Cumulative Effects of Land Uses and Conservation Priorities in Alberta's Southern East Slope Watersheds

Undertaken for the

ALBERTA CHAPTER OF THE WILDLIFE SOCIETY

ALCES

March 2020

1. FOREWORD

Despite decades of progress, watershed planning for the East Slopes of Alberta is still in its infancy. This is a busy landscape that continues to get busier with a growing population demanding more from resource extraction, recreation and water supplies. Meshing these demands with a landscape which forms an essential water source for downstream water users, unique biodiversity attributes, wild space and stunning scenery is a task requiring more than maintaining the status quo.

What Albertans draw from the East Slopes is substantial- economically, ecologically, socially and personally. Yet, the rate of reinvestment isn't proportional to the take and the signals of overuse are evident. Native trout declines are a message hard to ignore. Their plight is a signal that many of the values Albertans hold for the East Slopes are at risk. In some cases, like flooding, our land use decisions pose a risk to downstream communities.

The East Slopes do not represent an inexhaustible supply of benefits for Albertans. We need to set ecologically relevant limits and thresholds; without them we continue to spiral towards overuse. Investments need to be considered for restoration, especially where limits have been exceeded. Research needs, like better measurements of water quantity and quality, biodiversity and the effects of climate change require adequate resources.

At the centre is understanding and untangling the additive effects of every want and desire for the East Slopes. First, we have to understand where we are, compare that to where we were (the historical benchmark) and assess whether our land use trajectory will take us to a desirable future. Implicit in this is the sense we do not want to sacrifice attributes of the East Slopes in our present decisions that will have future, perhaps irreversible consequences.

Past cumulative effects exercises show the status quo approach (continuing to maintain land use pressures) is not favourable for future circumstances. Recognizing that, then a set of alternatives need to be posed and tested. That is the essence of this exercise of Cumulative Effects of Land Uses and Conservation Priorities in Alberta's Southern East Slope Watersheds. How we move forward in the East Slopes is a test- a test of our ability to be good stewards of an essential Alberta landscape.

Lorne Fitch, P. Biol

2. EXECUTIVE SUMMARY

The Alberta Chapter of The Wildlife Society (ACTWS) commissioned Cumulative Effects of Land Uses and Conservation Priorities in Alberta's Southern East Slopes to assist in an important dialogue on land use planning for the Southern East Slopes of Alberta. Part of the ACTWS mission is to advocate for science-based management. This document speaks directly to that mission. Cumulative effects analysis (CEA) was used as an appropriate method to test the status quo of land use management (business as usual) against other possible scenarios and predictions for both. As a science-based assessment this provides an opportunity to better understand different management scenarios and clearly show expected outcomes. With different management trajectories, there is an opportunity to make a real change in terms of conservation.

In the Southern East Slopes there is mounting evidence and concerns of issues related to hydrologic response (including floods), fish and wildlife habitat and populations, aesthetics, recreation and impacts on other commercial interests of the current and future land use footprint. Hence the need to create a focus on future needs and directions to guide sustainable land use decisions and, the wish to convene a conversation about future management, while opportunities for adjustment exist.

Alberta's population is expected to reach the 6.0 million mark by 2039. Much of provincial legislation and policies (e.g. the Forests Act) were made at a time when our population and the resulting pressure on our resources and landscapes were significantly lower. All Canadian provinces are committed to meeting the 2020 Biodiversity Goals and Targets for Canada. Included in these goals is Canada Target 1, which states:

"By 2020, at least 17% of terrestrial areas and inland water, and 10% of marine and coastal areas of Canada are conserved through networks of protected areas and other effective area-based measures"

Alberta currently has just under 15% of its lands and in-land waters protected. Therefore, this exercise to explore high-value (or cost-effective) opportunities for additional conservation measures is very timely.

Of particular concern is conservation of native fishes in Alberta's East Slopes. All three species of native stream trout (Westslope Cutthroat Trout, Bull Trout, and Athabasca Rainbow Trout) were once widespread and abundant, providing food and recreation for generations of Albertans. Now, all three have shown such shocking declines that each is a federally listed species at risk. This loss has caused economic hardships to Alberta's sport fishing industry, increased the business costs and regulations to resource industries, and infringed Alberta's Indigenous peoples' treaty rights. Protection and restoration of these resources is an obvious legal, economic, and social necessity.

These stream fishes are a strong indicator of the sustainability of their larger watersheds. The presence, distribution and abundance of these native trout provide a metric for watershed integrity. Declines in populations signal issues, which also include other aquatic and terrestrial species. Other biological indicators (i.e. Grizzly bears) display a similar pattern to that of the trout indices, demonstrating that impacts extend beyond trout to encompass the broader ecosystem.

The complex cumulative effects of increasingly intensive land use in the East Slopes requires the use of innovative techniques to understand, conceptualize and recommend future conservation priorities. In this project, the novel techniques of status and threats assessment for native fish (i.e. "Joe" Modelling) were logically combined with the ALCES cumulative effects process to provide a robust method of forecasting scenarios and assessing trade-offs. The concept of cumulative effects shows that, with increasing population and land use pressure, a healthy watershed environment cannot be maintained if everyone can do almost anything at any time, and anywhere.

The results of this exercise indicate cumulative effects of overlapping land uses present substantial risk to Bull Trout and Westslope Cutthroat Trout in the Southern East Slopes. As native trout species are a surrogate, or indicator of watershed integrity this indicates issues with the combined level of past and present land use activity. The setting of ecologically-relevant limits and thresholds should be of prime consideration to avoid the risk posed by additive land use effects on trout.

Watersheds in the western portion of the study area tend to have a higher natural capacity to support trout, and have also experienced less permanent conversion to agriculture and settlement, although the linear footprint (i.e. roads/trails) and the spatial footprint (i.e. logging, mining, oil and gas extraction) require reduction and restoration. As a result, preventing harmful future development, reclaiming temporary footprints, and managing access has a greater potential to improve trout performance in these watersheds, compared to ones to the east.

Climate change has the potential to negatively affect Westslope Cutthroat Trout and Bull Trout sustainability due to warming during this forecast. Despite the effect of climate change, suggested protection measures nearly doubled Bull Trout ability to persist, at the regional scale. Westslope Cutthroat Trout were less impacted by climate change, yet the situation improved for that species under protection measures.

Hydrologic changes (i.e. increased frequency, magnitude and timing of floods) are predicted with present and future land use footprints. The implications of this to trout include channel instability, more sediment additions and lower winter flows-all negatively impact trout survival. Changes in flood dynamics can also affect downstream infrastructure.

The impacts and benefits of land use vary substantially across the region due to historical development patterns, the distribution of resource potential, and management plans. Planning across large spatial scales can target those areas where there is a demonstrable impact of protecting or restoring values and where costs of protection can be minimized.

A practical trade-off between protection and resource extraction exists in the western watersheds. Identification of the appropriate balance between trout conservation (and watershed protection) and resource development can be informed by outcomes of the analysis. This can be the beginning of an important dialogue about the future of the Southern Eastern Slopes. However, failure to deal with the growing land use issue, in a timely and robust fashion, might signal further declines in watershed integrity and the species that find homes in those watersheds.

We cannot plan well for something we cannot see, especially the future. Cumulative effects analysis becomes a useful, pragmatic tool to provide factual knowledge allowing an informed choice to be made about future options. As a pathway to a sustainable future, an analysis of cumulative effects allows today's decisions to be measured against tomorrow's realities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

3. INTRODUCTION

The montane and foothills ecosystems of Alberta's Southern East Slopes are a vital source of ecological goods and services, including provision of freshwater to downstream communities such as Calgary and Lethbridge. The watersheds of the Oldman and Bow basins form essential habitat for threatened fishes such as Bull Trout (*Salvelinus confluentus*) and Westslope Cutthroat Trout (*Oncorhynchus clarki*). They are also known to support some of the highest biodiversity in Alberta. The region's natural resources also support timber production, oil and gas development, mining, agriculture, the residential sector, and recreation. Awareness of the ecological implications of land use in the Southern East Slopes is growing, including impacts to hydrology, water quality, fish, and wildlife. The Eastern Slopes Policy, the South Saskatchewan Regional Plan and work by the Oldman Watershed Council and the Bow River Basin Council, under the Water for Life strategy, have all deemed that the region's highest priority is for watershed management and headwaters protection. While no metric exists to test whether "watershed management and headwaters protection" has been achieved, the number of species at risk, and potentially at risk, in the watershed would suggest that a shift in focus towards conservation is required.

Ongoing planning initiatives provide an opportunity to ensure that land use and conservation strategies in the region support the goal of watershed management and headwaters protection. One such planning initiative is Livingstone-Porcupine Hills Land Footprint Management Plan, a sub-regional plan under the South Saskatchewan Regional Plan. The plan is intended to establish footprint thresholds to manage impacts to biodiversity and watersheds in Livingstone-Porcupine Hills. Although the approved plan identifies linear footprint thresholds, the thresholds may be insufficient, given future resource extraction. Further, the scope of the thresholds needs to be expanded to also include the spatial footprint (the use of "spatial" footprint in this report refers to those land use footprints that are generally polygonal, such as cutblocks, pastures, croplands, wellpads, and residential. The term spatial distinguishes these footprints from those that are often referred to as linear (roads, trails, seismic lines, pipelines, …). Another planning opportunity relates to the region's two forestry tenures, C5 and Spray Lakes Sawmills; both of these management plans are subject to periodic review.

To inform planning that is consistent with the priorities of watershed management and headwaters protection, a scenario analysis was completed to explore the cumulative effects of land use and climate change in the Southern East Slopes, a region encompassing the Oldman and Bow basins, extending from the headwaters of Banff south to the US border and from the BC border to just east of Highway 2. The project was initiated to provide input to the Livingstone-Porcupine Hills Footprint Management Plan, forest management planning and future sub-regional plans. Specifically, the intent was to provide guidance on implications of cumulative effects to valued ecosystem components, with a focus on exploring conservation priorities and options for threatened trout species.

This report presents the outcomes of the scenario analysis, and the underlying assumptions and methods. To provide context, outcomes are first summarized from an experts meeting that helped guide the initiative.

4. EXPERTS MEETING SUMMARY

On February 7 and 8, 2019 a group of content experts was convened in Airdrie, Alberta to provide guidance to the Southern East Slopes initiative. Included in this group were: a forest hydrologist with a background in assessing effects of logging on watershed systems, a forest ecologist, a wildlife ecologist, a fisheries ecologist with a background in species at risk management and recovery efforts, a species at risk biologist, two landscape ecologists with extensive backgrounds in modelling landscape cumulative effects, and a fisheries ecologist and modeller.

The project proposal was reviewed to develop ecological and land use levers, dose response modifiers and performance indicators. The levers and performance indicators were carefully scrutinized to ensure that they fit the project needs (model, budget, and available, accessible data).

A matrix was developed to illustrate how each of the elements fit, with lever cell values providing the opportunity to change scenarios and the performance indicators color-coded. The dose-response modifiers were represented as two dimensional relationships between levers and performance indicators.

Hydrological impacts of timber harvest were considered using a non-traditional approach that addresses the potential for alteration to geomorphic controls on aquatic ecosystems (Appendix B). This informed the discussion about the project intents and the inputs required to better assess implications for flood frequency and intensity, channel stability, water quality and impacts on threatened trout species like Westslope Cutthroat Trout and Bull Trout.

The linkage between the Alberta Cumulative Effects Assessment Methodology (the "Joe" model) was explored to provide insight into how provincial fisheries staff are using the model, to understand the variables affecting population recovery of threatened fish species. The model was seen to be an important consideration for inclusion into the initiative and arrangements were made to share information on dose-response curves and data for threatened trout species in the region.

Based on discussions there was an exploration of whether expanding the study area from the Livingstone-Porcupine Hills (encompassing the Oldman watershed), to the Southern East Slopes (Bow and Oldman watersheds) would increase the relevance of the analysis to recovery planning for Bull Trout and Westslope Cutthroat Trout. Additional benefits of expanding the study area beyond the C5 boundary (Livingstone-Porcupine Hills) included incorporating areas with different management practices (i.e. protected areas vs mixed use) and consideration of impacts to connectivity for species like Grizzly Bear (*Ursus arctos).*

Agreement was reached to compare current and potential future indicator condition to an estimated natural range of variation to assess status relative to a natural baseline. The group also agreed to assess future status by simulating land use over 50 years using the ALCES Online platform. Forestry, energy, residential, mining, recreation and transportation land uses were incorporated into the spatially explicit simulations as well as natural disturbance (fire), and climate change.

The discussion also concluded that assumptions for a Business as Usual scenario were needed. The intent of the scenario was to explore the consequences of extending current land use policy 50 years into the future. Conservation strategies were subsequently assessed to estimate potential benefits and priorities.

It was also clear that comparison of indicator condition with and without the conservation strategies would provide an estimate of the efficacy of the strategies. Although the simulations were completed at a finer resolution, current and potential future indicator status are reported at the scale of HUC 10 watersheds in order to link to trout recovery planning.

A feedback loop with the group was also established to allow for additional input to the initiative and to review outputs to ensure these meet the needs to better define the spatial footprint and implications to valued forest components like threatened trout species and water quality.

5. METHODS

The study area is the Southern East Slopes, a 30,000 km^2 region encompassing the upper portions of the Oldman and Bow basins, extending from the headwaters of Banff south to the US border and from the BC border to just east of Highway 2 (Figure 1). Although the project's focus was the Livingstone-Porcupine Hills Footprint Management Plan and the C5 Forest Management Plan, the study area was expanded to the Southern East Slopes in order to increase the relevance of the analysis to provincial recovery planning for trout species.

Two computer models were used to assess cumulative effects in the region. Alberta's method of assessing status and threats to fish, the "Joe" Model (MacPherson et al. 2019) was used to integrate the consequences of multiple threats to the status of Westslope Cutthroat Trout (MacPherson and Earle 2017) and Bull Trout (Reilly et al. 2016). ALCES Online was used to simulate land use and climate scenarios in order to explore potential future change in threats and explore the effectiveness of protection (Carlson et al. 2019). The utility of using native trout is that these species are indicators of watershed integrity and can provide signals of concern. Although a focus on the scenarios is the status of trout populations, other indicators were also assessed such as risk to Grizzly Bear, hydrologic change, and water quality. The resolution of the analysis was 200 m cells used in the ALCES Online simulations. Each cell could be multivariate in its composition (i.e., proportion of a cell belonging to each of a number of natural and anthropogenic cover types), but 200 m was the finest spatial scale at which spatial relationships (juxtaposition) were tracked. The response of most indicators, including trout, was subsequently summarized at the scale of HUC 10 watersheds (Alberta Environment and Parks 2017) (Figure 1).

The objectives to assess cumulative effects, especially with respect to trout, and explore strategies to mitigate risks, were addressed through two stages of analysis. First, impacts of plausible land use and climate change to indicators over the next five decades were simulated to assess cumulative effects. Second, priority areas for conservation action were identified by simulating each watershed's performance with and without protection to estimate each watershed's conservation cost-effectiveness. The analysis involved and is defined by the following steps: i) estimating the region's current landscape composition; ii) simulating future (50-year) changes in landscape composition under a plausible future development scenario; iii) simulating future changes in landscape composition in the absence of future land use; iv) calculating indicator response to estimate future risk to trout and economic performance with and without protection; and v) using the outcomes to prioritize watersheds for conservation based on cost-effectiveness of trout risk reduction. These steps are now described in greater detail.

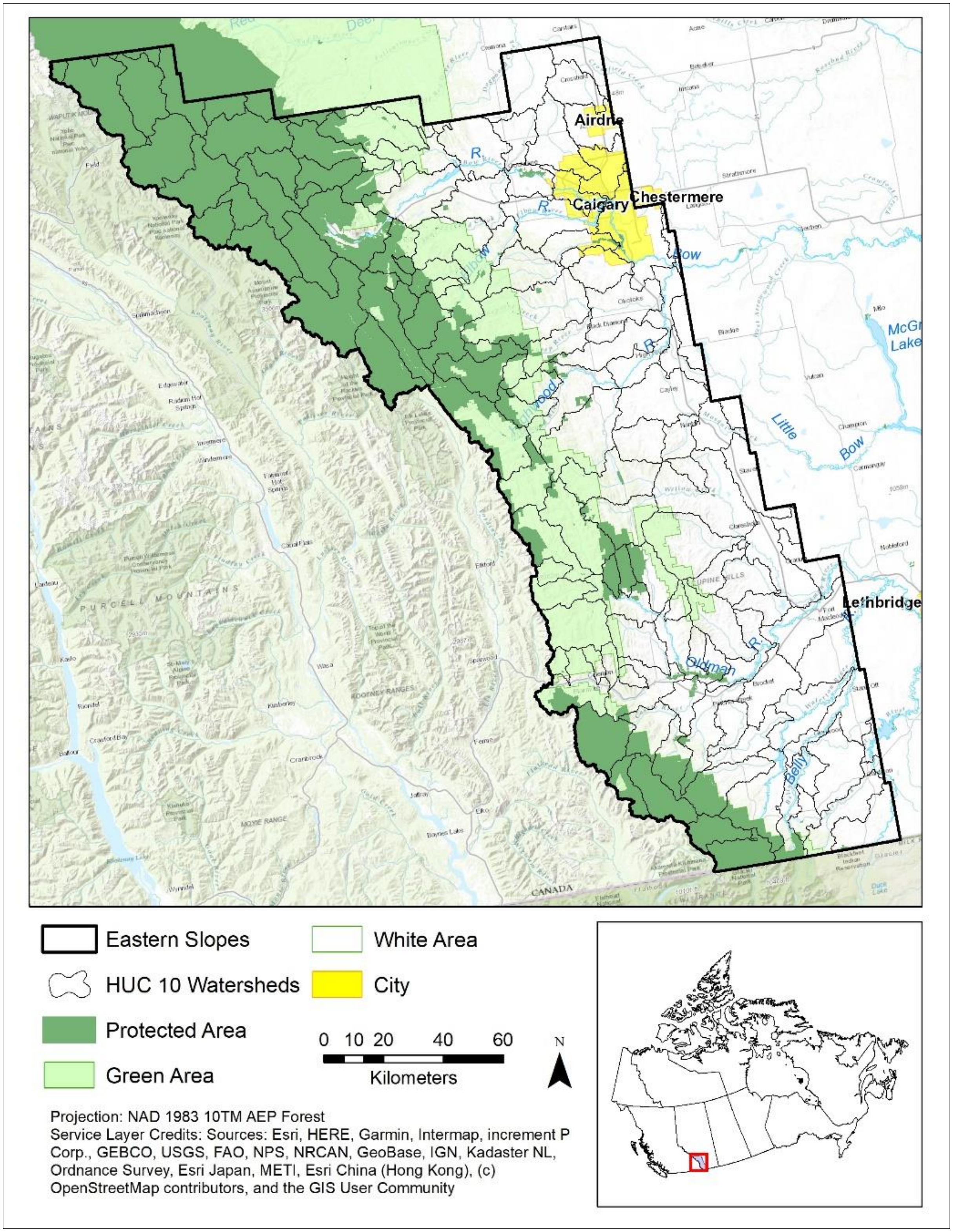


Figure 1. Map of the Eastern Slopes region showing HUC 10 watersheds as well as protected, forested (green), and settled (white) areas.

5.1. Current landscape composition

The current composition of the study area, including natural and anthropogenic cover types (Table 1), was derived from the integration of multiple land cover products including the ABMI Wall-to-Wall Land Cover Inventory and Human Footprint Data[1], Grassland Vegetation Inventory[2], Combined Wetlands Inventory, AltaLIS Hydrography, and numerous additional footprint inventories from Open Street Map, AltaLIS, CanVec, Alberta Energy Regulator, Alberta Environment and Parks, National Rail Network, ESRI Basemap, Trans Canada Trail, Crowsnest Pass QuadSquad, HikeAlberta, and municipalities (e.g., City of Calgary).

Table 1. Natural and anthropogenic cover types used to define the composition of the study area.

Name	Type	Area (km^2)
Forest Coniferous	Terrestrial Landscape	7148
Forest Deciduous	Terrestrial Landscape	1378
Forest Mixed	Terrestrial Landscape	623
Grassland	Terrestrial Landscape	6158
Shrubland	Terrestrial Landscape	2570
Exposed Land	Terrestrial Landscape	3386
Rock Rubble	Terrestrial Landscape	15
Snow Ice	Terrestrial Landscape	136
Wetland Total	Terrestrial Landscape	577
Water Lentic	Aquatic Landscape	331
Water Lotic	Aquatic Landscape	362
Agriculture Crops	Agricultural Landscape	2934
Agriculture Pasture	Agricultural Landscape	2754
Airport	Footprint	24
Cemeteries	Footprint	2
Feedlots	Footprint	38
Industrial	Footprint	193
Lagoons	Footprint	4
Landfill	Footprint	10
Major Road	Footprint	65
Mine Coal	Footprint	4
Mine Pits	Footprint	57
Minor Road	Footprint	201
Gas Well	Footprint	3
Oil Well	Footprint	5
Other Well	Footprint	18
Pipelines	Footprint	36
Rail	Footprint	6
Recreation	Footprint	78
Rural Settlement	Footprint	444
Seismic Lines	Footprint	61
Urban	Footprint	379
Towers	Footprint	1
Trails	Footprint	30
Trail/Winter Road	Footprint	9
Water Anthropogenic	Footprint	27

[1] http://www.abmi.ca/home/data-analytics/da-top/da-product-overview/GIS-Human-Footprint-Land-Cover-Data/Land-Cover.html

[2] http://www.albertapcf.org/native-prairie-inventories/gvi

The current age (i.e., time since disturbance) of forested landscapes was derived from a Canadian forest age dataset (Pan et al. 2011), corrected to incorporate more detailed age information from ABMI cutblock, Government of Alberta wildfire data, and the Grassland Vegetation Inventory. The cutblock and fire datasets superseded the Canadian forest age dataset due to their higher resolution (disturbance polygons of various sizes as opposed to the Canadian forest age dataset's 1 km^2 resolution). Age of cutblock or fire polygons was based on the year of disturbance.

5.2. Examples of Land Use Footprints

To assist those readers who have not travelled extensively within the East Slopes study area, or are unfamiliar with its land use footprints, a selection of aerial images are provided to illustrate examples of the aerial footprints associated with forestry (Figure 2), agriculture (Figure 3), hydrocarbon sector (Figure 4), residential (Figure 5, Figure 6), and recreation (Figure 7) sectors.

Figure 2. Aerial satellite imagery of a portion of the headwaters of the study area, illustrating examples of forest sector logging.

Figure 3. Aerial satellite imagery of a lower portion of the study area, illustrating examples of pasture and crops within the agricultural sector. The crops and pastures are found within the central portions of this image.

Figure 4. Aerial satellite imagery of a portion of the study area, illustrating examples of the hydrocarbon sector footprint (well pads, access roads, industrial facilities).

Figure 5. Aerial satellite imagery of a portion of the headwaters of the study area, illustrating towns occupying the Crowsnest Pass region.

Figure 6. Aerial satellite imagery of a lower portion of the study area, illustrating examples of small sized towns, rural residential and recreational (golf course) footprints.

Figure 7. Aerial satellite imagery of a portion of the headwaters of the study area, illustrating recreational footprints. In this case the access roads and campgrounds of the Little Elbow Recreational Area.

5.3. Simulating Future Development

Simulation of future land use in the focal study area required derivation of development trajectories for each influential land use in the study area, including energy, forestry, human settlements, mining, and transportation, as well as fire. In addition to the rate of development, assumptions were required regarding the intensity and spatial distribution of associated footprints. Assumptions governing the simulation of future land use and natural disturbance are described.

5.3.1. Hydrocarbon Sector Forecast Assumptions

The rate of oil and gas[3] well completions during the first decade of the simulation are based on projections developed by the Alberta Energy Regulator (AER) for 2018 to 2027 (AER 2018). After 2027, completion rates are assumed to continue at the 2027 rate from the AER projection because longer term projections for Alberta suggest that the rate of hydrocarbon development over the period is expected to remain relatively stable. Under the National Energy Board's[4] (NEB[4] 2017) reference case, gas well completions (across types) is projected to increase from 935 in 2027 to 1061 in 2040 (13% increase) and conventional light oil production is projected to increase from 341.97 thousand barrels per day to 421.23 thousand barrels per day (23% increase).

Oil and gas production from existing and new wells during the first decade was based on production rates from AER (2018). Thereafter, total production remains at the same level but shifts towards new wells as older wells become less productive. For example, production from wells existing at the start of the simulation continues to decline at the same rate assumed by AER (2018) for the first decade, whereby production in a given year is 90% that of the previous year.

The conventional oil and conventional gas well completion projections from AER are by Petroleum Services Association of Canada (PSAC) region. PSAC regions AB1 and AB2 overlap with the study area. Projections for these regions were adjusted (i.e., reduced) based on the proportion of each PSAC region's oil and gas wells that occur within the study area.[5] The location of new oil and gas wells is based on the location of oil and gas hydrocarbon deposits (Mossop and Shetsen 1994).

Exploration wells and seismic line footprint was created based on the relative abundance of these

---

[3] Shale gas wells were not included in the simulation because the study area has minimal overlap with Alberta's shale- and siltstone-hosted hydrocarbon regions as described in Rokosh et al. (2012).

[4] AER (2018) was used instead of NEB (2017) as the source for the projected rate of well completions because it provides greater spatial detail (by PSAC region instead of provincial) and greater detail on well type.

[5] The study area accounts for 94.62% and 3.43% of the Petrowell Oil Unityb footprint in PSAC AB1 and AB2, respectively; and 37.25% and 1.22% of the Petrowell Gas Unityb footprint in PSAC AB1 and AB2, respectively.

features and wells on the current landscape. Exploratory wells were created at a rate of 0.14 exploratory wells per development well (i.e., productive oil and gas wells), which is the ratio between exploratory and development wells drilled in western Canada over the past decade (CAPP 2017). Seismic line footprint area was created at a rate 1.22 times that of well footprint area, based on the relative abundance of seismic and well footprint in Alberta.[6] Pipelines were created as needed to link development wells to the existing pipeline network. Roads were created as needed to link all wells to the existing road network.

For all well types, completions were assumed to occur within 5 km of existing wells of that type, with higher likelihood of completions in closer proximity to the wells. Each well pad is assumed to house one well covering 1 ha. Seismic footprint was simulated to occur within 10 km of new well completions, with higher likelihood of completions in closer proximity to new wells. The intensity of seismic footprint (i.e., simulated footprint per cell) is based on current seismic footprint pattern in the study area.

Energy sector footprints are considered permanent in the context of a 50-year simulation. Seismic lines are assumed to be permanent, based on a retrospective study of 35-year-old seismic lines in northern Alberta that found over 90% of the disturbance to remain in a disturbed state (Lee and Boutin 2006). Seismic line footprints are simulated to not persist in farmland and grassland, and pipeline right of way footprint to not persist in farmland.

5.3.2. Coal Forecast Assumptions

While there are no active coal mines in the study area, the Grassy Mountain Coal Project is proposed in the vicinity of an inactive mine. The simulation makes the assumption that the project will proceed. New footprint at the Grassy Mountain mine includes pits, rock disposal areas, topsoil storage areas, ponds, ditches, coal handling and processing plan infrastructure, a covered conveyor/access road/powerline right of way, a railway loop, and a proposed golf course area as identified in the environmental assessment for the Grassy Mountain Coal Project (Riversdale Resources 2016). The proposed project is to be developed over the next 23 years. Development of the handling and processing plant infrastructure, ponds and ditches, railway loop, right of way, and topsoil storage occurs in the first decade of the simulation. Development of pits and rock disposal areas is spread across the mine's 23-year lifespan, with growth occurring outwards towards the perimeter of the pit and disposal area polygons. The project is expected to produce 93 million tonnes

[6] The ratio between seismic and well footprint in the study area is much higher (6.90) than it is in Alberta (1.22). The ratio for Alberta was used to avoid possible exaggeration of future seismic line development.

of coal.[7]

Since reclamation of coal footprint is not included in the simulation, the effects of coal mining on wildlife may be exaggerates. There are, however, additional coal mines proposed for the Oldman basin, for which insufficient details exist to simulate these mines in this project. As these proposals advance, and details emerge, additional simulations in Alces Online can be completed.

5.3.3. Forestry Forecast Assumptions

There are two management areas with forestry in the study area: C5 and the Spray Lake Sawmills Forest Management Agreement (FMA) area.

The C5 management area is divided into three forest management units C5(176), C5(179), and C5(181)), each of which occur in the study area. Planned harvest area was as per the C5 forest management plan, with the exception of C5(179). Subsequent to the most recent forest management plan, the majority of FMU C5(179) was protected through the establishment of Castle Provincial Park and expansion to Castle Wildland Provincial Park. To account for the new protected area, the C5 annual allowable cut was reduced from 197,226 m3 to 157,800 m3 (https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/formain15761/$FILE/fmuc5aact-ables_Feb17_17.pdf). Planned harvest area for the first four decades was as projected under the preferred forest management scenario (The Forestry Crop. 2006). The preferred forest management scenario from the timber supply analysis calls for harvest at 120% of coniferous AAC the first 2 decades to reduce susceptibility to mountain pine beetle, and then a reduction to 90% of coniferous AAC thereafter. Harvest in the first 2 decades is focused on FMU's C5 (176) and C5 (181) where pine is more abundant. Timber harvest in the fifth decade equalled the average of the third and fourth decades (i.e., following the reduction to 90% AAC). The spatial distribution of harvest was proportional to each FMU's planned harvest intensity (i.e., planned harvest area per total forest area) and was also influenced by forest age (oldest first). To be eligible for harvest, forest was required to be older than the minimum harvest age for coniferous forest (90 years), and slopes steeper than 45 degrees were avoided (The Forestry Corp 2006).

Five compartments from the Spray Lake Sawmills Forest Management Area occur wholly within the study area (Ghost River, Highwood River, Jumpingpound Creek, McLean Creek, Sullivan Creek), and an additional three compartments are partially within the study area (Atkinson Creek, Burnt Timber Creek, B9 Quota). Simulated forest harvest area for each compartment is as per that scheduled for the Preferred Forest Management Strategy as presented in Chapter 8 of the Spray Lake Sawmills Detailed Forest Management Plan (DFMP). The DFMP provides harvest area by

[7] http://www.rivresources.com/site/Projects/grassy-mountain-project2/overview3

compartment for multi-year intervals from 2001 to 2198 (Spray Lake Sawmills 2006). For a given multi-year interval, harvest area is assumed to be equal distributed across years within the multi-year interval. Annual harvest area compartments partially within the study area are adjusted based on the proportion of each occurring within the basin. Harvest rules are based on the Spray Lakes Sawmills DFMP, including harvest sequencing by forest age, a minimum harvest age of 80 years, and avoidance of slopes steeper than 45 degrees.

The size of simulated harvest patches is based on the size of forest patches harvested in the study area between 2000 and 2009 according to harvest data from ABMI. Cutblocks are simulated to recover to the pre-harvest forest type, with no regeneration lag. Roads are created during the simulation as required to link harvest patches to the road network. In-block roads are assumed to regenerate with cutblocks and are therefore not simulated.

5.3.4. Urban and Rural Residential Forecast Assumptions

Settlement footprint is simulated to grow at the rate of population growth according to the medium population growth projection from Alberta Government for the period of 2018 to 2046.[8] The population projection is extended out to 2068 by assuming constant population growth after 2046.[9] Population projections are available by census division (CD). Due to the substantial differences in projected population growth rate across CD's, separate settlement growth rates are assumed for each CD. Simulated rural settlement footprint took the form of acreages located within 1 km of existing rural settlement development. Simulated urban footprint is located at the periphery of existing settlements. For both rural and urban settlement footprint, the relative likelihood of simulated development is proportional to the patch size of existing developments (i.e., higher likelihood of development adjacent to larger existing developments). Roads are developed as needed to link acreages to the road network. Settlement footprint is excluded from protected areas.

5.3.5. Recreation

The major footprints of the recreational sector include golf courses, hiking trails, motorized trails, campgrounds, and random campsites. Simulation of recreation footprint focuses on golf courses, which account for 62% of the recreation footprint in the province[10]. The simulated expansion of golf

---

[8] https://open.alberta.ca/publications/5336155

[9] Constant as opposed to exponential population growth was assumed because the population projection for the period of 2018 to 2046 exhibited linear growth.

[10] Calculated with ALCES Online. ALCES Online was initialized using on a compilation of anthropogenic footprint inventories. Sources of inventories include Alberta Environment and Parks, ABMI, AltaLIS, CanVec, and GVI.

course footprint is proportional to the expansion of urban and rural residential footprint, based on the current ratio between golf course footprint and urban/rural residential footprint in each census division. Golf courses were simulated as either 0.5 km^2 (54% of new golf courses) or 1 km^2 (46% of new golf courses) based on the current size class distribution of golf courses in the province. Simulated golf courses are located within 30 km of cities and towns, a buffer that accounts for 92% of current golf course footprint in Alberta.

Roads and trails used for motorized recreational use were captured under the Development footprint as the two are linked. Although random camping is an additional recreation use, its footprint is often difficult to identify remotely. Selected locations of random camping is illustrated at large and small spatial scales in Figure 8.

Figure 8. The blue markers indicate selected locations that are regularly used for random camping within the study area. This is not a full survey but rather examples that illustrate the magnitude of random camping along the east slopes. The lower image shows the proximity of random camping vehicles to streams and their tributaries.

5.3.6. Aggregate Forecast Assumptions

Between 2005 and 2018, average annual gravel and sand production in Alberta was 62,184 kt (Natural Resources Canada 2019), with substantial interannual variation and minimal evidence of a directional trend. Of the 339.5 km^2 of gravel pit footprint in Alberta, 44.8 km^2 (13.2%) occurs in the study area[11]. Applying this proportion results in a production assumption of 8205.8 kt/year for the study area.

Assuming an average economic deposit depth of 5 m and a yield of 1.7 tonne/m3[12], a kt of gravel production requires the disturbance of 117.6 m^2. This factor is applied to convert the simulated production trajectory (tonne/year) to footprint creation (m^2/year). The simulated size of each gravel pit is 12.5 ha, based on the average size of a gravel mine in Alberta. Future gravel pits are distributed across census divisions in proportion to the current distribution, and are constrained to occur in the location of aggregate deposits. Simulated gravel pits are excluded from protected areas.

5.3.7. Agriculture Forecast Assumptions

Agricultural land did not expand during the forecast. Census divisions that overlap with the study area have exhibited a decline in farmland in recent years.

5.3.8. Fire Forecast Assumptions

The simulated fire rate is 0.06% x 2.5= 0.15% for the first 2 decades and 0.06% x 2.76=0.17% for the last 3 decades of the simulation. The historical rate for the Southern Cordillera homogenous fire regime zone (within which the study area is located) is 0.06%/year (Boulanger et al. 2014). The predicted increases in fire rate relative to historical for the 2011-2040 and 2041-2070 periods is 2.5 and 2.7, respectively, under climate scenario RCP2.6 (Boulanger pers. comm.). Fire is assumed to burn forest and shrub cover types. Fire location is stochastic but influenced by relative burn probabilities as per fire selection ratios by forest cover and age class (Bernier et al. 2016). Fire selection ratios are only available for forest types (deciduous, coniferous, mixedwood); shrubland is assumed to have the same relative burn probability as young deciduous forest, the forest category exhibiting the lowest fire selection ratio. Burns are distributed across size classes based on the size class distribution of fires according to Alberta's historical wildfire data.

---

[11] Based on a compilation of anthropogenic footprint inventories that was prepared for ALCES Online. Sources of inventories include: AEP, ABMI, AltaLIS, CanVec, and GVI.

[12] Table 1 of the document 2013_11_08_Full_Report_Aggregate_Supply_Demand_Update_and_Analysis.

5.3.9. Air Temperature Forecast Assumptions

Future monthly average temperature was as per projections of the second generation Canadian Earth System Model (CanESM2) for emission scenario RCP 2.6, a conservative climate change projection that assumes emissions are reduced. CanESM2 projections were collected from the ClimateNA software package, and downscaled to 200 m resolution using the approach of Wang et al. (2016).

5.3.10. Stream Temperature Forecast Assumptions

Future summer stream temperature was modelled as per MacDonald and Jones (2017) for the Bow River and Oldman River basins located within the study area. The model incorporates a covariate for mean summer (June, July, August) air temperature that is linked to CanESM2 projections, as well as covariates for coniferous forest, elevation, and slope.

5.4. Simulating Protection

A protection scenario was simulated to estimate if future status improved under a strategy that reflects up to the maximum conservation potential for the Eastern Slopes region. The strategy focuses on protecting watersheds from future development, restoring natural land cover through reclamation of temporary footprints (energy wells, seismic lines, access roads, and truck trails). Reclamation converted these footprints to natural land cover over a 20-year period. Oil and gas production from wells existing at the start of the simulation continued at a declining rate until wells were reclaimed.

It was assumed that access management in combination with a regulatory protection would reduce the effect of angling mortality on trout populations to levels observed in protected areas. Simulation of fire was identical to the development scenario so that any change in status between the two scenarios could be more directly attributed to conservation actions. The protected strategy was simulated across the entire study area and improvement in indicator status was mapped at the HUC 10 watershed scale to identify where strategies can be implemented for maximum impact.

5.5. Indicators

The following indicators are being assessed to explore the cumulative effect of land use:

1. Development footprint – the taking up of land by development was assessed as direct disturbance of land by industrial, settlement, and agricultural footprints and associated infrastructure.

2. Intact landscapes – natural land undisturbed by development. Cells (200 m) without any type of development or settlement footprint are considered intact.

3. Wildlife – grizzly bear exposure index.

4. Fish – fish sustainability indices for trout.

5. Hydrologic response - equivalent clearcut area.

6. Water quality – Water quality index based on nitrogen, phosphorous, and sediment loading.

5.5.1. Development Footprint

Total development footprint included the full set of anthropogenic features tracked in the simulations: energy sector footprints (wells, seismic lines, pipelines); settlement footprints (residential); mining footprints (coal mines and gravel pits); agricultural footprints (pasture and cropland); and other footprints (cemeteries, undifferentiated industrial, lagoons, landfills, power generation stations, powerlines, recreational footprint, and sumps).

5.5.2. Intact Landscapes

Intact core area was calculated as the total extent of cells that do not contain footprint or farmland. Intact patch size was calculated as the size of each patch of cells that does not contain footprint or farmland.

5.5.3. Equivalent Clearcut Area

Equivalent clearcut area (ECA) is a metric that approximates the hydrological effect of forest disturbance, with a higher value indicating less capacity of a forest canopy to intercept snow and a greater potential for altered rate and timing of runoff. ECA ranges from 0 (i.e., mature forest) to 100 (i.e., clear cut). ECA is calculated as follows (Winkler and Boon 2017):

$$ECA = A \times (1 - HR)$$

where A is forest area and HR is hydrologic recovery. Hydrologic recovery is 0 for forest converted to non-forest footprints (i.e., footprint). The hydrological effect of forest disturbance declines with time as regeneration of the forest occurs (Table 2). To estimate the relationship between recovery and time since disturbance, a hydrologic recovery curve for lodgepole pine dominated forest in the BC Kootenays was used (Winkler and Boon 2015). The hydrologic recovery curve was selected due to the proximity of Kootenays to the South Eastern Slopes and similarity in forest type. The curve estimates the relationship between hydrologic recovery and forest height (expressed as % of max height). Applying the curve in ALCES Online required that forest age be converted to forest height. The relationship between forest age and height for lodgepole pine forest in Alberta is provided by Huang et al. (1994). The relationship depends on site index (i.e., height at 50 years). The distribution of site index in the study area was estimated using a relationship between site index and average July temperature for lodgepole pine forest in Alberta (Monserud et al. 2006). When using climatic parameters to estimate site index, classification accuracy improved when wider site index intervals were used. Therefore, forest in the study area was classified into the following classes: SI 4 – 8, SI 9 – 13, SI 14 – 18, and SI 19 – 23. For each SI class, the relationship between forest age and height (or % of max height) was based on the relationship for the intermediate SI within the class (e.g., SI 6 for the class SI 4 – 8).

Table 2. Relationship between hydrologic recovery and forest height. Based on a relationship for the lodgepole pine in BC Kootenays, as presented by Winkler and Boon (2015).

Hydrologic Recovery	Forest Height (% of Mature)
0	15
0.25	30
0.50	40
0.75	50
0.90	60

5.5.4. Water Quality Index

To assess the effect of simulated changes in landscape composition and climate change on water quality, chemical load factors (CLF) from Table 6 in Donahue (2013)[13] are applied to natural and anthropogenic cover types and multiplied by annual precipitation to calculate sediment, phosphorus, and nitrogen load (kg/ha) (Table 3). The load estimates are then applied to calculate

[13] Donahue, W.F. 2013. Determining Appropriate Nutrient and Sediment Loading Coefficients for Modeling Effects of Changes in Landuse and Landcover in Alberta Watersheds. Water Maters Society of Alberta, Canmore, AB.

water quality indices for sediment, phosphorus, and nitrogen with values ranging from 0 to 1, with lower values indicating compromised water quality. This is done by dividing the load expected from undisturbed forest by the load calculated for the simulated landscape.

Table 3. Chemical load factors (Table 6 of Donahue 2013) used to calculate sediment, phosphorus, and nitrogen load.

Cover type	Chemical load factor (kg/mm*ha)		
	Phosphorus	**Sediment**	**Nitrogen**
Forest and shrubs	0.00061	0.55350	0.00340
Herbaceous	0.00013	0.07153	0.00202
Crops (flat)	0.00096	0.27041	0.01121
Pasture (flat)	0.00085	0.29718	0.00913
Feedlots	0.32423	4.99275	1.62012
Roads, Rail	0.00314	0.41330	0.09825
Trails (non-motorized)	0.00447	1.06635	0.00780
Mines	0.00068	0.42273	0.00531
Industrial plants	0.00184	1.08731	0.01426
Settlements (average of city core and suburban)	0.00169	0.48652	0.01108
Rural residential	0.00026	0.06309	0.00316
Recreation (golf courses)	0.00241	0.45450	0.02159
Transmission lines	0.00134	0.36043	0.00346
Pipelines	0.00201	0.54065	0.00519
Wellpads	0.00689	1.93873	0.01368
Seismic lines	0.00101	0.27032	0.00259

5.5.5. Grizzly Bear Exposure Index

The grizzly bear exposure index is based on an empirical modeling process undertaken to develop grizzly bear habitat relationships for use in ALCES (Nielsen and Boyce 2003). The index integrates selection and mortality probabilities to identify areas that are selected by grizzly bears but that also present high mortality risk. As such, the index identifies mortality traps, with higher index values indicating higher levels of risk. Nielsen and Boyce (2003) developed resource selection functions for both selection and mortality from southwestern Alberta radiotelemetry use and mortality data (Table 4). The resource selection functions are being applied in ALCES Online to calculate relative selection and mortality probabilities by applying the equation:

$$y = e^{(b_1x_1+b_2x_2+b_3)} \Big/ \left(1 + e^{(b_1x_1+b_2x_2+b_3)}\right)$$

where b_1 is the coefficient for road density coefficient, x_1 is the cell's road density (km/km^2), b_2 is the coefficient of other linear density, x_2 is the cell's density of other linear footprints, and b_3 is the area-weighted coefficient across landscape types. A cell's exposure is calculated by multiplying the selection and mortality probabilities together. Calculation of the exposure index is limited to the montane and foothills natural regions.

Table 4. Coefficients for grizzly bear selection and mortality, based on Nielsen and Boyce (2003).

Landscape Type	Selection	Mortality
Deciduous forest	-0.017	-0.293
Coniferous forest	0.194	-0.261
Shrubland	0.502	0.985
Grassland	0.357	1.045
Rock/Snow/Exposed	-1.249	-0.123
Water/wetland	-0.777	1.229
Farmland and rural residential	-1.51	2.281
Roads	0.347	0.755
Other footprints	-0.99	2.081
Road density	-0.009	0.681
Other linear density	0.045	0.314

5.5.6. Trout Fisheries Sustainability Indices

Alberta's process of assessing status and threats to fisheries, the "Joe" Model (Alberta Cumulative Effects Assessment Methodology) is being used to quantify impacts to trout populations (Bull Trout and Westslope Cutthroat Trout) in the region. The process of building and using these cumulative effects models is designed to include stakeholders and directly incorporate local, traditional, and academic knowledge. Ideally designed in an interactive workshop setting and refined through data analysis extensive exploration of the literature, a completed model results in clear statements of hypotheses of impact mitigation (e.g., given our assumptions, what is the predicted outcome from proposed actions?). Modelled results are treated as hypotheses needing testing, rather than forecasts. The results from these models are emphasized as simply the mathematical representation of the participants' best available understanding of threat quantity, effect and combination on the particular population. As such, the Joe Model serves two related strategic purposes: 1) it quantifies existing impacts to identify the hypothetical key drivers of population status; and 2) it allows scenario modelling of mitigation actions to explore and optimize potential combinations of recovery actions. In this project, dose-response curves developed using the Joe Model will be applied to link stressors (e.g., climate, linear disturbance, forest disturbance, water quality, stream crossings) to trout status. Stressors that are incorporated include temperature, direct mortality (e.g., entrainment, angling), stream network fragmentation by stream crossings and dams, competition or replacement (e.g., Brook Trout, Rainbow Trout, Lake Trout), hybridization, water quality (phosphorous, sediment), water quantity (surface water withdrawals, hydrologic change), selenium contamination, whirling disease, and habitat loss (MacPherson and Earle 2017, Reilly et al. 2016).

The dose-response curves were applied in ALCES Online to assess response of trout populations to cumulative effect scenarios and mitigation strategies. Trout status (FSA; Fisheries Sustainability Assessment) were assessed using risk rankings (Figure 2) that apply increased risk with further departure from reference (natural) conditions.

FSA Rank	Risk Assessment Rank	Percent (%) of Reference Population
5	Very Low Risk	100
4	Low Risk	70-100
3	Moderate Risk	50-70
2	High Risk	20-50
1	Very High Risk	<20
0	Functionally Extirpated	0

Figure 9. Risk assessment ranks that are being used for trout indicators, following MacPherson, et al, 2019.

5.5.6.1 Natural Limitations

Bull Trout and Westslope Cutthroat Trout Historic Adult Density FSI score for year 1900 was provided by the Government of Alberta for each watershed in the species' historic range. This measure represents the relative status of each species prior to extensive human disturbance and harvest and is used as a surrogate measure of overall natural limitations for Bull Trout and Westslope Cutthroat Trout populations within each HUC10 watershed (AEP 2016, 2017).

5.5.6.2 Temperature

Bull Trout and Westslope Cutthroat Trout are thermally sensitive species vulnerable to increased water temperature resulting from land disturbance and climate change (AEP 2016, 2017). To characterize the expected influence of warm temperature on the sustainability of Bull Trout populations, a dose-response curve was applied to Decadal August Average Temperature at the HUC10 watershed scale (Figure A1.1; AEP 2016). For Westslope Cutthroat Trout populations, a dose-response curve was applied to Summer Stream Temperature at the HUC10 watershed scale (Figure A1.2; AEP 2017).

5.5.6.3 Direct Mortality

There can be several causes of direct mortality among trout in a population, including natural causes, entrainment, angling, indigenous harvest, and research/monitoring activities (AEP 2016, 2017). Mortality levels from indigenous harvest and research/monitoring activities are currently estimated as insignificant and estimates of entrainment mortality are not strongly supported (AEP 2016, 2017). Natural mortality was assumed to be 20% of total annual mortality for Bull Trout populations (AEP 2016) and 35% for Westslope Cutthroat Trout populations (AEP 2017) and constant over time. During the business as usual scenario, angling mortality was simulated in ALCES Online at the HUC10 watershed scale based on an assumed linear relationship between road access and angling mortality. To do this, a regional access multiplier was calculated in each decade as the area of Total Road on the simulated landscape divided by the current area of Total Road and then applied to current estimates of angling mortality for each species provided by the Government of Alberta. To characterize the effect of direct mortality on Bull Trout sustainability, a dose-response curve was applied to total annual mortality measured as the sum of natural mortality and angling mortality (Figure A2.1; AEP 2016). For Westslope Cutthroat Trout, a similar dose-response curve was applied to total annual mortality measured as angling mortality in addition to natural mortality (Figure A2.2; AEP 2017).

Reclamation of minor roads (i.e., reduced access) alone was not sufficient to reduce angling mortality from levels observed under business as usual conditions. This suggests that regulatory protection in addition to reduced access is required to sustain trout populations, a combination which typically exists in federal and provincial protected areas. As a result, the protection scenario applied a constant effect of angling mortality based on levels estimated for Bull Trout in Banff National Park (FSI = 4) and for Westslope Cutthroat Trout in Peter Lougheed Provincial Park (FSI = 4).

5.5.6.4 Stream Network Fragmentation

Habitat connectivity for trout is reduced primarily by culverts and other improperly constructed/maintained crossing structures, as well as large dams that are not equipped with fish passage facilities (AEP 2016, 2017). To simulate stream crossing density in ALCES Online at the HUC10 watershed scale, it was assumed that increased road densities would result in increased stream crossing. A regional access multiplier was calculated in each decade as the area of Total Road on the simulated landscape divided by the current area of Total Road and then applied to current estimates of stream crossing density provided by the Government of Alberta. Species-specific dose-response curves (Figure A3; AEP 2016, 2017) were applied to simulated stream crossing density to characterize its effect on the sustainability of Bull Trout and Westslope Cutthroat Trout populations.

Qualitative estimates of habitat fragmentation caused by large dams (i.e., barrier dam effect size) were provided by the Government of Alberta at the HUC10 watershed scale and assumed to be a constant over time. A linear dose-response curve was applied to characterize its effect on the sustainability Bull Trout and Westslope Cutthroat Trout populations (Figure A4; AEP 2016, 2017).

5.5.6.5 Competition

Competition from non-native, invasive Brook Trout (*Salvelinus fontinalis*) and Lake Trout (*Salvelinus namaycush*) threaten Bull Trout populations whereas competition from Brook Trout, Rainbow Trout (*Oncorhynchus mykiss*) and hybrid cutthroat trout threaten populations of pure Westslope Cutthroat Trout (AEP 2016, 2017). The amount of habitat expressed as a percent of the total carrying capacity in which these species are out-competing Bull Trout or Westslope Cutthroat Trout was provided by the Government of Alberta at the HUC10 watershed scale and assumed to be a constant over time. A linear dose-response curve was applied to each trout species to characterize its individual effect on the sustainability of Bull Trout populations (Figure A5; AEP 2016) and Westslope Cutthroat Trout populations (Figure A6; AEP 2017).

5.5.6.6 Water Quality

High levels of phosphorous inputs degrade trout habitat through eutrophication and reduced water quality (AEP 2016, 2017). By calculating its inverse, an existing index of phosphorous load available in ALCES Online (and described in section 3.6.4) was modified for trout to represent phosphorous inputs on the simulated landscape relative to pre-development at the HUC10 watershed scale.

Species-specific dose-response curves (Figure A7; AEP 2016, 2017) were applied to the phosphorous index for trout to characterize its effect on the sustainability of Bull Trout and Westslope Cutthroat Trout populations.

High levels of sediment inputs can also damage trout habitat and reduce the biological productivity of aquatic ecosystems. By calculating its inverse, an existing index of sediment load available in ALCES Online (and described in section 3.6.4) was modified for trout at the HUC10 watershed scale to represent sediment inputs on the simulated landscape relative to pre-development. Species-specific dose-response curves (Figure A8; AEP 2016, 2017) were applied to the sediment index for trout to characterize its effect on the sustainability of Bull Trout and Westslope Cutthroat Trout populations.

5.5.6.7 Water Quantity

Large water withdrawals can reduce habitat quality for trout (AEP 2016, 2017). Current methods to calculate the percentage of water being withdrawn in a watershed compared to natural low-flow discharge during February (winter) and August (summer) are not accurate at the HUC10 watershed scale because they do not account for upstream contributions to flow. As a result, the effect of water withdrawal on the sustainability of Bull Trout and Westslope Cutthroat Trout populations was set constant at 5 (i.e., no effect).

Changes to a river's flow regime (i.e., magnitude and frequency of peak flow events) can also impact habitat quality for trout. Equivalent clearcut area (ECA; described in section 3.6.3) is a metric ranging from 0 to 100 that approximates the hydrological effect of forest disturbance. Using ECA as a surrogate for the percent of total footprint area, an index of hydrologic change was developed by applying the expected relationship between total footprint area and severity of hydrologic change (Figure A9.1; AEP 2016, 2017). A dose-response curve was applied to the index of hydrologic change to characterize its effect on the sustainability of Bull Trout and Westslope Cutthroat Trout populations (Figure A9.2; AEP 2016, 2017).

5.5.6.8 Contamination

Increased concentrations of selenium from natural and human-caused sources are toxic to trout (AEP 2016, 2017) but data on whole body tissue selenium concentration (ug/g) is not currently available. As a result, the effect of selenium contamination on the sustainability of Bull Trout and Westslope Cutthroat Trout populations was set constant at 5 (i.e., no effect). Parameters that have been set at "no effect" can be modified as data become available.

5.5.6.9 Disease

Westslope Cutthroat Trout are believed to be susceptible to whirling disease at high parasite doses (AEP 2016, 2017). Whirling disease was confirmed as present in the Bow River and Oldman River drainages in Alberta in 2016 and 2017 respectively but qualitative assessments of whirling disease risk have not been completed at the HUC10 watershed scale. As a result, the effect of whirling disease risk on the sustainability of Westslope Cutthroat Trout populations was set constant at 5 (i.e., no effect). As monitoring of disease progresses, this can be modified.

5.5.6.10 Habitat Loss

Habitat loss from the removal of portions of a natural stream or replacement of portions of a natural stream with a different landscape feature threatens Westslope Cutthroat Trout in some areas (AEP 2016, 2017). The percent loss of lotic habitat was calculated in ALCES Online at the HUC10 watershed scale by dividing the area of lotic habitat on the simulated landscape by the current area of lotic habitat and subtracting from one before converting to a percent. A linear dose-response curve was applied to simulated habitat loss to characterize its effect on the sustainability of Westslope Cutthroat Trout populations (Figure A10; AEP 2017).

5.5.6.11 Cumulative Trout Fisheries Sustainability Index (FSI)

An overall FSI score for Bull Trout and Westslope Cutthroat Trout that considers the cumulative effect of multiple stressors was calculated at the HUC10 watershed scale. This was done by combining the FSI effects of individual stressors multiplicatively and dividing by 5 to the power of (n-1), where n is the number of FSI effects.

5.5.7. Natural Resource GDP

Coefficients relating GDP to forestry production, farmland, and energy production were calculated from Statistics Canada data, and other data sources when required (Table 5). GDP coefficients were based on 2007 dollars.

- Timber production coefficients were calculated from: provincial GDP data (Statistics Canada tables 379-0030 and 282-0008) for forestry and logging, as well as support activities for forestry; and provincial timber production data from the National Forestry Database. Coefficients were based on data from years 2007 to 2011, which were the years for which data were available from both the Statistics Canada tables and the National Forest Database.
- Crop and cattle GDP coefficients were calculated from: provincial GDP data (Statistics Canada table 379-0030) for crop production and support activities for crop and animal production; crop area from ABMI land cover data; and cattle population data. The crop GDP

coefficient was based on data for the year 2010. The cattle GDP coefficient was based on data for the year 2012, the only year for which GDP data related to animal production were available.

- The GDP coefficient for coal mining was calculated from: provincial GDP data (Statistics Canada table 379-0030) for coal mining and support activities for mining; and coal production data from the Alberta Energy Regulator. The portion of support activities for mining GDP associated with coal mining was based on the portion of mining and quarrying GDP that was associated with coal mining. The GDP coefficient was based on data for the years 2008 and 2009, the only years for which GDP data related to coal production were available.
- The Statistics Canada tables did not provide energy sector GDP data in sufficient detail to be broken down by hydrocarbon type. The relative contribution of conventional oil, oil sands, and gas production to Alberta's GDP is provided by Timilsina et al. (2005) for the years 1990, 1995, 2000, and 2003. The relative contribution of the hydrocarbon types in 2000 and 2003 was combined with GDP data for oil and gas extraction and support activities (Statistics Canada table 379-0025) and hydrocarbon production data from the same years to estimate GDP contribution per unit of hydrocarbon production. Prior to calculating the coefficients, GDP data from Statistics Canada table 379-0025 were converted to 2007 dollars for consistency with other GDP coefficients.

Table 5. GDP, employment and royalty coefficients for land uses simulated in ALCES Online.

Land use	GDP coefficient	Employment coefficient	Royalty coefficient
Timber	22.97 $/m^3$	0.00016 jobs/m^3	1.07 $/m^3$
Crops	325.59 $/ha	0.00278 jobs/ha	0
Cattle	136.47 $/head	0.00523 jobs/head	0
Coal	17.43 $/tonne	0.00019 jobs/tonne	0.64 $/tonne
Oil	192.25 $/m^3$	0.00040 jobs/m^3	51.77 $/m^3$
Gas	0.1299 $/m^3$	2.82e-07 jobs/m^3	0.0342 $/m^3$

5.6. Calculating Cost-effectiveness of Trout Conservation

The response of trout and natural resource GDP indicators to the development and protection simulations was used to estimate environmental and economic effect of protection, at the scale of HUC10 watersheds. Only the estimated values from resource extraction were used for this scenario development. Conservation effectiveness was assessed as the difference in trout performance between the development and protection scenarios. Effectiveness was calculated for each trout indicator individually, and then averaged across the two species to calculate overall conservation effectiveness. Conservation cost was assessed as the difference in resource sector GDP between the development and protection scenarios. Each watershed's effectiveness (i.e., improvement in trout FSI) was then divided by its cost (i.e., loss in natural resource GDP) to estimate its conservation cost-effectiveness. Watersheds were prioritized for conservation based on average cost-effectiveness across the five decades of the simulations. For purposes of mapping, cost-effectiveness was normalized through division by the average cost-effectiveness across all watersheds.

The consequences of any number of protection scenarios can be assessed by assigning outcomes of the protection simulation to watersheds that are to be protected in the scenario and assigning outcomes of the development simulation to the remaining watersheds. The consequences of protecting incrementally more of the study area were assessed through a range of scenarios, each of which successively allocated one additional watershed to protection. Allocation of watersheds to protection was in order of conservation cost-effectiveness (highest cost-effectiveness first). The consequences of the scenarios to trout and natural resource GDP were plotted to depict the trade-off between trout conservation and natural resource production across a range of protection levels. The trade-offs are efficient in that, at each protection level, the most cost-effective watersheds are protected according to the assumptions articulated above. The consequences of cost-effective trout conservation strategies to the full range of environmental indicators (ECA, intact land cover, water quality, grizzly bear) was assessed by plotting regional indicator response to a range of protection levels (current -30%, 35%, 39%, 50%, 60%, 100%) and mapping indicator response to a scenario that increased protection from its current level of 30% to 50% of the study area.

6. RESULTS

The response of each indicator to development and protection scenarios is now summarized. First, however, prioritization of watersheds based on trout conservation cost-effectiveness is presented as it is the basis of the protection scenarios.

6.1. WATERSHED PRIORITIZATION

Improvement of the trout indices was greatest in the western portion of the study area that is not currently protected and within trout range (Figure 3). Watersheds in the western portion of the study area tend to have a higher natural capacity to support trout, and have also experienced less permanent conversion to agriculture and settlement. As a result, preventing harmful future development, reclaiming temporary footprints, and managing access has a greater potential to improve trout performance in these watersheds. Also important is that trout in western watersheds were less sensitive to climate change because water temperatures remained cooler that in lower elevation watersheds to the east.

Not surprisingly, cost-effectiveness of trout conservation followed the same pattern of higher values to the west. The primary reason for higher cost-effectiveness of western watersheds was their aforementioned greater improvement in trout performance with protection. Of secondary importance is that oil production, and its high contribution of natural resource GDP per unit area, was more prevalent in eastern watersheds making the cost of conserving eastern watersheds greater. Figure 4 demonstrates the gain in trout performance and decline in natural resource GDP as successively more watersheds are allocated to protection. The sharp initial increase in FSI as protection is increased emphasizes the greater conservation potential of the most cost-effective (i.e., western) watersheds.

If full-cost accounting was used in scenario development, including the economic values of recreation, protecting source water and biodiversity maintenance, the cost effectiveness of trout (and watershed) conservation with greater allocation of protected areas would be more favourable.

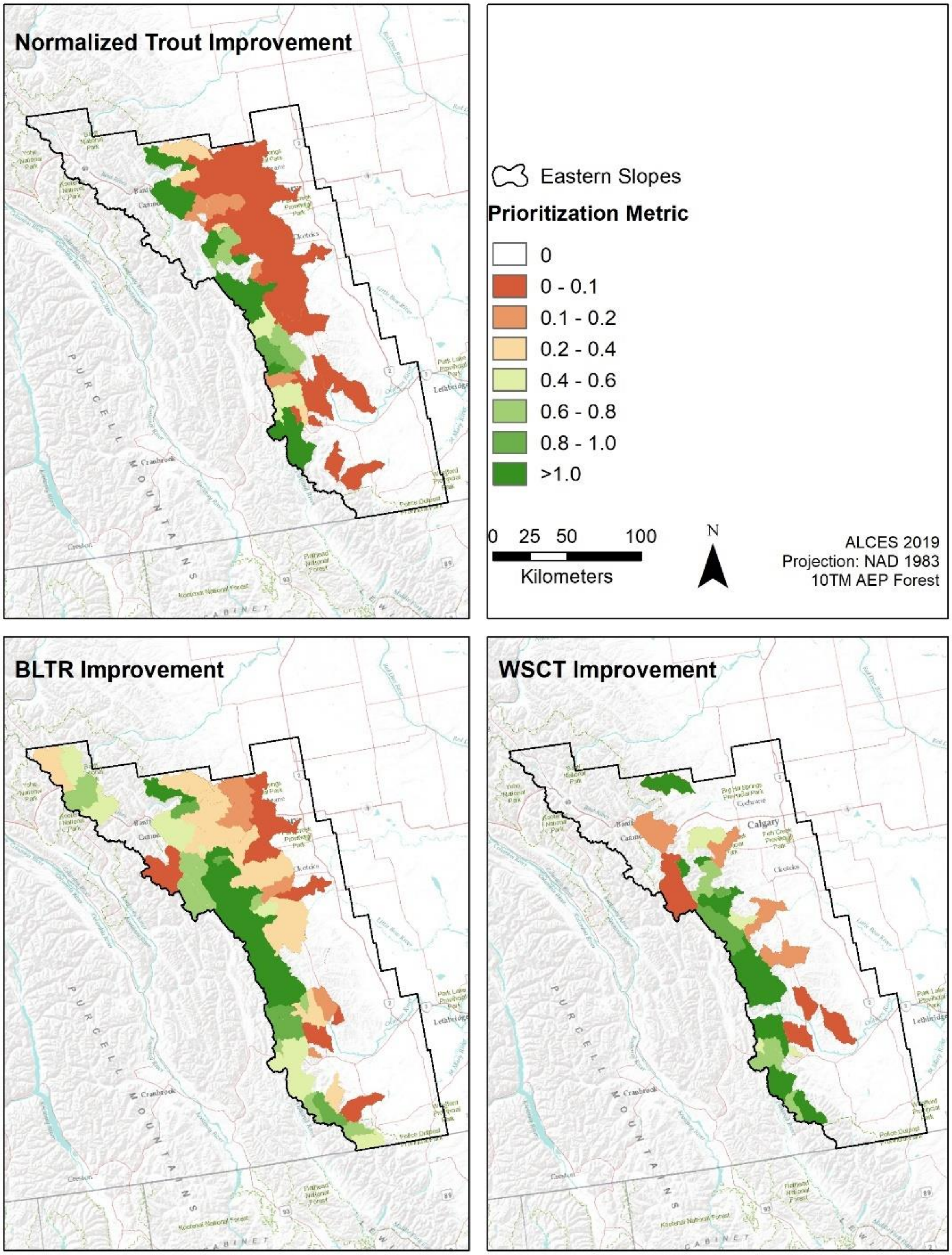


Figure 10. Conservation cost-effectiveness for Bull Trout (BLTR), Westslope Cutthroat Trout (WSCT), and the average of the two species. A higher value indicates the greatest conservation effectiveness for the lowest conservation cost.

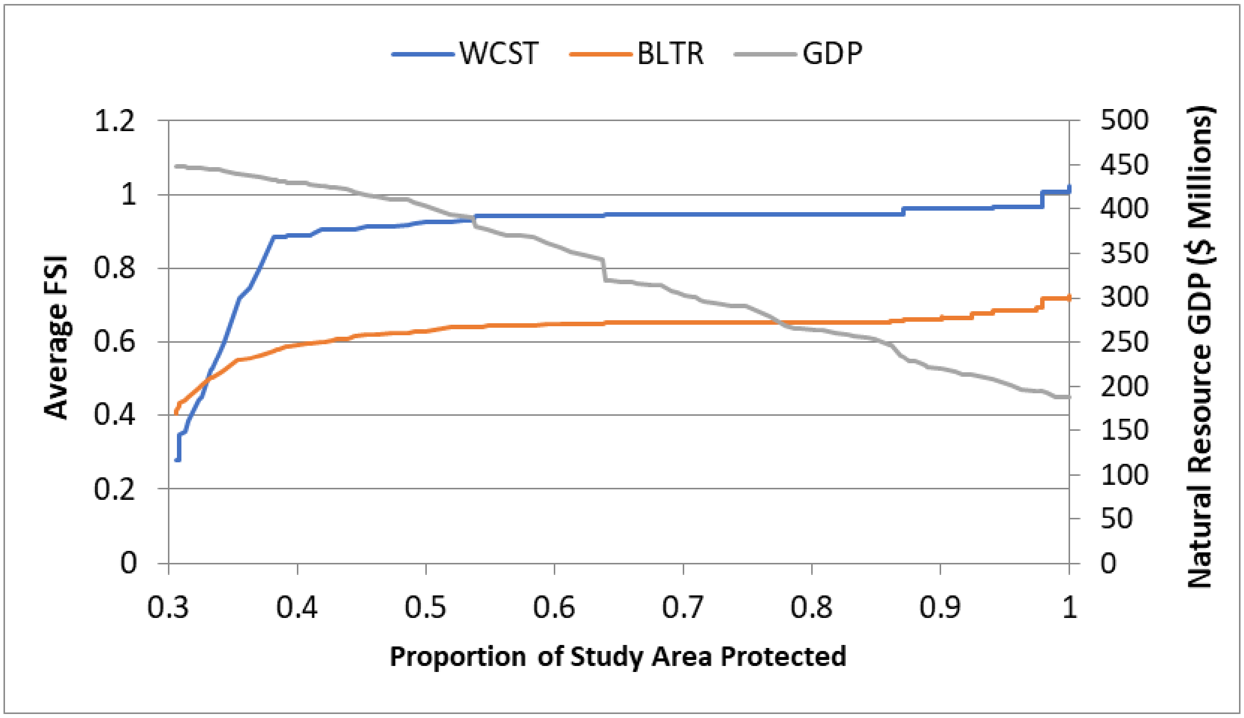


Figure 11. Trade-off between conservation effectiveness (FSI performance) and conservation cost (natural resource GDP performance) as successively more watersheds are allocated to protection. These scenarios only considered estimated values from resource extraction.

6.2. Anthropogenic Footprint

Anthropogenic footprint covers 7,885 km^2 of the study area, the majority of which is agricultural footprint (Figure 5) concentrated in the eastern portion of the study area (Figure 6). Settlement is the second most prevalent footprint followed by forestry and transportation (Figure 5). Footprint increased during the business-as-usual (BAU) scenario by an average of 176 km^2 each decade (Figure 7) driven largely by the forestry and energy sectors. Access roads to new cutblocks and well sites also contribute to an expanding road network. The majority of new footprint occurred in the western portion of the study area (Figure 6) whereas footprint in the east was primarily converted from existing agricultural footprint to settlements.

Under the protection scenario, anthropogenic disturbance was reduced to below current levels (Figure 7). Reduction was highest in the western portion of the study area (Figure 6) due to the reduction of forestry activity and the reclamation of temporary footprints such as well sites, seismic lines, and minor roads that occur at higher densities than in the east. The prevalence of permanent footprints in the eastern portion of the study meant that protection had comparatively little effect of reducing anthropogenic disturbance.

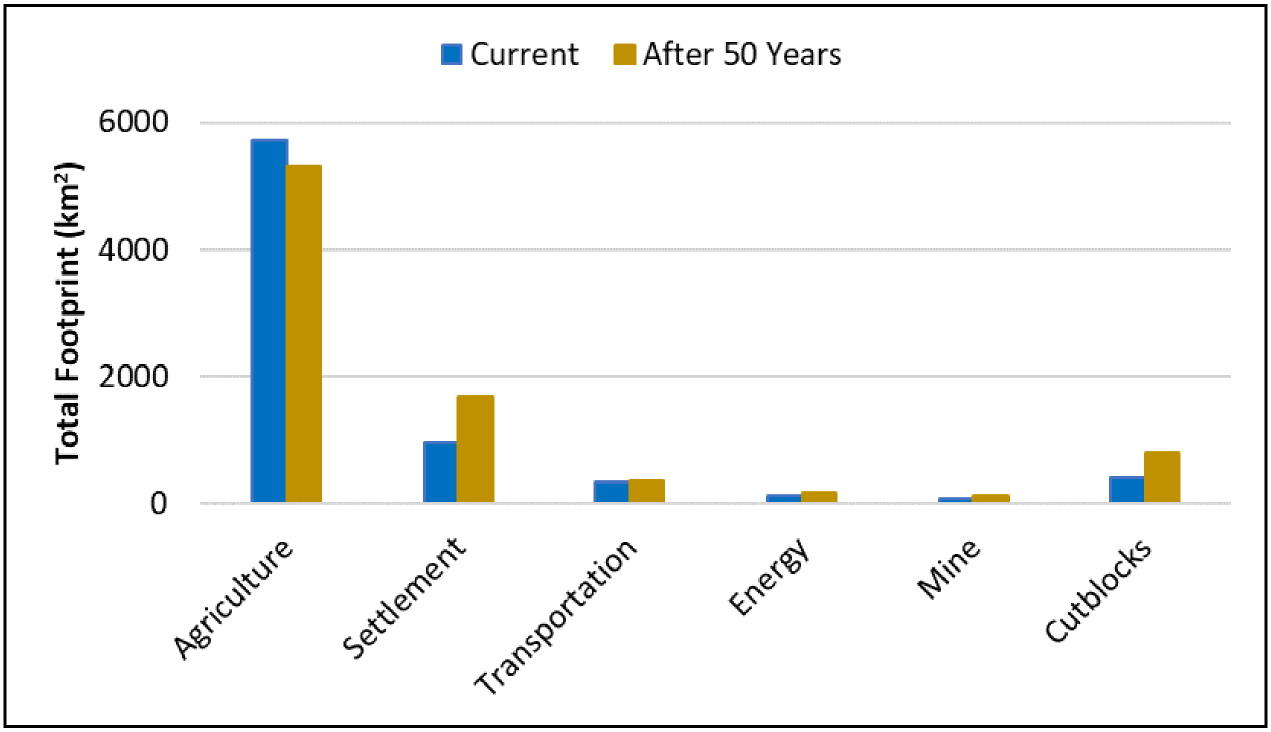


Figure 12. Anthropogenic disturbance by sector at the start (current) and end (after 50 years) of the simulated business as usual scenario.

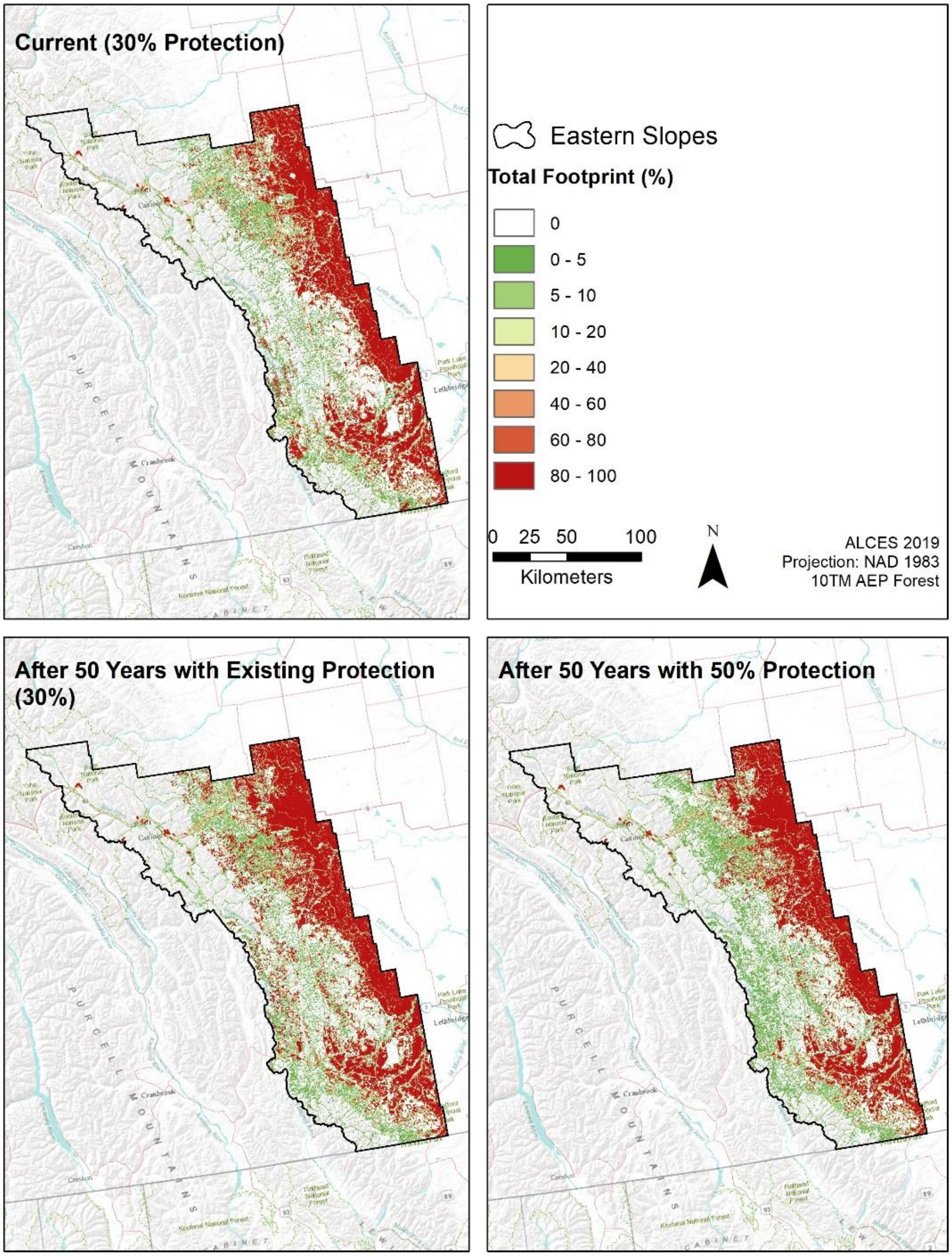


Figure 13. Anthropogenic disturbance at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

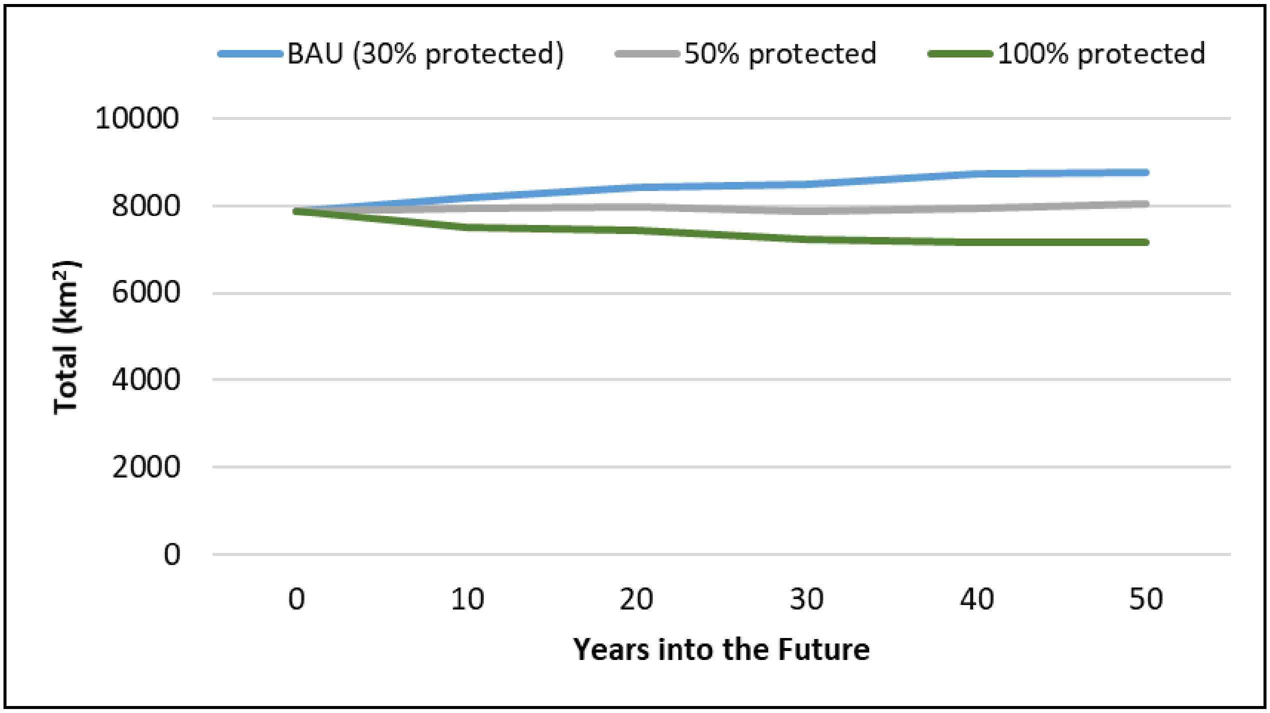


Figure 14. Anthropogenic footprint during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected.

6.3. Intact Land Cover

The current landscape composition includes just over 7,800 km^2 of intact land cover equating to approximately 26% of the study area. However, the majority of intact land cover is restricted to protected areas and forested areas in the western portion of the study area (Figure 8). Intact land cover decreased by approximately 15% (Figure 9) during BAU indicating that simulated resource development was not simply intensifying in areas where footprint already occurs but was expanding to forested lands outside of protected areas (Figure 8). As a result, protection (i.e., reducing continued resource development and reclaiming temporary footprints) had significant ability to not only preserve but also increase the amount of intact land cover over time (Figure 8, Figure 9).

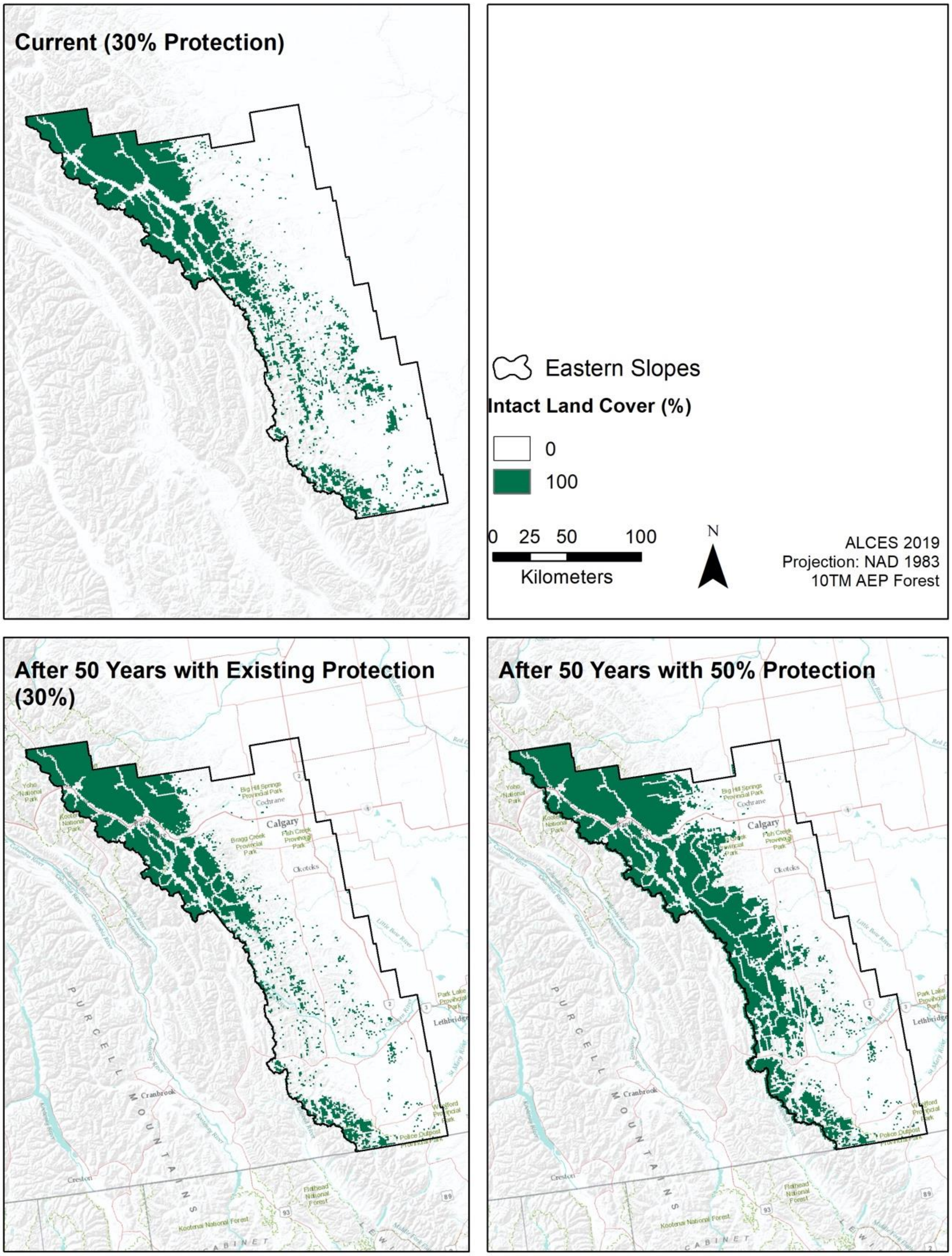


Figure 15. Intact land cover at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

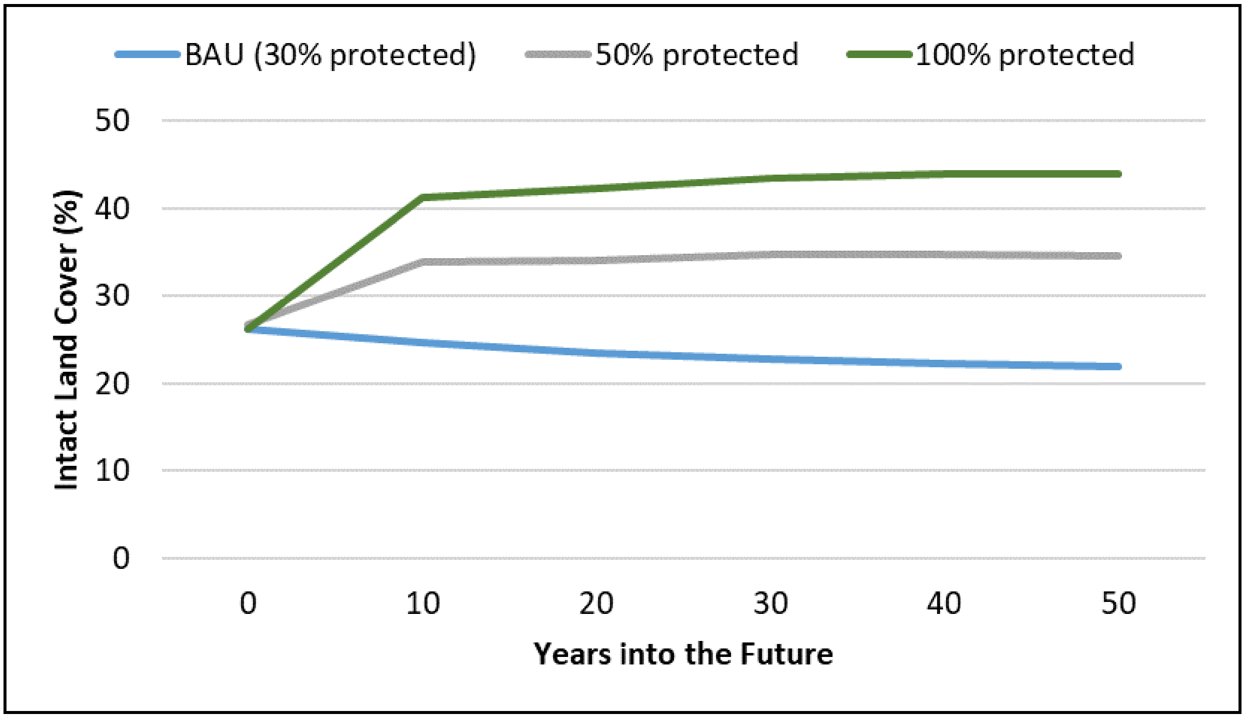


Figure 16. Intact land cover during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected. The relatively rapid increase in intact land cover during the first decade in the non-BAU scenarios can be attributed to the initial reclamation pulse of short-lived linear features such as seismic lines.

6.4. Equivalent Clearcut Area (ECA)

At the scale of the study area, equivalent clearcut area (ECA) in predominantly forested watersheds increased by 42% during the BAU scenario (Figure 10). ECA varied by watershed with the most noticeable increases occurring in areas managed for forest harvest (Figure 11). By the end of the simulation, the ECA of some watersheds was at or exceeding 30% indicating an elevated risk of altering the hydrologic regime over time (Winkler and Boon 2017).

Reducing continued resource development, particularly forestry, was able to significantly reduce ECA during the protection scenario (Figure 10). ECA dropped and remained below current levels when protection was applied across the study area (100% protected; Figure 10) because it affected all the forest management areas (FMAs) in the region. When 50% of the study area was protected, ECA was relatively stable around current levels on average (Figure 10) but is high within some watersheds due to continued forest harvest (Figure 11). ECA increases slightly over time regardless of scenario due to forest disturbance from stochastic fire events.

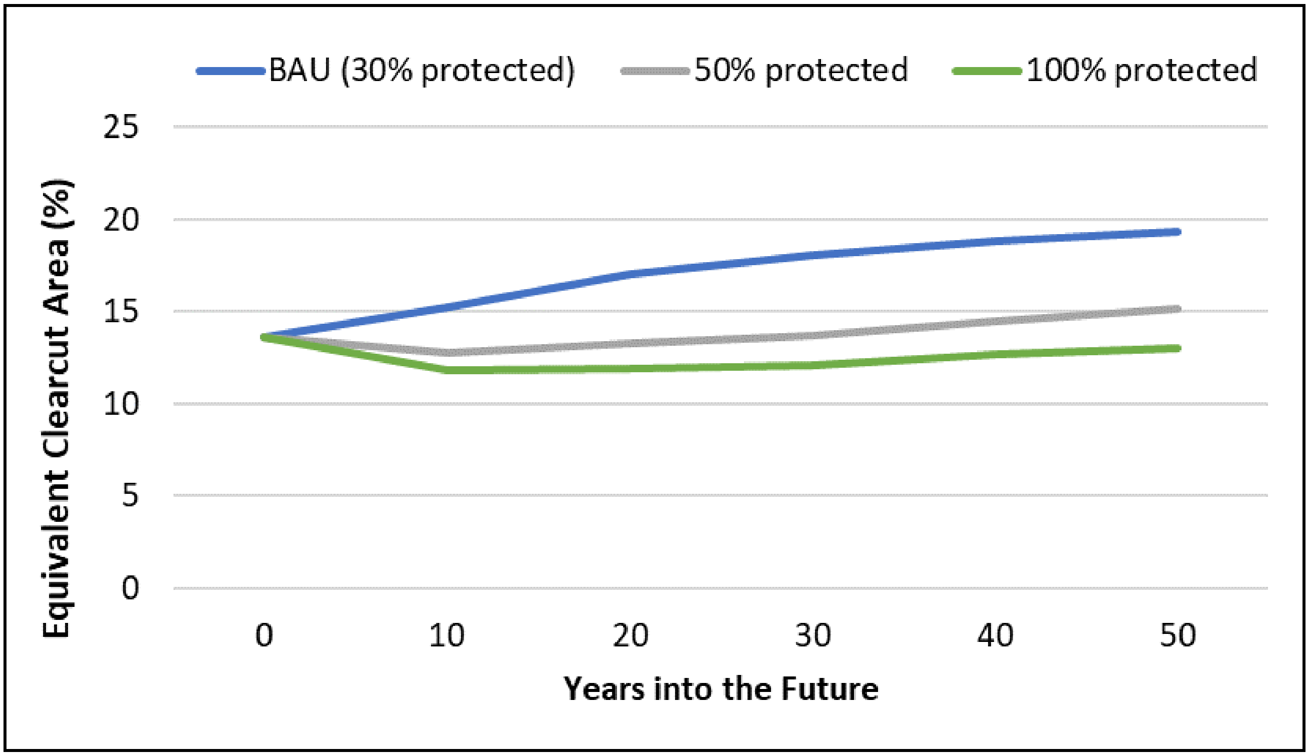


Figure 17. Equivalent clearcut area (ECA) during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected.

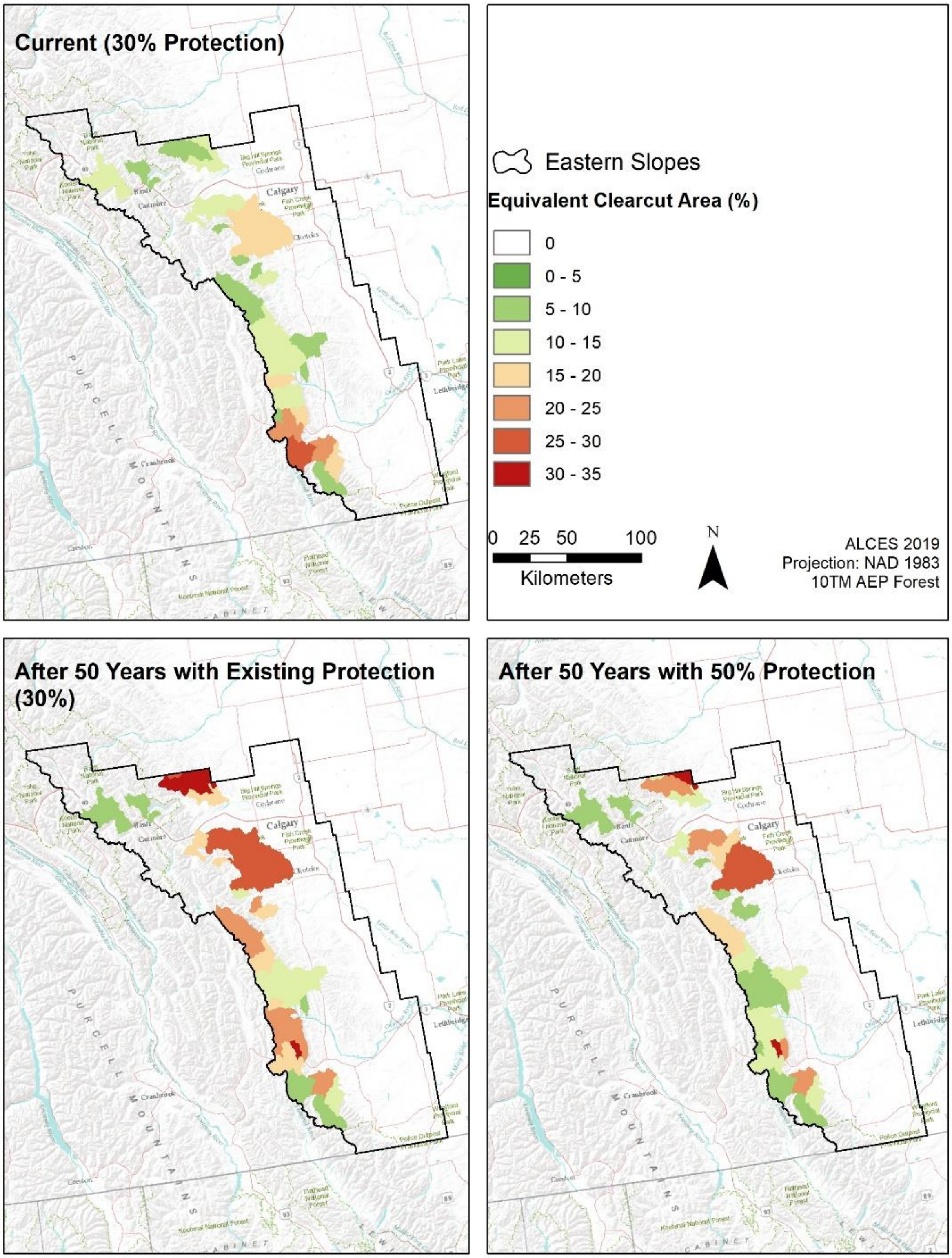


Figure 18. Equivalent clearcut area (ECA) at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

6.5. Bull Trout

Bull Trout populations are currently at very high risk (FSI ≤ 1) across the majority of their range at the watershed scale (Figure 12). A noticeable exception are watersheds within Banff National Park and Peter Lougheed Provincial Park in the north-west portion of the study area that are medium to low risk. The FSI of these watersheds was stable over time during BAU, but the FSI of watersheds outside of protected areas declined (Figure 12). As a result, FSI at the regional scale was low and declining during BAU (Figure 13). Comparison of the relative magnitude of individual stressors during BAU revealed that angling mortality and habitat fragmentation was limiting Bull Trout sustainability in the Eastern Slopes region (Figure 14). These threats increased slightly during the simulation due to increased road density attributed to forestry and energy activity. More apparent was a substantial increase in the threat presented by climate change (Figure 14) due to a simulated increased in air temperature over time.

Despite the effect of climate change, protection nearly doubled bull trout FSI at the regional scale (Figure 13). It was assumed that angling mortality would be low (i.e., essentially no effect to FSI) under a combination of regulatory protection and access management. The potential to reduce access and habitat fragmentation was highest in the western portion of the study area given the higher prevalence of reclaimable anthropogenic footprint. As a result, western watersheds show the greatest conservation effectiveness for Bull Trout with risk factors in several watersheds improving from very high (FSI ≤ 1) to high (FSI >1 and ≤ 2) or medium (FSI > 2 and ≤ 3) under protection (Figure 12).

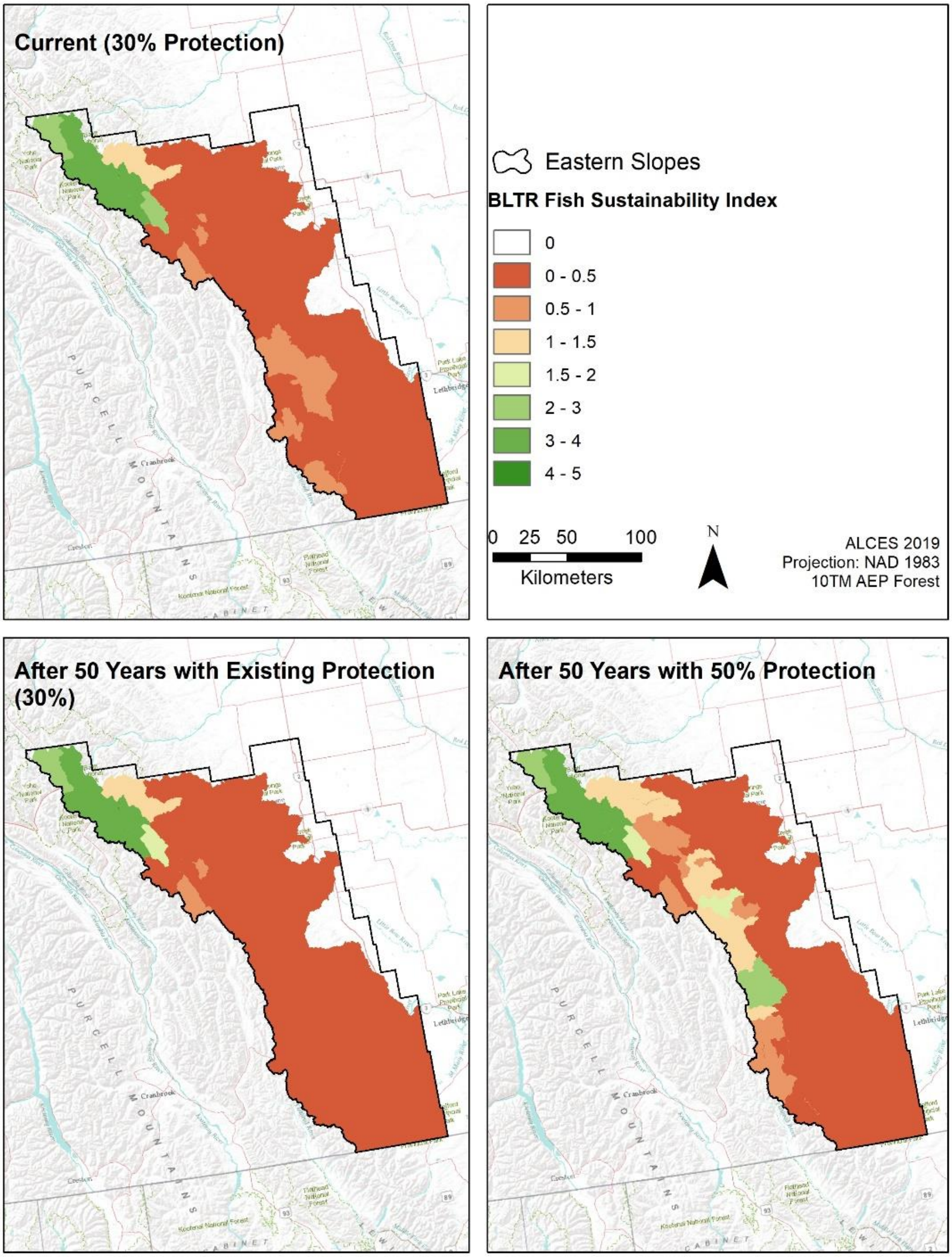


Figure 19. Bull Trout (BLTR) fish sustainability index (FSI) at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

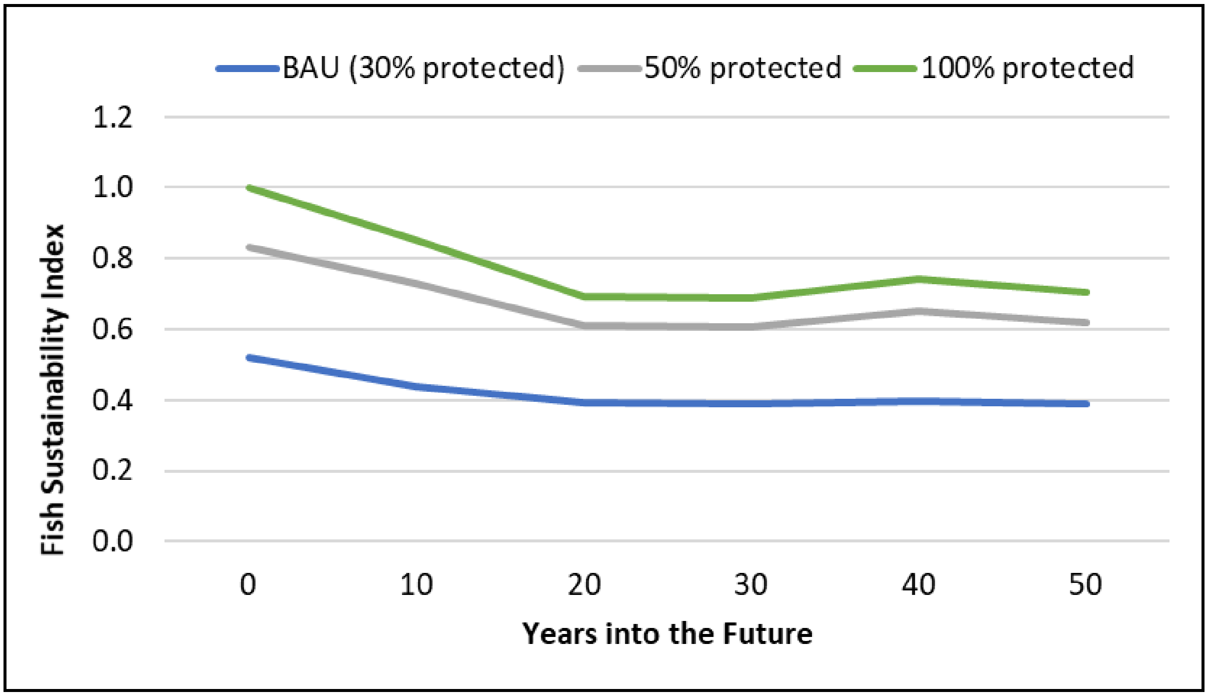


Figure 20. Bull trout fish sustainability index (FSI) during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected.

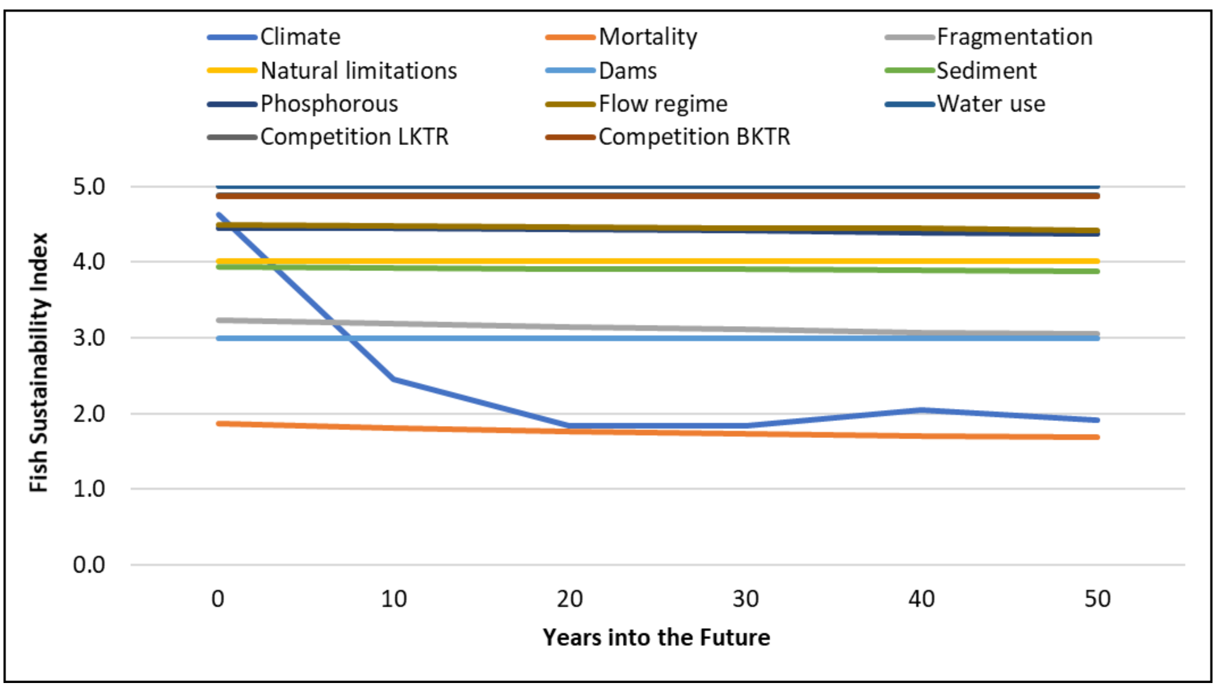


Figure 21. Response of Bull Trout fish sustainability index (FSI) to simulated threats according to business as usual and climate change scenarios.

6.6. WESTSLOPE CUTTHROAT TROUT

Westslope Cutthroat Trout populations are currently at very high risk (FSI ≤ 1) across their range (Figure 15) with further declines in FSI simulated during the BAU scenario (Figure 15, 16). Similar to Bull Trout, angling mortality and habitat fragmentation were limiting to Westslope Cutthroat Trout sustainability in the region (Figure 17), both of which are projected to increase under BAU to due to increased road densities. Competition from hybrid cutthroat trout was another significant limitation of Westslope Cutthroat Trout FSI (Figure 17). It is hypothesized that the reduction of Westslope Cutthroat Trout populations from over-exploitation and habitat degradation has enabled other trout populations to increase, leading to significant competition and further detriment to Westslope Cutthroat Trout sustainability (AEP 2017). Climate change negatively affected Westslope Cutthroat Trout sustainability due to warming during forecast, although the impact was not as severe as it was for Bull Trout. The lower sensitivity to climate change is partly due to differences in the dose – response relationship but also because Westslope Cutthroat Trout range is more restricted to higher elevations than Bull Trout, where projected warming is more moderate.

Under assumed low angling mortality, the capacity of protection to reduce access and habitat fragmentation resulted in a substantial increase of FSI at the regional scale (Figure 16). As described for Bull Trout, western watersheds show the greatest conservation effectiveness for Westslope Cutthroat Trout given the high reclamation potential in these areas but also because the range is largely limited to the western portion of the study area. Many watersheds improved from very high risk under BAU to high, medium or low risk under protection (Figure 15).

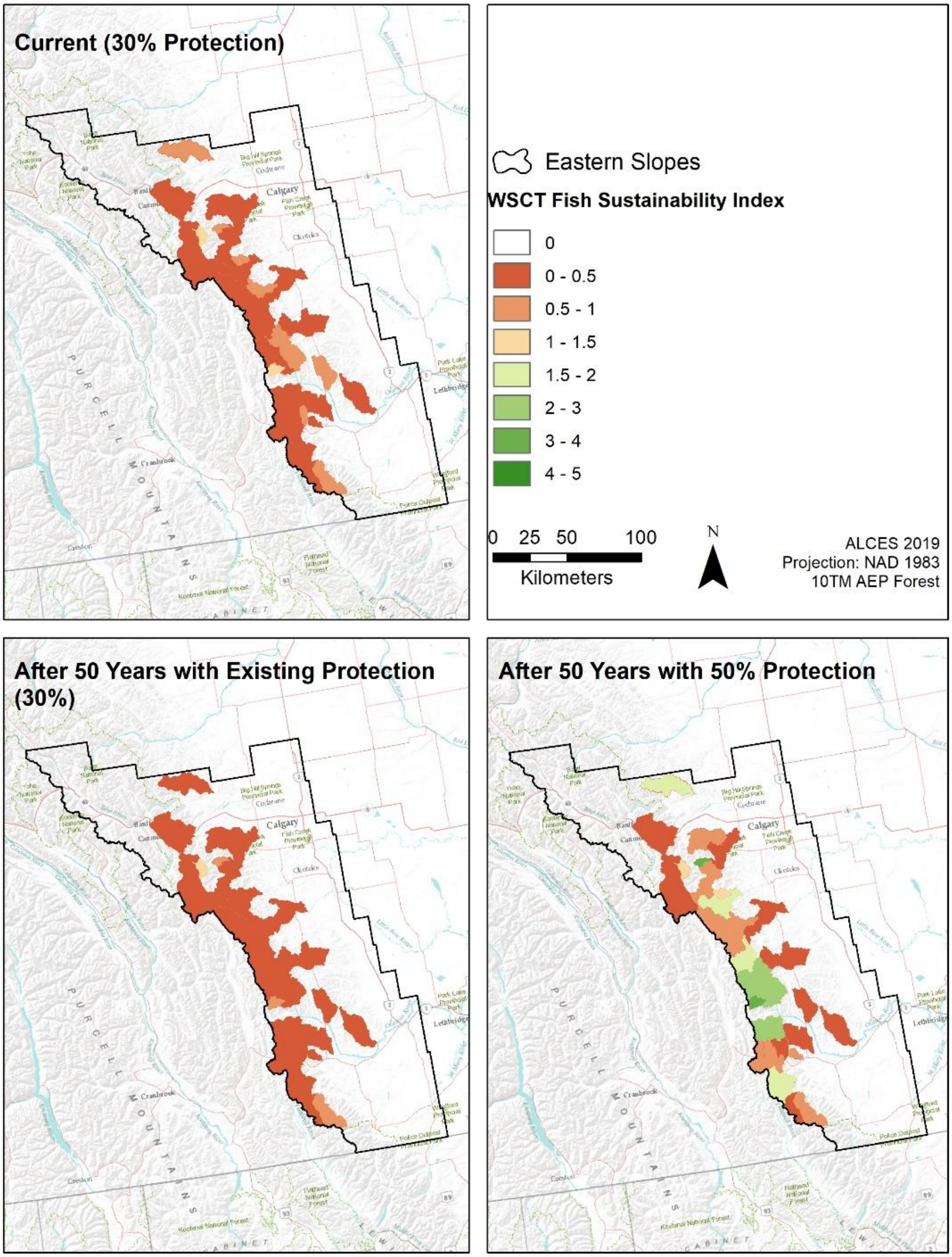


Figure 22. Westslope Cutthroat Trout (WSCT) fish sustainability index (FSI) at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

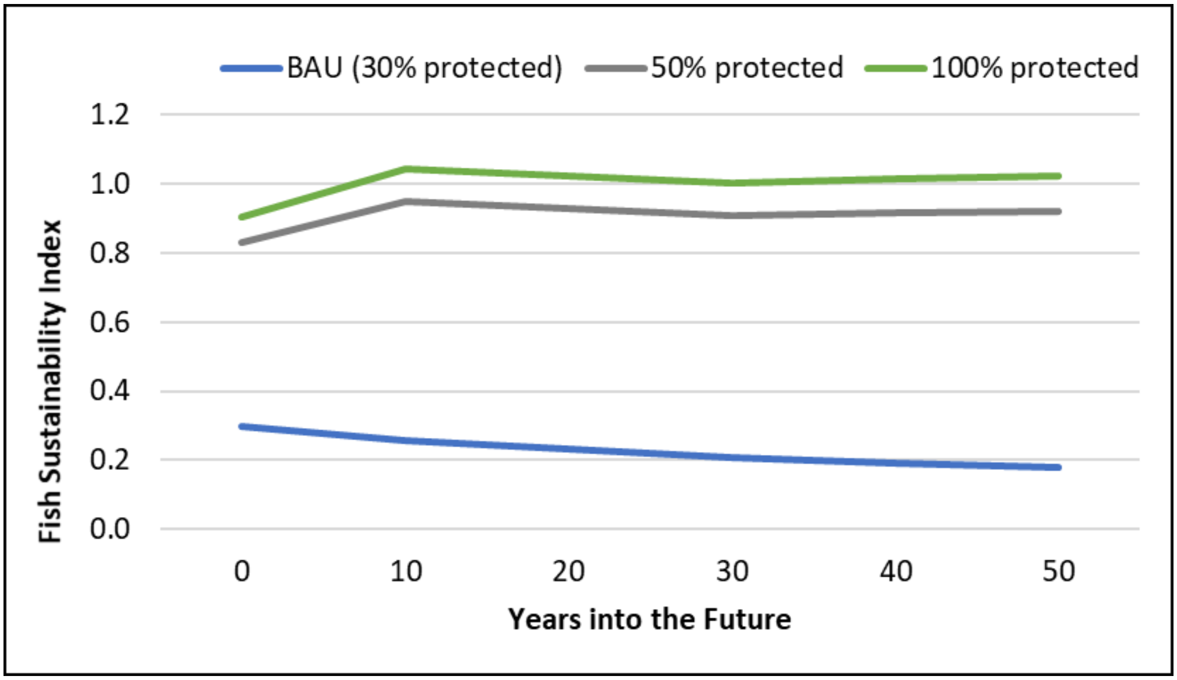


Figure 23. Westslope Cutthroat Trout fish sustainability index (FSI) during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected.

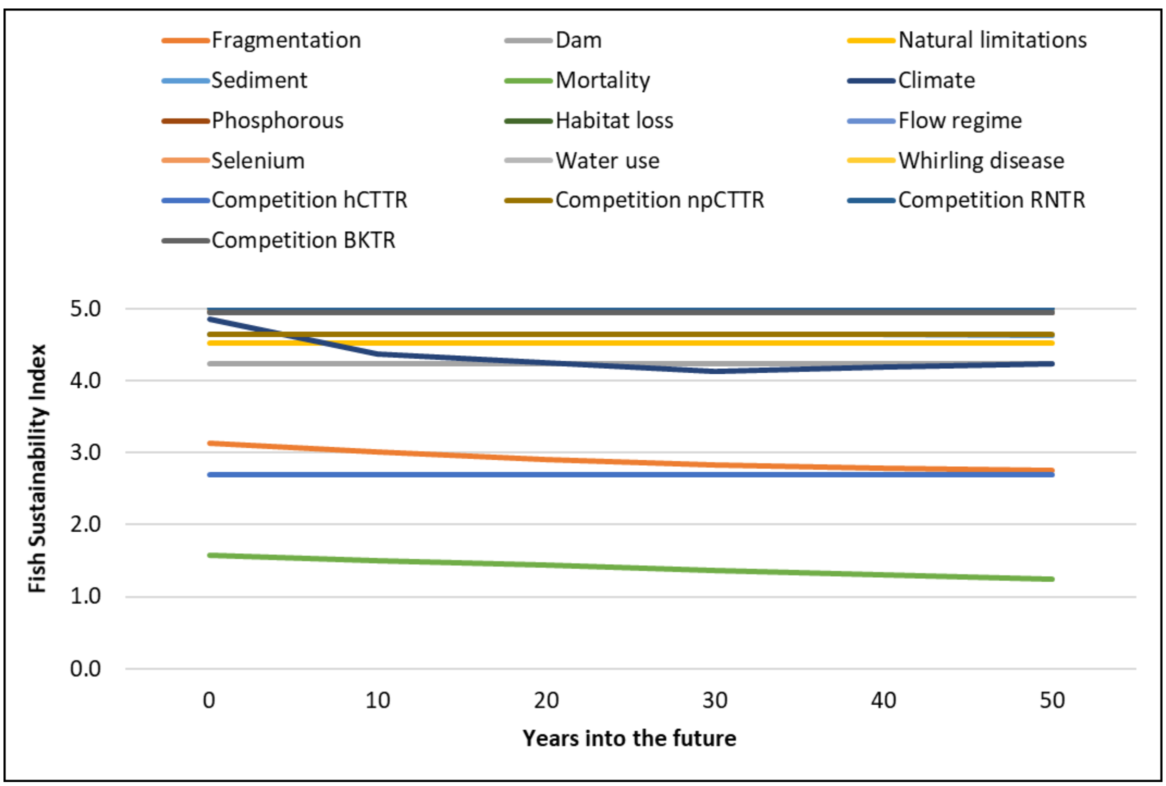


Figure 24. Response of Westslope Cutthroat Trout fish sustainability index (FSI) to simulated threats according to business as usual and climate change scenarios.

6.7. Water Quality Index (WQI)

WQI is currently lowest in the eastern portion of the study area where agriculture and settlement are the dominant land uses (Figure 18). This does not necessarily indicate water quality in western portions as “high”, or “good”. Change to WQI under either scenario was negligible at the regional scale (Figure 19). During BAU, continued resource development in the west did not cause noticeable change in WQI because the areal extent of new footprint such as roads were minor especially relative to the large historical conversion of natural land cover to farmland and settlement in the east. Although simulated cutblocks were extensive, they did not change WQI because the chemical load factors used in the analysis (Donahue 2013) did not incorporate the effect of forest age (Figure 18). As a result, the analysis likely underestimates the potential for land use in the western portion of the study area to degrade water quality, although research suggests that the effect of timber harvest on nutrient and sediment export may be minor[14]. However, aspects of sediment retention in stream substrates and “cementing” of substrate materials may be an issue for trout survival even though sediment exports from the land use footprint may appear low. Without appropriate water quality benchmarks from pristine watersheds for comparison there may still be significant deviations in water quality from the range of natural variation. Also, during the BAU simulation, the conversion of agriculture to settlement footprint in the eastern portion of the study area had little impact on WQI because chemical load factors for these two types of footprint were similar. When watersheds were protected, however, water quality improved slightly at the regional scale relative to BAU due to reclamation of temporary footprints (Figure 19).

---

[14] Research from Finland found that increases in nitrogen, phosphorous and sediment export may only be significant at high levels of forest disturbance (>30%) (Palviainen et al. 2013). Research from southeastern British Columbia found cutblocks to be a minor contributor to sediment runoff, whereas roads were an important contributor (Jordan 2006). Comparison of phosphorous export from unharvested and harvest subcatchments in the Boreal Plains of Alberta found that differences were minor (Evans et al. 2011).

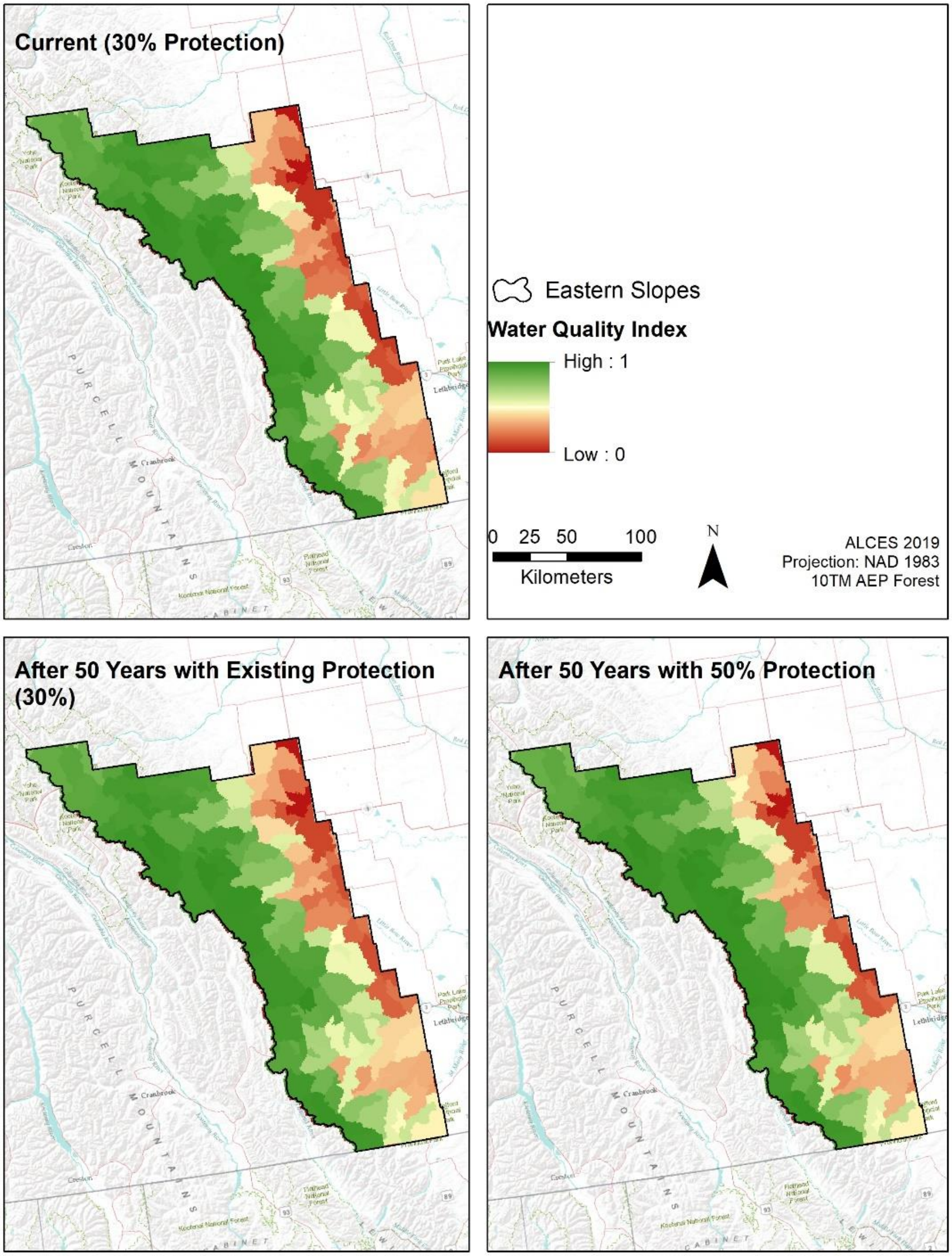


Figure 25. Water quality index (WQI) at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

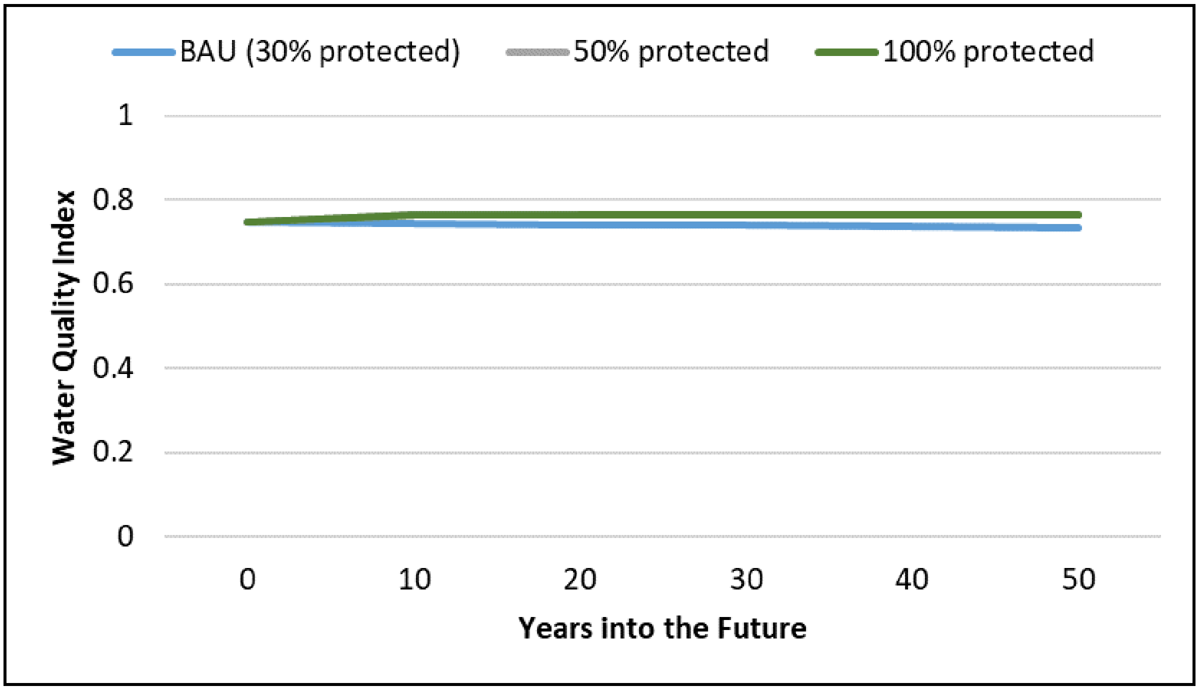


Figure 26. Water quality index (WQI) during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected.

6.8. Grizzly Bear Exposure Index

The grizzly bear exposure index was elevated in the west-central portion of the study area where there is the greatest overlap between industrial activity (e.g., timber production and associated roads) and high quality grizzly bear habitat (Figure 20). The lack of substantive change in the exposure index during the simulation (Figure 21) was because increases in footprint generally occurred in areas where the index was already elevated. The analysis did not explore the implications of conservation on the exposure index because information was not available to explore the consequences of access management on mortality and selection coefficients.

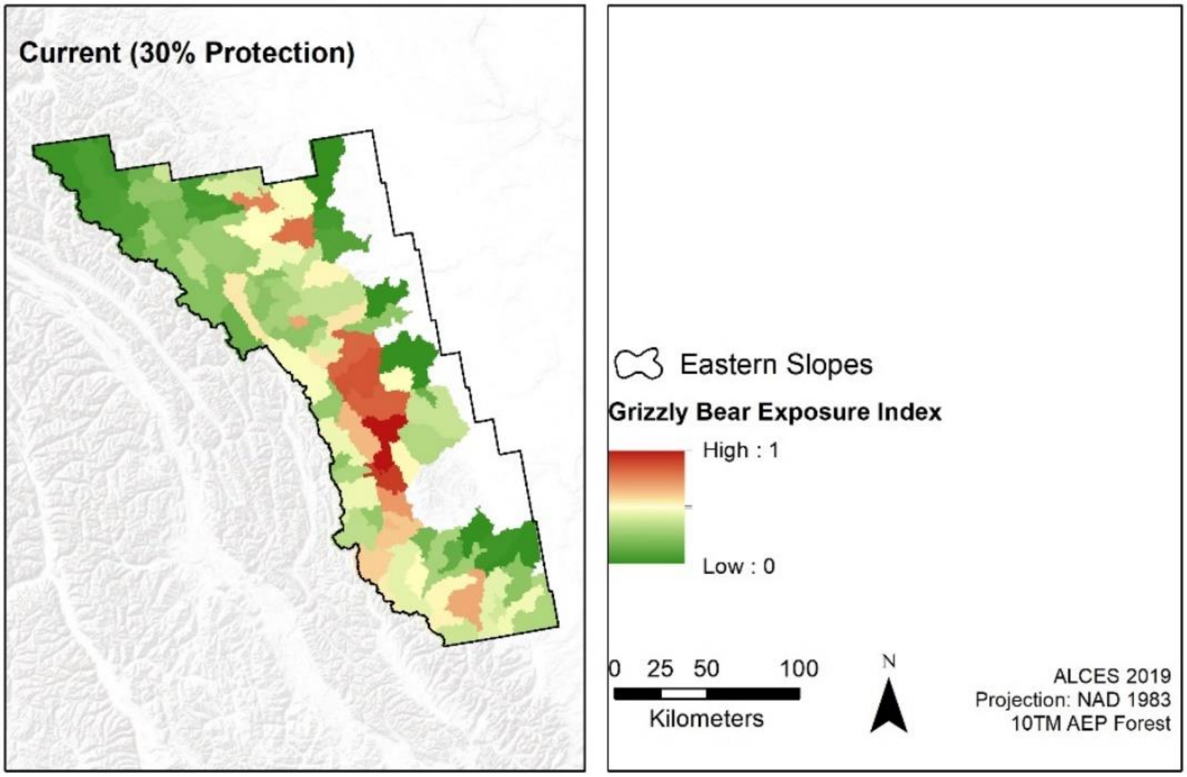


Figure 27. Grizzly bear exposure index at the start (current) and end (after 50 years) of simulation of business as usual (30% of the study area protected) and protection (50% of the study area protected) scenarios.

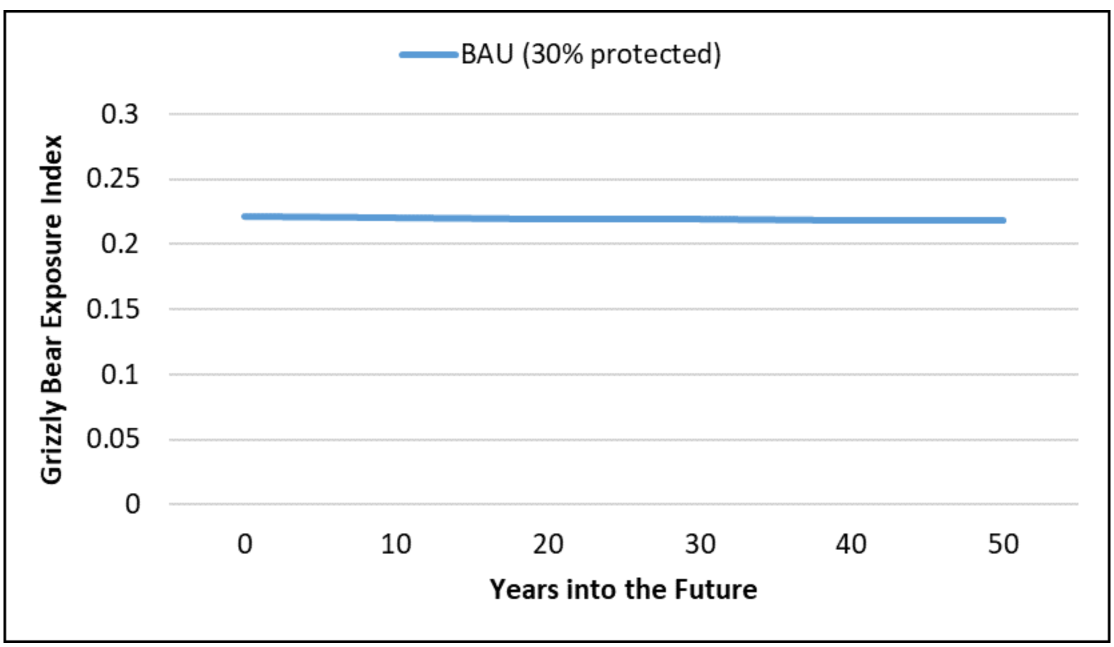


Figure 28. Grizzly bear exposure index during simulations of business as usual (BAU) and protection scenarios with 50% and 100% of the study area protected.

7. DISCUSSION

Previous studies have documented significant adverse effects to Alberta's native fish communities caused by angling, land use, climate change, and introductions of exotic fish species. Reported changes include reduced abundance and altered age class composition, species composition, and spatial distribution. A diversity of adverse factors, operating in isolation or in combination, are often cited, and include fish overharvest (Sullivan 2008, Post et al. 2013), increased access (Scrimgeour et al. 2008), water crossings/fragmentation (Park et al. 2008, MacPherson et al. 2012, Maitland et al. 2016), eutrophication (Schindler 2006), altered hydrology (Schwalb et al. 2015), increasing water temperatures (Mayhood 2009, Jones et al. 2014), and competition for limiting resources with exotic fishes (Mayhood 2009, Cleator et al. 2010). An ongoing challenge to the research community is separating correlative and causal dynamics as many of these factors co-occur in space and time. A resounding message of the scientific community is that our native fish communities are acutely sensitive to landscape/watershed mis-management, and that all precautionary measures are required if we are to encourage the persistence of Alberta's native fish communities.

As demonstrated by the scenario analyses with ALCES Online, cumulative effects of multiple land uses present substantial risk to Bull Trout and Westslope Cutthroat Trout in the Southern East Slopes of Alberta. Past land use development transformed much of the eastern portion of the region to farmland and settlements, resulting in a westward contraction of the trout range. The forested western portion of the region represents the last stronghold for trout populations in the region. Here too, however, trout are exposed to risks associated with land use. Timber harvest, mining, hydrocarbon exploration, and especially associated road development in the western portion of the study area negatively affect trout through fragmentation of habitat and elevated angling pressure facilitated by access along linear footprints. Linear features (i.e. roads/trails) can lead to increased trout harvest, hydrologic shifts including greater frequency and intensity of flooding, bedload movement and channel shifts, with increased sediment loads. The spatial footprint (i.e., cutblocks and other large polygonal features) of land uses are also implicated in hydrologic shifts, plus greater mobilization of phosphorous and sediment loads.

The cumulative impact of these stressors is such that risk to trout is assessed as very high with the exception of protected watersheds. Ongoing resource development in unprotected landscapes during the coming decades caused these threats to remain high in simulations. In fact, risk was seen to elevate in large part due to projected climate change warming and its negative implications for trout habitat.

Other indicators display a similar pattern to that of the trout indices, demonstrating that impacts extend beyond trout to encompass the broader ecosystem. Water quality and intact land cover are low in the eastern downstream portion of the study area where conversion of natural land cover to agriculture and settlement is widespread. During the forecast, resource development caused further fragmentation of the landscape with intact land cover being largely limited to protected areas after five decades. Simulated future timber harvest led to elevated equivalent clearcut area (ECA) levels, including some watersheds approaching or exceeding the 30% threshold used in British Columbia to limit risk of high peak flows (Winkler and Boon 2015).

Given the extent of cumulative effects of land use and climate change, maintaining trout and other natural capital values requires conservation action. To address cumulative effects, conservation planning should address scales at which biodiversity respond to drivers, and scales at which the drivers vary through space and time (Schultz 2010). Climate change, for example, is likely to have an increasing adverse effect on trout through time and the extent of that impact varies across the study area. It is prudent, therefore, that long timeframes and regional scales be considered so that conservation effort can be allocated to areas where targeted conservation values, such as trout, are likely to persist in the face of climate change. Similarly, the impacts and benefits of land use vary substantially across the region due to historical development patterns, the distribution of resource potential (hydrocarbons, wood fibre, crop production, recreation), and management plans. Planning across large spatial scales can target those areas where there is a demonstrable impact of protecting or restoring values and where costs of protection can be minimized.

By estimating the capacity of protection to avoid impacts otherwise likely to occur, the simulations completed with ALCES Online assessed the potential benefit of conservation and identified where it is best able to address drivers. Watershed protection resulted in substantial risk reduction in some watersheds. Compared to the business as usual simulation, risk to Bull Trout dropped from very high to moderate in three watersheds, and from very high to high in 18 watersheds. For Westslope Cutthroat Trout, risk was reduced from very high to low in two watersheds, from very high to moderate in four watersheds, and from very high to high in seven watersheds. At the same time, the benefit of protection was not universal and many watersheds exhibited negligible risk reduction. Risk reduction was greatest in the forested western portion of the study area outside of protected areas. Factors contributing to the effectiveness of protecting these watersheds include their higher elevation and therefore lower sensitivity to warming, their intactness relative to the highly disturbed eastern portion of the study area, the expansion of footprint that otherwise occurs largely due to forestry, and the presence of temporary footprints (e.g., access roads, seismic lines) that could be reclaimed. This means the negative effects of climate change, especially on native trout might be mitigated through reducing the land use footprint, providing these species with greater resilience to climate-related changes.

Protection can avoid ecological impacts, but also limit opportunities for natural resource development to the potential detriment of the regional economy. Conservation planning should seek to minimize this trade-off in order to balance conservation and economic objectives. Our analysis prioritized watersheds based on the cost-effectiveness of protection, where cost was interpreted as natural resource sector GDP and effectiveness was interpreted as reduction in risk to trout. Doing so, however, had minimal effect on prioritization of watersheds compared to using trout risk reduction on its own. The insensitivity of prioritization to cost was because the western portion of the study area, where the benefits of protection were highest, tended to receive minimal future energy sector development which is high in terms of its capacity to generate GDP. Future coal mine development may change this forecast. The most prevalent land use in the western portion of the study area is currently forestry, which has lower capacity to generate GDP. The analysis therefore suggests that the environmental benefits are greatest and the economic costs of protection are lowest in the western portion of the study area.

While lower than elsewhere in the study area, a trade-off between protection and resource production still exists in the western watersheds. Identification of the appropriate balance between trout conservation and resource development can be informed by outcomes of the analysis. As the protected areas network was expanded from 30% (current level of protection) to 40% of the study area, the trout sustainability indices exhibited a measurable improvement. Thereafter, improvement in the trout indices with further protection was more moderate. The rapid initial increase in trout sustainability with protection was due to the handful of forested watersheds in the western portion of the study area that were sensitive to protection due to factors described previously (higher elevation, relatively intact, and otherwise available for future development). Natural resource sector GDP, on the other hand, declined relatively slowly as these first watersheds were protected because they are unlikely to contain new oil and gas development. The rapid initial increase in trout sustainability with increased protection and the moderate decline in natural resource sector GDP suggest there is an opportunity to focus trout conservation efforts on a relatively small portion of the study area to maximize benefits and minimize costs

The scenario analysis reported here is a first step towards understanding conservation challenges and opportunities in Alberta's Southern East Slopes. We hope that the study generates discussion about actions to address cumulative effects in the region, while also providing a foundation for more detailed analysis. Recommended areas of focus for future study include an expanded investigation of ecological impacts, more detailed consideration of conservation options, and more complete assessment of conservation costs as well as opportunities to offset costs.

One ecological impact that warrants additional study is the impacts of forest disturbance on hydrology and trout habitat. The dose response relationship that was used to incorporate the impact of forest disturbance on trout via hydrological change assumed that impacts are minimal when ECA is less than 30%. It might be evident that a 30% ECA would not be considered a goal, but a ceiling and that some watersheds critical for trout have lower or 0% ECA. ECA, however, is a coarse approach for measuring the impact of forest disturbance on peak flow. More detailed hydrological modeling is required to understand how forest disturbance in the region impacts flood frequency (e.g., Green and Alila 2012) as well as intensity, and the implications to channel stability, water quality and, ultimately, trout. Of increasing concern is the availability of overwintering habitat for trout and the effect of hydrological changes on critical winter habitat (Benson 2019).

Other ecological impacts should also be evaluated in greater detail for comprehensive assessment of cumulative effects. One such opportunity is more detailed consideration of impacts to threatened terrestrial wildlife. As with trout, the western portion of the study area contain important habitat for threatened terrestrial mammals with large area requirements such as grizzly bear. The grizzly bear exposure index assessed in this study demonstrates the effect of land use, especially roads, on risk of mortality due to encounters with humans. The analysis could be expanded to also assess connectivity provided by current and simulated future landscapes along important wildlife corridors in the region. Doing so would aid in identifying cost-effective conservation strategies that address the needs of both aquatic and terrestrial biodiversity in the region.

The conservation scenarios explored in the analysis were relatively coarse, in that they assumed that additional natural resource development would not occur in areas selected for conservation. Further analysis could explore whether strategies other than full protection hold promise, such as strict access management, or modified forest harvest methods in the presence of some level of continued development. If effective, such strategies could reduce the trade-off between conservation and resource production.

It is worth noting, however, we do not expect that more detailed conservation strategies would substantially change which watersheds are prioritized for conservation because the prioritization was more sensitive to factors relevant to trout (e.g., higher elevation, relatively intact state) than to factors related to resource sector GDP. That said, a more detailed consideration of costs would also strengthen the analysis's consideration of trade-offs. For example, expanding the scope of the cost assessment to include the value of nature-based tourism or natural capital, like protection of water quality (Yarmoloy et al. 2013) would likely reduce the trade-off between trout and economic performance. The assessment could also be expanded to evaluate opportunities to shift natural resource production elsewhere to help offset costs. The triad approach to land use zoning provides one potential way forward in this regard, whereby the landscape is allocated to conservation, mixed-used, and intensive use as a way to balance competing objectives. Under the triad approach, lost resource production associated with expanded protection of forested watersheds to the west could be offset by intensive resource production such as forest plantations elsewhere in the region.

The conservation scenarios were also limited in that they treated all protected areas as equal and thus focused watershed prioritization in areas outside of protected areas. In reality it is important to acknowledge that management strategies vary by protected area, which could result in different conservation effectiveness for certain species. A good example of this is the access management (phase out) of off-highway vehicle use within the Castle Provincial Park and Castle Wildland Provincial Park that was not captured in the analysis but which could have significant benefit to trout. Further analysis could explore these management strategies in more detail to also assess the species-specific conservation effectiveness of existing protected areas.

8. GLOSSARY

ALCES	Alberta Landscape Cumulative Effects Simulator
BAU	Business as Usual
BKTR	Brook Trout
CTTR	Cutthroat Trout
ECA	Forest disturbance, whether natural or as a result of timber harvesting, directly affects stand-scale hydrologic processes through changes in interception, evaporation, and transpiration. The potential effects of forest disturbance on streamflow are often evaluated by examining the total area disturbed and the location(s) in a watershed where forest cover has been (or will be) altered. The assumption is that the greater the disturbed area, the greater the potential for hydrologic change. It is also assumed that these changes will diminish over time as the forest regrows. The extent of disturbance, accounting for regrowth, is referred to as the equivalent clearcut area (ECA). Extracted from: https://www.for.gov.bc.ca/hfd/pubs/Docs/En/En118.htm
FSI	Fish Sustainability Index
GDP	Gross Domestic Product
HUC	The **Hydrologic Unit Code** (**HUC**) Watersheds of **Alberta** represents a collection of five nested hierarchically structured drainage basin feature classes that have been created using the **Hydrologic Unit Code** system of classification developed by the United States Geological Survey (USGS).
INFI	Index of Native Fish Integrity
Joe Model	A model developed by Dr. Michael Sullivan that explores the numerical response of Alberta's fish species to various landscape and land use metrics. Named after Dr. Joe Nelson of the University of Alberta.
km	kilometre
km/km^2	kilometers of linear features (such as roads or seismic lines) per square km
kT	kilotonne
RNTR	Rainbow Trout
WQI	Water Quality Index

9. ACKNOWLEDGEMENTS

The Alberta Chapter of The Wildlife Society gratefully acknowledges the following funders for supporting work leading to Cumulative Effects and Conservation Priorities in Alberta's Southern East Slopes:

- Fisheries and Oceans Canada
- Canadian Parks and Wilderness Society
- Yellowstone to Yukon Conservation Initiative
- Oldman Chapter- Trout Unlimited Canada
- Cheryl Bradley
- Gordon Cartwright
- Ian Dyson
- Lorne Fitch
- Debby Gregorash
- Andrew Hurly
- Klaus Jericho
- Cody Johnson
- Allan Locke
- Elspeth Nickle
- Claudia Notzke
- Christyann Olson
- Gordon Peterson
- Two anonymous donors

Alberta Wilderness Association provided banking services for individual donors.

The ALCES Group provided pro bono services for a significant portion of the initiative.

Lorne Fitch played a critical role in defining the nature of the watershed issue this project addressed, in building a multi-stakeholder coalition to help fund the project, and providing guidance on how to bring a robust scientific approach to a critical watershed issue.

10.REFERENCES

Alberta Environment and Parks (AEP). 2016. Draft: Developing and Testing Hypotheses for Cumulative Effects of Land Use on Bull Trout in Alberta. Alberta Fish and Wildlife Policy Branch, Edmonton, Alberta.

Alberta Environment and Parks (AEP). 2017. Draft: Adaptive Management of Westslope Cutthroat Trout: Cumulative Effects Modelling and Potential Management Actions. Alberta Fish and Wildlife Policy Branch, Edmonton, Alberta.

Alberta Environment and Parks (AEP). 2017. Hydrologic Unit Code Watersheds of Alberta. Available online:https://maps.alberta.ca/genesis/services/Hydrologic_Unit_Code_Watersheds_of_Alberta/Latest/MapServer.

AER (Alberta Energy Regulator). 2018. ST98: Alberta's Energy Reserves and Supply/Demand Outlook. Available online: https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st98.

Benson, J. 2019. Ecology of Westslope Cutthroat Trout populations in three small Rocky Mountain headwater streams. University of Lethbridge Research Repository 2019-04-11.

Bernier, P. Y. et al. 2016. Mapping local effects of forest properties on fire risk across Canada. Forests 7, 157.

Boulanger, Y., S. Gauthier, and P.J. Burton. 2014. A refinement of models projecting future Canadian fire regimes using homogeneous fire regime zones. Canadian Journal of Forest Research 44:1-12.

CAPP (Canadian Association of Petroleum Producers). 2017. CAPP Statistical Handbook. Available online: https://www.capp.ca/publications-and-statistics/statistics/statistical-handbook.

Carlson, M., D. Browne, and C. Callaghan. 2019. Application of land-use simulation to protected area selection for efficient avoidance of biodiversity loss in Canada's western boreal region. Land Use Policy 82:821-832.

Cleator, H., K.A. Martin, T.C. Pratt, R. Campbell, M. Pollock and D. Watters. 2010. Information relevant to a recovery potential assessment of Lake Sturgeon: Saskatchewan River populations (DU2). DFO Canadian Science Advisory Secretariat Research Document 2010/081. 35 pp.

Donahue, W.F. 2013. Determining Appropriate Nutrient and Sediment Loading Coefficients for Modeling Effects of Changes in Landuse and Landcover in Alberta Watersheds. Water Matters Society of Alberta.

Evans, J.E., E.E. Prepas, K. Devito, and B.G. Kotak. 2011. Phosphorus dynamics in shallow subsurface waters in an uncut and cut subcatchment of a lake on the Boreal Plain. Canadian Journal of Fisheries and Aquatic Sciences 57(S2):60-72.

Green, K. C., and Y. Alila. 2012. A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments. Water Resources Research 48(10).

Huang, S., S.J. Titus, and T.W. Lakusta. 1994. Ecologically Based Site Index Curves and Tables for Major Alberta Tree Species. Alberta Environmental Protection, Edmonton, AB.

Jones, D.O., A. Yool, C.L. Wei, S.A. Henson, H.A. Ruhl, R.A. Watson, and M. GehleN. 2014. Global reduction in seafloor biomass in response to climate change. Global Change Biology, 20: 1861-1872.

Jordan, P. 2006. The use of sediment budget concepts to assess the impact on watersheds of forestry operations in the southern interior of British Columbia. Geomorphology 79: 27-44.

Lee, P. and S. Boutin. 2006. Persistence and development transition of wide seismic lines in the western Boreal Plains of Canada. Journal of Environmental Management 78:240-250.

MacDonald, R.J., and L. Jones. 2017. Stream temperature modelling for Alberta using ALCES Online. ALCES Landscape and Landuse Ltd. 4 pp.

MacPherson, L.M., M.G. Sullivan, A.L. Foote and C.E. Stevens. 2012. Effects of culverts on stream fish assemblages in the Alberta Foothills, North American Journal of Fisheries Management, 32(3): 480-490.

MacPherson, L., and J. Earle. 2017. Adaptive Management of Westslope Cutthroat Trout: Cumulative Effects Modelling and Potential Management Actions. Draft Report. Alberta Environment and Parks, Fisheries Management Branch.

MacPherson, L., M. Sullivan, J. Reilly, A.J. Paul. 2019. Alberta's Fisheries Sustainability Assessment: A Guide to Assessing Population Status, and Quantifying Cumulative Effects using the Joe Modelling Technique. Canadian Science Advisory Secretariat Research Document 2019/nn. Central and Arctic Region. 46 pp.

Maitland, B. M., M. Poesch, and A. E. Anderson. 2016. Prioritising culvert removals to restore habitat for at-risk salmonids in the boreal forest. Fisheries Management and Ecology, 23(6): 489-

502.

Mayhood, D. W. 2009. Contributions to a recovery plan for westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) in Alberta: threats and limiting factors. Report prepared for Alberta Fish and Wildlife, Cochrane, AB. FWR Freshwater Research Limited Technical Report No. 2009/05-2, Calgary, AB. 68 pp.

Monserud, R.A., S. Huang, and Y. Yang. 2006. Predicting lodgepole pine site index from climatic parameters in Alberta. The Forestry Chronicle 82(4):562-571.

Mossop, G., and I. Shetsen. 1994. Geological Atlas of the Western Canada Sedimentary Basin. Available online: http://www.ags.gov.ab.ca/publications/wcsb_atlas/atlas.html.

NEB (National Energy Board). 2017. Canada's Energy Future 2017: Energy Supply and Demand Projections to 2040. Available online: http://www.neb-one.gc.ca/nrg/ntgrtd/ftr/2017/index-eng.html.

Natural Resources Canada. 2019. Annual Statistics of Mineral Production. Available online: http://sead.nrcan.gc.ca/prod-prod/ann-ann-eng.aspx?FileT=2018&Lang=en.

Nielsen, S.E., and M.S. Boyce. 2003. Grizzly bear habitat selection and mortality coefficients of southern Alberta: Estimates for the Southern Alberta Regional Strategy (SARS)-ALCES project. A report for Forem Technologies.

Palviainen, M., L. Finér, A. Laurén, S. Launiainen, S. Piirainen, T. Mattsson, and M. Starr. 2014. Nitrogen, phosphorus, carbon, and suspended solids loads from forest clear-cutting and site preparation: long-term paired catchment studies from eastern Finland. Ambio 43(2): 218-233.

Pan, Y., J.M. Chen, R. Birdsey, K. McCullough, L. He, and F. Deng. 2011. Age structure and disturbance legacy of North American forests. Biogeosciences 8:715-732.

Park, D., M. Sullivan, E. Bayne, and G. Scrimgeour. 2008. Landscape-level stream fragmentation caused by hanging culverts along roads in Alberta's boreal forest. Canadian Journal of Forest Research, 38(3): 566-575.

Post, J.R. 2013. Resilient recreational fisheries or prone to collapse? A decade of research on the science and management of recreational fisheries. Fisheries Management and Ecology, 20(2-3): 99-110.

Reilly, J., K. Rees, A. Paul, M. Macullo, L. Macpherson, and M. Sullivan. 2016. Developing and Testing Hypotheses for Cumulative Effects of Land Use on Bull Trout in Alberta. Draft

Report.

Riversdale Resources. 2016. Section A: Project Introduction. Benga Mining Limited. Grassy Mountain Coal Project.

Rokosh, C.D., S. Lyster, S.D.A. Anderson, A.P. Beaton, H. Berhane, T. Brazzoni, D. Chen, Y. Cheng, T. Mack, C. Pana, and J.G. Pawlowicz. 2012. Summary of Alberta's Shale- and Siltstone-Hosted Hydrocarbons. ERCB/AGS Open File Report 2012-06.

Schindler, D. W. 2006. Recent advances in the understanding and management of eutrophication. Limnology and Oceanography, 51: 356-363.

Schultz, C. 2010. Challenges in connecting cumulative effects analysis to effective wildlife conservation planning. BioScience, 60(7): 545-551.

Schwalb, A.N., A.C. Alexander, A.J. Paul, K. Cottenie, and J.B. Rasmussen. 2015. Changes in migratory fish communities and their health, hydrology, and water chemistry in rivers of the Athabasca oil sands region: A review of historical and current data. Environmental Reviews, 23(2): 133-150.

Scrimgeour, G. J., P.J. Hvenegaard, and J. Tchir. 2008. Cumulative industrial activity alters lotic fish assemblages in two boreal forest watersheds of Alberta, Canada. Environmental Management, 42(6): 957-970.

Spray Lake Sawmills. 2006. Detailed Forest Management Plan 2001-2026.

Sullivan, M.G. 2008. Assessment of walleye stocking in Alberta, 1926 to 2007. Alberta Fish and Wildlife Division, Sustainable Resource Development. 62 pp.

The Forestry Crop. 2006. FMU C5 Forest Management Plan: Development of the Preferred Forest Management Scenario.

Timilsina, G.R., N. LeBlanc, and T. Walden. 2005. Economic Impacts of Alberta's Oil Sands, Volume 1. Canadian Energy Research Institute, Calgary, AB.

Wang, T., Hamann, A. Spittlehouse, D.L. and Carroll, C. 2016. Locally downscaled and spatially customizable climate data for historical and future periods for North America. PLoS One 11: e0156720.

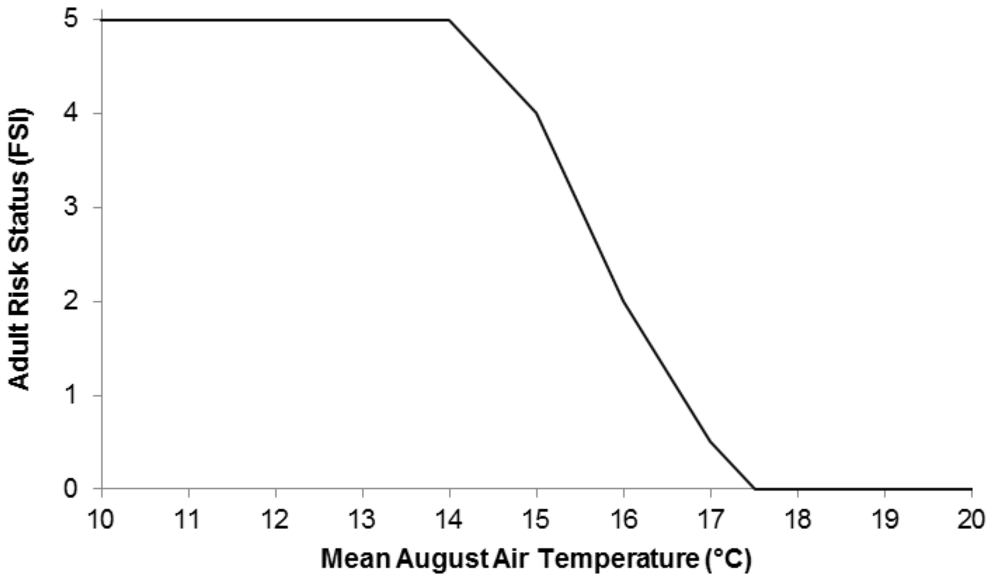
Winkler R. and S. Boon. 2015. Revised Snow Recovery Estimates for Pine-dominated Forests in Interior British Columbia. Prov. B.C., Victoria, B.C. Exten. Note 116. www.for.gov.bc.ca/hfd/pubs/Docs/En/En116.htm.

Yarmoloy, C. and J.B. Stelfox. 2013. An Assessment of the Cumulative Effects of Land Uses within the Ghost River Watershed, Alberta, Canada. Submitted to the Ghost River Watershed Alliance Group. https://www.ghostwatershed.ca/GWAS/ewExternalFiles/2011-GhostReport-web.pdf

APPENDIX A: TROUT SUSTAINABILITY DOSE RESPONSE CURVES

The following dose-response curves were provided by the Government of Alberta (AEP 2016, 2017) and applied in ALCES Online to assess response of trout populations to cumulative effect scenarios and mitigation strategies.

1)



2)

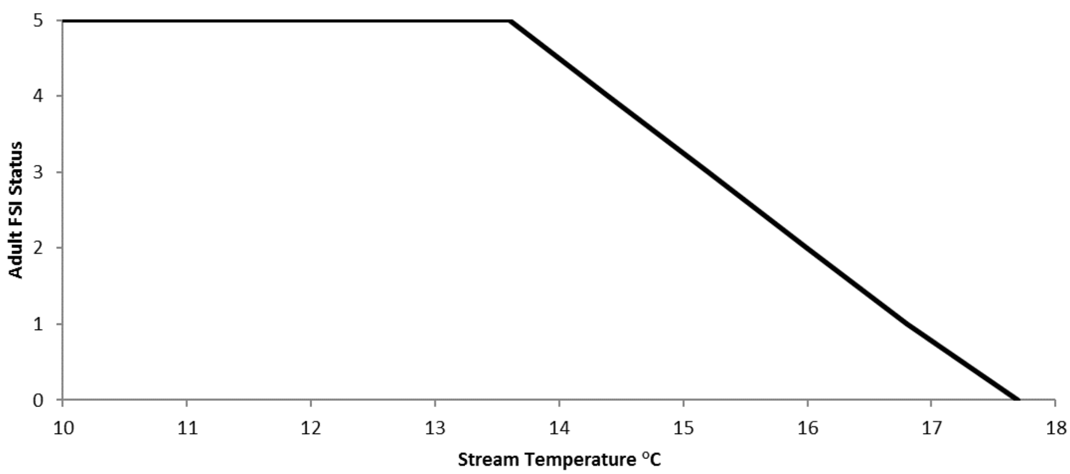
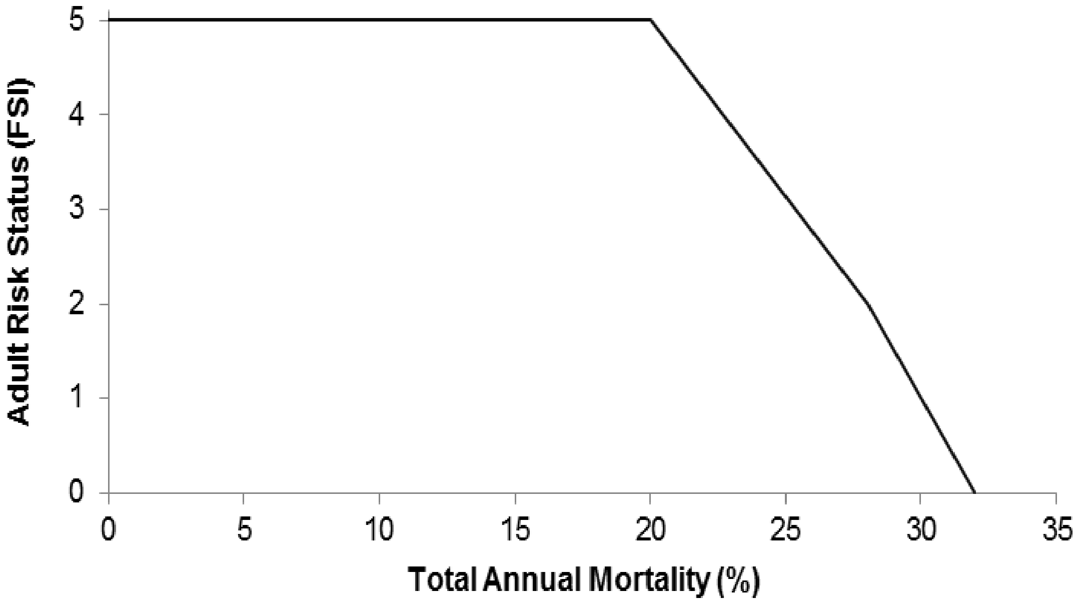


Figure A1. 1) Dose-response curve depicting the expected relationship between air temperature and sustainability of Bull Trout populations. 2) Dose-response curve depicting the expected relationship between modelled mean summer stream temperature and sustainability of Westslope Cutthroat Trout.

1)



2)

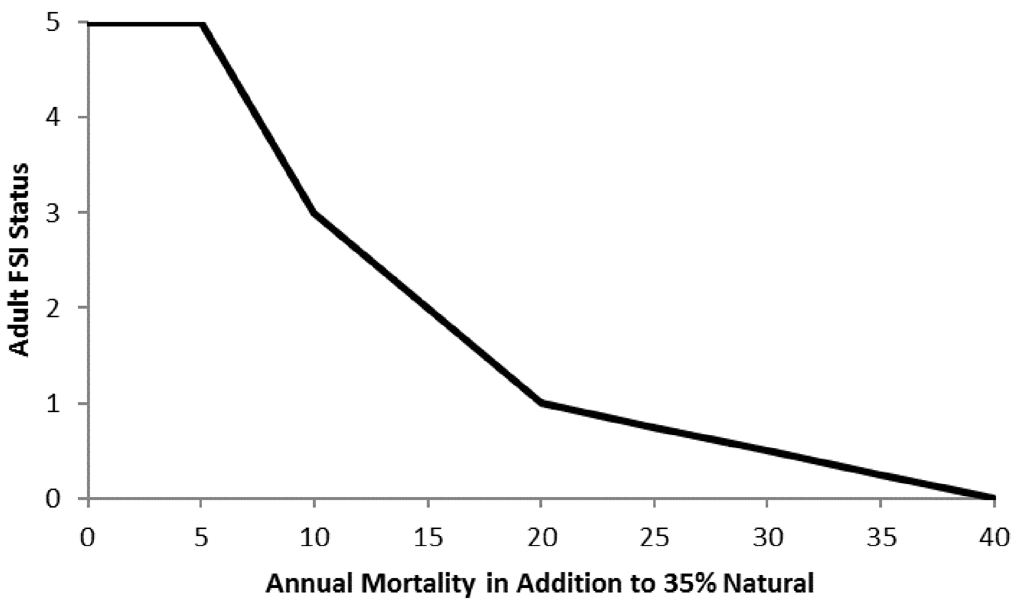
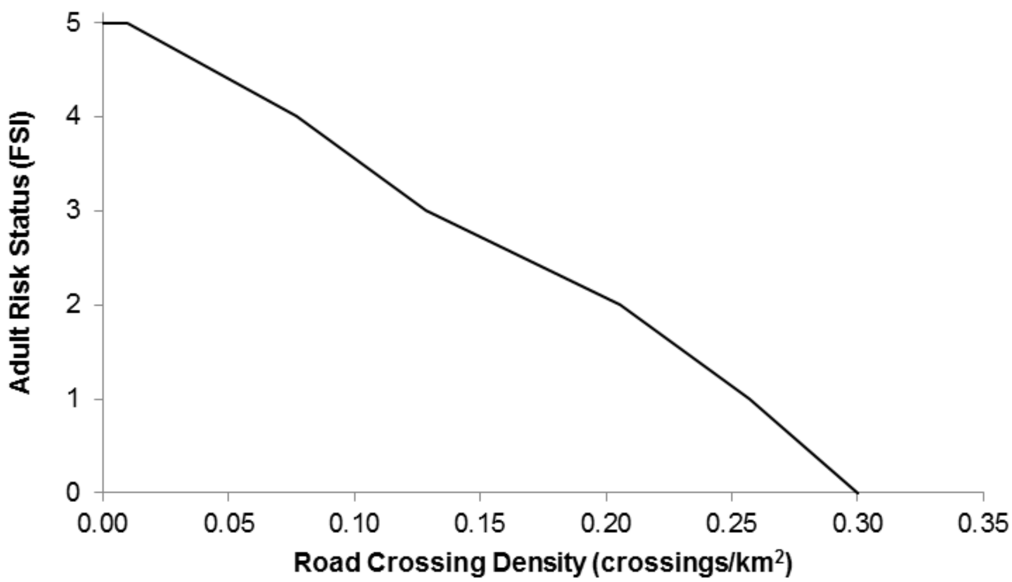


Figure A2. 1) Dose-response curve depicting the expected relationship between total annual mortality rate and the sustainability of Bull Trout populations. 2) Dose-response curve depicting the expected relationship between annual mortality in addition to the expected 35% natural rate and the sustainability of Westslope Cutthroat Trout populations.

1)



2)

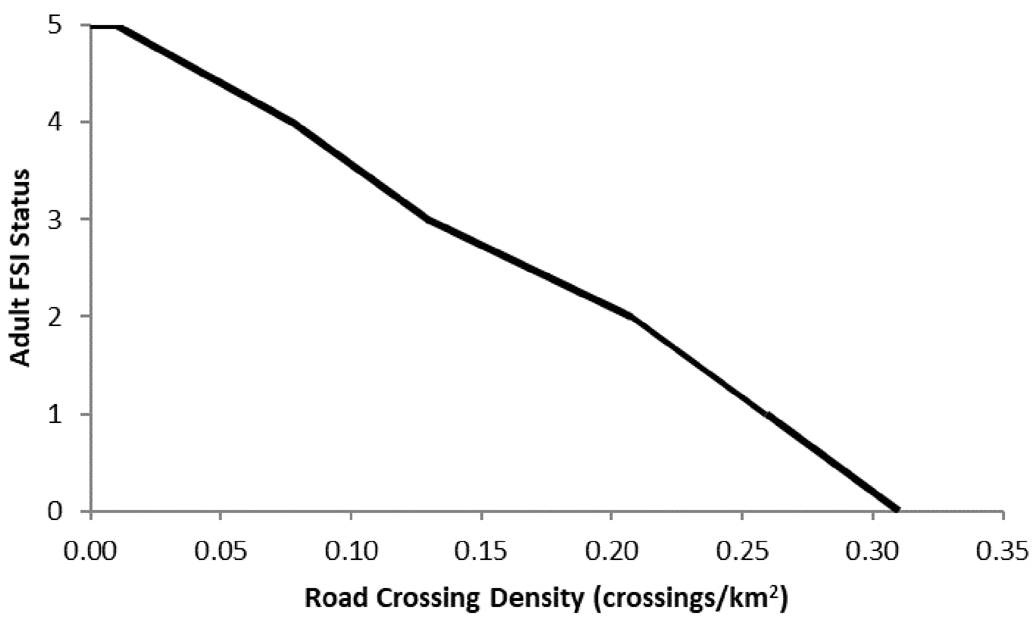


Figure A3. Dose-response curve depicting the expected relationship between road crossing density within a watershed and the sustainability of 1) Bull Trout populations and 2) Westslope Cutthroat Trout populations.

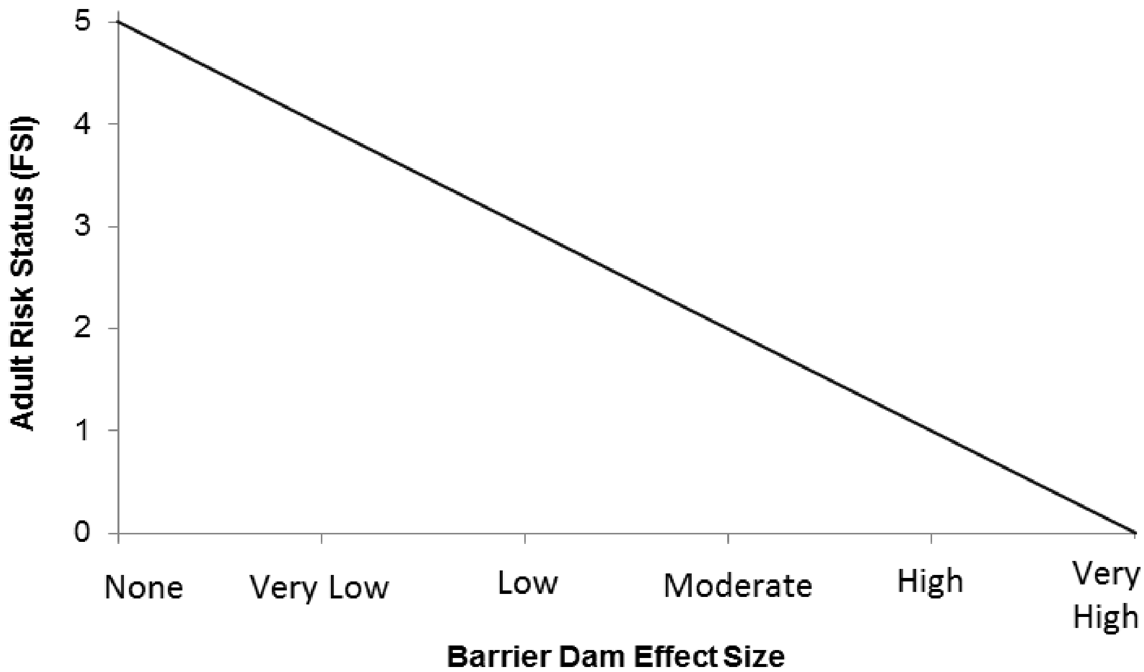


Figure A4. Dose-response curve depicting the expected relationship between barrier dam effect and the sustainability of Bull Trout and Westslope Cutthroat Trout populations.

1) **2)**

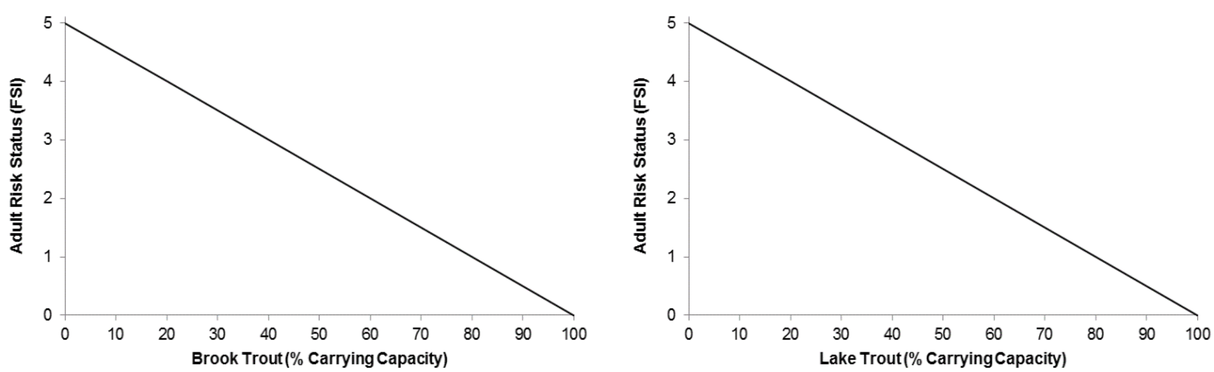


Figure A5. Dose-response curve depicting the expected relationship between 1) Brook Trout and 2) Lake Trout on the sustainability of Bull Trout populations considering the carrying capacity of the system.

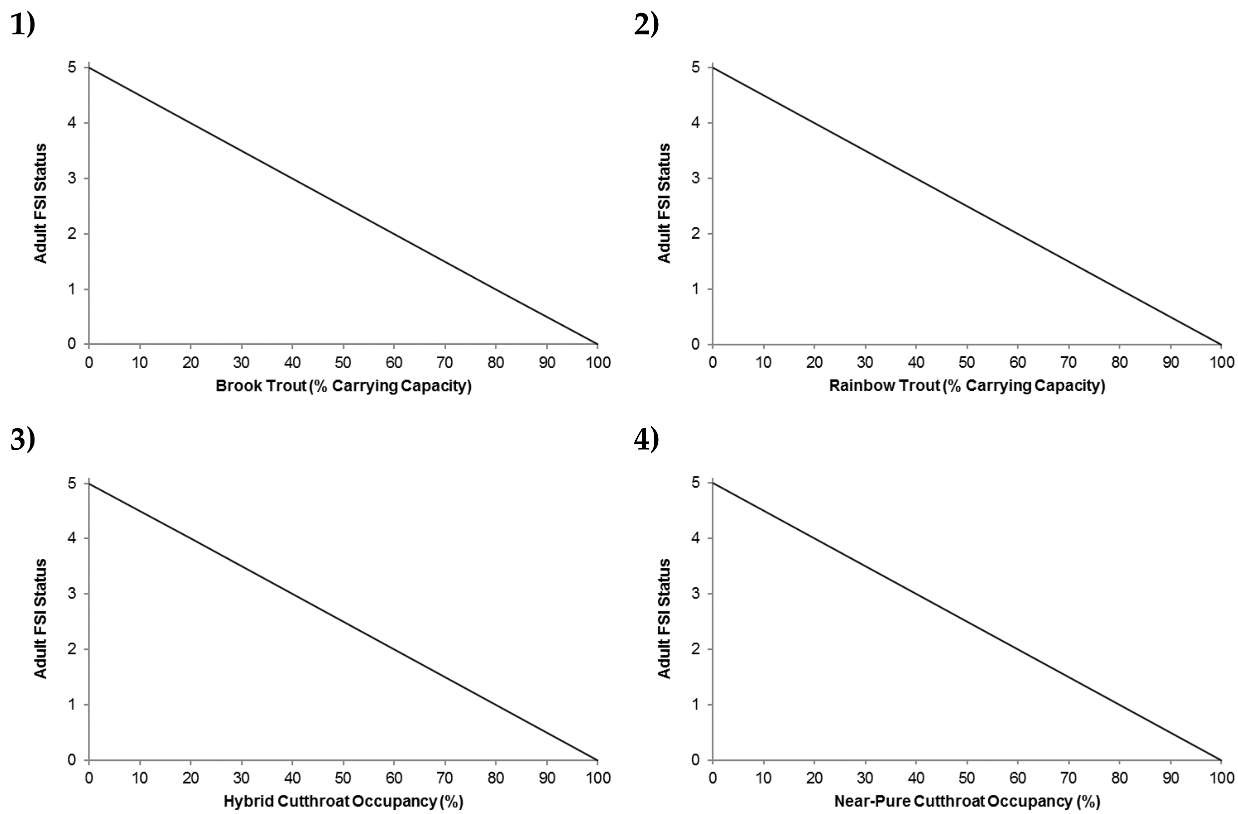
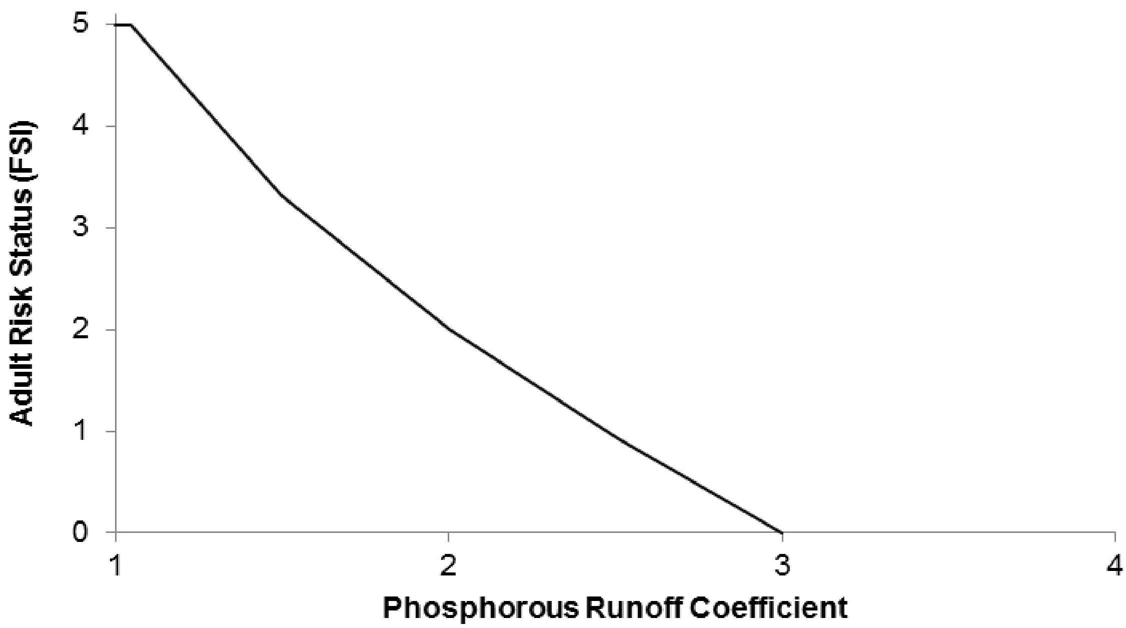


Figure A6. Dose-response curve depicting the expected relationship between 1) Brook Trout, 2) Rainbow Trout, 3) hybrid Cutthroat Trout, and 4) near-pure Cutthroat Trout on the sustainability of Westslope Cutthroat Trout populations considering the carrying capacity of the system.

1)



2)

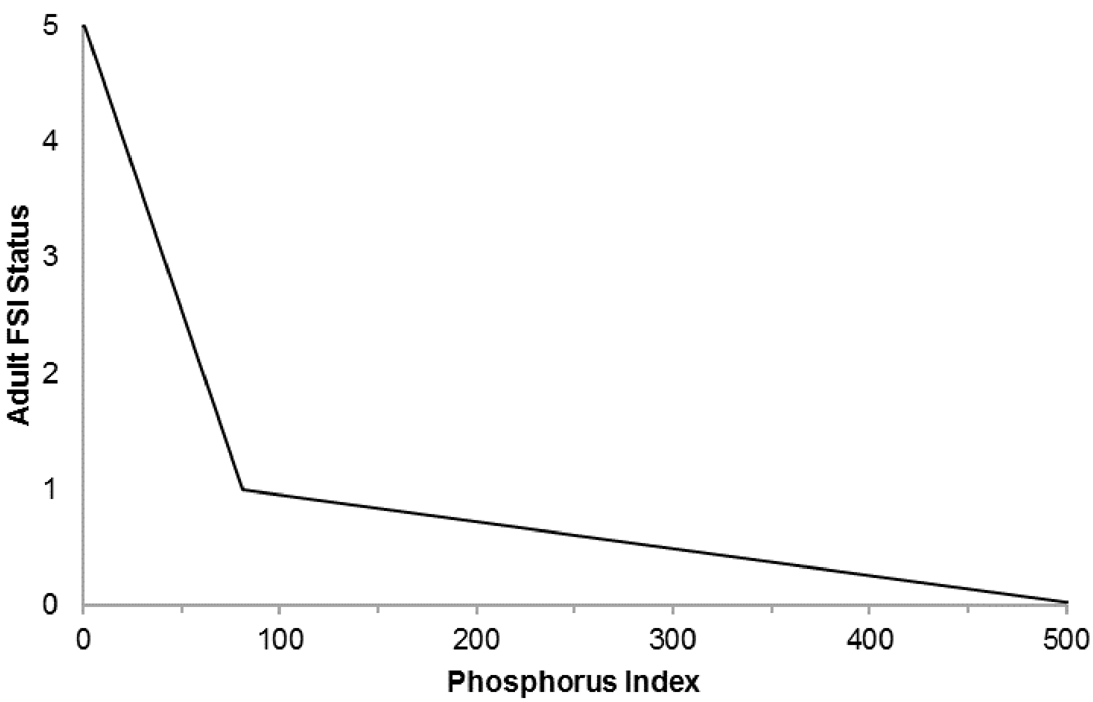
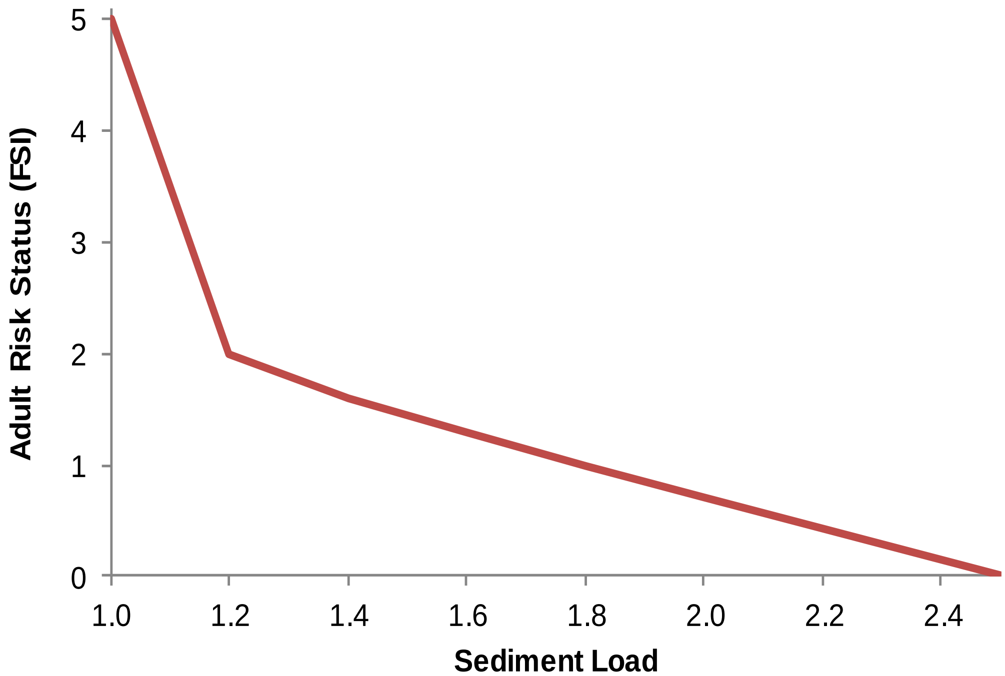


Figure A7. Dose-response curve depicting the expected relationship between phosphorus index score (increased phosphorus export at watershed level relative to pre-development) and the sustainability of 1) Bull Trout and 2) Westslope Cutthroat Trout populations.

1)



2)

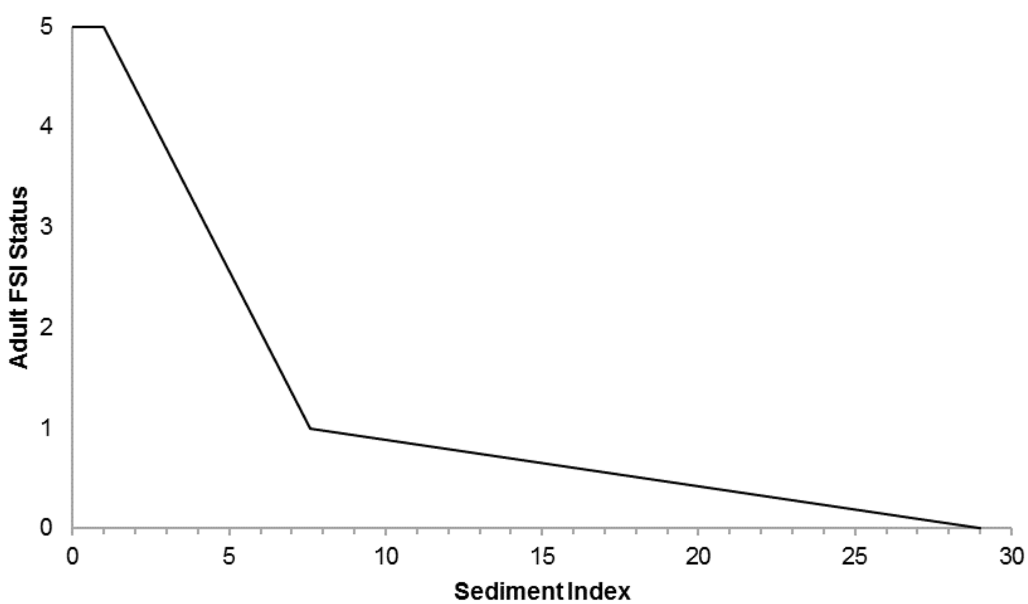
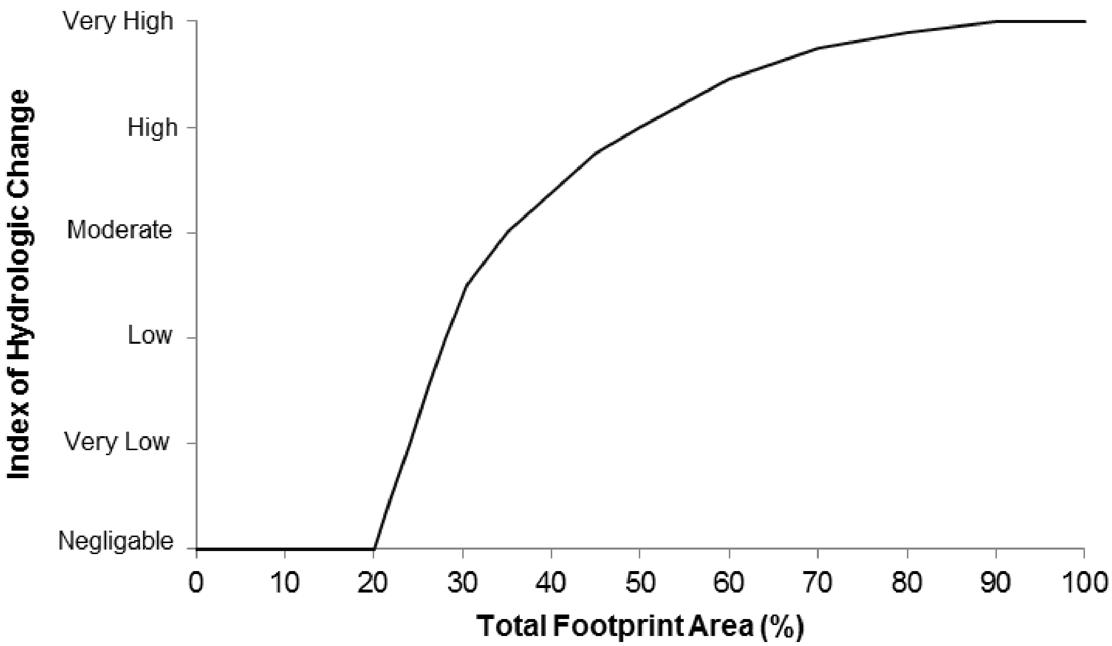


Figure A8. Dose-response curve depicting the expected relationship between sediment index score (increased sediment export at watershed level relative to pre-development) and the sustainability of 1) Bull Trout and 2) Westslope Cutthroat Trout populations.

1)



2)

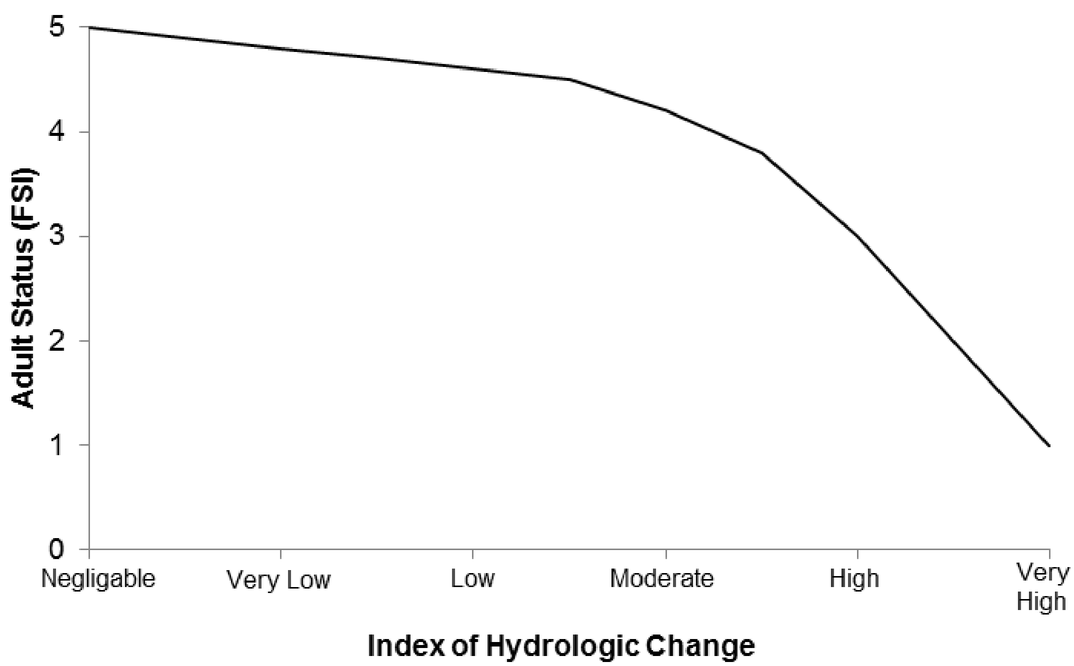


Figure A9. 1) The hypothetical relationship between Equivalent Clearcut Area (used as a surrogate for total human footprint area) in a watershed and the Index of Hydrologic Change and 2) the predicted effect of hydrologic change on the sustainability of Bull Trout and Westslope Cutthroat Trout populations.

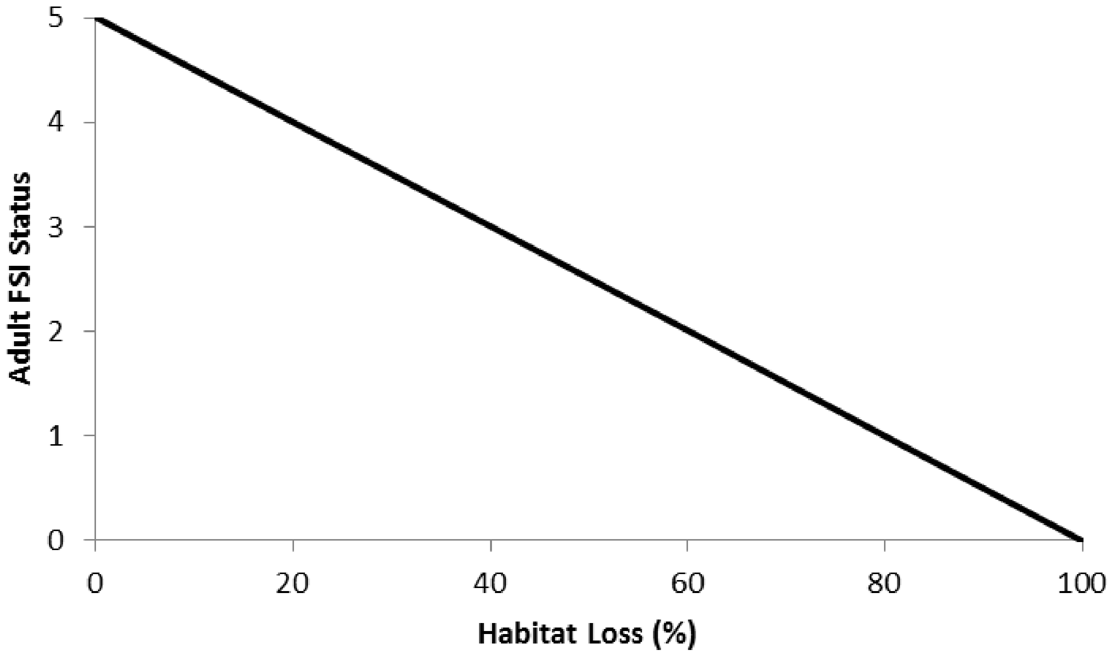


Figure A10. Dose-response curve depicting the expected Relationship between habitat loss and the effect on Westslope Cutthroat Trout population sustainability.

APPENDIX B: QUANTIFYING WATERSHED HYDROLOGICAL RESPONSE TO FOREST REMOVAL

Watersheds and their streams are dynamic and intimately linked systems. The physical appearance (morphology) of a stream channel reflects controlling processes of sediment supply, the flow of water including the magnitude, frequency and timing of peak flows, and the interaction of riparian vegetation with the stream channel. Aquatic ecosystems and their biota are adjusted to the natural dynamics of these watershed components across spatial and temporal scales.

In the Rocky Mountains, steep headwater channels provide a constant supply of sediment from talus slopes and remnant glacial deposits. Sediment is moved through the watershed in annual pulses controlled primarily by snowmelt during the spring freshet. The riparian forests along these headwater streams provide a continuous supply of large woody debris to the channels that shape the morphology and create sediment storage sites. Alterations to any one of these watershed components (i.e. flow regime, sediment regime or riparian function) has the potential to impact aquatic ecosystems (Figure B1).

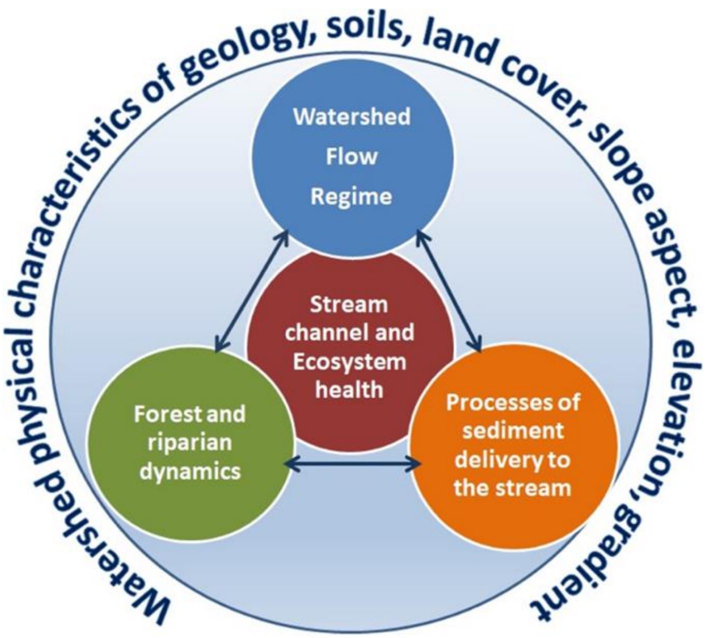


Figure B1. The watershed system (Green, 2018).

The majority of past studies intended to quantify impacts of forest disturbance (logging) on stream flows have limited their investigation to changes in peak flow magnitude and have ignored the more important and ecologically-relevant aspects of forests impacts on stream flows including changes in the frequency of peak flows and the timing of runoff. Changes in the frequency of bankfull and overbank peak flows can have dramatic impacts on channel morphology, sediment mobility and water quality.

Traditional methods of measuring the hydrological response of a stream to forest cover removal apply the BACI (Before-After-Control-Impact) method of measuring "treatment effects". In the BACI approach the magnitude of peak flows in the treatment watershed(s) are related to the magnitude of peak flows in a control watershed during a pre-treatment calibration period that usually lasts for five years or more. Treatment effects are measured as changes in the average predicted pre-treatment peak-flow to the average observed post-treatment peak flow (e.g. Moore and Scott, 2005).

This traditional chronological-pairing method of quantifying forests effects on the hydrological response of a watershed, which has been in use for over a century by the forest hydrology community, is misleading not only because it fails to account for changes in the frequency of geomorphically-effective peak flows but also because it results in incorrect outcomes. A comparison of predicted pre-treatment and observed post-treatment peak flow magnitudes will almost always result in the reporting of decreasing forest harvesting impacts with increasing peak-flow magnitude (Green and Alila, 2012). If the same predicted pre-treatment and observed post-treatment samples are compared using a frequency-based approach it becomes clear that the post-treatment sample of peak flows displays an increased frequency of larger-than-average (i.e. bankfull) peak flows even if the average magnitude of the post-treatment sample has not changed significantly. Several recent studies that have used frequency-paired analysis in forested snowmelt watersheds of western North America have begun to provide some clarity on how forest removal can affect the hydrological response of a watershed including the frequency of bankfull and overbank peak flows. These studies have determined that watershed physical characteristics of elevation and aspect distribution of slopes, slope gradient and watershed size all play a role in determining how responsive a watershed is to forest removal (Green and Alila, 2012, Schnorbus and Alila, 2013; Kuras et al., 2012). The greatest impacts to streams are likely to occur in predominantly forested, small to moderate sized (<100km^2) watersheds with limited aspect and elevation distribution (Figure B2).

The majority of HUC10 watersheds in the Oldman and Bow basins display physical characteristics consistent with highly responsive watersheds. Many have limited aspect and elevation distribution and minor alpine component. Fine-textured sedimentary rocks and glacial sediments underlying the East Slope watersheds result in highly responsive stream channels that are susceptible to changes in morphology given altered flow regimes.

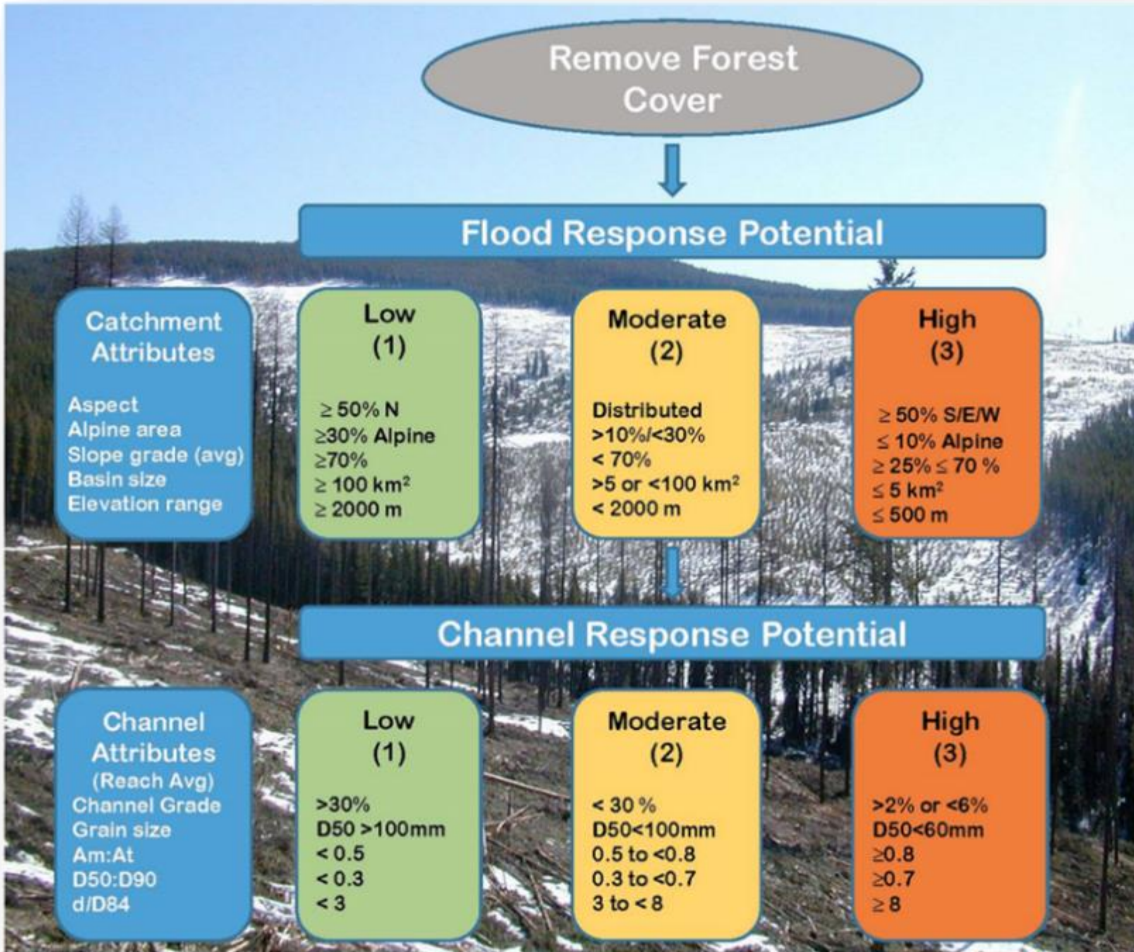


Figure B2. Conceptual model of watershed response potential (Green, 2013)

Literature cited

Green, K.C., (2018). Watersheds in Four Dimensions. Webinar presented to Engineers and Geoscientists of BC, October, 2018.

Green K.C., (2013). Forests, floods and channel processes: illuminating links between forest harvesting, the flood regime and channel response in snowmelt headwater streams. Unpublished PhD dissertation. Available from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0166834.

Green, K. C. and Y. Alila (2012), A paradigm shift in understanding and quantifying the effects of forest harvesting on floods in snow environments, Water Resour. Res., 48, W10503, doi:10.1029/2012WR012449

Kuras´, P. K., Y. Alila, and M. Weiler (2012), Forest harvesting effects on the magnitude and frequency of peak flows can increase with return period, Water Resour. Res., 48, W01544, doi:10.1029/2011WR010705.

Moore, R.D., and D.F. Scott (2005). Camp Creek revisited: Streamflow changes following salvage harvesting in a medium-sized, snowmelt-dominated catchment, Canadian Water Resources Journal, 30, 331–344.

Schnorbus, M., and Y. Alila (2013), Peak flow regime changes following forest harvesting in a snow-dominated basin: Effects of harvest area, elevation, and channel connectivity,Water Resour. Res.,49, doi:10.1029/2012WR011901.

APPENDIX C: ECA (EQUIVALENT CLEARCUT AREA) FOR HUC 10S IN STUDY AREA

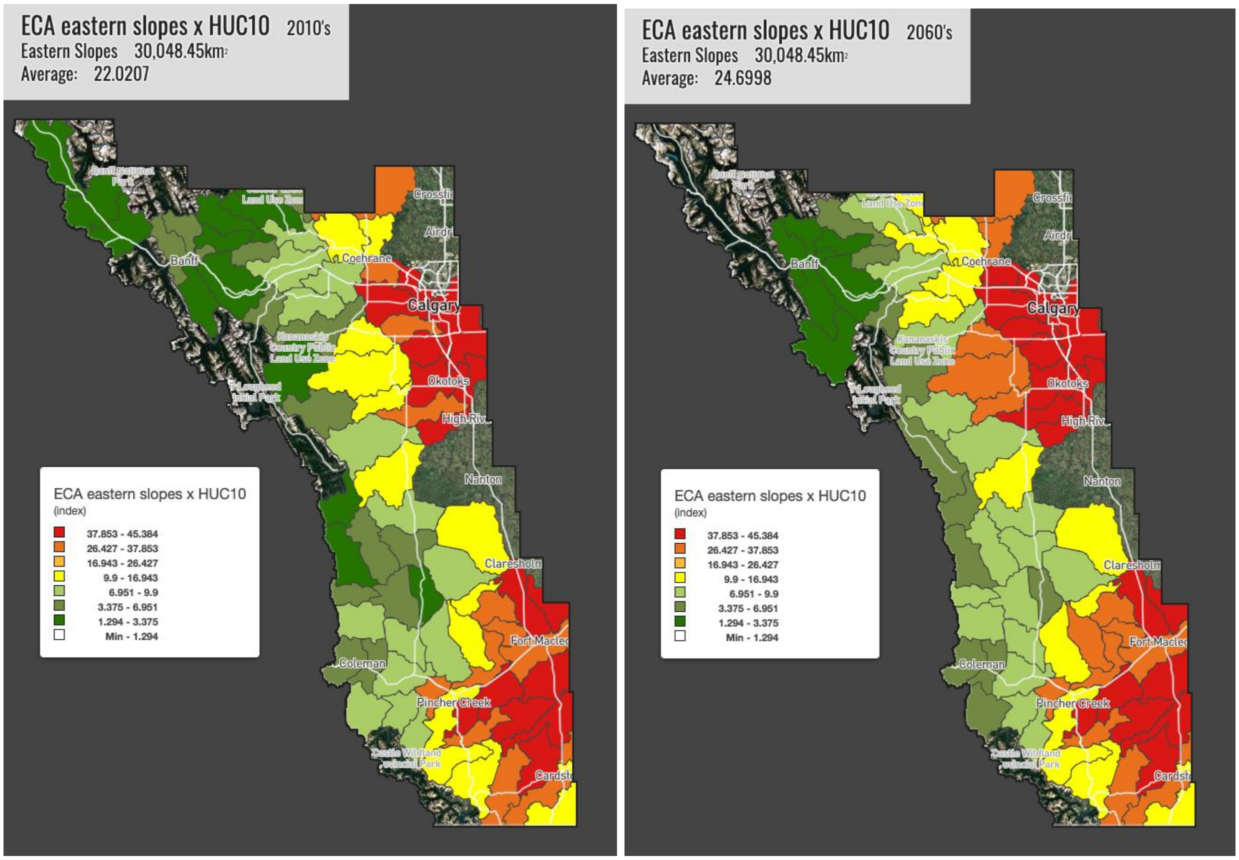


Figure 29. The estimated ECA for HUC 10s within the study area.

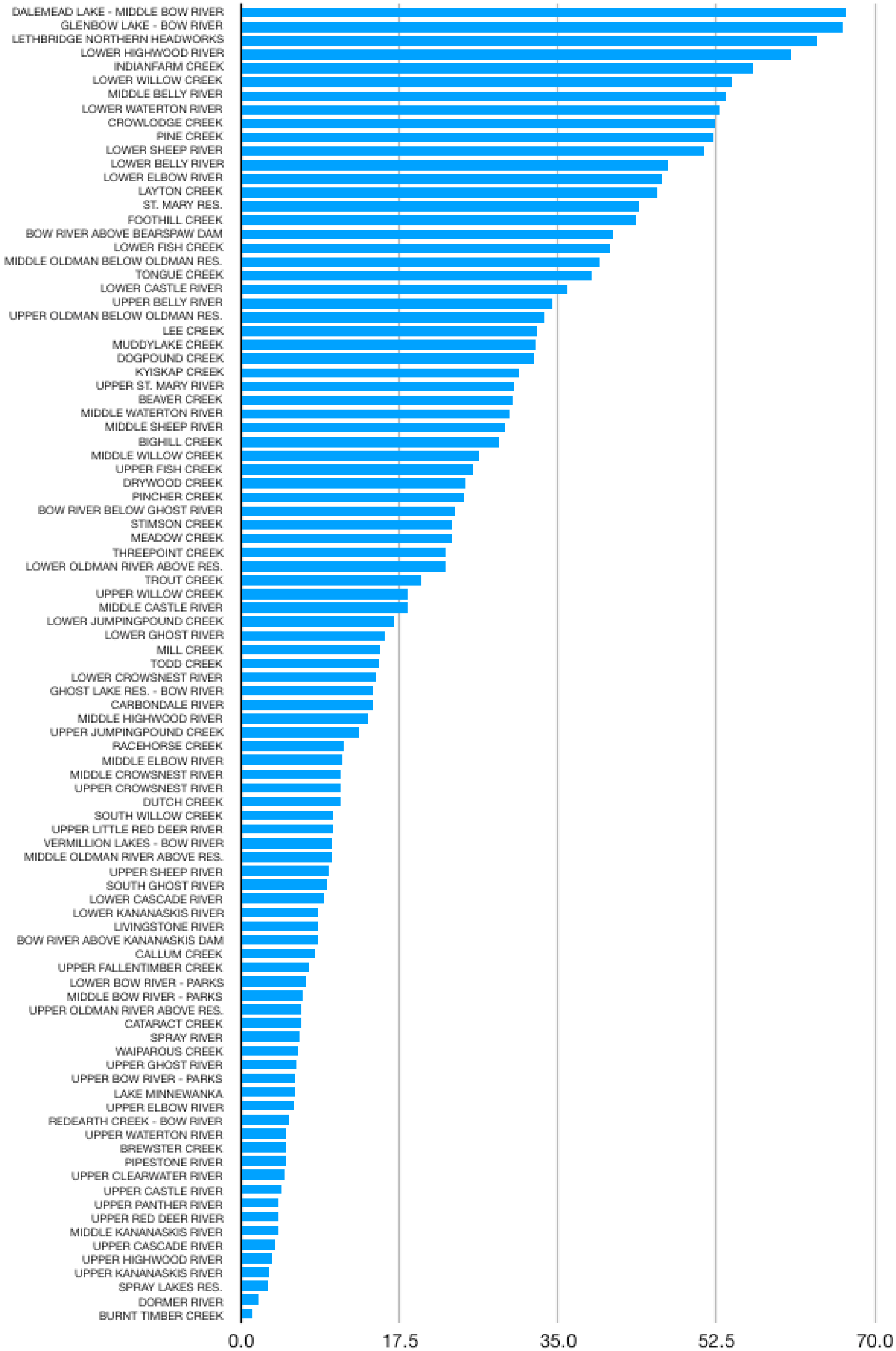


Figure 30. Rankings of the ECA values for HUC 10 watersheds within the study area.