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Informing Regional Planning in Alberta's Oilsands Region with a Land-use Simulation Model

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Abstract: Planning for regional sustainability requires strategic understanding of ecological and socioeconomic trade-offs associated with alternative land use options. We discuss a scenario analysis being undertaken to assess trade-offs for a 93,000 km^2 region in northeastern Alberta containing the world's second largest oil deposit. Due to its immense economic and ecological value, the region presents both an opportunity and challenge for the objectives of sustainable prosperity and healthy ecosystems put forth by the Alberta government's Land-Use Framework. ALCES® simulation and mapping software are being applied to inform government planners and stakeholders about possible future outcomes associated with land-use options. ALCES is well suited due to its capacity to simulate the cumulative effects of the major types of land use (hydrocarbon extraction, forestry, agriculture, residential) and natural processes (fire and meteorology) on a wide range of ecological and economic indicators. Scenarios assessed to date vary in terms of development rates, practices to minimize impacts, and land use zoning. Communication of results is aided through maps of simulation outcomes, and interpretation facilitated by presenting results in the context of range of natural variability. The scenario analysis provides a case study to discuss the technical aspects of ALCES and the Alberta Land-Use Framework's approach of facilitating learning through iterative scenario analysis.

Keywords: scenario analysis, cumulative effects, regional planning

1. INTRODUCTION

Environmental degradation has increased in frequency and intensity in recent decades due to expanding development and population growth. Responses to the environmental impacts have typically been reactionary and focused on specific symptoms rather than systemic drivers and effects (Reagan 2006). The result is fragmented government policy that is ill-suited to deal with environmental problems that are typically complex, multidimensional, and broad in spatial and temporal scale (Bellamy et al. 1999). Integrated resource management (IRM) was conceived to address the discordance between the complex problems yet simplistic management regimes. Rather than focusing on single developments or environmental issues, IRM seeks to manage all human activities in a system to balance a broad range of objectives (Cairns and Crawford 1991).

Practitioners of IRM are likely to encounter trade-offs when diverse environmental and socioeconomic goals come into conflict due to finite natural resources. An important component of IRM is scenario analysis to assess trade-offs associated with a range of contrasting but plausible assumptions about a region's management regime and ecological processes (Peterson et al. 2003). The scenario analysis should be broad enough in scope to consider the impact of all potentially influential anthropogenic and natural disturbances and to incorporate the broad spatial and temporal scales that define many ecological processes. Computer-based land-use simulation models are well suited for such an analysis due to their capacity to track potentially complex inter-relationships among numerous variables. Although incapable of predicting the future state of an ecosystem due to the uncertain nature of key drivers (e.g., human behaviour and natural disturbances), computer models can foster an understanding of how an ecosystem may respond to human actions by trialing management strategies prior to real-world implementation (Ford 1999).

The province of Alberta in western Canada is a poignant example of the benefits and challenges created by rapid and uncoordinated economic development. Over the past century, Alberta's population has grown at a rate of 2.1% per year, driven first by the conversion of native prairie to agricultural production and then development of the abundant hydrocarbons of the Western Canadian Sedimentary Basin and harvest of the province's expansive forests. Alberta has transformed into a jurisdiction whose export economy is of international importance, but rapid development has also generated environmental liabilities (Timoney and Lee 2001). The uncoordinated growth mandates of multiple resource sectors have impacted not only ecosystems but also each other, with land uses such as energy and forestry competing for a limited land base (Ross 2002).

In response to mounting concerns that existing management regimes may be inconsistent with long-term sustainability, the government of Alberta is embarking on an IRM planning exercise to identify land use strategies better suited to balance long-term ecological and socioeconomic objectives (Alberta Land Use Secretariat 2008). The planning process, referred to as the Alberta Land-use Framework (ALUF), has been partly informed by scenario analyses for the first two regional plans undertaken to date. In this paper, we discuss the role of scenario analysis in the ALUF and describe ALCES®, the land-use simulation model being applied to explore regional cumulative effects. As an example of how ALCES is informing the regional planning process, we draw from the ALUF's scenario analysis that focused on the oilsands region of northeastern Alberta. We conclude by discussing some of the challenges and opportunities of applying simulation models to inform IRM, focusing on the potential role of simulation models as educational tools to improve societal awareness of land use issues.

2. ALCES AND THE ALBERTA LAND USE FRAMEWORK

The ALUF, mandated by the Alberta Land Stewardship Act in October 2009, represents a shift from project-specific to regional environmental management. The focus is on strategic level issues and solutions such as the desired balance between ecological and economic performance and how provincial strategies such as economic development, protected areas, and regulations should align at the regional scale. While regional plans require approval from Cabinet, the plans are designed by multi-stakeholder groups through an iterative process informed by scenario analysis. The multi-stakeholder groups, referred to as regional advisory councils (RACs), are populated with a diverse collection of individuals who are collectively knowledgeable of the full range of land-use issues relevant to a region. With ongoing guidance from the RAC, a regional planning team (RPT) consisting of experts from relevant provincial government ministries structures a series of scenarios intended to demonstrate the implications of a range of management options. The process is fluid, with each subsequent scenario being informed partly by learnings from previous scenarios. Ultimately, the RAC applies learnings from the iterative scenario analysis, along with additional information and analysis supplied by the RPT, to recommend a regional land use strategy to Cabinet. If accepted, the regional strategy is then used to guide the development of subregional municipal plans that are consistent with regional objectives. More information about the ALUF is available at www.landuse.alberta.ca.

ALCES is being applied to inform the ALUF due to its capacity to examine inter-relationships among the full range of relevant land-use sectors and natural disturbances, and explore their environmental and socioeconomic consequences at large temporal and spatial scales (Hudson 2002, Salmo Consulting et al. 2001). ALCES is a stock and flow model built using the Stella modelling platform (www.iseesystems.com). The model was first developed by Dr. Brad Stelfox in the mid 1990's and has gradually expanded in scope to meet the needs of various regional planning initiatives in western North America. The following description provides an overview of ALCES structure and function. More details can be found on the ALCES Group website (www.alces.ca).

To achieve a synoptic view of regional cumulative effects, a wide-range of land uses and ecological processes are incorporated into the model as drivers. The various land uses and ecological processes can be turned on or off depending on the needs of the scenario analysis. For each land use operating in a region, the user defines development rates, the portion of the landscape available for development, and management practices such as the intensity and lifespan of associated industrial footprints. The influence of natural disturbances (fire and insects) and plant succession on landscape composition are also tracked. Hydrological processes are addressed with surface and groundwater modules, and climate change effects can be incorporated by defining temporal changes in natural disturbances rates, successional trajectories, landcover, meteorology and hydrology.

The first-order effects tracked by ALCES are landscape composition and resource production/supply. Using an annual time-step (although monthly time steps can be used for the meteorology module) the model modifies the area and length of up to 20 landcover and 15 anthropogenic footprint types in response to natural disturbances, succession, landscape conversion, reclamation of footprints, and creation of new footprints associated with simulated land-use trajectories. ALCES is a spatially stratified model, meaning that it tracks the area, length, and quantity of each footprint separately for each landscape type. ALCES does not, however, track the explicit geographic location of these features (e.g., latitude and longitude), a feature that greatly speeds up processing time (less than 1 second per simulation year) relative to a spatially explicit modelling approach. ALCES also tracks resource production and supply using approaches that are typical of sector-specific models such as forestry timber supply models and the Hubbert-Naill life cycle approach for simulating exploitation of hydrocarbon deposits (Naill 1973). By tracking resource supply, ALCES can reduce or stop the expansion of a land use if resource supply becomes inadequate. Changes to water quantity are also tracked by applying water use coefficients associated with each land use.

Land base composition and resource production attributes are translated into indicator variables using coefficients. A wide range of indicators are available so that trade-offs between diverse ecological and socioeconomic objectives can be assessed. Types of indicators that can be tracked by ALCES include wildlife habitat and populations, water quality and quantity, biotic carbon storage, air emissions, employment, gross domestic product, and social indicators such as family income and educational attainment.

By applying ALCES Mapper, ALCES tabular and graphical output can be augmented with maps illustrating the plausible future condition of landscapes and indicators. ALCES Mapper is a companion tool to ALCES developed by Alberta Innovates Technology Futures (formerly Alberta Research Council) as an ArcGIS application (www.esri.com). The tool divides the study area into grid cells of user-defined size, and calculates the initial landscape and footprint composition within each cell. Footprint growth and reclamation, landcover change, natural disturbances, commodity production and other variables as reported by ALCES are then applied to each cell, tracked, and displayed spatially. ALCES Mapper allows users to specify the general location (i.e., where specified land-use footprints can or cannot occur) and pattern (e.g., dispersed versus contagious) of future development. This feature provides flexibility to map transformations of landscapes through time according to different spatial rules, and is useful for visualizing the implications of different zoning or resource utilization strategies. Maps of future landscape condition can then be analyzed to evaluate the spatial response of indicators such as wildlife habitat to potential future landscapes associated with land-use scenarios.

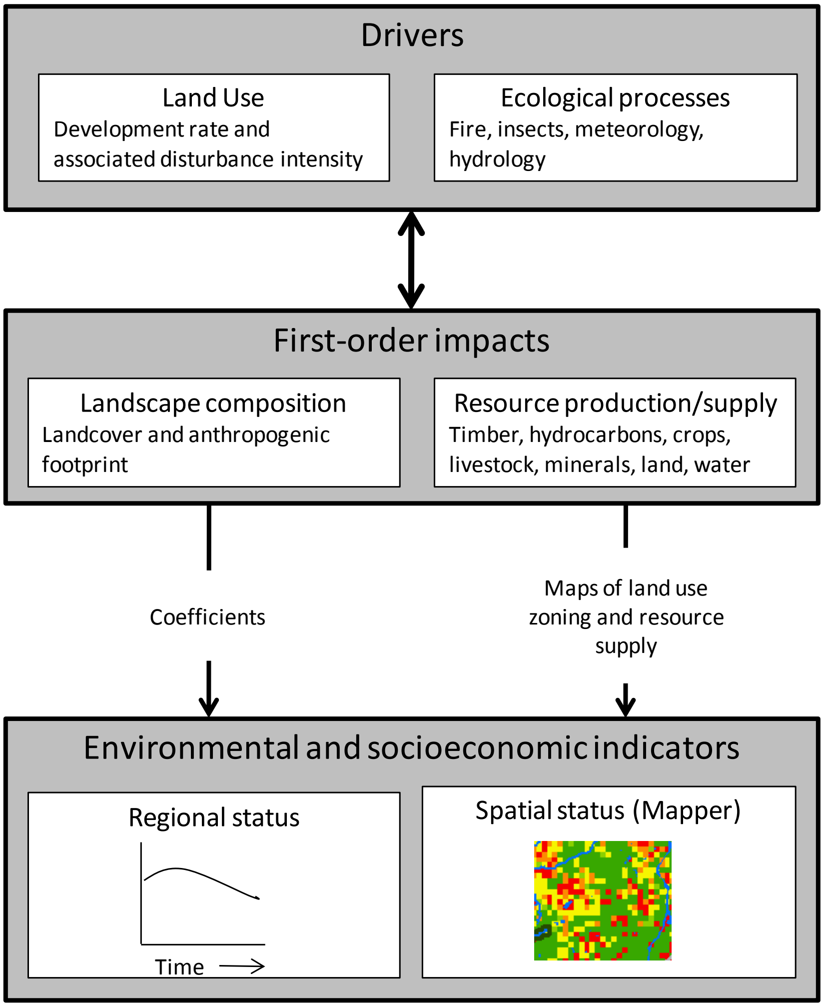

Figure 1. Overview of the ALCES land use simulation tool.

3. CASE STUDY: THE LOWER ATHABASCA REGIONAL PLAN

The Lower Athabasca Regional Plan (LARP) is the first of the seven regions in Alberta to be assessed as part of the ALUF. We do not attempt to summarize scenario analysis outcomes because LARP will not be completed until later this year. Rather, the scenario analysis approach is described to demonstrate how ALCES and ALCES Mapper can be applied to inform regional planning. ALCES simulations for LARP are being completed by the ALCES Group, under direction of the RPT. The scenario analysis approach used for LARP evolved over the course of the plan development and continues to be evaluated to seek refinements in how it can best inform development of future plans.

The Lower Athabasca Region occupies a 92,000 km^2 boreal landscape in northeastern Alberta. The region's forests, fen and bog complexes, lakes, and extensive lotic system support a diverse range of species. Although this region has supported 1st Nation communities for thousands of years, it is only during recent decades that large-scale industrial development has emerged including forestry, energy, and agriculture. The region contains the Athabasca Oilsands, one of the largest bitumen deposits in the world.

Land uses and ecological processes included in the simulations were energy, mining, forestry, agriculture, settlements, transportation, protected areas, fire, succession, and meteorology. To support a transparent modelling process, information to model these processes and define the initial composition of the landscape was either provided or vetted by government ministries, and modelling assumptions are extensively documented for each scenario. Further, the model has been previously validated and calibrated through expert review and comparison with outcomes from more detailed, sector-specific models (Hudson et al. 2002). The scenario analysis reported on approximately 50 indicators related to landscape composition, terrestrial and aquatic habitat and biota, water quality and quantity, air quality, and economic health. Indicator coefficients were defined by subject experts, and vetted by the RPT. Indicator coefficients were empirically derived when data were available from sources such as the province's biodiversity monitoring program (www.abmi.ca), and were otherwise based on expert opinion gathered during workshops or literature review.

As described previously, scenarios are being structured by the RPT based on input from the multi-stakeholder RAC. Scenario outcomes are presented to the RAC in a workshop setting, and feedback from the RAC is utlized by the RPT to structure the subsequent scenario. Scenario development by the government (RPT) and stakeholders (RAC), rather than the modelers, helps ensure that the scenario analysis considers land-use options that are relevant to the planning process. The first scenario evaluated sensitivity of indicator outcomes to the rate of bitumen development, the most important land use in the region. The next scenario assessed the "best available" management strategies, within technological and economic constraints, for limiting environmental degradation per unit of resource production. The suite of strategies, referred to as best practices, was identified through consultations with experts from government and industry. Included were strategies for minimizing the size and duration of industrial footprint, old forest protection, water conservation, and emissions reduction. A subsequent scenario focused on the potential of mitigating impacts to wildlife species through vehicular access management. The scenario analysis is ongoing, with land-use zoning being one potential scenario yet to be assessed.

A series of fifty 200-year simulations of stochastic fire and meteorology regimes in the absence of land use were completed to estimate the range of natural variability (RNV) for ecological indicators as a comparative benchmark to help interpret scenario results. The likelihood and severity (i.e., risk) of negative impacts to native wildlife and ecosystem services increase as environmental conditions depart from natural conditions. As such, natural conditions are a relevant benchmark for assessing the compatibility of land-use strategies with the ALUF's outcome of "healthy ecosystems and environment". For indices of wildlife abundance, departure from natural conditions was categorized into four zones of risk based on species evaluation thresholds used by Alberta's Endangered Species Conservation Committee (ESCC): stable (within 10% of RNV), low risk (10-50% from RNV), moderate risk (50-70% from RNV), and high risk (>70% from RNV). The quantity of information associated with outcomes for approximately 50 indicators has the potential to obscure key strategic lessons conveyed by land-use simulations. We therefore aggregated indicators into a small set of indices by converting outcomes to a common scale (percent departure from RNV) and averaging across indicators. Although useful for summarizing results, the indices must be carefully interpreted because of the potential to gloss over declines in specific species or ecosystem services.

When creating maps of simulation outcomes with ALCES Mapper, a variety of spatial map themes were applied to direct the location of future land-use features. These themes included bitumen deposits, the area allocated for timber production, towns and cities, the agricultural zone, and protected areas. Land-use expansion followed anchored, contagious, or dispersed growth patterns depending on the type of footprint. Levels of access management differed across the region depending on sub-regional management priorities. An example of map output is presented in figure 2.

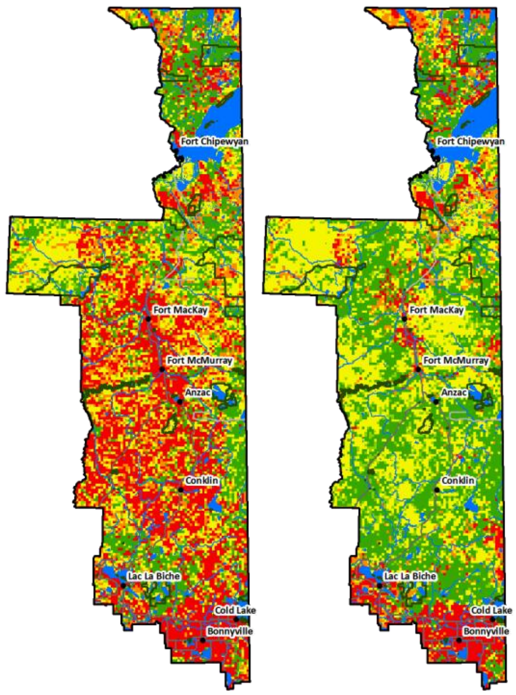

Figure 2. Potential response of a wildlife habitat suitability index at simulation year 60 in the Lower Athabasca Region without (left map) and with (right map) access management. Colours reflect the following levels of risk to moose: stable (green); low risk (yellow); moderate risk (orange), and high risk (red).

4. CONCLUSIONS AND RECOMMENDATIONS

The Alberta government has initiated the ALUF to identify land-use strategies capable of achieving: a healthy economy supported by land and natural resources; healthy ecosystems and environment; and people-friendly communities with ample recreational and cultural opportunities. Doing so requires tough decisions to address conflicting values and competing interests. Although the LARP process is still incomplete, we believe that the scenario analysis is succeeding in its role as an interactive learning tool to assist the RAC in identifying regional strategies capable of achieving a suitable balance between ecological and socioeconomic objectives. As described previously, the comprehensive nature of ALCES provides the broad scope needed to assess regional cumulative effects. Also important has been our reliance on experts from government and industry to provide coefficients and assumptions needed to parameterize the model. While time consuming, this approach has been essential for garnering trust in the validity of simulation outcomes.

The scenario analysis has not been without its challenges, and strategies for improving the modelling process for subsequent regions are becoming evident. Stakeholders and government staff frequently desire that scenario results be reported within subregions to better understand issues in their "own backyard". We think that future ALUF regional analyses can report on scenario outcomes at the subregional scale while still maintaining the regional, strategic consideration of key drivers. This could be achieved by summarizing ALCES Mapper indicator results for each reporting unit (i.e., municipality or watershed sub-basin). Presenting results at the scale of municipalities would highlight key planning issues and potential solutions within different areas, which could then be used to focus subsequent, more detailed municipal land-use planning.

Another challenge is ensuring that scenarios assessed during the modeling process span the full spectrum of possible futures. The modeling process is structured such that substantial effort is applied to develop a small set of scenarios that are supported by government and stakeholders as being representative of a plausible future trajectory. A drawback of this approach is that the consequences of unlikely or unforeseen events are not sufficiently considered. The implications of rare events such as very large fire years, heavy rainfall events, and catastrophic industrial accidents have not been evaluated. The modeling process has also not considered the potential implications of future trends in resource development, such as enhanced hydrocarbon recovery techniques that could result in extended economic benefits and environmental impacts. Inclusion a sensitivity analysis in the modeling process could help inform the development of a land-use plan that supports the resilience of the regional ecosystem and economy. Further, a sensitivity analysis could demonstrate the implications of uncertainty associated with relationships that are used to assess indicator response, and help prioritize future research.

Experts engaged in the modeling process to help parameterize ALCES frequently voice concerns about the coarse nature of ALCES relative to the detailed models that they are familiar with. As an example, ALCES focuses on emissions when assessing air quality, whereas tactical air quality models applied to help plan specific projects consider a wider set of variables such as topography and wind. We believe that the regional approach adopted by ALCES is appropriate for the ALUF and other similar planning processes because it maintains the focus on strategic issues such as the rate of regional development. However, an exciting opportunity exists to integrate the regional approach adopted by ALCES with more tactical modeling tools to improve the detail achieved by the scenario analysis while maintaining its regional focus. The linkage is made possible by ALCES Mapper's spatially explicit presentation of future landscapes and industrial activity. ALCES Mapper output can be used as inputs to tactical models which can then incorporate more detailed drivers such as spatial variation in meteorology and topography. An additional benefit of these models is that they are often well accepted by discipline experts, thereby aiding the acceptance of scenario results.

The scenario analysis described in this paper allocates substantial effort to informing a small but influential audience about the benefits and liabilities associated with alternative regional land-use strategies. Arguably the most important audience, however, is the general public for it will be their support that will ultimately determine the success of the ALUF. We suggest that land-use simulation models have a large and relatively untapped potential to contribute to educating the general public about land-use issues. Teaching the long-term effects of land use to ecosystems is a formidable challenge due to the large temporal and spatial scales and numerous relationships involved. Land-use simulation models can help address this educational challenge by bringing together key concepts and delivering them in an engaging and meaningful way to students. In recognition of this important opportunity, the ALCES Group is committed to applying our modeling expertise to help inform the general public about land-use issues. With support from a range of industry, nongovernment, and government organizations, we have developed a free, web-based educational version of ALCES (www.albertatomorrow.ca) and have linked the tool with Alberta's educational curriculum to facilitate application in classrooms. We are now partnering with the Alberta government to better link Alberta Tomorrow and the ALUF to improve public recognition of the regional planning process. We have also developed the ALCES Urban Growth Simulator© (http://www.abll.ca/aref/), a tool that allows citizens to visualize the future implications of urban growth in Alberta's towns and cities. Further, we have created an extensive library of the historical trajectories of a wide range of ecological, landscape, and land-use attributes in the province (http://www.abll.ca/library/Library_Home). The intent of all of these initiatives is to help inform the broader public about the long-term effects of land use. Such an understanding is essential for fostering societal support for the tough decisions that must be made during regional land-use planning to achieve environments in which we and our grandchildren thrive.

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