EXPLORING CUMULATIVE EFFECTS OF REGIONAL URBAN GROWTH STRATEGIES

A PLANNING SCENARIO CASE STUDY FROM THE CALGARY REGION OF WESTERN CANADA

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Downtown Calgary. Source: authors

INTRODUCTION

Tyranny of Small Decisions and Cumulative Effects

Fifty years ago, economist Alfred Kahn (1966) introduced a concept that he called the 'tyranny of small decisions'. Kahn noted that significant changes in the economy were the result of small decisions - "small in their individual size, time perspective, and in relation to their total, combined, ultimate effect." Ecologist William Odum (1982) noted similar effects in the environment and concluded "much of the current confusion and distress surrounding environmental issues can be traced to decisions that were never consciously made, but simply resulted from a series of small decisions." The result of these observations is that the physical form and socioeconomic consequences of regional landscape patterns arise more by default than intentional design.

Today we refer to these phenomena as 'cumulative effects' (Weber et al. 2012). The results of individual decisions accumulate across time and space both additively (e.g., 1 ha subdivision + 1 ha subdivision = 2 ha subdivision) and synergistically (e.g., 1 ha subdivision + 1 ha subdivision = 2 ha subdivision & an increase of CO_2 emissions that interact with other emissions to exacerbate climate change). Adding to the complexity of municipal development is that it rarely occurs in isolation, but rather in combination with other changes such as natural resource development and natural disturbances. The challenge here is that decision making often occurs in isolated jurisdictional silos with little communication between sectors. Changes in the physical landscape have significant ripple effects on social, ecological and economic conditions. Cumulative effects arise through the complexity and 'wickedness' of these interacting social-ecological systems (Game et al. 2014).

The form and function of any large city or region is a concrete expression of cumulative effects. The urban and regional planning consequences of multiple, autonomous decisions over space and time can (and often do) lead to a degradation of social, economic and environmental health. Faced with immense complexity, urban and regional planners require new approaches and tools to understand and better address cumulative effects of municipal development and other land use. New and emerging technologies have a critical role to play in assisting this broader dialogue toward holistic and integrative planning.

Modelling and Scenario Analyses

Planning in the face of cumulative effects is made challenging by complexity as well as uncertainty arising from knowledge gaps and contingency on unpredictable drivers (Peterson et al. 2003). These challenges make accurate prediction infeasible and related planning frameworks, such as optimal decision making, ill-suited to land-use planning. Instead, planning should assess the consequences of multiple possible futures that incorporate plausible but contrasting assump-

tions for drivers such as land use. A promising approach to address cumulative effects is the use of robust spatial scenario analysis to explore the potential interaction of decisions over time and space (Mahmoud et al. 2009, Weber et al., 2012). Benefits of scenario analysis include revealing implications of existing policies, identifying drivers that require attention, and illustrating the likely consequences of alternative land-use strategies (Shahumyan et al. 2014). Scenario approaches also allow planners to test the assumptions made in making development decisions through retrospective analysis.

By embracing the complexity of cumulative effects, scenario analysis can inform land-use decisions through understanding the trade-offs among environmental and socioeconomic objectives. However, assessing the consequences of overlapping human activities on diverse indicators is itself a complicated undertaking. Doing so is facilitated by the use of computer simulation models that apply mathematical relationships to dynamically articulate the implications of multiple overlapping drivers on future conditions. Modelling and scenario approaches can provide compelling evidence to support policy, planning and management decision making (Shahumyan et al. 2014).

In this paper we report on the results of a simulation modeling exercise using ALCES (A Landscape Cumulative Effects Simulator; www.alces.ca) to explore the cumulative effects of alternative growth strategies in the Calgary region of western Canada.

The Calgary Region

The City of Calgary lies east of the Rocky Mountains in western Canada. It is a relatively young and rapidly growing city. The greater region is currently home to approximately 1.2 million people and it is projected that the population will more than double in the next 60 years (Calgary Regional Partnership 2015). Economically, the region is a major driver of the national economy and is the corporate headquarters to Canada's oil and gas sector. Ecologically, the area is characterized by high amenity value in a semi-arid transition zone between the Rocky Mountains and the prairies. From the perspective of numerous societal indicators, the Calgary region is a diverse, vibrant, and rapidly evolving matrix of metropolitan centre (Calgary) and surrounding communities.

The Calgary Regional Partnership (CRP) is a voluntary collaborative regional network (the only one of its kind in Canada) of 13 municipalities working together to ensure growth occurs in a sustainable manner (Calgary Regional Partnership 2014a). The CRP takes a proactive approach to planning and is committed to employing innovative tools to assist in decision-making. The CRP developed the Calgary Metropolitan Plan in 2009 (updated in 2012 & 2014) to serve as a roadmap to determine how and where growth will occur in a manner that protects the diverse values of the region (Calgary Regional Partnership 2014b). The plan reflects the key principles of the CRP:

- *Protecting the natural environment and watershed;*
- *Fostering the region's economic vitality;*
- *Accommodating growth in more compact settlement patterns;*
- *Integrating efficient regional infrastructure systems;*
- *Supported through a regional governance approach.*

The CRP also developed a set of indicators to track progress on each of the key principles (Calgary Regional Partnership 2015c). The scenarios and modelling that we outline below are meant to assist planners in assessing the implications of the Calgary Metropolitan Plan on the distribution and density of human activity and indicators related to key CRP principles. The process of using the tool and considering the outcomes also serves as way to facilitate greater discussion between municipal planning and other land users (e.g., agriculture, oil & gas, energy transmission and forestry).

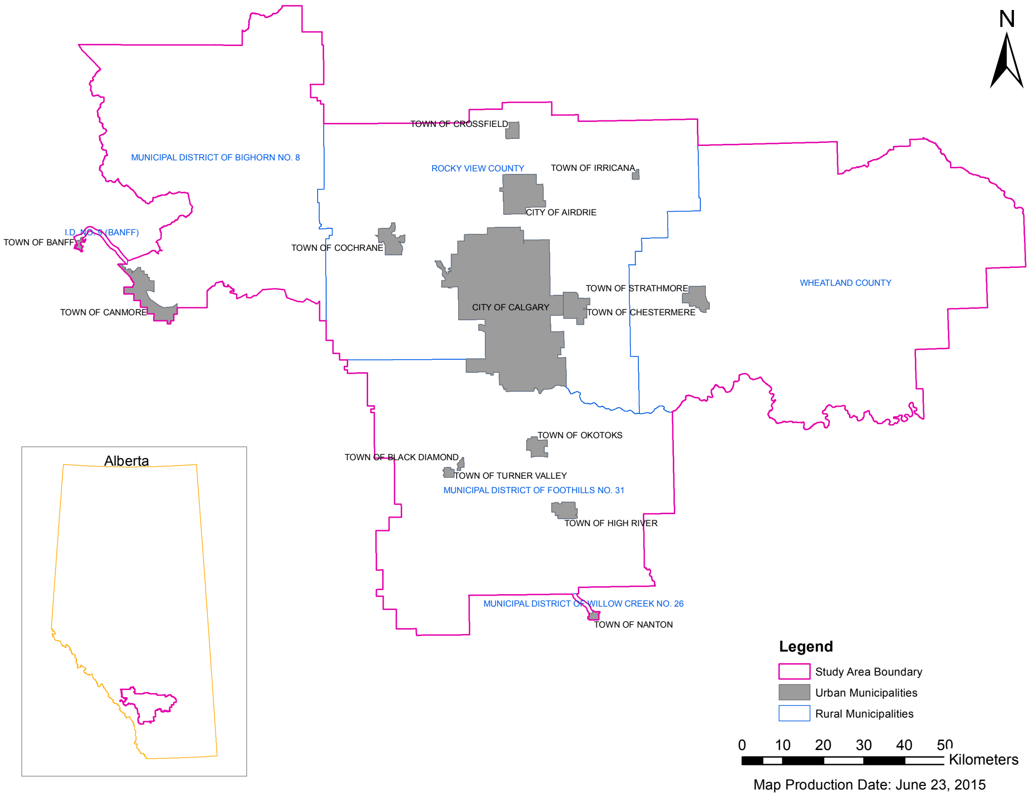

Figure 1: Context map of Calgary region

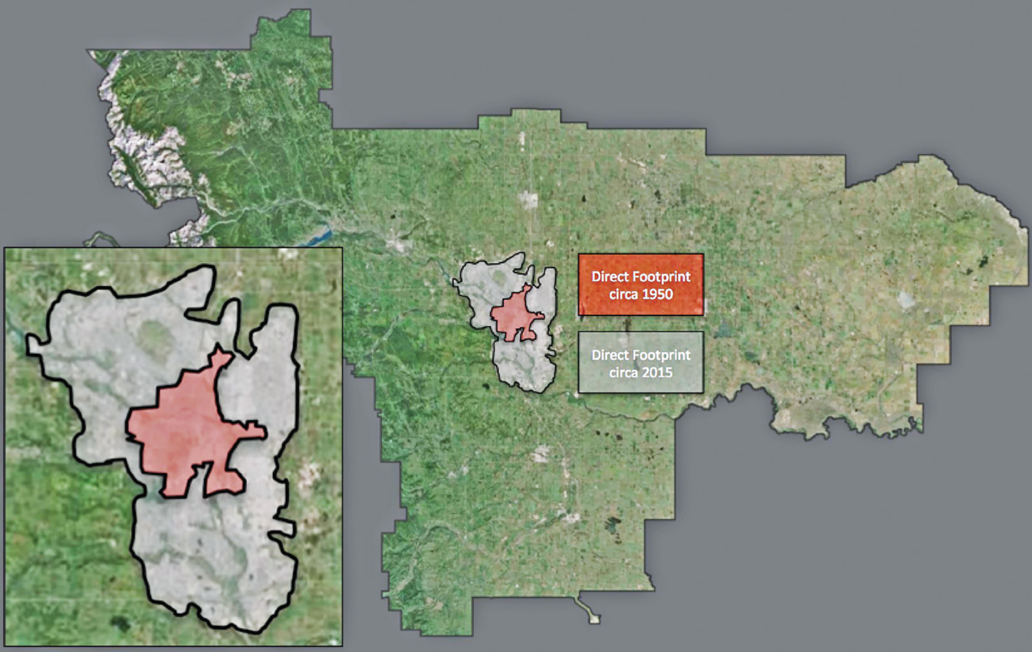

Figure 2: Historical growth of Calgary, and examples of suburban and rural residential developments in the region.

APPROACH

ALCES Land-use Simulation Toolkit

The long-term (50 year) consequences of development in the Calgary region were simulated using the ALCES land-use simulation toolkit. The toolkit has been used extensively to inform planning in Alberta (e.g., Carlson et al. 2010), as well as elsewhere in Canada, Australia, South America, and India. To achieve a holistic perspective, ALCES incorporates a wide-range of land uses and ecological processes as drivers. Each driver is parameterized in the model by defining its growth rate and spatial distribution and the intensity of associated footprints (urban areas, rural residential, roads, industrial features, farmland, cutblocks, burns). Defining these assumptions requires integration of information from disparate sources including management plans, historical data, projections, current landscape patterns, and resource inventories.

ALCES adopts a spatially explicit, cell-based simulation framework that allows individual cells to contain multiple natural and anthropogenic cover types. ALCES is not a predictive model, but instead projects the future outcomes of user-defined scenarios. Although the precise future is unknowable and can not be computed by any modeling approach, exploration of the logical consequences of plausible but contrasting land-use scenarios allows for better identification of management strategies that are consistent with objectives.

Modelling Scenarios for the Calgary Region

Comprehensive assessment of the Calgary region required simulation of rural and municipal residential development as well as other influential land uses (agriculture, energy, forestry, transportation) and natural disturbances such as wildfire. The current composition of each cell was calculated from spatial land cover and development 'footprint' inventories. Cell size was set at 0.25 km2 to balance spatial detail with strategic regional perspective. To simulate change in the composition of cells through time, regional land-use and reclamation trajectories were spatially allocated at an annual time step according to the expected spatial distribution of each activity. Although the scenario outcomes are calculated annually, due to space limitations, we only report the 50 year trajectory in the current paper.

Outcomes for two municipal development scenarios are presented in this report: business as usual (BAU) and Calgary Metropolitan Plan (CMP). Both scenarios incorporate the same CRP-endorsed population trajectory, increasing from 1.5 million to 2.8 million over 50 years with most (93%) growth occurring in urban municipalities. The scenarios differed, however, with respect to how population growth was spatially accommodated.

The BAU scenario applied a municipal development model consistent with the spatial distribution of population growth that has occurred in recent decades. Population expansion in urban municipalities occurred in new suburbs that supported the current regional average urban population density (27 people/km2) and were located at the periphery of towns. Rural population growth occurred in new acreages whose location was based on key determinants of acreage development to date, including driving distance to Calgary and the accessibility of mountain views and recreational activities.

In the CMP scenario we implemented strategies set forth in the Calgary Metropolitan Plan and other municipal planning documents to shift to a more compact development form. Densification of existing residential footprint accommodated 25% of population growth, except in Calgary where densification gradually increased to 50% as per the Calgary Municipal Development Plan. The

Calgary Metropolitan Plan Principle	Indicator
Phosphorous, nitrogen, and sediment runoff	Phosphorous, nitrogen, and sediment runoff
	Water use relative to licensed diversions
	Anthropogenic footprint area and edge
	Ecological connectivity index
	Biotic carbon storage
	Wetland area
Population density	Population density
	Settlement footprint
	Human health
	Farmland area
Infrastructure construction cost	Infrastructure construction cost

Table 1: Indicators and Corresponding Calgary Metropolitan Plan Principles Selected for Scenario Modeling
(Note – the current paper reports on a representative subset of this list)

location of densification followed municipal plans and was also influenced by the availability of redevelopment opportunities. Population growth not accommodated through densification occurred in new developments that adopted proposed minimum density standards (60 and 30 people/km2 in urban and rural areas, respectively) and were located in priority urban development areas and rural development nodes.

Reporting on Indicators

In consultation with the CRP, a variety of social, environmental, and economic indicators were selected for the analysis to link with CMP principles. The full list of indicators included in the scenario analysis is provided in Table 1. In this paper we report on a subset of indicators to illustrate the utility of the approach: anthropogenic footprint, ecological connectivity, nutrient runoff, infrastructure construction cost, and human health.

Ecological connectivity (Quinn et al. 2014) was derived from percolation theory and least-cost distance methods to assess how expanding anthropogenic footprint affected permeability among remnant natural areas. The effect of land use to water quality was assessed by calculating nutrient (phosphorous) runoff, using coefficients (kg/km2/year) derived for the region's natural and anthropogenic cover types (Donahue 2013). Anthropogenic features such as municipal footprint tend to have higher rates of runoff, and elevated nutrient runoff can contribute to eutrophication, as well as water treatment cost (ALCES Group, 2014). The cost of elevated nutrient runoff was estimated by applying cost coefficients for their removal at a water treatment facility ($25.45/kg phosphorous; ALCES Group 2014). To consider economic consequences of municipal development pattern, construction costs for road, water, and sewer were calculated using cost coefficients ($/km2/year) derived previously for the region (IBI Group 2009). Reduced risk to individuals of being overweight or obese in response of densification was calculated using a relationship derived from health and population data from 33 cities across Canada. While approximate, the relationship is consistent with numerous studies (e.g., Booth et al. 2005) that have found a positive association between population density and human health due to elevated physical activity and walkability.

Simulation outcomes were disseminated to

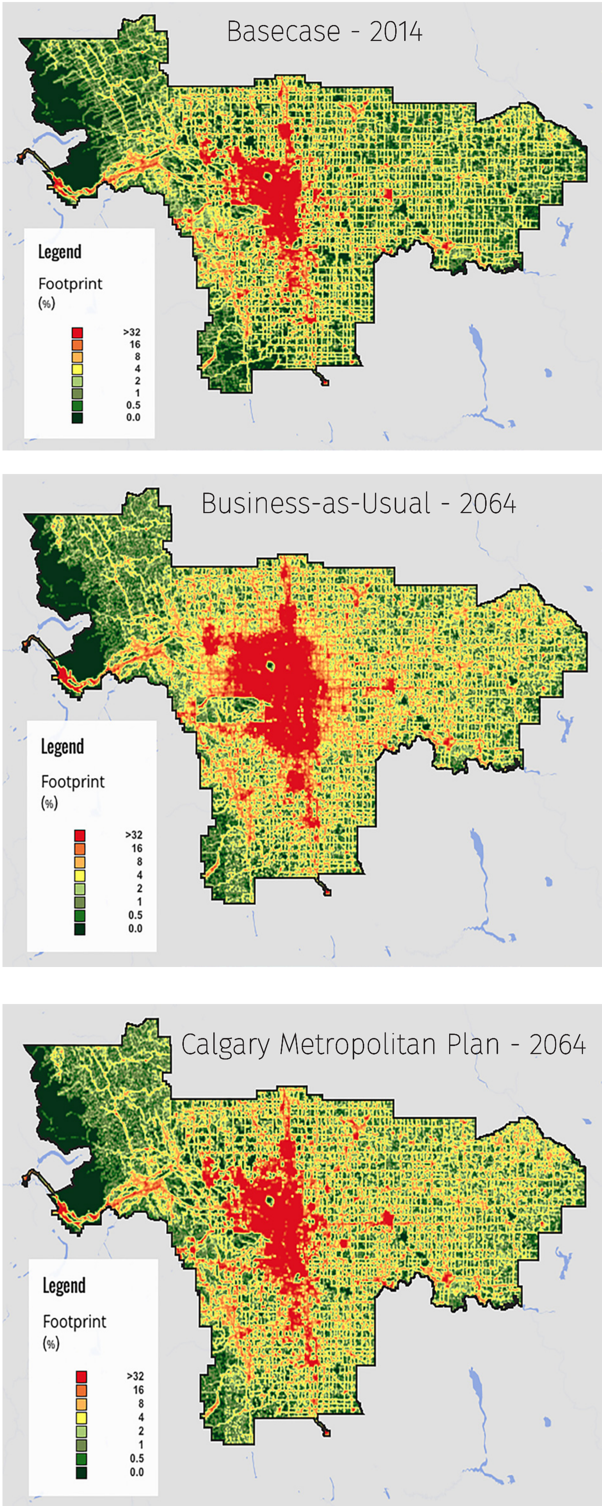

Figure 3: Development footprint by growth alternative.

the Calgary Regional Partnership using ALCES Online, a user-friendly web application for visualization, customization, and comparison of land-use simulations. A common deficiency of previous land-use simulation models is that their complexity limits their use to a small group of experts. As a result, the full potential of simulation modeling is often constrained where it matters the most: informing those responsible for making land-use decisions. ALCES Online addresses this limitation by enhancing the accessibility of scenario analysis to planners (Carlson et al. 2014). Maps of indicator outcomes that are included in this article were copied from the ALCES Online interface.

RESULTS

The Development Footprint

Town and rural residential footprint currently cover 3.1% and 2.4% of the region, respectively, and town industrial areas account for another 0.3%. The combined 1,015 km2 covered by these features makes settlement footprint the second most abundant anthropogenic feature in the region behind farmland. Land currently occupied by urban and rural footprint reflects a historical landscape transformation from native grasslands, forests and wetland communities. In the BAU scenario, settlement footprint increased by 670 km2 to accommodate population growth (Figure 3). Settlement expansion was greatest at the periphery of Calgary and the surrounding rural area, and exceeded the more dispersed growth of footprints associated with forestry and energy development. As a result, loss of farmland (527 km2), grassland (179 km2), and wetland (15 km2) was greatest in the central portion of the region. The CMP scenario required 53% less development of new town and rural residential footprint, such that 298 km2 of farmland, 110 km2 of grassland, and 8 km2 of wetland were conserved relative to the BAU scenario.

Economic, Social and Ecological Implications

Town and rural residential growth in the BAU scenario had negative long-term economic and environmental consequences. Construction of new road, water, and sewer infrastructure to service the new developments was estimated to cost $26.3 billion over 50 years (Figure 4). As well, connectivity between patches of relatively intact natural cover was reduced, indicating that ecological flows are likely to become increasingly inhibited, especially in the central portion of the study area around Calgary (Figures 5 & 6). Although further research is required to determine specific impacts, implications of diminished ecological connectivity could include reduced linkage of wildlife meta-populations and interruption of ecological processes such as hydrological flow. Another environmental impact of the BAU scenario was degraded water quality due to elevated nutrient runoff. By the end of the simulation, annual phosphorous runoff increased by 87.7 tonnes compared to today with much of the elevated runoff occurring around Calgary (Figure 7).

By constraining new settlement footprint to priority growth areas and rural development nodes, the CRP scenario avoided much of the environmental and economic cost associated with the BAU scenario. Over the course of the simulation, the CMP scenario avoided 2,266 tonnes of phosphorous runoff relative to BAU (Figure 7), achieving an estimated $58 million in water treatment cost savings over 50 years. More impressive is the estimated $18.4 billion saved over the 50 year simulation due to reduced road, water, and sewer construction needs (Figure 4). Another benefit of the CMP scenario is that ecological connectivity was better maintained in the central portion of the study area around Calgary (Figure 6). Connectivity cannot be expressed as a single metric, but the maps illustrate a critical loss

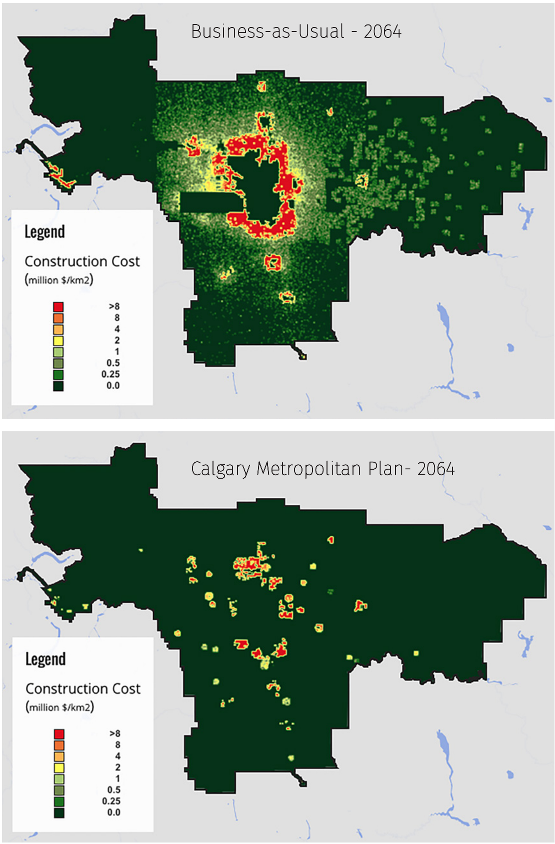

Figure 4: Infrastructure construction cost by growth alternative.

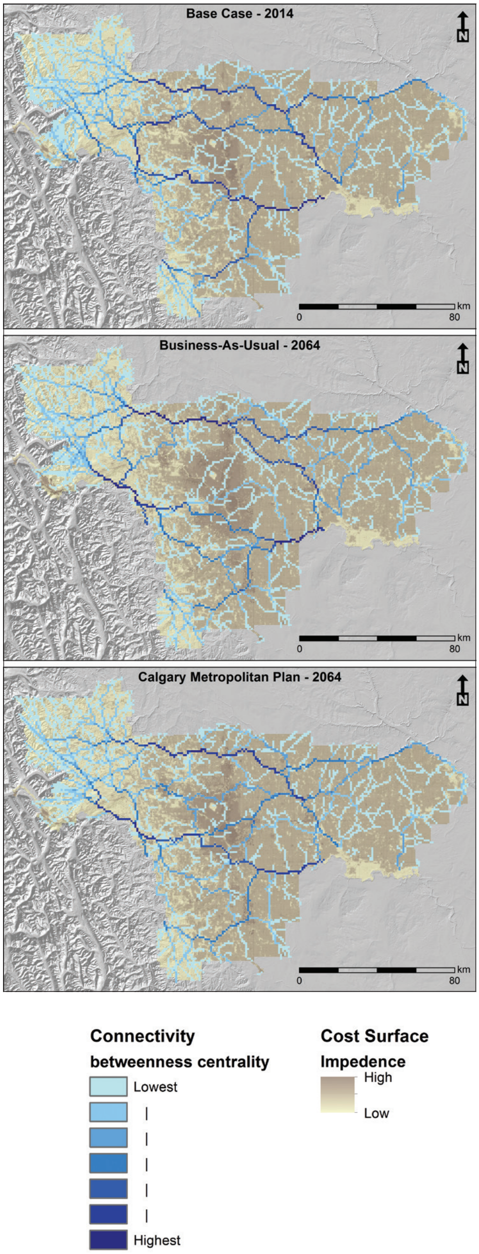

Figure 5: Ecological connectivity by growth alternative. Higher levels of connectivity occur in areas with lower footprint (i.e., low impedence).

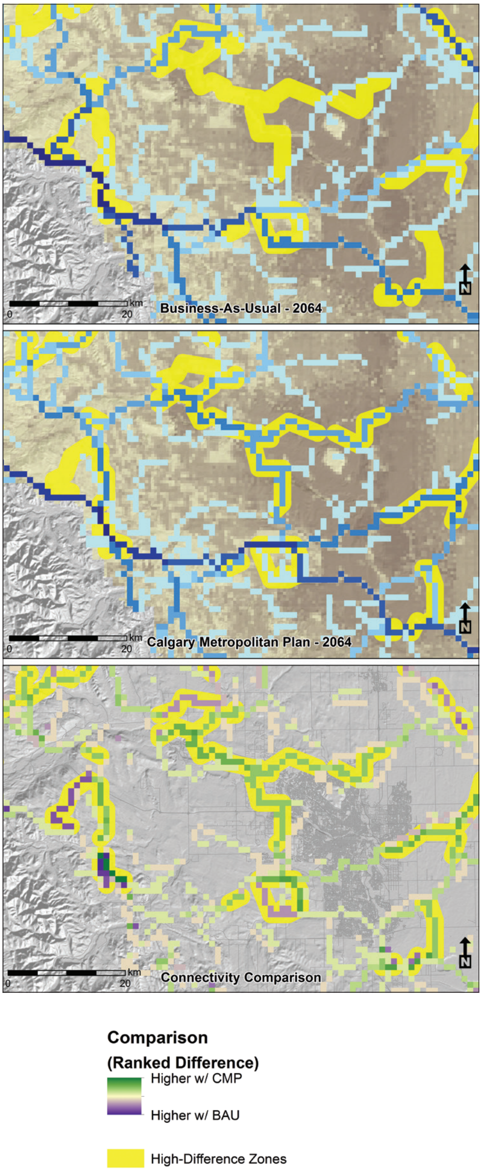

Figure 6: Ecological connectivity in the vicinity of the City of Calgary, by growth alternative (upper two maps), and ecological flow difference (bottom map) demonstrating the improvement in connectivity achieved by the CMP scenario.

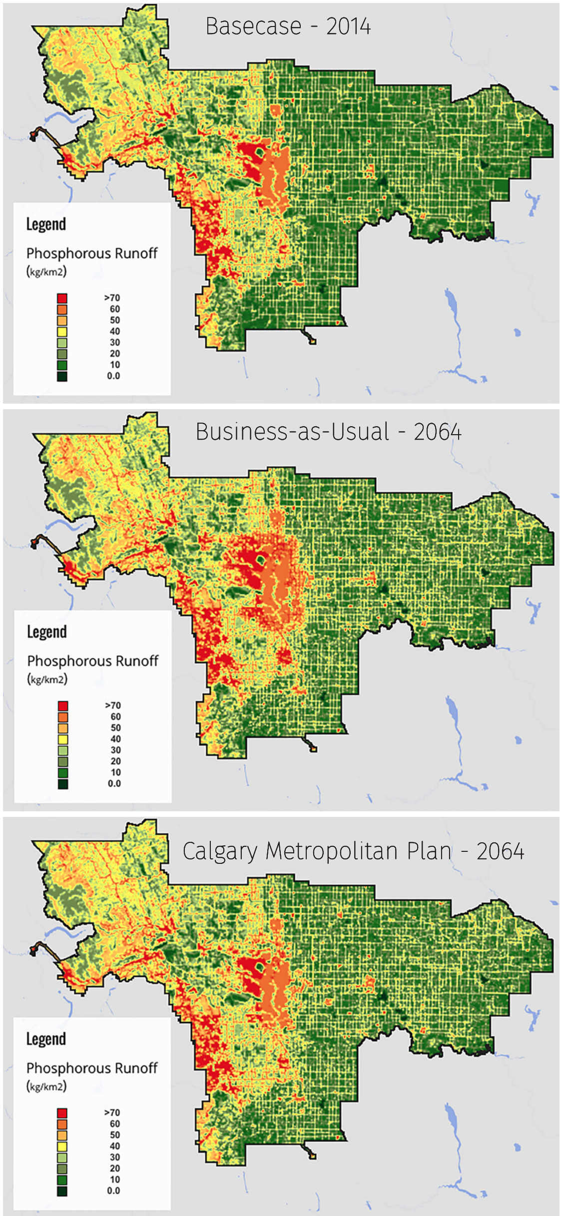

Figure 7: Phosphorous Flows by growth alternative

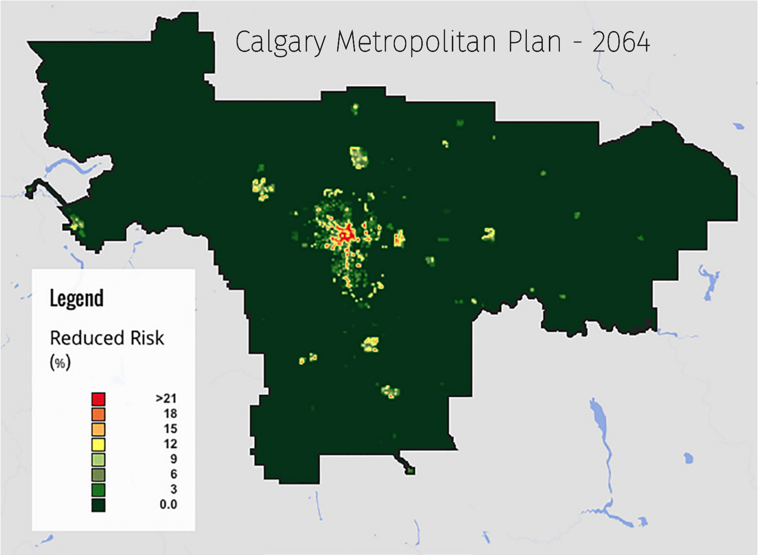

Figure 8: Reduction in risk of being overweight or obese as achieved through population densification of existing urban areas.

of potential ecological flows around the city. The effect is a long-term ecological isolation of the central urban area from the surrounding region. In effect, the BAU scenario shows that the city becomes a 'plug' in the regional flow of ecological goods and services.

It is important to note, however, that ecological connectivity still declined and nutrient runoff still increased in the CMP scenario relative to today, in part due to the impacts of forestry and energy development. The cumulative effects of multiple land uses underscores the importance of minimizing each sector's impact (e.g., by constraining settlement expansion), by adopting best management practices, and coordinating planning across sectors to ensure that conservation efforts from one sector are not negated by the impacts of others.

Hand in hand with the contrasting settlement expansion patterns are differences in population density. The extensive suburban and acreage developments of the BAU scenario served to create large areas of low population density. A growing body of research has identified several negative social consequences of low population density, including lower neighbourhood walkability leading to reduced physical activity and degraded human health. Constraining settlement footprint expansion in the CMP scenario not only curtailed negative environmental and economic impacts, it also improved the performance of social indicators by increasing population density relative to today. As an example, population densification within existing town footprint was estimated to reduce risk of being overweight or obese relative to today. The largest reductions occurred within Calgary's downtown core, where opportunities for redevelopment are greatest (Figure 8).

Figure 9: Calgary – city view.

CONCLUSIONS

A key challenge facing planners in rapidly changing cities and regions is selection of development patterns that promote collective benefits and reduce risks to a broad suite of social, economic, and environmental values. The challenge is complex, but the implementation of new and emerging information technology can help to reduce the complexity. Simulation tools, such as ALCES demonstrated here, provide planners with robust methods to test policy alternatives and communicate results with stakeholders. ALCES also provides an opportunity for planners to work directly with all regional interests in a participatory approach to scenario development. Engagement across all sectors of land use is essential in addressing cumulative effects.

Similar to many other areas, historical policies in the Calgary region have largely promoted low-density expansive residential patterns (i.e., suburbia and low-density acreages). These historical decisions have engendered many undesirable consequences, including loss of wetlands and productive farmland, increased commute times, unaffordable costs of infrastructure maintenance, reduced walkability, increased water pollution, and elevated landscape fragmentation causing reduced performance of social, economic and ecological processes. The BAU scenario developed for this paper clearly demonstrates the cumulative effects and economic costs associated with such growth.

There is, however, great opportunity for planners to embrace new residential strategies that help mitigate historical issues, and showcase an urban and peri-urban template better suited for the needs of CRP residents during the next century. We demonstrate that the plans for more concentrated growth proffered in the Calgary Metropolitan Plan are a significant improvement over business as usual. Ultimately, the future structure and function of CRP will be determined by the combination of growth management policies and how the residential marketplace responds to the different options made available by developers.

There is increasing evidence that society is changing in terms of its values related to residential form (Tian et al. 2015). Home buyers are seeking communities that deliver higher levels of societal interaction, reduced dependency on cars, increased opportunity for walkability, reduced carbon footprint, expanded opportunities for green space recreation within urban boundaries, and opportunities to secure local food that meets increasing standards of environmental sustainability. Calgarians, and those who reside in surrounding communities, are becoming increasingly aware of the importance of water (both quantity and quality) and are imploring politicians and planners to design urban strategies and residential policies that recognize the role and function of watersheds in defining the overall "livability" of cities that receive their water quality and quantity from the combined activities of all land uses that occur within their watersheds. Furthermore, as tax payers become more informed about the true costs of construction and maintenance of infrastructure, they are increasingly promoting urban growth strategies that can be sustained against current and future budgetary constraints. These values are clearly entrenched in the planning documents of the CRP.

This study illustrates that the CRP is at a cross-road, and is faced with important macro-architectural decisions that will define the ultimate form and function ("where and how") that guides how citizens will reside, move, and live in this region in the decades to come. The precise demands that future citizens place on the shoulders of planners and policy makers are both unknowable and evolving, and as such greater metropolitan planning has an inherent element of uncertainty. That said, it is clear that the historical urban and rural design strategies in cities and regions such as Calgary are unlikely to serve the future requirements of citizens whose knowledge of social and environmental sustainability is increasing, and who wish for these learnings to be embedded in sustainable urban and regional design. To this end, the results of this study provide empirical evidence of the social, economic, and environmental benefits of design strategies that reduce urban sprawl, promote walkability, and explicitly recognize the natural capital values of the CRP.

As with all modeling, the results of the scenarios reported here are only as good as the input data. We searched a wide array of literature to develop metrics linking environmental to social and economic factors. There is clearly a need for further research to refine our understanding of these linkages. In particular, although it is generally accepted that relationships exist between attributes of urban form (e.g., population density) and indicators related to quality of life (e.g., human health) and human behaviour (e.g., energy use), these relationships need to be better quantified. The strength of ALCES is that it is relatively simple to update the metrics as new and better information becomes available. Likewise, if a stakeholder objects to a certain assumption or value used in the model it can be quickly changed to conduct a sensitivity analysis.

The scenario approach and results illustrated herein help to reduce the complexity of understanding cumulative effects. The ALCES approach is highly effective in explicit identification of the trade-offs associated with different policy and planning initiatives. Moreover, the approach provides an effective alternative to the incremental and siloed methods of planning that exacerbate negative cumulative effects. The next challenge is to use this information to facilitate the ongoing discussion of desired future conditions for the region. The CRP will continue to explore the use of ALCES in the delivery of the CRP strategic plan and development of the next iteration of the Calgary Metropolitan Plan. The scenarios that we outline in this paper provide a foundation from which the CRP can develop and test further planning and policy initiatives to meet the needs of the region while protecting the values desired by residents.

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THE ALCES TOOLKIT FOR STRATEGIC LAND-USE SCENARIO ANALYSIS

Strategic land-use planning requires a holistic understanding of the implications of the full range of anthropogenic and natural processes affecting landscapes. The ALCES toolkit provides comprehensive yet user-friendly simulation of multiple overlapping land-use sectors through the seamless integration of three types of software: ALCES Integrator, a Stella-based stock and flow model; ALCES Mapper, an ArcGIS application; and ALCES Online, a web application.

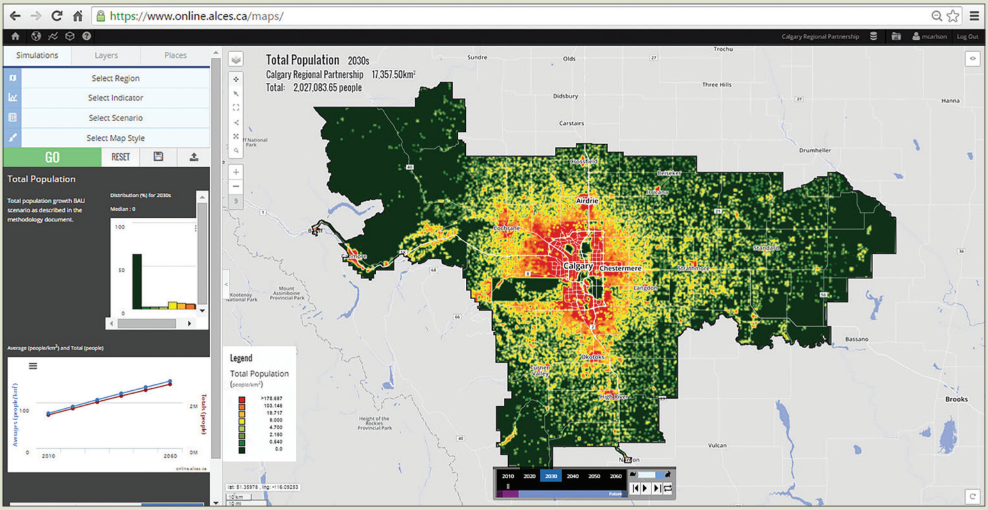
ALCES Integrator rapidly simulates long-term, regional land-use and natural-disturbance trajectories and their consequences to the area, edge, and age of natural and anthropogenic land cover. Resource production and supply as well as population growth are also simulated, such that simulations respond to resource availability.

ALCES Mapper creates maps of regional dynamics as simulated by ALCES Integrator by tracking changes to the composition of cells of user-defined size. The initial composition of each cell is calculated from spatial inventories of land cover and anthropogenic footprints. Changes to the composition of cells are then simulated by spatially allocating regional dynamics according to the expected spatial distribution of each activity and spatial characteristics such as disturbance size and coordination between disturbance types. Simulated maps of landscape condition, resource production, and population are translated into environmental, economic, and social indicators using relationships such as wildlife habitat preferences, employment associated with resource production, and social implications of population density.

Indicator performance as simulated by ALCES Integrator and Mapper are disseminated to planners and stakeholders using ALCES Online, a web application for visualization, customization, and comparison of land-use simulations. Through an intuitive interface and rapid delivery of simulations, ALCES Online enhances the accessibility of scenario analysis, thereby increasing its potential to influence land-use planning. ALCES Online also provides flexibility by allowing the user to build new indicators, assess outcomes at sub-regional scales (e.g., municipalities), and explore zoning scenarios that apply different land-use strategies to portions of a study area.

The ALCES toolkit's flexible and accessible approach to land-use scenario analysis has informed a diversity of planning processes that span a range of scales, organizations, and issues.

More information is available at **www.alces.ca**.



ALCES Online, a web-application for delivery of comprehensive land-use scenario analysis to stakeholders and planners.

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