Temporal and Spatial Changes in the Natural Capital of the Upper Bow River Basin, Alberta, Canada

Prepared for Action for Agriculture
Prepared by the ALCES Group

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Disclaimer

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This natural capital project was made possible by the previous work completed as part of the Upper Bow River Basin Cumulative Effects initiative that started in 2009. The authors and sponsors of this phase extend our appreciation to all who contributed to the findings of this large initiative. Phase 1 described historic changes in key indicators during the past century and projected likely changes in these indicators for the next 70 years under a “business as usual” (BAU) scenario. Phase 2 extended the analyses of the Upper Bow River Basin by contrasting the business as usual scenario with a “best management practices” (BMP) scenario to explore potential utility of adopting improved land use management practices.

This project recognizes the hard work of the GIS analysts (Mika Sutherland, Karen Manuel), the mapping simulations and natural capital methodology overseen by Matt Carlson, and the provision of natural capital coefficients by Sara Wilson of Natural Capital Research and Consulting. Scott Heckbert provided an excellent critique of the natural capital approach used in this project, and offered many excellent suggestions about how to improve the natural capital methodology. The project team and sponsors recognize the important contributions of both Cornel Yarmoloy and Terry Antoniuk to earlier phases of this project. Bob Holmes and Sarah Stelfox provided excellent editorial comments of the final manuscript.
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1 A Preamble from Harvey Buckley of Action for Agriculture

The importance of functioning landscapes and the ecological goods and services they provide must be understood.

The Land is Everything
Once it is Gone - It is Gone Forever

The Board of Directors saw a need to provide land use decision makers (land planners and municipal councillors) with a better understanding of the value of natural capital in the Upper Bow River Basin to better inform tradeoffs that will be faced as these assets are lost from production or converted to land uses that reduce ecosystem services. Municipal councillors, in particular, must understand these tradeoffs, and once informed may shift to protecting natural capital and agricultural lands, and move away from the perspective of unrestricted development.

The Board of Directors believe that for too long the dominant development paradigm has been that there were only two kinds of capital for development, financial and human, the latter being knowledge skills, creativity and education.

We have been living with the perspective that the environment and its natural capital is available free of charge. Population growth places ever greater demands for goods and services from ecosystems and today may be near the tipping point of over-spending this flow of valuable services.

This study can be applied to any watershed in Alberta.

We believe the next step is to establish a framework through which revenue streams could be utilized to encourage land-owners to rebuild and maintain natural capital.

Alberta’s sustainable future is dependent on striking the right balance between traditional development and conserving natural capital. A broader understanding of the different forms of value that accrues from landscapes will assist in understanding these tradeoffs.

Food for Thought Video - New Solutions for New Challenges

On October 1, 2012 Action for Agriculture brought together ten farmers and ranchers from across southern Alberta to hear the results of the Upper Bow River Basin Natural Capital study and to discuss what they mean to businesses, industry, and society. Based on the presentation itself and the dialogue among the ranchers that followed, a video was produced entitled “Food for Thought”. This video was produced with the support of the Bow River Basin Council (www.brbc.ab.ca) and is available for viewing at http://www.actionforagriculture.com/home/food-for-thought-video.
2 Executive Summary

This report summarizes key findings of the Upper Bow River Basin Natural Capital Study – a project tasked with quantifying the current condition, historical changes, and future projections in natural capital for the Upper Bow River Basin, Alberta. These findings are intended to inform and assist land use decision-makers required to devise regional plans that consider natural capital trade-offs.

The report's main conclusion is that current land-use practices in the Upper Bow River Basin are eroding the ability of the watershed to provide ecological services of providing abundant clean water, carbon storage to mitigate climate change, food security, and recreational value. If current practices continue, the loss of these ecological services is projected to reach a dollar value of more than $500 million per year for the Upper Bow River Basin alone. If policymakers adopt a suite of best land-management practices, however, the annual cost can be reduced to little more than half that value.

The watershed of the Upper Bow River has reached a critical point in its development. Recognized internationally for its natural beauty, the watershed possesses an exceptional abundance of natural resources, including forests, grasslands, rivers, diverse flora and fauna, and majestic scenery. However, during the past several decades, human land use has rapidly increased in the region. The burgeoning metropolis of Calgary and its surrounding bedroom communities demand land and water, while rural residential, croplands, forestry, livestock grazing, oil and gas extraction, hydro-electrical, hunting, fishing, and non-motorized and motorized recreation have also grown to satisfy the expanding local population and increasing regional, national, and international demand for resources, both renewable and non-renewable.

These growing, often overlapping land uses are already creating conflict among stakeholders, and the problem will only worsen as growth continues. To note just one example, the Bow River's water is already fully allocated, and many stakeholder communities are concerned about a future of water scarcity in a world increasingly shaped by climate change.

Until now, the Government of Alberta has managed the region according to a "multiple use" paradigm. This approach assumes that multiple overlapping land uses can co-occur without interfering with one another or significantly compromising the performance of key ecological, social, and economic indicators.

That assumption is no longer tenable, and the laissez-faire multiple-use approach must be re-evaluated in light of the conflicts between uses that are increasingly being demonstrated in recent assessments. In 2011, the Phase 1 report of the Upper Bow River Basin found that “business-as-usual” (BAU) land uses have already caused clear and quantifiable declines in water quantity, water quality, recreation potential, fish and wildlife indicators, timber supply sustainability, and agricultural land base. Projections using the ALCES landscape simulator (www.alces.ca) showed that these declines are likely to continue and worsen in the future. Phase 2 then contrasted this BAU scenario to a suite of best management practices (BMP) intended to mitigate the adverse effects of land use on social, economic, and environmental
indicators. Phase 1 and 2 reports can be downloaded from the ALCES website at http://www.alces.ca/projects.

The present report represents Phase 3 of the project, which assesses changes in the dollar value of natural capital accounts of the Upper Bow River Basin under both business-as-usual (BAU) and beneficial management practices (BMP). It was commissioned from ALCES in 2010 by Action for Agriculture, with funding from the Bow River Basin Council, Government of Alberta, Royal Bank of Canada (Blue Water Project), Rocky View County, Calgary Regional Partnership, Hanen Society, and the Municipal District of Big Horn.

The project provides a uniquely powerful approach to understanding trends in natural capital, because it combines biologically realistic modelling of natural processes such as fire and other disturbances, along with all significant human land uses in the region, along with explicit dollar values for ecological services. This novel synthesis yields a whole-system simulation of the implications of past, present and future land use policies on society's financial bottom line.

The results of the analyses are clear and consistent with published literature. Historical patterns of land use have created significant benefits in classic economic performance indicators such as GDP, employment, and sector-specific revenue. However, these benefits have masked a significant economic loss to natural capital accounts. Specifically, present-day and historical land uses have caused key losses to the following accounts:

- Accelerated runoff of precipitation to mainstem rivers and reduced recruitment into aquifers.
- Increased surface runoff of sediment and nutrients to mainstem rivers, causing a reduction in surface water quality, which has in turn led to greater dependence on costly technological solutions to make water potable for downstream users.
- Reduced biotic carbon (vegetation, LFH, soil) because of intensive cropland agriculture (reduced soil organics), additive disturbances to forests (fire and logging), and transformation of natural plant communities to anthropogenic features (transportation, settlements).
- Loss of food production potential because of loss of cropland and grazing land to expanded urban and rural residential developments.
- Reduced tourism/recreation potential caused by a landscape that looks progressively less natural and has reduced ecological function.

These negative trends in natural capital in the Upper Bow River Basin are likely to continue, if not accelerate, in the next several decades under a “business as usual” (BAU) scenario, according to our simulations with the ALCES model.

However, our simulations also show that an alternative land use/landscape future is possible, one in which commodity production (crops, livestock, wood fiber, oil and gas, tourism, human population and residency) can persist and ecological functions are either maintained or improved. This improved option requires land managers in the Upper Bow River Basin to abandon the historic ad-hoc land use approach that has focused on individual projects and
short periods of time. In its place would emerge a “management by objective” philosophy that would explicitly identify the desired future performance of ‘triple bottom line’ indicators (social, economic, environmental) and describe the specific combinations of land use and best management practices that achieve these desired future conditions.

In essence, we would be replacing an “everything, everyone, everywhere, all the time” land use ethic with one that fundamentally recognizes that landscapes and ecosystems have finite capacities of natural capital and commodity flow. Under this new paradigm, managers would devise and implement optimal land use plans that ensure sustained flow of natural capital through multiple human generations. Some may see this as an anti-business approach. We feel, however, that it is decidedly pro-business – but one which defines economic performance more broadly, and which explicitly recognizes the need to assess natural capital (water, air, land, biodiversity) as carefully as GDP, royalties, or employment.

This approach will not be easy – not for planners and not for the general public. It requires the full suite of stakeholders to discuss and define the desired future condition of the basin - that is, what quantity and quality of commodities and services should the Upper Bow River Basin provide to future generations?

- Should the Upper Bow River Basin continue to produce food (crops, livestock), and if so, how much? If food production is a desired future condition, then we need to ensure our agricultural landscapes persist at an agreed-upon scale.

- Should the Upper Bow watershed support viable populations of endangered species such as grizzly bear? If so, then we must recognize the need to maintain appropriate area and connectivity of natural landscape where bear mortality is managed within an acceptable level.

- Is the production of timber and hydrocarbons part of the desired future of the Upper Bow River landscape? If so, how should these land uses be conducted to ensure that they do not compromise other desired indicators (water quantity, water quality, biotic carbon, recreation and tourism)?

- Should the Upper Bow River Basin be required to deliver clean water to Calgary and other downstream users? If so, then stakeholders must define a desired level of water quality and land managers must assess the consequences of each land use on movement of nitrogen, phosphorus, sediment and other contaminants. The benefits of best management practices on minimizing loss of water quality must be understood. Where helpful, and cost effective, these improved measures will need to be adopted.

For this new management dialogue to succeed, all participants need to recognize that every land use affects natural capital indicators and also other land uses. This will not be easy. People are naturally reluctant to give up rights they currently hold, a tendency that economists term "loss aversion". As a result, many will argue that the Upper Bow should continue to host the full suite of land uses it supports today. To overcome this, stakeholders must have the insight and fortitude to make hard decisions about how much of the natural capital “pie” of the Upper Bow can be sliced up to each of the land uses of cities, acreages, croplands, irrigation, pasturelands, timber harvest, habitat for wildlife, and areas for tourism and recreation.
An important part of the answer lies in the adoption of best management practices. Reducing
the total area of a land use is not the only management lever available to planners to mitigate
adverse effects on natural capital. Once stakeholders embrace the importance of natural capital
within a business context, it becomes possible to adjust tactical practices to minimize adverse
effects while still ensuring an acceptable level of commodity production. This broadened
perspective also allows for new business generation and diversification, as land uses can begin
to offer a suite of products beyond traditional commodities, potentially diversifying into
providing clean water, biodiversity, carbon credits, and aesthetically pleasing landscapes for
tourism revenue.

This study identified several key best management practices that should be examined carefully
by landscape planners in order to maintain or improve natural capital in the basin:

• Urban settings such as Calgary and surrounding settlements should minimize future
  sprawl and adopt strategies that allow for greater amounts of mixed-use and population
densification. Improved urban growth strategies that encourage cities to grow up,
rather than out, reduce the impetus for cropland loss or displacement.

• Rural residential area should be minimized, limited, or capped, as appropriate, and
developed in a nodal fashion that minimizes its footprint and hence loss of natural
landscapes, cropland, and pastureland.

• Rangeland grazing should be encouraged in preference to intensive agriculture on these
  fragile foothill lands. Extensive cow/calf grazing operations that maintain or enhance
native grasslands are more compatible with natural capital than intensive crop and
livestock production systems. In addition, extensive livestock systems must improve
their practices by reducing the frequency with which cattle enter streams, rivers and
riparian habitat. Stocking rates, fencing, and grazing systems that encourage greater
levels of soil carbon should be adopted, for example by rotating herds off areas with
recent high grazing intensity.

• Croplands should not continue to drain wetlands or expand into remaining native
  grasslands.

• Commercial forestry should adopt BMPs such as longer harvest rotations, increased
  residual green trees, improved road crossings, improved protection of riparian forests
  and ephemeral draws, and faster reclamation of in-block roads. These should replace
current harvest and silvicultural practices that prioritize wood production, often at the
expense of wildlife habitat, water quality, water quantity, and biotic carbon.

• Recreation and tourism, like other land uses, must focus its best practices on limits and
distribution. Examples of solutions include restriction of motorized off-highway vehicles
to dedicated and properly constructed OHV trail networks to reduce erosion; active
reclamation of existing and future roads, seismic lines, and other linear features created
by industry such that edge density remains below a defined limit; and construction of
human waste facilities in those portions of the basin where recreational activity will
continue at high levels.
Temporal and Spatial Changes in Natural Capital of the Upper Bow River Basin

Readers wishing to understand the individual best management practices in detail, and how they were evaluated in the ALCES Integrator simulation model, are encouraged to read the Phase 2 Upper Bow Basin Cumulative Effects report. This report can be downloaded from the ALCES website at: http://www.alces.ca/reports/download/126/UBBCES_Phase-1_2_Modeling_Report_Final_190511.pdf

The BMPs described above are an important, albeit incomplete, list of land-use improvements that will be needed to maintain or recover natural capital in the Upper Bow River Basin while also continuing a desired level of resource commodity production. Embracing these improved practices, and the concept of thresholds in terms of how much land is allocated to each land use, will be a challenging conversation. All too often, land use stakeholders concede that there is an issue of degraded natural capital, only to frame the problem as one created by some land use other than their own. Acreage owners frequently blame forestry, forestry blames recreationalists, ranchers blame urban sprawl, and recreationalists blame industry.

Experienced land use analysts can detect when multi-stakeholder communities have collectively matured to a point where they want to constructively address the issue of overlapping land uses and conservation of natural capital. It occurs when their language reflects the understanding that all land uses create both benefits and liabilities, ecological systems are finite, and land managers must devise land use plans that explicitly recognize these trade-offs. At this juncture, stakeholders begin to understand that there is no magical win-win-win solution, but rather a series of difficult, but informed, decisions that collectively create a landscape more capable of delivering the desired set of commodities and natural capital that provide the greatest benefits over time.

The new legislation of the Alberta Land Stewardship Act (ALSA), and the Alberta Land Use Framework (ALUF) it spawned, suggests that such an inclusive land use conversation is now beginning in Alberta. That is not to say that there have not been many Albertans in past decades that have implored the province to deal with the issues of land uses and their cumulative effects. All too often, the voices and words of these visionaries (for example, Peter Lougheed, Grant MacEwan, and Andy Russell) were obscured by a larger societal clamor focusing on unconstrained economic growth. Currently, the signal to society for the need to balance the triple bottom line is growing louder, and as such it is more expedient for governments to address these issues with new and progressive policies.

Navigating the transition from silo-style management planning that addresses each land use separately, towards an inclusive multi-sectoral approach that considers the effects of all land use in combination, will require new legal, institutional and economic instruments. Key to these instruments will be new economic mechanisms designed to reward land users for maintaining and enhancing natural capital.

Readers may also wish to read the report Cumulative Effects of Land use in the Ghost River Watershed sponsored by the Ghost Watershed Alliance Society (available at: http://www.alces.ca/projects/index?key=ghost). The Ghost watershed is fully within the Upper Bow River Basin study area and this study addressed objectives similar to the Upper Bow River Basin report.
3 The Rationale for Natural Capital

Natural capital is the ‘stock’ of environmental commodities that yield benefits to people by providing ecosystem goods and services such as clean and abundant water, food and fibre, contributions to global climate regulation, scenic landscapes, and flood control. This merely extends to the natural world the economist’s general definition of capital as a stock that yields a flow of services over time.¹ Biodiversity and ecosystems can broadly be seen as part of our natural capital, and the flow of ecosystem services is the “interest” on that capital that society receives.² The terms natural capital and ecosystem services are used interchangeably throughout this report, with the qualification that ecosystem services are in fact the flow of benefits accruing from natural capital.

Although it is universally recognized that natural capital contributes to peoples and society’s well-being, land use planners have not adequately incorporated these values in their planning process. This is because natural capital is not as readily measured as traditional economic goods and services, whose price is known and well understood in a conventional marketplace. How do we make trade-off decisions with things we can’t easily measure? Because of this, it is relatively easy to measure the conventional economic costs of a land use project (for example, the cost of building a road is well known, and its benefits to industry can be estimated clearly), but difficult to measure the costs and benefits to natural capital (for example, how much will the road affect natural processes, and how will that change affect people?).

Because of the difficulty in measuring changes in natural capital, decision-makers generally only consider market values in weighing benefits and costs of a given project or policy. As such, the immense value of natural capital is often not taken into account in economic decisions and planning.³⁴⁵⁶ As a result, natural capital can be degraded, or “drawn down”, in the process of converting it to other forms of economic value. For example, value from water filtration performed by a forest ecosystem can be converted to value from timber for market sale. “Conventional economics does not recognize natural assets and their benefits (e.g. ecosystem services) as monetarily valuable until they become so degraded or scarce that human infrastructure has to replace the natural services that had been provided for free.”⁷ “... A country could cut all of its forests and deplete its fisheries, and this would show only as a positive gain to GDP despite the loss of the capital asset.”⁸ If natural capital is not adequately considered in trade-off decisions, the result can be a degradation of ecological assets and a reduction in standard of living. This loss occurs in part because the goods and services provided by natural areas are not precisely known, despite the fact that valuation studies suggest that the economic value of these natural areas to society can outweigh gains from converting them for human uses such as urban development or intensive agriculture.⁹

Economic valuation of ecosystem services and biodiversity can make explicit, to society in general and policy makers in particular, that biodiversity and ecosystem services are limited commodities, and that their depreciation or degradation has associated costs to society. If these costs are not considered, then policy will be misguided, resources will be misallocated, and society will be worse off.¹⁰ Recognizing native ecosystems as natural assets with economic and social value can help promote responsible decision-making.¹¹ Without valuation of natural capital, resources might not be properly managed, and the benefits of ecosystem services may
not be taken into account in decision-making. “Public policy follows measurement, people follow measurement. If you can’t measure it, it does not count, if you can measure it, it does count.”

The Upper Bow River Basin Natural Capital Study builds upon two previous projects that assessed water resources and alternative regional growth management strategies in the Upper Bow River Basin (Figure 1). The current Upper Bow River Basin Natural Capital Study, commissioned by interested individuals and organizations, is aimed at measuring and spatially mapping the economic value of selected natural capital indicators. Such measurement may help ensure that natural capital wealth is efficiently managed for the economic and environmental prosperity of Albertans (and those beyond Alberta’s borders who benefit from its natural capital). Ecosystem services maps are important tools for decision makers, enabling them to spatially identify area to be conserved due to their high supply of ES, and to assess spatial trade-offs among ES, as well as to prioritize areas that will allow alignment of multiple conservation goals.

Figure 1. The Upper Bow River Basin looking from south to north. Source: Google Earth.
4 Human Populations and Their Demand for Natural Capital

As many of the natural capital values assessed in this study are affected by, and in turn affect, human populations and their settlement patterns, it makes sense to discuss this paramount driver. During the past 100 years, the city of Calgary has grown in area at an average annual rate of 3.3%. The size and population of Calgary in 1951, 2007, and the projected changes by 2057 if these historic patterns persist, are shown in Figure 2. Many people observing this future growth in Calgary are dubious about its plausibility, in the same way that most of our grandparents would have doubted in 1951 that Calgary would grow to a million people and over 500 km² by the year 2007. Figure 2 is shown here not to predict Calgary’s future growth as accurate for any given location on the map, but to remind readers of a possible, and alarming, conclusion if the outdated urban design policies of past decades were to persist. The undesirable consequences of urban sprawl are now widely discussed by Calgarians, civic leaders, and the membership of the Calgary Regional Plan. A key component of their future urban design plans focuses on the need for densification and a broader acceptance of mixed-use urban footprints.

The historic urban growth pattern shown in Figure 2 and Figure 4 (top) is considered a “base case” growth strategy against which the improved urban development strategies shown in Figure 3 (bottom) and Figure 4 (bottom) may be contrasted.

Figure 2. Historic (1951, 2007) and future (2057) projected size of the City of Calgary based on simplifying assumptions that historic growth rate in population size and settlement area will also occur in the future. This visualization, as created by Alberta Settlement Simulator (http://www.alces.ca/home/Free_Tools/ALCES_Urban) is not intended to suggest a desirable or predicted future but rather as a reminder of how Calgary could grow if planners and residents do not adopt sustainable urban design principles being discussed by the Calgary Metropolitan Plan.
Figure 3. Location of current Calgary footprint (above) and potential future urban growth nodes (shown in pink) as identified in the Calgary Metropolitan Plan.
Figure 4. Projected 2080 urban footprint of the Upper Bow River Basin under an unconstrained business as usual scenario (upper) and 2080 urban footprint using alternative urban growth strategies guided by Calgary Metropolitan Plan. All simulations completed in ALCES and ALCES Mapper.
5 Study Objectives

Based on the principles outlined in the previous section, the following objectives and questions were explored in this study:

1. **Taking Stock of Natural Capital Values**: What is the estimated current value of selected indicators of natural capital in the Upper Bow River Basin, how does this compare to conditions prior to European settlement, and what specific areas within the Upper Bow River Basin currently provide significant values related to water, carbon storage, tourism/recreation and food security? Of equal value is an understanding of those regions within the study area that have experienced a significant loss in natural capital.

2. **The Future with Business as Usual Approaches**: What changes in natural capital values are anticipated to occur from residential, industrial, recreational, and agricultural development over the next 70 years under 'business as usual' assumptions, and what would this look like in different regions within the Upper Bow River Basin?

3. **The Future with Beneficial Management Practices**: What changes in natural capital are anticipated to occur from residential, industrial, recreational, and agricultural development over the next 70 years under improved growth management strategies, including four key measures identified by the Calgary Metropolitan Plan:
   a. nodal and clustered development for rural residential
   b. no net wetland loss
   c. expanded riparian buffers
   d. avoidance of undisturbed areas for future land use footprint

4. **Municipal Growth Management Opportunities**: How can municipalities in the Upper Bow River Basin balance growth and trade-offs in natural capital?

This approach is intended to encourage a new mental model by which society assesses performance, one based on both traditional economic and natural capital indicators (Figure 5).

![Assessing True Economic Performance in the Upper Bow River Basin](image)

Figure 5. Performance metrics that consider both traditional indicators and Ecosystem Services.
6 Biophysical and Anthropogenic Description of Study Area

Almost all of the Upper Bow River Basin study area is in the upstream shadow of Alberta’s largest city, Calgary, which is experiencing phenomenal growth fuelled by the hydrocarbon sector and its desirable proximity to the Rockies. The 15,589 km² (1,558,885 ha) study area encompasses the Upper Bow River Basin upstream from the Carseland weir, 45 km downstream of Calgary, to its headwaters in the Rocky Mountains (Figure 6). The study area includes the headwaters of the Bow River and the full extent of drainage basins for the Pipestone, Cascade, Spray, Elbow, Kananaskis, Highwood, Sheep, and Ghost rivers in Banff National Park and adjoining foothill regions, to the border separating Alberta from British Columbia.

The Upper Bow River Basin study area spans significant elevational variation that includes the natural subregions of alpine (>2300 m above sea level), subalpine (1,600-2,300 m a.s.l.), montane (1,300-1,600 m a.s.l.), foothills (~1200-1300 m a.s.l.), and grasslands (~950-1,200 m a.s.l). Rugged mountains, steep sided ravines and flat valley bottoms characterize much of the western extent of the landscape (Figure 7, Figure 8). Dominant overstory tree species include white spruce (Picea glauca), lodgepole pine (Pinus contorta), Engelmann Spruce (Picea engelmannii), subalpine fir (Abies lasiocarpa), and trembling aspen (Populus tremuloides). Tree species composition changes markedly based on elevation, relief, and soil properties. Native grasslands, dominated by native fescues, were the dominant plant community in the eastern regions of the study area prior to the arrival of cultivated crops. Whereas most of these native grasslands in lower elevations have been lost to human land use during the past century, some significant areas of fescue grassland remain.

The climate is characterized by long cold winters and short cool summers (Janz and Storr 1977). Average annual precipitation varies greatly with elevation, from <500 mm along the foothills and montane, to ~800 mm in the subalpine and alpine zones (McKay et al. 1963). The coldest month is January and the warmest is July. Warm winter winds (chinooks), created by dry air masses descending leeward from the Rockies, frequently remove all or significant amounts of snowpack on lower elevational areas during winter months.

The significant east-to-west gradients in increasing elevation, slope, precipitation, evaporation and runoff are illustrated in Figure 7 to Figure 12. These graphics clearly illustrate the key importance of the Bow River Basin headwaters in receiving, holding, and releasing water, which is critical to a broad suite of ecological processes and downstream land uses.

Wildfires have been a dominant natural process shaping the composition, structure, and age class of plant communities in this region since the retreat of glacial ice sheets several thousand years ago. The heterogeneity in plant communities created by fire contributed to a diversity of floral and faunal communities. During the past century, fire suppression has reduced the frequency and extent of wildfires, and this has led to a forest biome that is older than those found in pre-European times.
Figure 6. Major jurisdictions within the Upper Bow River Basin study area.
Figure 7. Elevational gradients of the Upper Bow River Basin. Source: ALCES Online.

Figure 8. Slope gradients of the Upper Bow River Basin. Source: ALCES Online.
Figure 9. Temperature gradients (degrees C) of the Upper Bow River Basin. Source: ALCES Online.

Figure 10. Precipitation (mm/yr) gradients of the Upper Bow River Basin. Source: ALCES Online.
Figure 11. Evapotranspiration (mm/yr) gradients of the Upper Bow River Basin. Source: ALCES Online.

Figure 12. Simulated surface water runoff (mm/yr) gradients of the Upper Bow River Basin. Source: ALCES Online.
Settlements within the study area include Lake Louise, Banff, Canmore, Cochrane, Exshaw, Bragg Creek, Redwood Meadows, Benchlands, Longview, Eden Valley, High River, Turner Valley, Black Diamond, Okotoks, and Airdrie. First Nation reserves include those of the Stoney and Tsuu T'ina Nations. Federal lands in the study area include Banff National Park, and provincially administered lands are managed by the County of Rocky View, and the Municipal Districts of Bighorn and Foothills.

The current landscape and footprint composition of the study area is summarized in Table B5 in appendix B and in Figure 13, Figure 14, and Figure 15. Currently, the study area supports a diverse mixture of rock and ice (15%), forests (40%), grasslands (10%), waterbodies and wetlands (~8%), and human land use footprints (27%).

The juxtaposition of Alberta’s largest community against the magnificent backdrop of the Rockies, and the international prestige of Banff, combine to make this region the cornerstone of Alberta’s tourism sector. This iconic region is the key setting used in print and electronic media to entice national and international visitors to Alberta. Albertans perceive and promote this region as ecologically intact, sustainably managed, and of unparalleled scenic beauty.

The results of this study, however, suggest a future with a different trajectory. The study area, particularly the eastern portion, has experienced a profound transformation in composition during the past century, driven by a suite of overlapping land uses that include agriculture (crops and livestock), forestry, mining, energy, residential (both urban and rural), and transportation. These changes have converted natural landscapes into human footprint and infrastructure.

No other region in Alberta, or nationally, is growing at a consistently faster rate. As the population grows, so does demand for a broad suite of commodities such as water quantity, water quality, tourism, recreation, and area for expanding settlements and acreages. These demands frequently overlap with historically large and extensive land uses of croplands, grazing lands, and commercial forestlands.

![Figure 13](image-url)
Figure 14. Current landscape type composition of Upper Bow River Basin Study Area.

Figure 15. Current footprint type composition of Upper Bow River Basin Study Area.
7 Key Ecosystem Services

Natural capital is required to sustain society’s quality of life – drawing down these natural assets could ultimately lead to a loss of prosperity and wealth and increase technological costs required to replace lost or degraded natural capital services. “Natural capital needs investment and maintenance, like other forms of capital.”\textsuperscript{16,17} In keeping with this philosophy, stakeholders such as Rocky View County, MD of Bighorn, City of Calgary, and Action for Agriculture\textsuperscript{18} acknowledge the land as natural capital and seek to establish appropriate land use policies to preserve and enhance this investment.\textsuperscript{19}

The natural landscapes upstream of Calgary are largely responsible for the supply of relatively clean drinking water from both surface and ground water sources. The City of Calgary waterworks department is currently spending approximately $200 million to upgrade their two drinking water treatment plants. However, they also recognize the value of high quality source water and watershed protection to minimize treatment costs. “We actively participate to protect and restore our watersheds to ensure we have a high quality raw water source.”\textsuperscript{20}

Denver, Colorado, is often referred to as Calgary’s sister city. Similar to the Upper Bow River watershed, Denver Colorado’s upstream watershed provides for a regional population of ~1.3 million people. Managers have identified upstream regulation of water supply as increasingly important in light of warming (and drying) trends caused by climate change. Denver, in partnership with the U.S. Forest Service, is proactively investing $33 million in forest management practices that ensure water regulation services by the region’s forests are maintained or enhanced. The goal is to manage forests to reduce fire hazard, promote recreation, and minimize sediment deposits in upstream reservoirs that would otherwise result in loss of water storage capacity and expensive remedial programs.\textsuperscript{21}

Based on previous work undertaken in Phase 1 and 2 of the Upper Bow River Basin Cumulative Effects Study\textsuperscript{22}, five key ecosystem goods and services indicators have been identified and are the focus of the current natural capital project. These five indicators are: water quality, water supply, biotic carbon storage, quality of tourism/recreation, and food security. These ecosystem services were selected because of their perceived ecological, social, and economic value to area residents. The ASPEN study, relating to areas adjacent to the Upper Bow, estimated that 91.1% of ecosystem value was captured by these indicators.\textsuperscript{23} Raudsepp-Hearne et al. (2011) identify beneficiaries for ecosystem services for a smaller case study within the larger Bow River study area, with key ecosystem services identified for the region (Table 1).
<table>
<thead>
<tr>
<th>Ecosystem Service</th>
<th>Ecosystem Pilot Definition</th>
<th>Beneficiary Group in the Case Study Area</th>
<th>Sub-Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Supply and Storage</td>
<td>Storage and Retention of water in wetlands for domestic, industrial and municipal water use</td>
<td>Agriculture</td>
<td>Farmers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residential Dwellings</td>
<td>Home owners, Developers, Municipalities</td>
</tr>
<tr>
<td>Carbon Storage</td>
<td>The stock of organic carbon stored in soils for Class 3, 4 and 5 wetlands. Note: Class 1 and 2 were not included due to methodology limitation</td>
<td>Albertans</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Flood Control</td>
<td>The timing and magnitude of runoff and flooding can be strongly influenced by changes in wetlands</td>
<td>Residential Dwellings</td>
<td>Home owners, Developers, Municipalities</td>
</tr>
<tr>
<td>Water Filtration/Purification</td>
<td>Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water; assimilation and detoxification of compounds through soil and subsoil</td>
<td>Agriculture</td>
<td>Farmers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>municipalities/Government</td>
<td>Rocky View County, Calgary, Alberta Government</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residential</td>
<td>Municipalities, Home owners, Citizens</td>
</tr>
<tr>
<td>Pollination</td>
<td>The fertilization of floral plants</td>
<td>Agriculture</td>
<td>Farmers, Buyers, Grocery Stores</td>
</tr>
<tr>
<td>Soil Formation</td>
<td>Process by which organic material is decomposed to form soil</td>
<td>Agriculture</td>
<td>Farmers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Residential</td>
<td>Municipalities, Home Owners, Citizens</td>
</tr>
<tr>
<td>Recreation and Tourism</td>
<td>Providing opportunities for recreational activities. Including: eco-tourism, sport fishing and other outdoor activities</td>
<td>Recreation Groups</td>
<td>Birders, Botanists, Hikers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tourism</td>
<td>Local, provincial, others</td>
</tr>
<tr>
<td>Heritage</td>
<td>The value that individuals place on knowing that a resource exists, even if they never use that resource</td>
<td>First Nations</td>
<td>First Nation Groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Settlers, Citizens</td>
<td>Historical associations, societies, Citizens</td>
</tr>
<tr>
<td>Science and Educational Value</td>
<td>Ecosystems and their components and processes provide the basis for both formal and information education in many societies</td>
<td>Education Groups</td>
<td>Schools, Government, Outreach/ENGO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Science</td>
<td>Schools, Universities, Research Groups</td>
</tr>
<tr>
<td>Food and Crops</td>
<td>That portion of gross primary production extractable as food for human and/or Cattle production</td>
<td>Agriculture</td>
<td>Farmers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public</td>
<td>Buyers, Grocery Stores</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Beauty and enjoyment provided by landscape within wetlands</td>
<td>Citizens</td>
<td>Local, Recreation and Tourism Groups</td>
</tr>
<tr>
<td>Erosion Control</td>
<td>Retention of soil within an ecosystem. Role ecosystems play in retaining and replenishing soils</td>
<td>Residential</td>
<td>Home owners, Developers, Municipalities</td>
</tr>
</tbody>
</table>
7.1 Water-Related Ecosystem Services

Natural landscapes provide societal benefits by purifying water (removing sediment and nutrients) for downstream users. Water quality values often change based on the amount of this natural purification service, which depends on the level of contaminant loading, the purification capacity of the landscape and vegetation, and the movement of water over time. Conversion of natural landscapes has altered landscape characteristics such that water quality levels have progressively declined over time. A number of water quality valuation studies have found that decreasing water quality reduces human benefits, such as through reduced housing prices, reduced demand for recreation activities, and most obviously the decreased quality of water for human consumption and ecosystem functioning. The ability of landscapes to provide water purification affects a number of values such as provisioning services (providing drinking water), and supporting services (support of aquatic ecosystems). A typology of different ecosystem services is described in further detail in Appendix D. As such, values for this ecosystem service represent a suite of human values that depend on the broad concept of water ‘quality’.

When wetlands are altered, drained or degraded, a cost can be incurred by society if services that were previously provided at no cost by wetlands need to be replaced by built infrastructure. Examples of costs include:

- Increased water treatment costs
- Increased health costs
- Irrigation water shortages
- Increased storm water infrastructure costs,
- Threats to biodiversity
- Increased insurance costs due to flooding
- Decreased property value due to degraded aesthetic qualities
- Decreased revenues from tourism activities associated with healthy ecosystems, and aesthetic and spiritual value losses, among others.

Contaminant contributions and also landscape composition determine water quality. The “Ecosystem Services Approach Pilot on Wetlands” study uses a US EPA method (WESPUS) to assess wetland health and the potential for mitigating water quality, based on wetland area, pollutant sources, pollutant removal opportunity, pollutant transport potential, potential significance of purification, and recharge potential.

Raudsepp-Hearne et al. used an "avoided cost" method to estimate the costs of conventional water treatment, constructed wetlands and wetland restoration. Initial construction costs of wetlands are relatively low compared with traditional water treatment systems, and because wetlands require little maintenance, long-term costs are also quite low. As a result, the cost of the constructed wetland is about 50 % to 90 % less than the cost of using conventional techniques. The study assumed uptake rates of 80.3 kg/ha/yr for phosphorus, and 547.5 kg/ha/yr for nitrogen. The cost of phosphorus treatment was estimated at $360 to $1,764/kg removed. A related study reports costs of $86,450 to $370,500/ha for constructed treatment wetlands, and cites estimates of $10 to $49/kg for removal of total suspended solids (TSS) and $360
to $1,764/kg for removal of P from constructed treatment wetland29 Restoration of existing wetlands is the most cost-effective method of removing phosphorus from the landscape, but even artificially constructed wetlands are more cost-effective than conventional water treatment approaches.

Water supply and quality is an issue of increasing concern in southern Alberta because of rapid population and economic growth, uncertain effects of climate change, a continuing decline in water quality, high per-capita use of water and a finite (and possibly diminishing) supply of water from the Bow and Elbow Rivers.30 Communities are predominately located close to readily accessible surface water sources, generally lakes and rivers, but also to groundwater supplies, and pay large sums of money to build pipelines, dams and reservoirs to ensure sufficient water availability. The upstream network of dams and reservoirs on the Bow, Kananaskis, and Elbow Rivers help to ensure a reliable water supply for Calgarians during winter and summer low-flow periods and these structures reduce, but do not eliminate, flood risk during high-flow periods (Figure 16, Figure 17). In addition, water treatment facilities are required to ensure potability of drinking water for Calgarians and other communities. From 1955 to 2002, the study area’s regional Paskapoo aquifer has experienced water level declines of ~3 meters.31 This may “… suggest a broad-scale drawdown of the hydraulic head in the Paskapoo overtime, which in turn suggests that long-term sustainable withdrawal rates for the Paskapoo are limited and may already be exceeded.”32

Conversion of natural landscapes such as forests, wetlands, and grasslands to agricultural crops, cutblocks (Figure 18), and other land use footprints (settlements, transportation, energy) can decrease the landscape’s ability to retain surface moisture, slow runoff, replenish ground water supplies, and produce clean water. If surface water moves more quickly overland into rivers and streams because of reduced water retention capacities, these water volumes are lost to the upstream basins and the land uses that are dependent on them. This is one of the key reasons underlying the construction of storage reservoirs. Natural landscapes, through the natural process of regulating or holding water (Figure 19), also reduce the frequency and intensity of flood events and can help mitigate costs associated with flood damage.

The 2005 and 2013 flood events of southwest Alberta left lasting memories of the extremes in precipitation and flow that can occur in these watersheds. Equally, these events should remind basin residents and policy makers about the importance of proper land use management in these headwaters. Although both events were caused primarily by intense rainfall events, properly functioning watersheds can play an important role in storing and releasing water in a manner that can significantly reduce flood risk and damage to downstream infrastructure.

Poor land management practices and/or loss of natural areas in upstream watersheds can increase water treatment costs and reduce reservoir storage capacity through increased sediment deposition, resulting in increased costs to downstream taxpayers and industry.33 This has been clearly demonstrated in other jurisdictions such as the City of New York, which paid $1.8 B (U.S.) in direct purchases and subsidies to private landowners to protect the natural filtration and purification processes in New York City’s upstream watersheds. The alternative to this investment in natural capital was to build upgraded water treatment systems estimated at
$6\text{-}8\text{ B (U.S.), with annual operating costs of }$300\text{ M (U.S.), a significant potential and unneeded economic burden to taxpayers.}\text{[34]}

Policy makers, planners, and managers are also becoming increasingly aware that well-managed upstream watersheds produce clean and inexpensive water through natural filtration processes that minimize sediment, pollutants and pathogens in our drinking water supplies. As such, it is important that studies such as this one determine economic changes in water quantity and quality associated with increasing industrialization of watershed landscapes.

Figure 16. Flood in East Elbow Park, Calgary, 2005; photo by Dean Turner\textsuperscript{35}

Figure 17. Flooded portions of Calgary, June, 2013. Source: www.newinfills.ca
Figure 18. Past cutblocks in headwater basins of southwest Alberta. Source: Google Earth. This image illustrates the loss or reduction of riparian habitat along ephemeral and permanent streams.

Figure 19. An example of a network of beaver dams and impounded water in the headwaters of the Bow River Basin. Source: Jenny Earle.
7.2 Biotic Carbon Storage

Carbon stored in biomass comprises a key component of the total landscape greenhouse gas (GHG) balance. From a regulatory perspective, the contribution of GHG is accounted for by sectors, for example by contributions from transport, manufacturing and energy. Biotic carbon is tracked under the land use sector, termed ‘land use and land cover change’, which is separate from the agricultural sector, and is of increasing interest as markets for carbon begin to form in response to strategies to mitigate global climate change. Land management authorities are increasingly interested in knowing how stocks of biotic carbon may change under different land use trajectories, and what the value of additional carbon sequestration might be in landscapes. The value of maintaining carbon stocks should be considered in land use planning, given that carbon markets, offset schemes, and payments for ecosystem services programs are currently being developed and are likely to be large market drivers in the future.

There are many reasons to be concerned about potential loss of biotic carbon stocks in the Upper Bow River Basin watersheds. Expanding croplands can lead to loss of native grasslands and the carbon-rich soils they support. Commercial forestry, in conjunction with altered fire regimes, can lead to a younger forest landscape that has lower levels of biotic carbon (Figure 20). Impermeable anthropogenic ground covers (settlements, transportations, wellpads) cause the direct loss of biotic carbon and prevent its re-establishment. Draining of wetlands for rural residential complexes can reduce the rate at which the landscape captures or sequesters carbon. Grazing rates that are too high can lead to incremental loss of soil carbon. Together, these factors cumulatively decrease a watershed’s biotic carbon accounts.

Figure 20. The combined frequency of logging and fire collectively shape the age class structure of forest communities, which in turn affects the amount of carbon stored in trees, understory, and soils. Source: Google Earth.
7.3 Tourism / Recreation Values

Tourism and recreation services provide important benefits to Albertans, and the Upper Bow River Basin is one of the most popular destinations for these services in Alberta (Figure 21, Figure 22). The value of the experience to the recreationalist, however, is heavily influenced by the intensity of land use in the region and the capacity of land uses to not degrade ecosystem services.

Trade-offs exist in the way benefits are derived from recreational activities. For example, off-road vehicle use can generate measurable contributions to GDP and increases the motorist’s appreciation for natural landscapes, but it may adversely affect other ecosystem services such as water quality (Figure 23). Determining the relative values of these ecosystem services, and their beneficiaries, is important.

A key task of the Alberta Land Use Framework is promoting a conversation among both the motorized and non-motorized recreational communities. Both sectors wish to see their activities maintained and, in most cases, grow in spatial extent or intensity. Solutions that balance the trade-offs between these often-incompatible recreational uses must include zoning and thresholds.

Figure 21. The Upper Bow River Basin is well known for its non-motorized recreation.
Figure 22. Metropolitan centres such as Calgary are important sources of increasing demand for a broad suite of recreational and tourism activities in Alberta.

Figure 23. The off-highway vehicle recreational sector is rapidly increasing in population and activity in the study area, as are their effects on water quality and enjoyment by the non-motorized recreational sector.
7.4 Food Production and Security

All societies require food that is reliable and adequate in quality and quantity. Although Alberta has been a net exporter of both grains and meat during the past century, it has also become an importer of other foods (fruit, vegetables, processed commodities) not commonly grown or refined here. On a caloric basis (energy content), when one computes both export and imports during the past 100 years, Alberta has been largely a net exporter of food calories. Recent province-wide analyses completed by the ALCES Group, in conjunction with the Alberta Land Institute, have shown a trend of reduced cropland area and reduced meat production on a per-capita basis during the past several decades (Figure 24, Figure 25).

This trend is the result of a rapidly increasing human population and settlement area leading to the loss of agricultural land, particularly land of high soil quality in the Edmonton to Calgary corridor, due to urban sprawl, rural residential development, and the footprint of the hydrocarbon sector. Should this trend continue, Alberta could become a net importer of both crops and livestock within the next 4-6 decades. Although it has been argued by some that an affluent Alberta can readily buy food produced elsewhere and thus does not require the luxury of provincial food security, others argue strongly that food self-sufficiency is a desired goal in a future where food importation costs could rise to undesirable levels. Although food prices in Alberta are comparatively low today, much could change if the cost of hydrocarbon fuels were to escalate.

The Upper Bow River Basin is not the focal area of the province for crop or livestock production (Figure 26). Croplands, most of which are not irrigated, are found in the eastern portions of the study area. Ongoing and incremental expansion of Calgary, surrounding towns, and rural residential areas continue to be a major cause of loss of high quality cropland (Figure 27).

Cattle production is distributed throughout much of the eastern half of the study area and is characterized mostly by extensive cow/calf operations on native and improved grasslands (Figure 28). Feedlots and intensive husbandry are not a defining feature of the meat industry in this region of Alberta. Although the cattle population in the study area is a small fraction of the total provincial herd of ~6 million head (2012 estimate), the extensive cow-calf grazing system of the Upper Bow Basin can, with proper management strategies, maintain native grasslands or reclaim damaged rangelands and their soils. As with croplands, expansion of urban and rural settlements contributes to ongoing loss of livestock rangeland (Figure 29).
Figure 24. Historic, Current and Projected Future trends in per-capita cropland in Alberta. Source: ALCES Simulator.

Figure 25. Historic, Current and Projected Future trends in meat surplus/deficit in Alberta. Source: ALCES Simulator.
Figure 26. Distribution of croplands in Upper Bow River Basin relative to distribution in Alberta. Values refer to the percent of each 5 x 5 km grid that is in cropland production. Source: ALCES Online.

Figure 27. Incremental loss of cropland to expanding settlement and rural residential near Airdrie.
Figure 28. Distribution of cattle density in Upper Bow River Basin relative to distribution in Alberta. Values refer to the cattle density of each 5 x 5 km grid. Source: ALCES Online.

Figure 29. Loss of native and improved grassland south of Cochrane as a result of urban and rural residential growth.
8 Project Methodology

The project combined the tools of scenario analysis and ecosystem service valuation to convey the potential future consequences of land use to natural capital using a common currency ($). Building upon previous phases of the Upper Bow River Basin study, the scenario analysis tool ALCES tracked the response of five ecosystem services to simulated land-use trajectories. Assessing the dollar value of these changes required the development of valuation methods that specifically addressed the ecosystem service attributes tracked in the simulations. The approach was novel in its capacity to dynamically simulate the response of ecosystem service value to land use, and harnessed the substantial effort applied in previous phases of the project. Scenario analysis and ecosystem service valuation methods are now described in turn.

8.1 ALCES Landscape Simulator

A detailed description of the key structure and assumptions of the ALCES simulator used in the Upper Bow River Basin Natural Capital Study is provided in the Appendices at the end of this report (Appendix A, model structure; Appendix B, Model Assumptions; and Appendix C, water quality coefficients). Additional information on model architecture is provided at www.alces.ca.

The most basic outline of the project steps is shown schematically in Figure 30. Pre-industrial and current GIS datasets are summarized and entered into the ALCES simulator for each of the spatially stratified landscape and footprint types. Drawing on user-defined relationships describing the backcast period (pre-industrial to current) ALCES reconstructs the pre-industrial landscape and then subjects it to the dynamics of natural disturbance regimes such as meteorology and fire. It also builds a plausible reconstruction of the backcast period to illustrate how the pre-industrial landscape changed annually to become the current landscape. By allowing weather and fire to occur as random events, ALCES generates spatial and temporal variation in plant community structure and hydrology. These processes, in turn, affect the performance of many key indicators.

To project future scenarios, ALCES draws upon a set of user-defined land use and natural disturbance regime assumptions to simulate alternative future landscapes that compare and contrast the performance of key economic, social, and environmental indicators. The ALCES simulator generates annual output in both tabular and graphic form. Tabular output data from ALCES is then captured by ALCES Mapper to produce spatially explicit maps depicting spatial and temporal performance of desired indicators. The rules used by Mapper to distribute land use across the basin are based on existing land use policies. For example, timber harvest is restricted to Forest Management Units, agricultural expansion occurs only into arable land, and energy development (and other land uses) are excluded from protected areas. Towns grow in a contagious fashion and, in the case of the best practice scenario, are constrained to urban growth nodes identified in the Calgary Metropolitan Plan (Figure 2). Rural residential grows along the periphery of cities and towns, with more rural residential occurring in proximity to larger (e.g., Calgary) than smaller (e.g., Longview) communities.
8.2 Ecosystem Services Valuation Methods

Based on the previous work undertaken in Phase 1 and 2 of the Upper Bow Basin Cumulative Effects Study, five key ecosystem services were identified for modeling purposes in Phase 3: water quality, water regulation, carbon storage, recreation, and food security. Limitations of time and funding prevented us from assessing the total value of all ecosystem services for the study area. However, studies that have attempted to assess the total value of ecosystem services typically conclude that services related to climate regulation (e.g., carbon storage) and provision of fresh water (e.g., water purification and regulation) account for a large portion of a region’s ecosystem service value. The services assessed by this study are therefore well suited for identifying landscapes of high value due to their provision of ecosystem services.

A recent review of methods for mapping the supply of ecosystem services concluded that the most common approach was to estimate the relationship between ecosystem service supply and available biophysical data (e.g., land cover, resource inventories), and then apply the biophysical data to map service supply across the region. This approach was applied here and extended by estimating changes in ecosystem service supply from simulated changes in biophysical attributes.

As per the recommendation of the TEEB (The Economics of Ecosystems and Biodiversity) framework, ecosystem service values were derived from market-based valuation approaches. Market-based valuation approaches use information from actual markets to assess the value of...
services, as opposed to revealed or stated preference approaches that use hedonic pricing methods or surveys to assess willingness to pay for a service.

A range of market-based valuation approaches are available to do this. Most straightforward are price-based approaches, whereby market price can be used to value a service if commodities produced by the service are traded on markets (e.g., carbon). A related approach uses production functions that estimate how much a service contributes to the delivery of another service or commodity that is traded on existing market. A third option is cost-based approaches based on estimates of the costs that would be incurred if an ecosystem service is lost or degraded. Cost-based techniques include the avoided cost method (i.e., what costs are avoided by maintaining the service), replacement cost method (i.e., what costs are incurred to recreate the service), and the mitigation or restoration cost method (i.e., what costs are incurred to restore the service).

We applied both price-based and cost-based techniques depending on the information available to value the services. The value of natural land cover’s capacity to limit nutrification and sedimentation of water was assessed using the avoided cost method, by applying the cost of removing nutrients and sediments at water treatment plants. The value of natural land cover’s capacity to regulate water availability was assessed using the production-function method, by applying the price of municipal water to that portion of the Bow River’s flow that is attributable to baseflow (i.e., from groundwater seepage). A price-based approach was used to value ecosystem carbon storage, by averaging carbon prices discussed in government policies. A price-based approach was also used to assess value of natural landscapes for recreation, using nature-related tourism expenditures in the region.

The objective of the study was to demonstrate the spatial distribution of key ecosystem service values across the basin, and how these services may change in response to future land use. To maintain a consistent metric with which to assess the response of ecosystem service to land use, coefficients used to calculate ecosystem service value (i.e., $ per unit of service) remained constant throughout the simulations. The approach of propagating current prices 70 years into the future ignores elasticity, which refers to the potential for prices to change in response to variables such as scarcity (which would tend to increase price), technology (which would tend to reduce price), or cultural shifts. The approach also ignores the related concept of substitutability, whereby services obtained from ecosystems may be acquired elsewhere (e.g., from other ecosystems). Thus, it is important to recognize that ecosystem service values are approximate and that their reliability declines as the simulation advances into the future. It seems likely, however, that as human population continues to grow, demand for services such as clean water, natural landscapes, and carbon will increase. As such, maintaining constant ecosystem service coefficients may underestimate the future value of the Basin’s ecosystem services. Regardless, assuming a constant price provides a consistent and transparent approach for assessing the sensitivity of the basin’s ecosystem service values to land use.

Approaches for assessing ecosystem service supply and its value are now described in greater detail for each service. The methods were developed in collaboration with ecological economist Sara Wilson. A backgrounder on ecosystem valuation is available as Appendix D.
8.2.1 Water Quality

Land cover and footprint types vary with respect to their ability to retain phosphorous, nitrogen, and sediment (PNS). Anthropogenic cover types tend to have lower capacity to retain PNS (Table 2), such that conversion of natural landscapes to footprint or farmland leads to increased release of PNS from terrestrial landscapes to aquatic ecosystems. Maintaining natural land cover therefore avoids the release of PNS that would otherwise occur with conversion. To quantify the avoided runoff, avoided runoff coefficients (Table 3) were calculated as the difference between the average anthropogenic runoff coefficient and the runoff coefficient for a given cover type. The value of the avoided PNS runoff was calculated by applying the low cost estimates for removal of PNS at water treatment plants. These costs, corrected for inflation to 2011, are: $25.45/kg phosphorous, $3.54/kg nitrogen, and $10.65/kg sediment. Avoided cost coefficients by land cover type are provided in Table 4. Applying these coefficients to the study area’s composition calculates the water treatment cost that is avoided by not converting the entire study area to anthropogenic land cover.
Table 2. Runoff and avoided runoff coefficients for phosphorous, nitrogen, and sediment by cover type. Runoff coefficients are from a previous phase of the Upper Bow River Basin Study, with the exception of wetland and riparian areas. Avoided runoff is calculated as the difference between the average anthropogenic runoff coefficient and the cover type’s runoff coefficient. The best practices scenario assumed that PNS runoff can be reduced for some cover types. Coefficients in brackets are those associated with the best practices scenario.

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Phosphorous Runoff (kg/ha)</th>
<th>Avoided Runoff (kg/ha)</th>
<th>Nitrogen Runoff (kg/ha)</th>
<th>Avoided Runoff (kg/ha)</th>
<th>Sediment Runoff (kg/ha)</th>
<th>Avoided Runoff (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>0.13</td>
<td>1.00</td>
<td>1.44</td>
<td>3.40</td>
<td>168.00</td>
<td>682.74</td>
</tr>
<tr>
<td>Riparian</td>
<td>-120</td>
<td>121.11</td>
<td>-349.45</td>
<td>354.29</td>
<td>304.90</td>
<td>545.84</td>
</tr>
<tr>
<td>Wetland</td>
<td>-120</td>
<td>121.11</td>
<td>-349.45</td>
<td>354.29</td>
<td>0</td>
<td>850.74</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.10</td>
<td>1.03</td>
<td>0.95</td>
<td>3.89</td>
<td>62.00</td>
<td>788.74</td>
</tr>
<tr>
<td>Badlands</td>
<td>0.10</td>
<td>1.03</td>
<td>0.95</td>
<td>3.89</td>
<td>250.00</td>
<td>600.74</td>
</tr>
<tr>
<td>Rock/Ice</td>
<td>0.09</td>
<td>1.04</td>
<td>0.85</td>
<td>3.99</td>
<td>250.00</td>
<td>600.74</td>
</tr>
<tr>
<td>Cropland</td>
<td>0.33</td>
<td>0.80</td>
<td>5.00</td>
<td>-0.16</td>
<td>514.00</td>
<td>336.74</td>
</tr>
<tr>
<td>Pasture</td>
<td>0.23</td>
<td>0.90</td>
<td>2.50 (1.88)</td>
<td>2.34</td>
<td>400.00</td>
<td>450.74</td>
</tr>
<tr>
<td>Major/Minor Road</td>
<td>3.5</td>
<td>-2.37</td>
<td>10.00</td>
<td>-5.16</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
<tr>
<td>Inblock Road</td>
<td>3.5</td>
<td>-2.37</td>
<td>10.00</td>
<td>-5.16</td>
<td>1000.00</td>
<td>-149.26</td>
</tr>
<tr>
<td>Recreation Trail</td>
<td>3.5</td>
<td>-2.37</td>
<td>10.00</td>
<td>-5.16</td>
<td>1000.00</td>
<td>-149.26</td>
</tr>
<tr>
<td>Transmission Line</td>
<td>3.5</td>
<td>-2.37</td>
<td>10.00</td>
<td>-5.16</td>
<td>1000.00</td>
<td>-149.26</td>
</tr>
<tr>
<td>Mine</td>
<td>1.5</td>
<td>-0.37</td>
<td>8.60</td>
<td>-3.76</td>
<td>869.00</td>
<td>-18.26</td>
</tr>
<tr>
<td>Feedlot</td>
<td>255 (127.5)</td>
<td>-253.87</td>
<td>1950.00</td>
<td>-1945.16</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
<tr>
<td>Industrial Feature</td>
<td>7.95</td>
<td>-6.82</td>
<td>260.00</td>
<td>-21.16</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
<tr>
<td>Town</td>
<td>2.6</td>
<td>-1.47</td>
<td>5.00</td>
<td>-0.162</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
<tr>
<td>Rural Residence</td>
<td>2.6 (0.65)</td>
<td>-1.47</td>
<td>5.00</td>
<td>-0.162</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
<tr>
<td>Agricultural Residence</td>
<td>2.6</td>
<td>-1.47</td>
<td>5.00</td>
<td>-0.162</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
<tr>
<td>Energy Footprint</td>
<td>5.0</td>
<td>-3.87</td>
<td>10.00</td>
<td>-5.16</td>
<td>2000.00</td>
<td>-1149.26</td>
</tr>
</tbody>
</table>
Table 3. Avoided cost of water treatment due to retention of phosphorous, nitrogen, and sediment by land cover type. Avoided cost water treatment calculated by applying treatment costs per unit of phosphorous, nitrogen, and sediment to avoided runoff coefficient in Table 2. The best practices scenario assumed that PNS runoff can be reduced for some cover types. Avoided costs in brackets are those associated with the best practices scenario.

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Phosphorous</th>
<th>Nitrogen</th>
<th>Sediment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>25.37</td>
<td>12.03</td>
<td>7.27</td>
<td>44.67</td>
</tr>
<tr>
<td>Riparian</td>
<td>3082.42</td>
<td>1254.18</td>
<td>5.81</td>
<td>4342.42</td>
</tr>
<tr>
<td>Wetland</td>
<td>3082.42</td>
<td>1254.18</td>
<td>9.06</td>
<td>4345.66</td>
</tr>
<tr>
<td>Grassland</td>
<td>26.13</td>
<td>13.77</td>
<td>8.40</td>
<td>48.30</td>
</tr>
<tr>
<td>Badlands</td>
<td>26.13</td>
<td>13.77</td>
<td>6.40</td>
<td>46.29</td>
</tr>
<tr>
<td>Rock/Ice</td>
<td>26.39</td>
<td>14.12</td>
<td>6.40</td>
<td>46.90</td>
</tr>
<tr>
<td>Cropland</td>
<td>20.28</td>
<td>-0.57</td>
<td>3.59</td>
<td>23.29</td>
</tr>
<tr>
<td>Pasture</td>
<td>22.82</td>
<td>8.28</td>
<td>4.80</td>
<td>35.90</td>
</tr>
<tr>
<td>Major/Minor Road</td>
<td>-60.40</td>
<td>-18.27</td>
<td>-12.24</td>
<td>-90.91</td>
</tr>
<tr>
<td>Inblock Road</td>
<td>-60.40</td>
<td>-18.27</td>
<td>-1.59</td>
<td>-80.26</td>
</tr>
<tr>
<td>Recreation Trail</td>
<td>-60.40</td>
<td>-18.27</td>
<td>-1.59</td>
<td>-80.26</td>
</tr>
<tr>
<td>Transmission Line</td>
<td>-60.40</td>
<td>-18.27</td>
<td>-1.59</td>
<td>-80.26</td>
</tr>
<tr>
<td>Mine</td>
<td>-9.50</td>
<td>-13.32</td>
<td>-0.19</td>
<td>-23.01</td>
</tr>
<tr>
<td>Feedlot</td>
<td>-6461.07</td>
<td>-6885.87</td>
<td>-12.24</td>
<td>-13359.19</td>
</tr>
<tr>
<td>Industrial Feature</td>
<td>-173.65</td>
<td>-74.91</td>
<td>-12.24</td>
<td>-260.80</td>
</tr>
<tr>
<td>Town</td>
<td>-37.49</td>
<td>-0.57</td>
<td>-12.24</td>
<td>-50.31</td>
</tr>
<tr>
<td>Rural Residence</td>
<td>-37.49</td>
<td>-0.57</td>
<td>-12.24</td>
<td>-50.31</td>
</tr>
<tr>
<td>Agricultural</td>
<td>-37.49</td>
<td>-0.57</td>
<td>-12.24</td>
<td>-50.31</td>
</tr>
<tr>
<td>Residence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Footprint</td>
<td>-98.57</td>
<td>-18.27</td>
<td>-12.24</td>
<td>-129.09</td>
</tr>
</tbody>
</table>
8.2.2 Baseflow
Terrestrial landscapes contribute to the availability of surface water through baseflow, which refers to the discharge of groundwater into rivers and streams. Baseflow is estimated to account for 20% of the Bow River’s flow\textsuperscript{42} and, perhaps more importantly, provides flow during periods when surface runoff is low such as winter months and droughts. Baseflow is important for drinking water supplies, aquatic habitat and fish species in the watershed’s rivers, and summer flow for irrigation of croplands. Groundwater supply and, ultimately, baseflow relies on the infiltration of a portion of precipitation. By slowing surface runoff, the vegetation and organic soils of natural landscapes allow for infiltration to occur. Disturbing or removing vegetation and soil accelerates surface runoff and reduces infiltration of precipitation to groundwater. Anthropogenic activities can further diminish groundwater through the removal of water from aquifers (i.e., wells). As a consequence, anthropogenic landscapes are less able to regulate the availability of water through supply of baseflow to rivers and streams.

During the parameterization of ALCES in an earlier phase of the Upper Bow Study, each landscape and footprint type was assigned rates for precipitation, infiltration and, for certain footprint types such as rural residences, groundwater removal. These coefficients were used to calculate groundwater balance (m$^3$/ha) by landscape and footprint type. A 1:1 ratio between groundwater and baseflow availability was assumed. Although this may be a limiting assumption, it is consistent with other research, which models the provision of capacity of groundwater to supply baseflow.

As expected, groundwater balance is higher for natural land cover than for footprints and farmland. The groundwater balance coefficients were applied to the approximated presettlement landscape composition and simulated future landscape composition to calculate spatial changes in groundwater balance. The regional decline in the groundwater supply (as simulated by ALCES at the scale of the basin) was then distributed across the landscape relative to the spatial distribution of declines in groundwater balance. For example, if a cell’s decline in groundwater balance accounted for 5% of the total decline in groundwater balance across the watershed, then that cell’s groundwater stock was assumed to decline by an amount equivalent to 5% of the watershed’s total decline in groundwater. In this manner, spatiotemporal changes in groundwater supply\textsuperscript{43} were approximated from maps of simulated future landscape composition.

The value of groundwater for baseflow was based on Calgary’s 2011 usage rate ($1.38/m^3$). However, to avoid exaggerating the value of the groundwater stock, the value was applied only to the portion of groundwater that contributes to baseflow. Baseflow accounts for approximately 20% (600 million m$^3$) of the Bow River’s annual flow of three billion m$^3$. The total groundwater stock, however, is estimated to be 104 billion m$^3$, which implies that baseflow accounts for only 0.58% of the groundwater supply. The value of avoided groundwater loss was therefore set at $0.008/m^3$, which is 0.58% of the usage rate.

Although valuation of groundwater focused on baseflow, it is important to note that groundwater within aquifers is also utilized (i.e., wells). Agriculture is typically the largest user of water, but the marginal value of water in agriculture is often lower than in other sectors such as household, mining and manufacturing use. If the rate of extraction exceeds the long-term
recharge rate of an aquifer, its use also entails an opportunity cost, through foregoing opportunities to use the resource in the future. As an example, the cost to substitute groundwater with external water sources for agricultural use has been estimated at $215/ML. Given that only baseflow was considered when estimating ecosystem service value, this study likely underestimates the value of groundwater.
Table 4. Groundwater balance and avoided groundwater loss coefficients by cover type. The value of each cover type’s contribution to baseflow was estimated by multiplying the avoided groundwater loss coefficient by $0.008/m^3$, which is the estimated value of the groundwater supply in terms of its contribution to the Bow River’s flow.

<table>
<thead>
<tr>
<th>Land cover type</th>
<th>Groundwater balance (m$^3$/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous forest</td>
<td>625.35</td>
</tr>
<tr>
<td>Mixedwood forest</td>
<td>527.74</td>
</tr>
<tr>
<td>Spruce forest</td>
<td>632.50</td>
</tr>
<tr>
<td>Pine forest</td>
<td>685.23</td>
</tr>
<tr>
<td>Montane forest</td>
<td>498.30</td>
</tr>
<tr>
<td>Riparian forest</td>
<td>498.95</td>
</tr>
<tr>
<td>Wetlands</td>
<td>172.30</td>
</tr>
<tr>
<td>Fescue</td>
<td>496.50</td>
</tr>
<tr>
<td>Badlands</td>
<td>1400.00</td>
</tr>
<tr>
<td>Rock/Ice</td>
<td>1744.50</td>
</tr>
<tr>
<td>Reservoir</td>
<td>1474.00</td>
</tr>
<tr>
<td>Lakes</td>
<td>1430.00</td>
</tr>
<tr>
<td>Rivers</td>
<td>1894.00</td>
</tr>
<tr>
<td>Annual crop</td>
<td>-0.69</td>
</tr>
<tr>
<td>Specialty crop</td>
<td>-22.84</td>
</tr>
<tr>
<td>Pasture</td>
<td>-2.12</td>
</tr>
<tr>
<td>Major road</td>
<td>0.00</td>
</tr>
<tr>
<td>Minor road</td>
<td>95.07</td>
</tr>
<tr>
<td>Recreation trail</td>
<td>103.32</td>
</tr>
<tr>
<td>Inblock road</td>
<td>102.43</td>
</tr>
<tr>
<td>Transmission line</td>
<td>97.73</td>
</tr>
<tr>
<td>Mine</td>
<td>233.10</td>
</tr>
<tr>
<td>Feedlot</td>
<td>-14922.77</td>
</tr>
<tr>
<td>Industrial plant</td>
<td>0.00</td>
</tr>
<tr>
<td>Agricultural residence</td>
<td>-57.57</td>
</tr>
<tr>
<td>Town</td>
<td>-93.87</td>
</tr>
<tr>
<td>Rural residence</td>
<td>19.00</td>
</tr>
<tr>
<td>Seismic</td>
<td>99.40</td>
</tr>
<tr>
<td>Wellsite</td>
<td>94.51</td>
</tr>
<tr>
<td>Pipeline</td>
<td>98.56</td>
</tr>
<tr>
<td>Canal</td>
<td>1407.90</td>
</tr>
</tbody>
</table>
8.2.3 Carbon

Natural landscapes play an important role in mitigating climate change by storing carbon in vegetation and soils. Land use disturbs vegetation and soils and thus releases carbon into the atmosphere. To track consequences of simulated land use to ecosystem carbon, the carbon densities of landscape and footprint were estimated from a variety of sources. Carbon stored by forest vegetation was calculated from biomass estimates by seral stage (e.g. age class of trees) and species group. The carbon stored by forest soils was estimated based on the mean organic soil carbon content for cordilleran eco-climatic zone from the Canadian Forest Carbon Budget\(^45\) (112 tonnes of carbon/ha). When biomass and soils carbon were combined, forest carbon density ranged from 127 tonnes to 166 tonnes/ha, with carbon density increasing with forest age. Carbon storage by cropland, pasture, and grassland was 110, 123, and 124 tonnes/ha, respectively, based on research conducted in central Alberta\(^46\). Wetland carbon storage data for the study area could not be identified. Instead, research from the BC Lower Mainland was applied, which found average carbon storage of wetlands to be 339.7 tonnes/ha\(^47\). However, during the mapping of ecosystem service values, a large classification error between wetlands and riparian forest was discovered in the land cover data. Since the two cover types could not be reliably distinguished, we averaged the carbon storage for wetlands (339.7 tonnes/ha) and prairie riparian (124 tonnes/ha) and treated both cover types as having carbon storage of 231.8 tonnes/ha.

Anthropogenic footprints were simulated as having reduced carbon storage relative to natural landscapes. “Hard” anthropogenic footprints (major and minor roads, mines, feedlots, industrial plans, towns, canals) were assumed to have no soil carbon. “Soft” anthropogenic footprints (recreation trails, inblock roads, transmission lines, seismic, wellsites, pipelines) were conservatively assumed to have no impact on soil carbon. Anthropogenic footprints that are intermediate between “hard” and “soft” (agricultural residences and acreages) were assumed to lose 50% of their predisturbance carbon.

Government regulations and other efforts to curtail the release of greenhouse gases are resulting in a price being assigned to carbon. Turnover on global carbon markets was US$144 billion in 2009, and this rate of transaction is expected to increase substantially if concerted efforts are made to mitigate global warming.\(^48\) Examples in North America include: the Alberta government’s Emission Reduction Regulation for large emitters, which sets a carbon price of $15/tonne CO\(_2\)-e; Environment Canada’s Regulatory Impact Analysis Statement on the Renewable Fuels Regulations, which adopts a social cost of carbon of $25/tonne CO\(_2\)-e; and the US federal government, which estimates the social cost of carbon to be in the range of $5 to $65/ton CO\(_2\)-e with a central estimate of $21/ton CO\(_2\)-e. After adjusting for inflation, the average of these three carbon costs is $20.35/ton CO\(_2\)-e or $74.69/tonne C. To annualize this carbon storage value, an annuity coefficient of 0.0802 was applied to reflect a 20 year discount period with a 5%/year discount rate\(^49\).

8.2.4 Recreation

Recreation and tourism are important components of the provincial economy and key to our overall quality of life. Within the province, there is no region that is better known or receives more recreational pressure than the watersheds above Calgary. The region’s natural
landscapes draw millions of visitors annually due to their beauty and opportunities for outdoor recreation (skiing, hiking, biking, etc.). Disturbance of natural landscapes by industrial development and the expansion of settlements can reduce their attractiveness for outdoor recreation.

A study of natural capital in the Southern East Slopes region estimated that nature-based recreation areas have a value of $418.32/ha (in 2006$)\(^{50}\), based on a 1996 national survey undertaken by the Canadian Wildlife Service and Environment Canada. This value was adopted as the recreational value of natural landscapes in the Upper Bow Basin, which overlaps with a portion of the Southern East Slopes study area; the value was adjusted to $621.41 to account for inflation and the 35.2% increase in Alberta’s population (and therefore recreation demand) between 1996 and 2011. Anthropogenic cover types were assumed to provide reduced recreational value. The decline in recreational value was related to the intensity of disturbance, with pasture supporting the full recreational value ($621.41), cropland 50% of the recreational value ($310.70), and other anthropogenic footprints 0% of the recreational value. A study of visitation to Banff National Park suggests that protected forest landscapes in the region are of greater value. In 2004, three million visitors spent $700 million in direct tourism expenditures\(^{51}\). Inflated to 2011 dollars ($798.3 million), this expenditure amounts to $1,202 for each of Banff National Park’s 664,100 ha. This value ($1,202) was adopted for protected forest landscapes in the Upper Bow Basin. The value was also applied to lakes, rivers, and reservoirs regardless of their level of protection because aquatic cover types are typically a focal point for recreation.

8.2.5 Food Security

Food production is a critical form of natural capital for society. Loss of arable land to other uses (e.g., expansion of settlements) reduces the capacity of ecosystems to provide food. This study did not assess the dollar value of food production, but rather the basin’s food security, interpreted here as the basin’s capacity to provide food for its human population. During the pre-industrial era, food (i.e., meat, berries) was largely available and captured where it was required by resident First Nation communities. As Europeans arrived, and cultivated crops and livestock herds expanded, the spatial discrepancy between supply (crops and herds) and demand (cities and towns) intensified. Today, human populations are focused in urban areas but are dependent on foods grown on the agricultural landscape.

Food security was calculated as the balance between food supplied by the basin and food consumed by the basin’s human population. This approach does not allow us to assign a dollar value to food security that can be compared directly with the other ecosystem services included in this study. However, it does highlight trends in future ability to meet society’s needs for this crucial service. Food supplied by cropland was estimated at 9,592,090 kcal/ha/year based on the region’s crop mix\(^{52}\) and average provincial yields\(^{53}\), converted to calories using the USDA National Nutrient Database. Similarly, food supply by pasture was estimated at 287,950 kcal/ha/year based on the animal density that can be supported by the forage yield\(^{54}\), with animal density converted to calories using the USDA National Nutrient Database\(^{55}\). Food consumption was estimated to be 860,743 kcal/person/year, based on average per capita food consumption in Canada\(^{56}\). This approach for assessing food security ignores complexities such
as the global food marketplace in favor of providing a simple metric of the basin’s balance between food production and consumption. This balance is fundamental to food availability and, hence, food security.

The analysis assumed that food production is restricted to cropland and pasture. However, it was not that long ago (1-2 generations) that many urban families grew a significant portion of their food needs using either backyard gardens or shared community gardens. The practice of growing family and community gardens may play a key role in this region in future decades in helping balance food demand and supply.
9 Results

9.1 Water Quality

The historic and projected future changes in water quality of the study area reflect the spatial and temporal changes in landscape loading of nutrients (nitrogen, phosphorus) and sediment at a township scale (Figure 31, Figure 32). Nutrient loading has always been high and will continue to be high in the future in the mountain regions of the study area due to runoff from steep un-vegetated landscapes. The largest changes in overall loading during the past 100 years occur in the eastern half of the study area as a result of conversion of natural herbaceous landscapes to croplands and to settlements. Removal of riparian plant communities during past decades has also led to conspicuous loss of water quality. Urban sprawl and the development of rural residential complexes are likely to cause major reductions in future water quality. This loss of natural capital (water quality) can be significantly mitigated through the adoption of beneficial management practices (BMP) such as urban densification and nodal development, protection of remaining natural landscapes, and improved agricultural practices to minimize loss of nutrients into waterways.

The loss of natural capital in terms of water quality through increased landscape loading of sediment and nutrients is currently costing $10 M/yr in annual water treatment costs (water treatment plants in towns and cities). Under a business as usual scenario, water quality continues to decline and water treatment costs continue to rise, so that by 2080, annual water treatment costs would approach $75M/yr. Adoption of BMP can significantly reduce nutrient movement into water and keep water treatment costs to ~21M/yr by 2080, a savings of ~$54M/yr over BAU. The bottom line is that Calgary and surrounding communities can anticipate a ~7.5 fold increase in water treatment costs related to NPS during the next 7 decades if BAU principles persist, while this cost can be reduced by ~75% if BMP practices are adopted.
Figure 31. Pre-industrial (RNV), current and future change (comparison of BAU and BMP) in water quality for the Upper Bow River Basin.

Figure 32. Simulated trend in water treatment costs (which reflect the trend in loss of water quality) for two scenarios over 70 years. Business-as-usual is compared to best practices, showing a difference of ~$54M under the two scenarios.
9.2 Water Supply

Although empirical data on groundwater aquifers in the study area is far from complete, modeling results estimate a reduction in groundwater volume of 17.5 billion m³ over the next 70 years, in large part due to settlement expansion in the Calgary region (Figure 33). The reduction in groundwater is due to a combination of increasing levels of hardened surfaces such as roads, buildings, and other anthropogenic features and a continuing increase in groundwater withdrawals for residential, agricultural and other uses. These modeling results are generally consistent with previous historical trends in groundwater levels. With the decrease in aquifer volume, our simulations predict that the ability to supply baseflow will be reduced by 101.5 million m³/year, causing a reduction in ecosystem service value of $140 million/year if Calgary’s water usage rate ($1.38/m³) is applied. The decline in groundwater supply and, hence, baseflow was marginally less during the BMP simulation due to a reduction in the area converted to footprints such as residential areas that impede infiltration of precipitation to groundwater. Under the BMP scenario, the drop in annual baseflow value after 70 years was $125 million, a $15 million improvement relative to the BAU scenario (Figure 34).

Figure 33. Pre-industrial (RNV), current and future change (comparison of BAU and BMP) in base flow value for the Upper Bow River Basin.
Figure 34. Trend in loss of baseflow water supply for two scenarios over 70 years. Business-as-usual is compared to best practices, showing a difference of 11% under the two scenarios after 70 years.

9.3 Carbon Storage in Forests, Wetlands, Grasslands and Agricultural Soils
Natural levels of biotic carbon are highly variable in space (Figure 35) due to the large differences in biomass production and decomposition for different landscape types. The non-vegetated rock and ice regions of the Rockies have low biotic carbon densities, the riparian regions have elevated levels of carbon, the forested foothill regions have uniformly high densities, and the expansive native grasslands of the eastern portions of the study area also contribute significant values. During the past 100 years, a significant fraction of biotic carbon in the region has been lost to the combined effects of all land uses (Figure 36). This loss is greatest where settlements exist (Calgary and surrounding communities), where riparian forest has been lost, and where natural grasslands have been replaced by croplands. An additional 16% will be lost during the next 7 decades according to the BAU simulation, equating to a current market value of $200 M. Approximately 45% of this future forecasted loss can be reduced through the adoption of best management practices. Key management levers in the reduction of carbon loss are urban design strategies that allow communities to grow up (densification and mixed use) and not out (sprawl), reduction in growth rate of acreage complexes, and improved practices in croplands (full adoption of no-till) and forestry (longer forest rotations).
Figure 35. Pre-industrial (RNV), current and future change (comparison of BAU and BMP) in biotic carbon natural capital for the Upper Bow River Basin.

Figure 36. Temporal changes in EGS associated with biotic carbon.
9.4 Recreation and Tourism Potential

Alberta boasts a tourism sector that is conservatively estimated at ~$5.5 Billion annually (2010, Alberta Tourism, Parks, and Recreation). Since this value does not incorporate direct and indirect expenditures of non-tourism recreation, the combined economic contributions of the recreation and tourism industry is significantly greater. Recreation and tourism are important components of the provincial economy and key to our overall quality of life. Within the province, there is no region that is better known or receives more recreational pressure than the watersheds above Calgary. Based on the methodology adopted by this study, the current recreational value of this landscape is estimated at ~$1.35 B annually.

Our analyses suggest that recreational potential of this landscape will decline, under a BAU scenario, from $1.35B/yr to $1.21 B/yr within seven decades, an annual revenue loss of $140M, due to the loss of natural landscapes (Figure 37). The adoption of BMP in the study area can arrest ~60% of this loss of natural capital, but would still result in a loss of $50M/yr by year 2080.

The spatial results (Figure 38) illustrate that most of the historic loss in recreational potential has occurred in the eastern portions of the landscape that have experienced conversion from natural plant communities to croplands and settlements. Although future simulations suggest that the western (mountainous) regions of the study area will continue to have high recreation value in decades to come, the foothill regions reveal a pattern of ongoing incremental loss of recreational value (under BAU assumptions) caused by settlement sprawl, acreage complexes, cutblocks, conventional livestock husbandry, and footprints of the hydrocarbon sector. Encouragingly, the BMP scenario suggests that adoption of new practices can significantly reduce this loss of natural capital. Of the various BMP practices explored, good urban design demonstrated the greatest benefits. The importance of curbing urban sprawl and rural residential expansion is clear and has benefits that extend to all aspects of ecological goods and services.
Figure 37. Temporal trends in ecosystem-based recreational value for two scenarios over 70 years, contrasting BAU and BMP scenarios. Important to note that total recreation-based expenditures are likely to increase in the future as those activities not related to ecosystem performance will more than offset losses in performance of ecosystem-based recreation.

Figure 38. Pre-industrial (RNV), current (~2006) and future change (comparison of BAU and BMP) in ecosystem-based recreation/tourism natural capital for the Upper Bow River Basin.
9.5 Food Security

The graphs and maps below condense the complexity of food production and consumption into a very simple equation. What is the human population demand (calories/ha/yr) and supply (calories/ha/yr) on each spatial cell of the Upper Bow River Basin? The value of this approach is found in its ability to catalyze a discussion among stakeholders as to whether it is wise to manage landscapes in such a manner that food production can satisfy the needs of local (or regional) populations. Using this approach, it is clear that residents of settlements within the study area already have food demands that greatly exceed supply at the scale of townships, and the extent of these areas of food deficit will increase in the future (Figure 39). Simply put, human densities are high in cities and there is currently very little food grown there.

In a spatial context, the maps can be a bit misleading. The light green value indicates that supply and demand is generally equal. It is for this reason that the mountainous region in the western portion of the study area is in balance, because in these regions there is often no food production or requirement. Where towns do exist within the mountain regions (Banff and Canmore, for example) they are clearly in food deficit and in need of food importation to feed its population.

The key message illustrated by the mapping is that expanding human populations (cities, towns, and acreages) in the eastern portion of the study area are increasing food demand and reducing food production. The extent to which food production capacity is compromised is illustrated nicely in the comparison between the BAU and BMP scenarios. If urban design principles that focus on densification are adopted, and rural residential complexes are not allowed to expand, then the food production/demand issue can be mitigated.

It is not only the relative change in food security that is of concern; it is the locations of loss. In this region, it is the black chernozemic soils that are suitable for growing crops and gardens. It is precisely these regions that are being lost at an alarming rate to urban and peri-urban sprawl (Figure 40).
Figure 39. Pre-industrial, (RNV) current (2006), and future change (comparison of BAU and BMP) in food security balance for the Upper Bow River Basin.

Figure 40. Dominant soils types of the Upper Bow River Basin.
Combined Ecosystem Services

The combined current value of the ecosystem services was estimated to be $3.9 billion ($2,502/ha) annually across the watershed (Figure 41). This value, while substantial, is conservative relative to other watershed valuation studies. The Credit River watershed in Ontario was estimated to provide an ecosystem service value of $3,710/ha. The Lake Simcoe basin, also in Ontario, was estimated to provide an ecosystem service value of $2,948/ha. A point of comparison closer to home is an assessment of ecosystem services provided by a 274 km² landscape to the east of Calgary that overlaps with a portion of the 15,589 km² Upper Bow watershed. Findings from the analysis included an estimated cost of $338 million to replace flood control services provided by wetlands, carbon storage valued at $16.7 million, and recreational value of over $4 million.

Conversion of natural landscapes to other anthropogenic uses has degraded ecosystem service value in the Upper Bow watershed (Figure 42) especially in urban and rural residential areas, but also in farmland. Ecosystem services continued to decline in our simulation of future land use, resulting in an estimated loss of $550 million of ecosystem services provided annually by the watershed. Best management practices, especially those focused on limiting the spread of settlement footprint, were able to avoid $250 million of this annual cost (Figure 41, Figure 42). This point is worth emphasizing: Failure to follow best management practices for land use is projected to cost Calgary and the rest of the Upper Bow River Basin $250 million per year in lost ecosystem services.

When each of the natural capital categories of water quality, water quantity, biotic carbon and recreational/tourism are combined, the resulting graphics and maps tell a compelling story (Figure 41, Figure 42). In contrast to the general perception that Calgary and its upstream basin are the epitome of economic prosperity in Canada, these major declines in natural capital remind society that something fundamentally important is being incrementally lost as this high profile region becomes more populated, more anthropogenic, and more demanding on water, land, air, and wildlife.

If something so vitally important is being lost, it is fair to ask why the residents of the Bow River Basin have not been more vocal during the past several decades. While it is true that the environmental community of this region (including Alberta Wilderness Association, Canadian Parks And Wildlife Society, Pembina Institute, and community-based watershed groups) has repeatedly voiced their concerns about loss of natural capital, these commentaries have largely not expanded into a broad societal conversation.

One explanation for this apparent lack of societal engagement is that these trends have happened so gradually over long periods of time that they remain largely undetected by the general public. In examining these datasets for the Upper Bow River Basin, the majority of growth in land use, and loss in natural capital, has occurred at rates of less than 2% per year. Although a sustained loss of natural capital of even half of 1% for extended time can be profound (for example, a fixed loss of ½ of 1% of an initial value annually over 100 years is equal to a net loss of 50% of the initial value), the average Albertan may notice the change and thus may not flag the problem as a key issue for their political representatives to address.
If a slow, but insidious, trend in natural capital degradation is the reason for the non-conversation on this key issue, then perhaps this project may encourage more Albertans to become aware of the need to consider natural capital across “meaningful” time and space.

Surely, the key objective of land management is not to maximize benefits of landscape and natural capital to the current population if this significantly reduces options for future generations. A careful examination of current and future benefits and liabilities, both today and for many centuries into the future, is required if we are to be satisfied that our stewardship decisions today will pass the test of time.
Temporal and Spatial Changes in Natural Capital of the Upper Bow River Basin

Figure 41. Pre-Industrial (RNV), current and future change (comparison of BAU and BMP) in combined ecosystem services (natural capital) for the Upper Bow River Basin.

Figure 42. Current conditions for combined ecosystem services values (water quality, water quantity, recreation, carbon, food).
10 Discussion

During the past century, the Upper Bow River Basin has undergone a profound landscape transformation, with greatest changes occurring in the eastern half of the study area. The regional changes documented in this report are the result of several overlapping land use sectors each trying to satisfy its growing market demands. The ultimate driver for all demands is the expanding human population at local, regional, provincial, national, and global scales. The result has been a significant expansion in production of crops, livestock, settlements, rural residential, commercial forestry, recreation, and hydrocarbon exploration and extraction. The Bow River basin, once considered to be a large and pristine landscape hosting few people and minimal demands, is now being recognized for its true status: that of a delicate and fragile ecosystem that is being pulled in many directions by conflicting and intensifying land uses.

While the Upper Bow River Basin has contributed significantly to Alberta’s economy during the past 100 years, it is also increasingly obvious that these land use trajectories have led to a substantial loss in ecological goods and services—a loss expected to reach a dollar value exceeding half a billion dollars per year within 70 years under current policies. Collectively, the documented declines in water quality, water supply, soil organics, food security, and ecosystem-based recreational potential have created a huge economic liability that has been largely ignored by historical land use decisions.

There are many contributing factors to this slow degradation of natural capital, but the key explanation is ongoing loss of natural landscapes. From this perspective, all land uses of the Upper Bow River Basin are part of the challenge and hence all must be part of the solution. Historic and current drivers of loss of natural capital in the study area include:

- Conversion of native grasslands to cultivated crops
- Expansion of urban centres into surrounding natural habitat and cultivated crops, displacing farmers and leading them to convert natural landscapes into crops
- Rapid expansion of rural residential acreage complexes whose inhabitants want to live in areas of natural capital but in turn reduce its utility to others.
- Commercial forestry that alters the structure and diversity of forests. Current harvest and silvicultural strategies are designed primarily to maximize wood fiber growth and not to optimize other forms of natural capital (biotic carbon, water quality, water quantity, wildlife habitat, and aesthetics)
- Energy sector footprints (seismic lines, access roads, wellpads, pipelines) that alter ecosystem function and the aesthetics and accessibility of the landscape to a broad range of society (non-motorized recreationalists, motorized recreationalists, hunters, fishers)
- Ranching practices that allow cattle to reside in or near streams.

For those familiar with the Upper Bow River Basin, the above list highlights many paradoxes and underscores the complex challenges involved in building solutions among a diverse stakeholder community. For example:
Many of the hiking, skiing, and horseback riding trails in the study area were first built by the forest, mining, or energy sectors. In this example, those footprints that allow the recreation sector to experience the backcountry are also part of the problem.

Expanding settlements that consume surrounding natural landscapes may be undesirable, but how would we have a thriving tourism and recreation sector in Banff National Park if the townsite of Banff did not exist? The same could be said for Canmore, Cochrane, Bragg Creek, and Calgary itself.

Rural residential acreage developments in the Upper Bow introduce our children to a “natural” landscape where they will learn and appreciate “mother nature” and outdoor recreation. But at the same time, these rapidly expanding rural residential footprints destroy natural plant communities and compromise water quality and habitat connectivity, thereby degrading what we seek to enjoy.

While cattle defecating and urinating in foothill streams is clearly undesirable for water quality, if this form of extensive livestock sector were removed, would it be replaced by more intensive land uses such as croplands or acreages?

The narratives above emphasize the delicate nature of the conversations required within society to move to a more mature discussion about the “why and how” of landscape management. It’s not that fragile landscapes in Alberta’s east slopes cannot support land uses, as they most certainly can. It is about society recognizing that these ecosystems are undeniably finite in their capacity to support land use, and as such we have no choice but to make difficult decisions about allocating area and natural capital to each of the land uses of settlements, acreages, forestry, croplands, livestock grazing, recreation, transportation, and mining.

Discussing, developing, and deploying balanced combinations of these land uses that can sustain and rebuild natural capital in the Upper Bow River Basin is perhaps the most important conversation confronting residents and land managers in this unique and precious watershed. Opportunities for addressing ecosystem services in land use planning and natural resource management are described in Appendix E.

The recently enacted Alberta Land Stewardship Act reminds all land planners (provincial, federal, municipal) of the core requirement that ecosystem services be considered when devising policies and plans. This new approach will require planners to abandon the historic tradition of focusing on individual projects and instead embrace the concept of “meaningful” time and space. Planners must consider all land use trajectories across lengthy periods and broad regional geographies in order to properly understand both the benefits and liabilities that attend them. There remains an important role for short-term tactical planning, but this approach must be complemented by rigorous strategic-level assessments of land use trajectories if Albertans are to engage in an informed discussion about the future.

Perhaps those interested in explaining natural capital need to steal a page from financial planners who engage Albertans about the need to invest small amounts of funds regularly over long periods (decades) of time to ensure a quality retirement. Individually non-significant events (small but regular deposits into bank accounts, small but regular loss in natural capital)
happening repeatedly over long periods can create massive benefits (fiscal independence of retirees) but can also create massive liabilities (degraded natural capital).

In the same way, a series of small, apparently insignificant improvements in land-use practices can over time accumulate to produce significant benefits to natural capital. This report identifies a series of best management practices that can collectively preserve natural capital and ecosystem services worth $250 million per year by 2080. Financial planners teach that now is always the best time to begin a savings program. Similarly, now is the best time for society to embark on its own savings program for natural capital.
11 Glossary

a.s.l. Above sea level.

Access Management. An approach to land use whereby spatial and temporal restrictions are imposed on the public or other stakeholders to minimize the adverse effects of motorized or non-motorized activity.

AFA. Action for Agriculture.

Annual Allowable Cut (AAC). The annual amount of wood harvest authorized to achieve stated wood fiber or landscape objectives. The actual harvest in any given year may exceed or be less than the long-term average AAC.

Anthropogenic. Made by humans.

B. Billion

Backcasting. Simulations addressing historical patterns.

BAU. Business-as-Usual

Benefit transfer: the benefit estimated from one or more sites or policy proposals is used to assign benefit or value to other, comparable sites or policy proposals.

Buffer. The area adjoining linear or polygonal features that experiences either lower or higher levels of density or activity of wildlife species or ecological function.

Clear-cutting. A form of forest harvest where all, or nearly all, merchantable trees are removed during a single harvest event.

Contingent valuation. A survey-based technique that uses survey participants’ stated preferences to establish values for ecological services and/or changes in ecosystem conditions.

Core Area. That fraction of a forest stand that is interior to a buffer adjoining linear features.

Correction Coefficient. A numerical value that when multiplied by a different value, creates an adjusted value.

Driver. An important component of an ecological system that affects the performance of the overall system.

Ecological Services. The goods and services provided by ecosystems and their functions (often used interchangeably with environmental services or ecosystem services).

Edge Density. The amount of land use footprint edge expressed per unit of area, generally km/km².

Edge. The length of a land use footprint (such as roads, pipelines, edge of wellpad). It is against the edge of a footprint that buffers are applied.

EGS. Ecological goods and services.

Engineered Trail Network. An intentionally designed network of trails that minimized adverse effects on ecological indicators and provides safe and enjoyable experiences for users.
Equestrian. People who participate in riding of horses.

ES. Ecosystem services.

Fire Regime. A numerical description of fire, including such metrics as average fire rate, fire return interval, fire size distribution, and pattern of inter-annual fire events.

FMA. Forest Management Agreement.

Forecasting. A simulation event focusing on future events.

Forest Age Class. A terms that describes the distribution of different forest age classes (seral stages)

Forest Cover. A description of the tree species composition of a forest. Term can also refer to the fraction of the stand that is occupied by the canopy of trees.

FT. Footprint Type.

Full-cost accounting. The process of collecting and presenting a complete set of economic, social, and environmental costs and benefits for proposed alternatives when a decision is necessary.

GIS. Geographic Information System.

Growth and Yield. Values that describe how trees grow in volume or height as they age.

GWAS. Ghost Watershed Alliance Society.

Harvest Fall-Down. A shortfall, or deficit, in available harvest volume relative to desired or authorized volume.

Hung Culvert. A culvert whose downstream exit is elevated above the average water level of the stream. This situation is caused by incorrectly installed culverts or culverts that are too small relative to flow levels.

In-Block Retention Levels. The fraction of green trees within a forestry cutblock that are not harvested and left as residual green trees.

Inblock Forestry Road. Permanent or temporary roads constructed within forestry cutblocks for the purpose of removing harvested wood.

INFI. Index of Native Fish Integrity.

Land use Footprint. Anthropogenic (man-made) features associated with land use. Examples include cutblocks and inblock roads (forestry), seismic lines, wellsites, pipelines (energy), farmyards, acreages, towns (settlements).

Linear Feature Disturbance. A land use footprint that is long and narrow such as roads, pipelines, and seismic lines.

LT. Landscape Type

m. Meters

M. Million
m³. Cubic meter
Marginal Benefits. The change in total benefit as a result of protecting or restoring one more unit of a particular good or service.
Market Instruments. Economic transactions in a market that encourage preferred behavior.
Merchantable Age. The age of a tree that makes it eligible for harvest.
Metrics. Numbers that help define features that are either anthropogenic or natural.
ML. Million liter
Natural capital valuation. The process of assigning value to the market and non-market goods and services provided by ecological systems.
Natural Capital. The stock of resource and environmental assets, including the flows of ecological services, that exist in a region at a given point of time.
OHRV. Off-highway recreational vehicle
Patch Cutting. A form of forest harvest
PNS. Phosphorus, Nitrogen, and Sediment
Polygon. A GIS term that describes an area of the earth that is relatively homogenous and contiguous.
Population Sink. A breeding group that does not produce enough offspring to maintain itself in coming years without immigrants from other populations.
Pulse Reclamation. A management strategy intended to accelerate reclamation of unwanted land use footprints by intentional pulses of reclamation.
Range of Natural Variation. The natural temporal variation in the performance of ecological indicators in systems characterized only by natural processes.
Riparian. Plant communities close to surface water.
RNV. Range of Natural Variability.
Rotation Age. The average age of forests when harvested. This value equates to the average number of years between successive harvest events on a given forest stand.
SASS. Southern Alberta Sustainability Strategy.
SCC. Social cost of carbon.
Seismic Lines. Long, thin disturbances created by the energy sector to assist in the spatial delineation of hydrocarbon reserves.
Selective Cutting. A form of forest harvest that is not clear-cutting. This approach intentionally retains a significant fraction of green trees within the boundary of a cutblock.
Seral Stage. Group of plants within a successional sequence of similar age.
SES. Southeastern Slope Ecosystems Study.
SLS. Spray Lakes Sawmill

Stakeholder. A person, or group, having a defined interest in the outcome of management decisions.

T. Tonne

Total economic value. The sum of all values derived from the user or existence of a good or service.

UBBCES. Upper Bow River Basin Cumulative Effects Study.

Watershed. The region draining into a river, river system, or other body of water.

Willingness to accept. A monetary measure of the minimum amount an individual would accept to forgo a positive change in the quantity or quality of a good or service or agree to a negative change in the quantity or quality of a good or service.

Willingness to pay. A monetary measure of the maximum amount an individual would pay to obtain a positive change in the quantity or quality of a good or service or avoid a negative change in the quantity or quality of a good or service.
12 Appendix A: ALCES® III Landscape Simulation Model

The ALCES Integrator and its companion mapping tools (ALCES Mapper, ALCES Online) provide strategic land use planning guidance by examining inter-relationships among the full range of relevant land use sectors and natural disturbances, and by exploring their environmental and socioeconomic consequences at large temporal and spatial scales (Figure A1). ALCES is a stock and flow model built using the Stella modeling platform (www.iseesystems.com). The model was first developed by Dr. Brad Stelfox in the mid 1990s 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 is also tracked. Hydrological processes are addressed with surface-water and ground-water 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 Integrator is a spatially stratified model, meaning that it tracks the area, length, and quantity of each footprint separately within each landscape type. ALCES Integrator 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 .2 second per simulation year) relative to a spatially explicit modeling approach. ALCES also tracks resource production and supply using approaches that are typical of sector-specific models such as forestry timber supply models. 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 is 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, food production and demand, employment, gross domestic product, and social indicators such as family income and educational attainment.

By applying ALCES Mapper and ALCES Online, the tabular and graphical output from ALCES Integrator can be augmented with maps illustrating the plausible future condition of landscapes.
and indicators. ALCES Mapper is a companion tool developed by the ALCES Group with previous assistance provided 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.

To prepare for ALCES® scenario modeling, data must be entered that describe the study area, land uses and other parameters such as climate, water balance and use coefficients, and footprint reclamation rates and trajectories. For this project, assumptions were drawn from previous work conducted by the Upper Bow River Basin Cumulative Effects Study, Alberta Environment Southern Alberta Sustainability Strategy, Southern Foothills Study, and Alberta Environment/Alberta Sustainable Resource Development Southern East Slopes Study.
Figure A1. Overview of the ALCES land use simulation tool.
13 Appendix B: Key Modeling Assumptions

The key modeling assumptions pertaining to natural disturbance regimes (meteorology, fire) and land uses (forestry, energy, agriculture, transportation, residential, mining) used for the Upper Bow River Basin Study are described in detail in the Phase 1 and 2 Technical Report called “Our Water – Our Future; Upper Bow River Basin Cumulative Effects Study”. This study can be downloaded directly from the ALCES website (www.alces.ca) by clicking on the link: http://www.alces.ca/img/static_content/downloads/UBBCES%20Phase%201%20Technical%20Report%20Final%20190511.pdf

Those who wish to explore the Upper Bow River Basin simulator in detail should contact Brad Stelfox directly at bstelfox@alces.ca to arrange an online demonstration of the model.

Those interested in better understanding the structure of the ALCES Integrator are encouraged to download a copy of the ALCES V.5.0 Manual from www.alces.ca.

13.1 GIS Inputs for Initial Landscape Composition

ALCES® requires three basic GIS data inputs:

Landscape Type (LT) classification – these are the natural, non-anthropogenic landscape classes that characterize the earth surface. The classification is user-defined, and can be derived from any type of spatial information, either raster (classified satellite imagery) or vector (forest cover mapping, etc.). ALCES® can utilize a maximum of 20 LTs.

Footprint Type (FT) classification – these are the anthropogenic features/disturbances on the earth surface. The classification is user-defined, and can be derived from any type of spatial information, either raster or vector. Vector GIS data (e.g. .shp, .e00, etc.) usually works best for the FT mapping, as linear features and feature geometry are better represented. ALCES® can utilize a maximum of 15 FTs.

Landscape Type age – the time since disturbance age-class of LTs is required to understand age-class related plant community dynamics. This is more critical for Forested LTs, but ALCES® also has the ability to model succession in non-forested LTs.

GIS information developed for the South Saskatchewan Regional Plan area was provided by Alberta Sustainable Resource Development for use by the Upper Bow River Basin Cumulative Effects Study/Ghost River. The South Saskatchewan Regional Plan also used the ALCES® model for scenario simulations, so GIS information was already divided into ALCES®-compatible LTs and FTs.
## Table B1. Initial landscape and footprint type composition of the Upper Bow River Basin Study Area.

<table>
<thead>
<tr>
<th>Landscape Type</th>
<th>Area (ha)</th>
<th>LT Area (%)</th>
<th>Footprint Type</th>
<th>FT Area (ha)</th>
<th>Edge (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forest Types</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardwood (Poplar)</td>
<td>24,498</td>
<td>1.7</td>
<td>Major Road</td>
<td>8,348</td>
<td>3,491</td>
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<td>Mixedwood</td>
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<td>0.7</td>
<td>Minor Road</td>
<td>10,907</td>
<td>8,228</td>
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<td>Rec Trail - OHV</td>
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<td>546</td>
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<td>Pine</td>
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<td>9.8</td>
<td>Inblock Road</td>
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</tr>
<tr>
<td>Montane</td>
<td>218,560</td>
<td>15.2</td>
<td>Transmission Line</td>
<td>1,913</td>
<td>606</td>
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<td></td>
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<td></td>
<td>Wind Energy Features</td>
<td></td>
<td></td>
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<td><strong>Other Landscape Types</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prairie Riparian</td>
<td>25,220</td>
<td>1.8</td>
<td>Coal and Gravel</td>
<td>2,650</td>
<td>246</td>
</tr>
<tr>
<td>Wetlands</td>
<td>92,096</td>
<td>6.4</td>
<td>Feedlot</td>
<td>65</td>
<td>12</td>
</tr>
<tr>
<td>Foothills Fescue</td>
<td>150,293</td>
<td>10.4</td>
<td>Industrial Plant /</td>
<td>9,619</td>
<td>1,189</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Recreation Site</td>
<td></td>
<td></td>
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<tr>
<td>Badlands</td>
<td>297</td>
<td>0.0</td>
<td>Agricultural Residence</td>
<td>482</td>
<td>162</td>
</tr>
<tr>
<td>Rock/Ice</td>
<td>231,511</td>
<td>16.1</td>
<td>Town / City</td>
<td>70,976</td>
<td>2,163</td>
</tr>
<tr>
<td>Reservoir</td>
<td>6,091</td>
<td>0.4</td>
<td>Rural Residence</td>
<td>7,120</td>
<td>4,456</td>
</tr>
<tr>
<td>Lakes</td>
<td>13,584</td>
<td>0.9</td>
<td>Seismic Line</td>
<td>1,592</td>
<td>2,654</td>
</tr>
<tr>
<td>River/Stream</td>
<td>8,728</td>
<td>0.6</td>
<td>Wellsite</td>
<td>1,592</td>
<td>746</td>
</tr>
<tr>
<td>Annual</td>
<td>94,151</td>
<td>6.5</td>
<td>Pipeline</td>
<td>2,436</td>
<td>3,481</td>
</tr>
<tr>
<td>Specialty</td>
<td>2,221</td>
<td>0.2</td>
<td>Canal</td>
<td>44</td>
<td>14</td>
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<tr>
<td>Pasture/Forage</td>
<td>217,314</td>
<td>15.1</td>
<td>TOTAL</td>
<td>118,071</td>
<td>27,994</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>1,440,814</td>
<td>100.0</td>
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</table>

<table>
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<th>Category</th>
<th>Area</th>
<th>Fraction</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Forest</td>
<td>624,528</td>
<td>40.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>150,293</td>
<td>9.6%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>28,403</td>
<td>1.8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock / Ice</td>
<td>231,808</td>
<td>14.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetland</td>
<td>92,096</td>
<td>5.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>313,686</td>
<td>20.1%</td>
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<td></td>
</tr>
<tr>
<td>Non-Agricultural Footprint</td>
<td>118,071</td>
<td>7.6%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Anthropogenic</td>
<td>431,757</td>
<td>27.7%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Study Area</strong></td>
<td>1,558,885</td>
<td>100.0%</td>
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</tr>
</tbody>
</table>
14 Appendix C: Relative Water Quality Index

Aquatic health can be measured using various chemical, physical, and biological criteria (North/South 2007). One metric - water quality - was identified as a high priority issue by the Upper Bow River Basin Cumulative Effects Study (UBBCES) Steering Committee and the Ghost Watershed Alliance Society. A survey commissioned for the Southern Foothills Study found that maintaining high water quality was the most important issue for both rural and urban residents of the region (SALTS 2007).

One of the challenges of defining water quality is that it can convey different meanings to different people. For example:

- **most residents** are concerned about the quality and safety of water that comes out of their taps or wells and used for domestic purposes;
- **recreational users and acreage owners** are concerned that water in lakes and streams looks clean, is safe to touch and recreate in, to drink with minimal treatment, and supports healthy plant, fish, and wildlife communities;
- **water and wastewater managers** are concerned that regulated 'point source' water discharge quality (e.g., sewage treatment plants or industrial plant outfalls, Figure) complies with drinking, recreational, or aquatic life water quality guidelines and that upstream activities do not inadvertently increase their treatment costs;
- **ranchers and farmers** are concerned about the safety of stock water in dugouts, ponds, and streams; and
- **fish and wildlife managers** are concerned about chronic (long-term low dose) effects of unregulated 'non-point' sources (e.g., runoff from urban areas and agricultural lands, Figure C1) that gradually alter habitat quality, even where short-term water quality guidelines have been exceeded infrequently.

![Figure C1. Non-point sources of water pollution (from LCEA nd).](image-url)
Most definitions of water quality incorporate the instantaneous or average measurements of physical elements (e.g., sediment, temperature), biological inputs (e.g., organic carbon), nutrients, metals, and ions (e.g., nitrogen, phosphorus, chloride), and toxic compounds (e.g., pesticides, trace organics) in a waterbody (river, lake, pond). Instantaneous or average water quality may be affected by both point sources and non-point sources.

The concept of the "Relative Water Quality Index", as used in the ALCES landscape simulator, focuses on both non-point and point sources and is based on the principle that equal areas of different landscape types release statistically defined rates of nutrients and sediment that have predictable probabilities of reaching surface waterbodies. As nutrient and sediment emitting landscape types (for example; cultivated crops, roads, settlements, feedlots, acreages) become more common, and absorbing landscape types (e.g., riparian vegetation, native grasslands) become less common, loading to surface waters increases in a predictable fashion. The general statistical approach was endorsed by Alberta Environment’s (AENV) Southern Alberta Sustainability Strategy (SASS) initiative at a workshop held in June 2003, with participants from AENV (Al Sosiak, Wendell Koning, Pat Kinneir), academia (Dr. David Schindler and Dr. Bill Donahue, University of Alberta), and the ALCES Group (Dr. Brad Stelfox, Dr. Dan Farr).

The 'Relative Water Quality Index', as used in the ALCES model, reflects the relative landscape loading of three water quality parameters: two nutrients (total nitrogen and total phosphorus) and sediment (non-filterable residue or total suspended solids). Increased loadings of these components from landscape changes are negatively and linearly related to overall water quality in this model. In “real-world” situations, however, changes in water quality from increased nutrient and sediment loadings may not be linear but exhibit exponential or asymptotic relationships.

Water quality deterioration has been widely shown to be correlated with landscape and land use features such as forested area and composition, fire history, road density, agricultural extent, urban sprawl, livestock density, and Off-Highway Recreational Vehicle use (Anderson et al. 1998a; Carpenter et al. 1998; Cooke and Prepas 1998; Carignan et al. 2000; Beaudry 2004; Burke et al., 2004; Croke and Hairside 2006; Clearwater 2006; Ouren et al. 2007; Cows and Fish (no date provided). Although consistent correlations between landscape composition and water quality are reported in the primary literature, it is important to note that landscape composition may not predict water quality accurately at small spatial or temporal scales, where topography or specific precipitation events emerge as better short-term predictors.

Sediment and nutrients were also used as aquatic health indicators in a recent provincial Water for Life assessment (North/South 2007). As stated in that assessment, “These indices are not intended to replace the conventional process of analyzing and interpreting water quality data in detail; rather, they should be utilized as qualitative and complementary assessment tools.”

When considered alone, or combined into what we refer to here as our Relative Water Quality Index, total nitrogen, total phosphorus and sediment releases provide a useful measure of relative changes in the regional export of these parameters from the study area over time. The ALCES® model provides the user with the option to adopt one of two approaches:
Calculate total nitrogen, total phosphorus and sediment loads or combined loads of the three parameters in the study area relative to average “range of natural variability” loading to forecast relative changes in nutrient and sediment release; or

Estimate the portion of total surface nitrogen, total phosphorus and sediment loading that is deposited into waterbodies by including a ‘discount’ coefficient caused by 1) vegetation types that intercept and deposit nutrient and sediments (Corley et al. 1999), or 2) physical and chemical processes that occur within waterbodies (Wetzel 1975). With this approach, simulated nutrient loads can be calibrated against measured average water quality values to ensure that they reflect historical or current landscape composition.

Option 1 was selected for the UBBCES study because AENV and City of Calgary water managers were concerned that results could be misinterpreted by a non-technical audience. With this option, the Relative Water Quality Index (RWQI) is reported as a value between 0.00 and 1.00, where 1 reflects average natural conditions of RNV, and 0 represents extremely high loading (very poor water quality). An increase loading of 200% of natural conditions would equate to ½ or 0.5 RWQI. In other words, relative water quality is considered to degrade from excellent to poor as values become smaller.

Regional sediment, nitrogen, and phosphorus inputs and outputs were calculated based on water quantity simulations and coefficients defining the rates (tonnes/ha/yr) at which nitrogen, phosphorus, and sediment are exported from various landscape and footprint types. Coefficients used in this study were based on Southern Alberta Sustainability Strategy (SASS) compilation study of Jeje (2003). Nitrogen runoff coefficients for roads were based on Davidson et al. (2010) because these values were not provided in Jeje. Table C1 summarizes the water quality coefficients used in this study to compute relative water quality index.

Nutrient and sediment coefficients derived for South Saskatchewan Regional Plan modeling and results of the CAESAA water quality monitoring program (Anderson et al. 1998a,b; Casson et al., 2008; Jedrych 2008; Lorenz et al., 2008) were also considered at the request of AENV and Alberta Agriculture and Rural Development. Small watershed nutrient export rates documented by the CAESAA water quality monitoring program were lower than those provided in Jeje (2003), and were shown to be correlated with surface runoff rate and landscape characteristics; sediment export rates were not provided. In general, streams in higher agricultural intensity watersheds (based on census data rather than land use metrics) had the highest concentrations of nutrients (Lorenz et al. 2008).

There is no doubt that sediment and nutrient loading for any given catchment or sub-catchment is strongly correlated to the areal water yield, which varies over time from drought to flood conditions. However, there also is no doubt that strong associations exist between loading rates and the various land cover types and land uses with a catchment or sub-catchment. Unfortunately, there have been no detailed assessments in Alberta of sediment and loading rates that quantify the degree to which precipitation, runoff, or water yield affect loading rates. For this reason, anyone who attempts to model the effects of land use change on water quality is necessarily limited to using values for loading rates that derive from academic and government studies performed in Alberta or elsewhere. For the purposes of this study, we have used loading rates from studies performed in Alberta.
It is arguable that we should be using broader statistical distributions of loading rates for each different landscape or footprint type that would yield a range of water quality index changes that internalizes varying water yields over time. However, the results from our backcasting scenarios are consistent with historical changes in water quality that have been identified and described throughout Alberta, and act as an appropriate calibration test for this approach. It is for this reason that we describe here relative changes in water quality on broad temporal and spatial scales that are associated with large-scale changes in land use.

Table C1. Relative water quality loading coefficients used for the Upper Bow River Basin and Ghost River Cumulative Effects Studies.

<table>
<thead>
<tr>
<th>Landscape or Footprint Type</th>
<th>Nitrogen Runoff (tonnes/ha/yr)</th>
<th>Source</th>
<th>Phosphorus Runoff (tonnes/ha/yr)</th>
<th>Source</th>
<th>Sediment Runoff (tonnes/ha/yr)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood Forest</td>
<td>0.00051</td>
<td>foothills parkland from Jeje 2003</td>
<td>0.0000575</td>
<td>foothills parkland from Jeje 2003</td>
<td>0.3049</td>
<td>foothills parkland from Jeje 2003</td>
</tr>
<tr>
<td>Mixedwood Forest</td>
<td>0.00051</td>
<td>foothills parkland from Jeje 2003</td>
<td>0.0000575</td>
<td>foothills parkland from Jeje 2003</td>
<td>0.3049</td>
<td>foothills parkland from Jeje 2003</td>
</tr>
<tr>
<td>Spruce Forest</td>
<td>0.00275</td>
<td>subalpine from Jeje 2003</td>
<td>0.0002</td>
<td>subalpine from Jeje 2000</td>
<td>0.251</td>
<td>avg forest from Jeje 2003</td>
</tr>
<tr>
<td>Pine Forest</td>
<td>0.00275</td>
<td>subalpine from Jeje 2003</td>
<td>0.0002</td>
<td>subalpine from Jeje 2001</td>
<td>0.251</td>
<td>avg forest from Jeje 2003</td>
</tr>
<tr>
<td>Montane Forest</td>
<td>0.00275</td>
<td>subalpine from Jeje 2003</td>
<td>0.0002</td>
<td>subalpine from Jeje 2002</td>
<td>0.251</td>
<td>avg forest from Jeje 2003</td>
</tr>
<tr>
<td>Prairie Treed / Riparian</td>
<td>0.00051</td>
<td>foothills parkland from Jeje 2003</td>
<td>0.0000575</td>
<td>foothills parkland from Jeje 2003</td>
<td>0.3049</td>
<td>foothills parkland from Jeje 2003</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0.00055</td>
<td>from Jeje 2003</td>
<td>0.00001</td>
<td>from Jeje 2003</td>
<td>0.251</td>
<td>avg forest from Jeje 2003</td>
</tr>
<tr>
<td>Foothills Fescue</td>
<td>0.00061</td>
<td>from Jeje 2003</td>
<td>0.00011</td>
<td>median from Jeje 2003</td>
<td>0.0621</td>
<td>median from Jeje 2003</td>
</tr>
<tr>
<td>Badlands</td>
<td>0.0018</td>
<td>1/2 montane; per Jeje 2003</td>
<td>0.00009</td>
<td>median alpine from jeje 2003</td>
<td>0.502</td>
<td>twice forest</td>
</tr>
<tr>
<td>Rock Ice</td>
<td>0.0018</td>
<td>1/2 montane; per Jeje 2003</td>
<td>0.00009</td>
<td>median alpine from jeje 2003</td>
<td>0.251</td>
<td>avg forest from Jeje 2003</td>
</tr>
<tr>
<td>Reservoir</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Lentic (lakes and ponds)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Lotic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Annual Crop</td>
<td>0.0012</td>
<td>from crowfoot crk median, Jeje 2003</td>
<td>0.00032</td>
<td>from crowfoot crk median, Jeje 2003</td>
<td>1.44</td>
<td>S AB, from Jeje</td>
</tr>
<tr>
<td>Specialty Crop</td>
<td>0.0012</td>
<td>from crowfoot crk median, Jeje 2003</td>
<td>0.00032</td>
<td>from crowfoot crk median, Jeje 2004</td>
<td>1.44</td>
<td>S AB, from Jeje</td>
</tr>
<tr>
<td>Pasture, Forage, Tame Grass</td>
<td>0.0051</td>
<td>avg from Jeje 2003</td>
<td>0.0007525</td>
<td>avg from Jeje 2003</td>
<td>0.457</td>
<td>avg from Jeje 2003</td>
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<tr>
<td>Major Road and Rail</td>
<td>0.01</td>
<td>Davidson et al. 2010, water air soil poln</td>
<td>0.0035</td>
<td>from Jeje 2003</td>
<td>2</td>
<td>SASS - urban from Jeje 2003</td>
</tr>
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</table>
Table C1 Relative water quality loading coefficients used for the Upper Bow River Basin and Ghost River Cumulative Effects Study (cont.).

<table>
<thead>
<tr>
<th>Landscape or Footprint Type</th>
<th>Nitrogen Runoff (T/ha/yr)</th>
<th>Source</th>
<th>Phosphorus Runoff (T/ha/yr)</th>
<th>Source</th>
<th>Sediment Runoff (T/ha/yr)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor Road</td>
<td>0.01000</td>
<td>Davidson et al. 2010, water air soil pollin</td>
<td>0.00350</td>
<td>from Jeje 2003</td>
<td>2.000</td>
<td>SASS - urban from Jeje 2003</td>
</tr>
<tr>
<td>Recreational Trail OHV</td>
<td>0.01000</td>
<td>Davidson et al. 2010, water air soil pollin</td>
<td>0.00350</td>
<td>from Jeje 2002</td>
<td>1.000</td>
<td>half major and minor roads</td>
</tr>
<tr>
<td>Inblock Roads</td>
<td>0.01000</td>
<td>Davidson et al. 2010, water air soil pollin</td>
<td>0.00350</td>
<td>from Jeje 2003</td>
<td>1.000</td>
<td>half major and minor roads</td>
</tr>
<tr>
<td>Transmission Lines and Wind Farms</td>
<td>0.01000</td>
<td>Davidson et al. 2010, water air soil pollin</td>
<td>0.00350</td>
<td>from Jeje 2003</td>
<td>1.000</td>
<td>half major and minor roads</td>
</tr>
<tr>
<td>Mines</td>
<td>0.00860</td>
<td>from Jeje 2003</td>
<td>0.00150</td>
<td>from Jeje 2003</td>
<td>0.869</td>
<td>industrial from Jeje 2003</td>
</tr>
<tr>
<td>Feedlot</td>
<td>1.95000</td>
<td>from Jeje 2003</td>
<td>0.25500</td>
<td>median from Jeje 2003</td>
<td>2.000</td>
<td>SASS - urban from Jeje 2003</td>
</tr>
<tr>
<td>Industrial Plant\Recreational</td>
<td>0.00225</td>
<td>from Jeje 2003</td>
<td>0.00795</td>
<td>from Jeje 2003</td>
<td>0.869</td>
<td>industrial from Jeje 2003</td>
</tr>
<tr>
<td>Agricultural Residence</td>
<td>0.00152</td>
<td>lawns from Jeje 2003</td>
<td>0.00050</td>
<td>mixed ag from Jeje 2003</td>
<td>0.209</td>
<td>residential from Jeje 2003</td>
</tr>
<tr>
<td>Town or City</td>
<td>0.00525</td>
<td>avg from Jeje 2003</td>
<td>0.00123</td>
<td>avg from Jeje 2003</td>
<td>2.000</td>
<td>urban from Jeje 2003</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>0.00152</td>
<td>lawns from Jeje 2003</td>
<td>0.00050</td>
<td>mixed ag from Jeje 2003</td>
<td>0.209</td>
<td>residential from Jeje 2003</td>
</tr>
<tr>
<td>Seismic</td>
<td>0.00152</td>
<td>lawns from Jeje 2003</td>
<td>0.00019</td>
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<td>0.209</td>
<td>residential from Jeje 2004</td>
</tr>
<tr>
<td>Wellsite</td>
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<td>lawns from Jeje 2003</td>
<td>0.00019</td>
<td>lawns from Jeje 2003</td>
<td>0.209</td>
<td>residential from Jeje 2005</td>
</tr>
<tr>
<td>Pipeline</td>
<td>0.00152</td>
<td>lawns from Jeje 2004</td>
<td>0.00019</td>
<td>lawns from Jeje 2004</td>
<td>0.209</td>
<td>residential from Jeje 2006</td>
</tr>
<tr>
<td>Canal</td>
<td>0</td>
<td></td>
<td>0</td>
<td></td>
<td>1.440</td>
<td>S AB, from Jeje</td>
</tr>
</tbody>
</table>

Note: Please refer to the Upper Bow River Basin Cumulative Effects Study – Phase 1 & 2 Technical Report for citations.¹

14.1 Selected References for Water Quality Appendix


Temporal and Spatial Changes in Natural Capital of the Upper Bow River Basin


Lassevils, J.F. & Berrux, D. 2000. Sources of phosphorus to surface waters: comparing calculated with measured P loadings for three French rivers, Geoplus Study for Centre European d’Etudes des Polyphosphates. 68pp


Appendix D: Ecosystem Service Valuation Backgrounder

15.1 Framework for Ecosystem Services Valuation
Measuring dollar values for ecosystem services is a complex task. The challenge in valuation is two-fold: First, ecosystem services include a variety of natural processes, such as hydrology, ecology, and biogeochemical cycles, and changes in these are difficult to measure. Second, the valuation process that assigns dollar values requires a potentially significant research investment to accurately estimate values. Ecosystem services values can be elicited through custom-designed research activities that collect data on observed prices and behavior and statistically infer values (revealed behavior techniques), or by asking survey respondents to reveal their willingness to pay for the service (stated preference techniques). Where performing original research for case studies is too expensive, researchers often rely on results from other studies amended appropriately to local conditions. This is termed the ‘benefit transfer’ technique, and is useful for estimating ballpark values.

This project uses the computer simulation tool ALCES to estimate changes in the biophysical supply of ecosystem services, and draws upon the scientific literature to support selected dollar values. There are other software tools that calculate changes and values in ES, such as Invest and Aries. These tools calculate biophysical quantities of various ecosystem services under a baseline scenario, compare them to an alternative scenario, and then attach a dollar value to the difference between the two on a per-unit measure (i.e. tonnes of carbon, cubic meters of water). The approach taken here is consistent with the valuation methods used in other ES valuation software; however, this application is novel given that the ALCES model uses a more robust representation of biophysical processes, and is a dynamic simulation model whereas other ES valuation models are static comparisons of proposed scenarios.

Measuring ecosystem services requires a typology of services, in order to ensure values are correctly identified and not overlooked or double counted. The primary work that defines ecosystem services typologies is the United Nations’ 2005 Millennium Ecosystem Assessment (MA), which reports the condition of the world’s ecosystems and their ability to provide services over time. MA defines ecosystem services as the benefits derived from ecosystems. These benefits are dependent on ecosystem functions, which are the processes (i.e. physical, chemical and biological) or attributes that maintain ecosystems and the people and wildlife that live within them. ES can include products received from ecosystems (e.g. food, fibre, clean air and water), benefits derived from processes (e.g. nutrient cycling, water purification, climate regulation) and non-material benefits (e.g. recreation and aesthetic benefits).
The MA framework focused on the linkages between ecosystem services and human well-being, and categorized ecosystem services into four categories:

- Supporting services: nutrient cycling, soil formation, and primary production
- Provisioning services: food, fresh water, wood and fiber, fuel
- Regulating services: climate regulation, flood regulation, disease regulation, and water purification
- Cultural services: aesthetic, spiritual, educational and recreational services

The MA’s conceptual framework, including its typology of ecosystem services, provided a springboard for several subsequent initiatives and programs, namely The Economics of Ecosystems and Biodiversity (TEEB) – an international initiative led by the United Nations, the European Commission, and the German and UK governments. TEEB emphasizes the difference between ecological functions, their contribution to human well-being, and the benefits that they provide. As a result, TEEB’s typology for ecosystem services has taken out supporting services as a category, and has added habitat services as an additional category to reflect the importance of habitat for migratory species and for maintaining genetic pools (Table D1).

Martinez-Harms & Balvanera (2012) performed a recent review of methods for mapping ecosystem service supply, reviewing 70 peer-reviewed publications. They found that regulating services were the most commonly mapped, followed by provisioning, cultural and supporting services. Most studies were performed at the regional or national scale. The most commonly used method was to develop models of biophysical relationships and determining ES values from primary data, and then applying them spatially across the study area based on the service provision models. The approach in this study is consistent with this method, but again is novel given the foundation of biophysical simulation modeling.

Ecosystem services can be categorized by ecosystem type or landscape type for the UBBCES study area. A full list of the potential ecosystem services and benefits provided by each landscape/footprint type is identified in Table D2. Natural or agricultural landscape types may provide positive benefits in terms of ES, while hardened anthropogenic footprints such as roads, parking lots, and intensive urban and industrial features may produce negative ES benefits. Anthropogenic footprints are built on, or over, natural landscape types. This generally reduces the ability of the landscapes to store carbon, produce clean water, or contribute to baseflow water supply. Provisioning services were not included because they tend to be market goods, rather than non-market ecosystem services.

Based on the previous work undertaken in Phase 1 and 2 of the Upper Bow River Basin Cumulative Effects Study (Table D3), five key ecosystem services were identified for modeling.
purposes in Phase 3. These five ES are water quality, baseflow water supply, carbon storage, tourism/recreation, and food security. The purpose of the study was to determine which landscape types in the study area provide the greatest relative value in terms of ES production based on the four criteria selected. The goal was not to assess the total value of all ES for the study area as this was beyond the time and funding resources available. However, it was felt that the four ES services selected would provide a method to evaluate which landscape types were of the greatest value, as well as the location of these landscape types.

Table D1. Ecosystem Services and Potential Benefits/Values by Ecosystem Type

<table>
<thead>
<tr>
<th>Provisioning Services</th>
<th>Regulating services</th>
<th>Habitat services</th>
<th>Cultural Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Food</td>
<td>• Air quality regulation; climate regulation; moderation of extreme events</td>
<td>• Maintenance of life cycles of migratory species</td>
<td>• Aesthetic information</td>
</tr>
<tr>
<td>• Water</td>
<td>• Regulation of water flows</td>
<td>• Maintenance of genetic diversity</td>
<td>• Opportunities for recreation and tourism</td>
</tr>
<tr>
<td>• Raw materials</td>
<td>• Waste treatment</td>
<td></td>
<td>• Inspiration for culture, art, and design</td>
</tr>
<tr>
<td>• Genetic resources</td>
<td>• Erosion prevention</td>
<td></td>
<td>• Spiritual experience</td>
</tr>
<tr>
<td>• Medicinal resources</td>
<td>• Maintenance of soil fertility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ornamental resources</td>
<td>• Pollination</td>
<td></td>
<td>• Information for cognitive development</td>
</tr>
<tr>
<td></td>
<td>• Biological control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecosystem/Landscape Type (LT)</td>
<td>Ecosystem Services (Typology of ES from TEEB)</td>
<td>Potential Benefits for Human Well-being</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------</td>
<td>---------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Wetlands/Riparian</td>
<td>Storage of fresh water</td>
<td>Food provision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regulation of water flows</td>
<td>Climate regulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waste treatment</td>
<td>Flood control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carbon storage</td>
<td>Waste processing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cultural services</td>
<td>Water supply</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amenity/tourism/recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cultural/heritage conservation</td>
<td></td>
</tr>
<tr>
<td>Lakes &amp; Rivers</td>
<td>Waste treatment</td>
<td>Food provision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance of life cycles of migratory</td>
<td>Water supply</td>
<td></td>
</tr>
<tr>
<td></td>
<td>species</td>
<td>Drainage and natural irrigation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintenance of genetic diversity</td>
<td>Transportation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cultural services</td>
<td>Erosion prevention</td>
<td></td>
</tr>
<tr>
<td>Forests</td>
<td>Habitat services</td>
<td>Biological and genetic diversity,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pollination</td>
<td>Amenity/tourism/recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air quality regulation</td>
<td>Cultural/heritage conservation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carbon storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water filtration</td>
<td></td>
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<tr>
<td></td>
<td>Erosion prevention</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil fertility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biological control</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cultural services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland &amp; Shrubland</td>
<td>Habitat services</td>
<td>Climate regulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pollination</td>
<td>Flood control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air quality regulation</td>
<td>Erosion control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carbon storage</td>
<td>Air quality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regulation of water flows</td>
<td>Biological and genetic diversity,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Erosion prevention</td>
<td>Amenity/tourism/recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil fertility</td>
<td>Cultural/heritage conservation</td>
<td></td>
</tr>
<tr>
<td>Well-Managed Cultivated</td>
<td>Pollination</td>
<td>Provision of food</td>
<td></td>
</tr>
<tr>
<td>Areas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carbon storage</td>
<td>Pollination of crops</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Erosion prevention</td>
<td>Amenity and recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil fertility</td>
<td>Cultural/heritage conservation</td>
<td></td>
</tr>
<tr>
<td>Green Urban Areas</td>
<td>Pollination</td>
<td>Abatement of air/noise pollution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pollination of plants</td>
<td>Property enhancement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pollution control</td>
<td>Inspiration/spiritual enhancement</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Filtering of dust particles</td>
<td>Amenity/tourism/recreation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cultural/heritage conservation</td>
<td></td>
</tr>
</tbody>
</table>
Table D3. Key Ecosystem Services Identified for Valuation for UBBCES Study

<table>
<thead>
<tr>
<th>Ecosystem/Landscape Type (LT)</th>
<th>Ecosystem Services (Typology of ES from TEEB)</th>
<th>Potential Benefits for Human Well-being</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands/Riparian</td>
<td>Carbon storage Water filtration Recreation</td>
<td>Climate regulation Water supply Tourism/recreation</td>
</tr>
<tr>
<td>Lakes &amp; Rivers</td>
<td>Recreation Water Supply</td>
<td>Tourism/recreation</td>
</tr>
<tr>
<td>Forests</td>
<td>Carbon storage Water filtration Recreation</td>
<td>Climate regulation Water supply Tourism/recreation</td>
</tr>
<tr>
<td>Grassland &amp; Shrubland</td>
<td>Carbon storage Water filtration Recreation</td>
<td>Climate regulation Amenity/tourism/recreation</td>
</tr>
<tr>
<td>Cultivated Areas</td>
<td>Carbon storage Recreation</td>
<td>Climate regulation Amenity and recreation</td>
</tr>
</tbody>
</table>
15.2 Ecosystem Services Valuation Methods

In economic terms, ecosystem services contribute to different elements of ‘Total Economic Value’, which comprises both use values (including direct use such as resource use and recreation, and indirect use from regulating services) and non-use values, such as the value people place on protecting nature for future use (option values) or for ethical reasons (bequest and existence values). The economic importance of most of these values can be measured in monetary terms, with varying degrees of accuracy. Measuring the value of goods or services is fairly straightforward when they have a market value. However, determining the non-market values for ecosystem services is much more difficult because they do not have an established price and there is often a lack of ecological and economic information.

Ecosystem services valuation studies may be impractical in many policy settings because they take too long to deliver, and as a next-best method, the ‘benefit transfer’ approach can be applied in a relatively inexpensive and timely manner. This procedure estimates the value of an ecosystem service by transferring an existing valuation estimate from a similar ecosystem. If care is taken to closely match policy and study sites or to adjust values to reflect important differences between sites, it can be a useful approach to estimate the value of ecosystem services. Benefit transfer methods generally transfer values either in terms of value per beneficiary (e.g. value per person or household) or value per unit of area of ecosystem (e.g. value per hectare). Table D4 summarizes a number of valuation studies from watershed services globally, and presents estimated per hectare ecosystem service values according to the MA typology.
Table D4. Estimates of economic values of watershed services (from Smith et al. 2006)

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Service Provided</th>
<th>Developed Economies (US$/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisioning Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water for People</td>
<td></td>
<td>45-7,500</td>
</tr>
<tr>
<td>Fish/Shrimp/Crabs</td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Agriculture and Grazing</td>
<td></td>
<td>40-520</td>
</tr>
<tr>
<td>Wildlife (for food)</td>
<td></td>
<td>40-520</td>
</tr>
<tr>
<td>Fibre/organic raw material</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>Medicinal plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inorganic raw material</td>
<td></td>
<td>15-160</td>
</tr>
<tr>
<td>Regulating Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Quality Control</td>
<td></td>
<td>60-6,700</td>
</tr>
<tr>
<td>Flood Erosion</td>
<td></td>
<td>15-5500</td>
</tr>
<tr>
<td>Groundwater Replenishment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erosion Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Sequestration</td>
<td></td>
<td>130-270</td>
</tr>
<tr>
<td>Microclimate Stabilization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supporting Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiversity Conservation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural and Amenity Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreation and Conservation</td>
<td></td>
<td>230-3,000</td>
</tr>
<tr>
<td>Cultural/Religious Activities</td>
<td></td>
<td>30-1,800</td>
</tr>
</tbody>
</table>

There are several techniques that have been developed to determine economic values for non-market ecosystem services. These include:

1. Direct market valuation approaches such as 'market-based', 'cost-based', and 'production function-based' valuations. Direct market valuation methods use data from actual markets. For example, 'avoided damage cost' assesses the value for ecosystem services based on what society would have to pay if ecosystems and their services are diminished and/or damaged. In other words, the value is the costs avoided that would normally be incurred in the absence of those services. 'Replacement cost' is related to avoided cost but focuses on ecosystem services that could be replaced using another natural source or human-made systems.

2. 'Revealed preference' approaches such as travel cost and hedonic pricing methods are based on the observation of individual choices that are related to the ecosystem service under study.

3. 'Stated preference' approaches such as contingent valuation, choice modeling, and group valuation methods estimate demand for ecosystem services using surveys of
hypothetical scenarios. These surveys assess the willingness to pay or willingness to accept compensation for changes in ecosystem service provision.\textsuperscript{12}

There are reasonable estimates of the value of many provisioning services – in cases where well-developed markets exist – but there are few reliable estimates of the value of most non-marketed cultural and regulating services.\textsuperscript{13} The TEEB framework recommends that ES values be derived from market-based valuation approaches where possible. In the absence of this information, values can be derived from market information indirectly associated with the service. If both direct and indirect market-based information are not available then hypothetical scenarios created by stated preference methods may be used to determine the value.\textsuperscript{14}

Market price-based approaches are most often used to obtain the value of provisioning services, since the commodities produced by provisioning services are often sold, for example, in agricultural markets. In well-functioning markets, preferences and marginal cost of production are reflected in a market price, which implies that these can be taken as accurate information on the value of commodities.\textsuperscript{15} Cost-based approaches are based on estimations of the costs that would be incurred if ecosystem service benefits needed to be recreated through artificial means. Techniques include the avoided cost method, the replacement cost method, and the mitigation or restoration cost method. Production function-based approaches estimate how much a given ecosystem service (e.g., regulating service) contributes to the delivery of another service or commodity which is traded on an existing market. These service flows are valued for marginal changes in their provision.\textsuperscript{16}
### 16 Appendix E: Ecosystem Services Programming

**16.1 Introduction**

People value what is measured. When the value of ecosystem services is measured it helps us understand what the natural environment contributes to human well-being. When we consider that our decisions and actions can have negative or positive influences to ecosystem services, understanding the value of those services may influence the choices we make. This can help decision makers and others compare land use changes or development applications in a more balanced manner by considering economic and environmental impacts and benefits in more comparable terms.

**16.2 Applying Ecosystem Services Valuation to Programs or Management Approaches**

Once we begin to value ecosystem services and understand how the natural environment supports our daily lives we can begin to incorporate this information into our land use planning, natural resource management and conservation programming decisions. An ecosystem services approach has been applied in many ways around the globe. The following list provides a description of different ways of applying an ecosystem services approach.\(^\text{61}\)

**Regulation** provides a mandatory mechanism instituted by government that limits, prevents or prescribes certain activities or practices. Having an understanding of the value of ecosystem services can help set limits and help recognize the impact or benefits of certain activities or practices.

**Education** programs provide ecosystem services valuation information to decision makers, land managers, developers, etc. through workshops, one-on-one discussions, manuals, brochures, news articles, online resources, etc. in an effort to encourage more balanced and better informed decisions.

**Financial Instruments / Market Based Instruments (MBI)** (e.g., tax incentives, tax relief or direct payments, offset markets, reverse auctions, certification, etc.) are used to influence the behavior of resource users with the intention of ensuring resources are used more efficiently. Ecosystem services valuation information can be used by government and non-government organizations (NGO) to influence land management. Recognizing there is not always a market mechanism that provides a competitive alternative to some land use decisions (even when valuation exercises show significant value to the affected ecosystem services), financial instruments can help to even out the cost/benefit of various land management actions. Using ecosystem service values can provide support for creating a financial instrument program and can act as a basis for determining how much financial instruments may be worth to land managers.

**16.3 Applying Ecosystem Services Values in Alberta**

The Alberta Land Stewardship Act, enacted in 2009, lays the foundation for the application of an ecosystem services approach to evolve in Alberta. This Act includes two main components: 1) the requirement for seven watershed based regions in the province to have regional land use plans and 2) reference to conservation and stewardship to support land conservation objectives.
As information is gathered and studies done to understand the value of the services provided to humans by Alberta’s natural environment, this information can be applied to the creation of the regional land use plans, by the municipal decision makers, by government departments and NGO’s working to reach conservation objectives and by land managers making business decisions.

If regional plans describe conservation goals, objectives and thresholds, information on ecosystem services valuation can be very helpful in the design of the tools used to help met those targets. Part three of ALSA, Conservation and Stewardship Tools, describes potential for the province to support research, development and funding to protect, conserve and/or enhance the environment, natural scenic or esthetic values and/or agricultural land. Four ‘tools’ are specifically enabled in ALSA: conservation easements, conservation directives, conservation offsets and transfer of development credits. Three of these are voluntary for landowners to participate, but all provide a financial return for conservation actions. Ecosystem services valuation may provide a useful basis as these programs continue to be developed and initiated in the province.
17 References and Endnotes

1 Costanza, R. et al. (2011) Valuing ecological systems and services. F1000 Biology Reports 3: 14
5 Anielski, M., Wilson, S., Counting Canada’s Natural Capital: Assessing the Real Value of Canada’s Boreal Ecosystems. Pembina Institute


18 http://www.actionforagriculture.com/


22 Reports and powerpoints of Phase 1 and 2 of the Upper Bow River Basin Cumulative Effects Study can be downloaded at: http://www.alces.ca/projects/view/22.


27 Ibid.

28 Ibid.
Temporal and Spatial Changes in Natural Capital of the Upper Bow River Basin


32 Ibid.


39 The average anthropogenic runoff coefficient was calculated as the area-weighted average coefficient across footprint and farmland.

The runoff coefficients for wetlands and riparian areas were adjusted to account for the role of wetlands in removing phosphorous and nitrogen entering the wetland and riparian areas from other landscape types. Conservative estimates of removal rates based on a literature review are 350 kg/ha/year for nitrogen and 120 kg/ha/year for phosphorous. Wetlands were assumed to be neutral with respect to sediment runoff.


When assessing the spatial distribution of groundwater supply, the simplifying assumption was made that the estimated 122 billion m$^3$ pre-settlement groundwater stock was equally distributed across the basin. While this assumption is undeniably wrong, it is appropriate for demonstrating which locations have lost capacity to replenish groundwater supply relative to pre-settlement condition. The 122 billion m$^3$ pre-settlement groundwater stock is estimated based on the Phase 1 and 2 report which states a current groundwater stock of 104 billion m$^3$, and a 15% decline in groundwater since pre-settlement.


The crop mix of Census Division 6 was applied, as per http://www.statcan.gc.ca/pub/95-629-x/2007000/4123849-eng.htm.

Average provincial yields from the past 10 years were applied, as per http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd12061.
Temporal and Spatial Changes in Natural Capital of the Upper Bow River Basin

Forage yield was the average hay yield in Alberta over the past 10 years (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd12061). Forage yield was converted to cattle production using the conversion factor of one animal unit (i.e., 1000 kg cattle) per 362 kg forage per month (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1201).

Prior to converting cattle density to annual calorie production, a factor of 0.25 was applied to animal units (i.e., 1000 kg cattle) to reflect an average slaughter rate of 25% of the cattle population per year. Further, a dressing percentage of 59% was applied to convert live cattle weight to slaughtered rate (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sis12389).


Important to note that a new set of sediment, nitrogen, and phosphorus runoff coefficients were recently developed by Dr. Bill Donahue following the completion of the Upper Bow River Basin study. These coefficients do not alter the overall pattern of nutrient runoff for nitrogen and phosphorus but do suggest a much smaller contribution of sediment from the mountainous western portion of the study area. As such, the maps illustrating the cost of water treatment likely overstate the level of poor water quality contributed by the steep headwater portions of the Bow River Basin watershed.


