is typically conducted by engineers or scientists interested in allocations, short-term water supply projections, flood mapping as well as other localized or regional design and watershed management issues.

The purpose of this document is to evaluate the strategic level hydrologic capabilities of the ALCES[®] model. Basic background information is provided on macroscopic hydrological parameters such as the hydrologic cycle and water budgets. How ALCES[®] conceptualizes the water budget is then presented followed a discussion of each of the water budget terms and how they are represented in the model. This discussion is followed by a few recommendations on how to improve future applications of ALCES[®].

C-5: Review of the ALCES[®] Model

A detailed review of the ALCES[®] model used in the NSWA-ALCES[®] cumulative effects assessment is presented in Hudson (2002). This report is available from the NSWA in electronic format here:

<http://nswa.ab.ca/sites/default/files/ALCES%20review%20by%20Dr.%20R.J.%20Hudson%202002.pdf>

Excerpt

ALCES[®] (A Landscape Cumulative Effects Simulator) has been selected as one of several tools to support the development of regional resource and environmental strategies. This report defines the role of ALCES[®] in the regional planning process, evaluates its utility for that purpose, and provides guidelines for its productive use. It defines the scope and recommends a development path.

ALCES[®] fills a vacant niche among natural resource management models in providing a comprehensive framework to study cumulative effects among a wide variety of land uses ranging from human settlement, protected areas, recreation, agriculture, forestry and energy. It is an exploratory tool for strategic analysis and complements more detailed and focused models used for tactical analysis and operational planning.

Although there is general agreement that regional planners need strategic models, there is uncertainty of what that means in terms of model design. A widespread notion is that land-use models should be spatially explicit. Accuracy of forecasts is considered to be critical by most participants in regional planning. However, the criteria by which models are evaluated depend heavily on the specific purpose to which it is assigned. For example, a strategic tool that imparts insights may be more important than one that is accurate in a non-transparent way.

ALCES[®] was developed in Alberta with integrated land management as a key focus. It is as much a service as a product. It serves as a tutorial on integrated resource management as well as a tool to forecast key indicators under alternative management regimes and global trends in climate and commodity prices.