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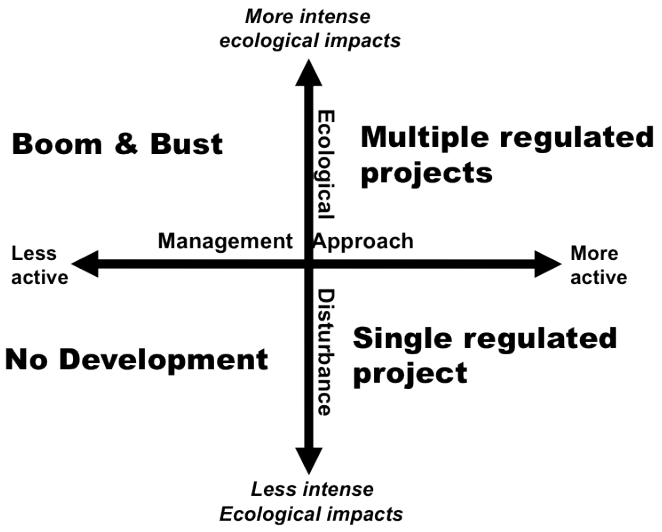
An integrated assessment of the cumulative impacts of climate change and industrial development on salmon in Western BC

Long-term assessment of cumulative effects using the CEA toolkit



Natural resource scenario analysis of the Upper Nass/Iskut-Stikine

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Prepared by:

Andrew Fall, Gowlland Technologies Ltd.

Don Morgan, BC Ministry of Environment & Bulkley Valley Research Centre

info@bvcentre.ca • Box 4274 Smithers, BC V0J 2N0 Canada

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Executive Summary

The Cumulative Effects Toolkit is being developed to support cumulative effects analysis at landscape-scale in British Columbia (BC), Canada. As a demonstration, a cumulative effects analysis (CEA) toolkit was developed and applied in the Upper Nass/Iskut-Stikine area of northwestern BC.

Cumulative effects can be defined as the combined effects of past, present and foreseeable natural processes and human activities over time, on environmental and social values in a particular place. Natural processes in the study area include tree species succession, wildfire, hydrological flow, flood erosion, water balance and glacier mass balance. Human activities include mining, gas well and pipeline development, logging, road development and hunting. Ecological and social values include grizzly bear populations (assessed by secure natal habitat), moose populations (assessed by winter habitat), water quality (sedimentation) and quantity (high and low flows), timber supply and mineral supply.

The primary purpose of scenario analysis is to ask “what if” questions about different rates and extent of development and their interactions with natural events. To assess the combined effects of natural and human processes on key values requires selecting a timeframe. The scenario analysis focuses on long-term development pathways of different fundamental trajectories, with a time horizon of 250 years. Other aspects of the CEA framework focused on current conditions (foundational assessment) and foreseeable future (short-term development options).

Assessing scenarios also requires selecting the particular assumptions and objectives for the assessment. Assumptions include controls on natural processes and biophysical aspects of human activities (e.g. growth and yield, resource potential). Objectives include economic resource targets (e.g. timber harvest level, number of gas well cases to place) or socio-ecological objectives (e.g. management of grizzly secure areas), and represent choice made regarding management of a landscape. Assumptions and objectives are collectively “parameters” in the context of the CEA toolkit. Parameters may be single numbers (e.g. fire rotation, mean fire size), tables (e.g. stand succession trajectories), spatial inputs (e.g. land-use zones), or even spatial time series (e.g. monthly grids of precipitation and temperature used to drive water balance).

Together the timeframe and parameter settings comprise a “*scenario”*. Given the large number of toolkit components, there are many parameter options. Some variations in parameters are used primarily for model verification, validation and sensitivity analysis, in particular parameters related to natural processes. An “*assessment scenario”* defines a set of parameters for objectives that represents a particular management theme. Assessment scenarios may or may not represent a feasible management alternative, but are generally designed to illuminate particular aspects of the study system.

Four scenarios were designed to capture different possible trajectories that could be taken in the study area based on historical and current conditions, the fast and slow drivers of the system, and the positive and negative feedbacks. The scenarios were designed to be qualitatively different and internally consistent, and all assessment scenarios include natural processes:

- No development scenario: represents no further human activities, to form a boundary of how the system would be expected to respond in the absence of further development.
- Single regulated project: represents a low level of industrial development, with logging and a single highly regulated mineral project in development at any time.
- Multiple regulated projects: represents moderate to high levels of industrial development, with logging and several regulated mineral projects in development at any time. The goal of the regulation aspect is to spatially constrain development activities to mitigate ecological impacts.
- Boom-bust scenario: represents very high levels of industrial development, with logging and an oscillating cycle of large numbers of mineral projects (on 50 year cycles) with little mitigation effort. One aim of this scenario is to form a boundary on effects of development.

In addition to these long-term scenarios, a short-term (20 year horizon) “maximum development” scenario was included to form a boundary of how the system would be expected to respond to high levels of unregulated development. It is the same as the boom-bust scenario in terms of mineral development, but also removes cut control from harvest (so logging is only limited by economically available stands and specific forest cover constraints for wildlife and visual management).

This document describes the assessment of these scenarios in the Upper Nass/Iskut-Stikine area using the CEA toolkit, and describes the details of the scenario assumptions and objectives and key analysis results.

Acknowledgements

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1. Introduction

The ***Cumulative Effects Toolkit***[1] is being developed to support cumulative effects analysis at landscape-scale in British Columbia (BC), Canada. As a demonstration, a cumulative effects analysis was conducted in the Upper Nass/Iskut-Stikine area of northwestern BC using the Toolkit.

Cumulative effects can be defined as the combined effects of past, present and foreseeable natural processes and human activities over time, on environmental and social values in a particular place. Natural processes in the study area include tree species succession, wildfire, hydrological flow, flood erosion, water balance and glacier mass balance. Human activities include mining, gas well and pipeline development, logging, road development and hunting. Values are the things that people and governments care about and see as important for assuring the integrity and well-being of communities, economies, and ecological systems (Province of BC 2012). In this study area, ecological and social values include grizzly bear and moose populations (assessed using habitat), water quality and quantity, fish habitat, timber supply and mineral supply.

To examine the combined effects of natural and human processes on key values over the long term (250 years), we designed and applied several *assessment scenarios* that represent different management trajectories. Assessment scenarios may or may not represent feasible management alternatives, but are generally designed to illuminate particular aspects of the study system with a consistent set of objectives.

Scenarios were identified using the CEA framework[2] and quantitatively assessed using the CEA toolkit. All scenarios included natural disturbance and differed in management objectives, which ranged from no and low regulated development, moderate regulated development, and high unregulated development.

The Cassiar case study scenario assessment is presented to demonstrate the quantitative approach to scenario analysis with direct summary output from the analysis components, and as a background to the risk analysis conducted under the Northwest Cumulative Effects project. The case study illustrates the broader social-ecological concepts and how they can be practically applied, including the components and relationships of the social-ecological system, fast and slow drivers of change, and feedbacks. The example concludes with the composition of a set of future scenarios, based on the study area's social and ecological variability and uncertainty, designed to reflect the behaviour of the social-ecological system and the mechanisms of change.

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[1] Fall and Morgan 2013

[2] Morgan and Daust 2013

2. Methods

2.1. Level of assessment and time horizon

Broad scale assessment consists of a hierarchy of assessments, including Current Condition, Foreseeable Future (short term development options) and Long-Term Assessment (long-term development pathways). This document focuses on using scenario analysis in support of Long-Term Assessment. It considers a long time horizon – in this case 250 years, although some scenarios focus on the foreseeable future with a short-term horizon of 20 years.

Resource development and natural disturbance area are modeled using quantitative models, applying the CEA toolkit. Long-Term Assessment helps decision-makers understand trade-offs among valued services and inform strategic decisions about the rate and extent of development, including mitigation. They help inform land use planning by assessing the long-term consequences of management for different valued services. Furthermore, limits can be explored under different environmental and industrial development conditions.

2.2. Study area, spatial scale and data inputs

The study area encompasses a portion of the Cassiar Timber Supply Area (specifically the part covered by the Iskut-Stikine Land and Resource Management Plan) and the entire Nass Timber Supply area, in northwestern BC. This is an area of about 6.9 million hectares.

The study area is located in north-western BC, and encompasses 6 million hectares. The area is composed of two Timber Supply Areas, the Cassiar and the Nass. The area is expected to go through extensive resource development. At the same time it is regarded for its ecological integrity, including intact predator-prey systems and abundant salmon stocks. The study area provides a good example of a social-ecological system in transition from a historic configuration to some future, more human dominated, arrangement.

The study area is currently relatively pristine, however prompted by B.C. Hydro's construction of the Northwest Transmission Line it is anticipated that the area could go through a phase of rapid industrial development. Development includes the construction of several mines, hydroelectric facilities and associated roads. Social direction in the area is supplied by the Cassiar LRMP, Nass South Sustainable Resource Management Plan (SRMP), Tahltan land use plan, Nisga Treaty and the Gitanyow land use plan. Timber harvesting has historically made up a small portion of human activity in the area. The study area has a number of large rivers, abundant salmon and fairly intact predator-prey system with the economy being more typically dominated by traditional hunting and fishing activities. Being remote the area is not extensively managed for fire resulting in a more natural expression of disturbance dynamics.

Spatial data were provided by the BC government, which was converted to raster grids at a resolution of 1ha (100m x 100m). Some attributes were also stored at finer resolutions (e.g. elevation at 25m x 25m grid cells) and coarser resolution (e.g. climate data at 400m x 400m grid cells), as appropriate and with different resolutions nesting. Most of the analysis is done at a resolution of 1ha (100m x 100m grid cells), with a time horizon from several decades to several centuries.

Key attributes include a digital elevation model (particularly elevation, from which slope and aspect can be computed), land cover (non-forest, biogeoclimatic zone, glaciers), forest cover (species, stand age site index, etc), mining attributes, habitat attributes for moose and grizzly, climate variables, and reporting attributes (e.g. watershed assessment unit). The specific requirements for each toolkit component are provided with the description of the component in the appendices.

Key natural processes in the study area include tree species succession, wildfire, water and glacier mass balance, mass wasting, and climate change. Key human activities include gas development, transmission lines, logging and road building. Key values of importance include wildlife, water quality and local jobs.

2.3. Scenario analysis methods: CEA toolkit

We applied the CEA toolkit, developed as a general approach to support short and long-term projections in a CEA and adapted to the Upper Nass/Iskut-Stikine study area (Fall and Morgan 2013). This toolkit is a network of model components, in which output from one component may be used as input to one or more other components. Components were developed to capture natural processes (e.g. tree species succession, wildfire, flood erosion, snow avalanche hazard, coarse sedimentation hazard, water balance, glacier mass balance) and for human resource development processes (e.g, road development, gas well and pipeline development, mining development, logging). Collectively, for a given scenario, these create projections of likely changes in landscape condition over the selected time frame. These projected conditions are used as input to value indicator models (e.g. moose winter habitat, grizzly secure habitat, water quality and quantity, timber supply). Finally, the output from the value indicator models is used for assessing risk of the scenario to the important values.

Details on the toolkit and individual components[3], s scenario purpose, construction and analysis[4], and risk assessment[5] can be found in associated documents.

2.4. Scenario analysis outputs

The primary values explored in the scenario analysis element of the CEA are timber production, gas production, mineral production, roads developed, moose winter habitat, grizzly bear secure habitat, water quantity (expected changes in peak and low flows) and water quality (expected changes in coarse sedimentation). This document presents the base outputs for value indicators, with risk assessment applied as a separate step and described elsewhere.

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[3] Fall and Morgan 2013

[4] Morgan and Daust 2013

[5] Daust and Morgan 2013

2.5. Scenarios assessed

A scenario is “a structured account of a possible future”[6], and when applied to natural resource systems includes social and ecological dimensions. In contrast, predictions are estimates of future conditions, based on what we know about the world today and on hypotheses of how the world may change. Predictions are ideally based on experiments to derive parameters of system behaviour. Predictive models have served forest management well in the past, however, uncertainty about future conditions is increasing as Canada’s forests undergo rapid transformation, driven by changes in key driving forces such as technology, global markets, MPB, and climate change. Predictions may not provide the insights required to manage for such an uncertain future. In contrast, scenarios take broad uncertainties into account; they are structured to include a range of plausible futures of what could be and do not predict what will be. Scenarios are designed to lend insight into system drivers, to explore uncertainties in system behavior, and to allow managers to explore how actions or inactions may play out across a range of possible futures; scenarios are not about providing support for one particular future[7].

In the case study exercise, 5 scenarios were assessed (Table 1), which varied by their rate of development (logging, gas wells and pipelines, mining) and the intensity of ecological impact (ranging from less to more intense ecological disturbance based on mitigate effort). A natural fire regime, un-influenced by climate change is considered for simplicity. The *Maximum development* scenario focused on the near term, while all others focus on long-term.

Maximum development scenario (or more shortly *MaxDev*): represents the hypothetical extreme case of all possible projects proceeding[8]. This scenario was examined to assess a worst-case risk to value scenario and would effectively contrast current conditions in bounding risk to values. It applies a maximum rate of resource development, with high levels of uncoordinated mining and gas well development. Timber harvesting is rapid, up to the limit of constraints applied in the timber supply review process, such as hydrological green-up, visual objectives and landscape level biodiversity targets (but no limit on harvest rate).

No development scenario (or more shortly *NoDev*): represents no further human activities, to form a boundary of how the system would be expected to respond in the absence of further development.

Single regulated project (or more shortly *SingleReg*): represents a low level of industrial development, with logging based on current management (and AAC) and a single highly regulated mineral project and gas well project in development at any time.

Multiple regulated projects (or more shortly *MultipleReg*): represents moderate to high levels of industrial development, with logging based on current management (and AAC) and several regulated mineral and gas well projects in development at any time. The goal of the regulation aspect is to spatially constrain development activities to mitigate ecological impacts.

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[6] Peterson et al. 2003

[7] Morgan 2011

[8] described in Morgan and Daust 2013, and includes the “maximum forest depletion” sub-scenario

Boom-bust scenario: represents very high levels of industrial development, with logging and an oscillating cycle of large numbers of mineral and gas well projects (on 50 year cycles) with little mitigation effort. One aim of this scenario is to form a boundary on effects of development.

The *No Development* and *Single Regulated Project* scenarios were anticipated to have minimal ecological impacts. Conversely, the *Maximum development*, Boom *and Bust* and *Multiple Regulated Projects* scenarios were expected to have the potential for more severe ecological consequences. These were structured to be more environmentally intrusive and contain less mitigation measures that might minimize their impact, with the *Boom-bust* scenario having no mitigation and the *Multiple Regulated* scenario constrained somewhat by concentrating development.

Table 1. Summary of scenarios assessed

Scenario name	**Time horizon**	**Natural processes**	**Logging**	**Mine development rate**	**Gas well development rate**
MaxDev (maximum development)	20 years	Historic[9]	Max. subject to constraints	1/year	1 case/year
NoDev (no development)	250 years	Historic	None	None	None
SingleReg (single regulated project)	250 years	Historic	Current AAC	1/decade	1 case/decade
MultipleReg (multiple regulated projects)	250 years	Historic	Current AAC	2/decade	2 case/decade
Boom-bust (multiple unregulated projects, oscillating)	250 years	Historic	Current AAC	50 year cycle: 1/year in 1st decade; none for next 40 years	50 year cycle: 1/year in 1st decade; none for next 40 years

3. Results

3.1. Timber production

The logging component of the toolkit was benchmarked with the Cassiar timber supply review (TSR) analyses (Iksut block, which coincides with the Cassiar portion of the study area) and Nass TSR analyses[10]. The current AAC applied in the Iskut block of Cassiar TSA was 187,000 m^3/year. The current AAC applied in the Nass TSA was 820,000 m^3/year for 1st decade, 738,000 m^3/year for 2nd decade,

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[9] No climate change as assessed in these scenarios.

[10] Fall and Morgan 2013

dropping 10%/decade until decade 8 and 407,000 m^3/year thereafter. All scenarios except *MaxDev* applied the current AAC as a target. The *MaxDev* scenario applied a target of 1,100,000 m^3/year for Iskut block and 3,000,000 m^3/year for Nass TSA. These levels were derived as approximately maximum harvest levels that could be supported for 10 years.

The resulting timber production for each scenario (Table 2) is very close to the current AAC for scenarios other than *MaxDev*. Long-term values may be lower than the AAC due to interactions with the stochastic fire (Table 3) and flooding regimes. In a full CEA, multiple replicates should be run to generate mean and variance statistics to account for natural variation in disturbance and succession. Differences in natural disturbance are higher when looking a shorter time intervals (i.e. 1st and 2nd decade) than longer term (i.e. years 21-250). For fires, differences depend to a large extent on the number of dry and very dry years stochastically selected during a model run.

Table 2. Summary of timber production for scenarios assessed

Scenario name	**Average timber produced (m^3/year)**		
	Years 1 – 10	**Years 11 - 21**	**Years 21 - 250**
MaxDev	3,530,000	494,100	N/A
NoDev	0	0	0
SingleReg	1,037,100	955,000	623,200
MultipleReg	1,037,000	955,100	612,800
Boom-bust	1,037,100	955,000	547,000

Table 3. Summary of area forest burned in wildfires for scenarios assessed (note: only one replicate was run)

Scenario name	**Average area burned (ha/year)**		
	Years 1 – 10	**Years 11 - 21**	**Years 21 - 250**
MaxDev	8,200	3,000	N/A
NoDev	53,200	2,400	13,700
SingleReg	700	11,100	10,000
MultipleReg	23,700	18,000	10.600
Boom-bust	63,200	14,800	16,800

3.2. Mineral production

Scenarios applied one of two mine placement options. The *SingleReg* and *MultipleReg* scenarios applied "coordinated" mine placement, in which the area available for mineral exploration and development (everywhere outside protected areas and private land) was divided into relatively large "coordination zones" that are sequentially enabled for 50 year periods (i.e. only one zone active at any time). New mines must be placed within the active coordination zone to reduce and concentrate road development. The *MaxDev* and *Boom-bust* scenarios applied "uncoordinated" mine placement, where mines are situated independently. In all mine development scenarios, mines are otherwise placed stochastically, with probabilities derived based on historical mines by metal rank zone (low, low-moderate, moderate, moderate-high, high)[11].

For this project, we assumed that all mines were hard rock minerals (copper, gold, lead, zinc, silver). While there are proposed coal mines, which could easily be handed in the analysis methodology, we wanted to keep results simple for illustrative purposes. We don't attempt to classify mine ore types since uncertainty is too high, but instead apply an average annual ore concentrate production (200,000 tonnes/year for each mine) and mine productive longevity (20 years), which can be used to bound number of jobs expected and amount of road traffic produced. Hence, the mineral production outcome for each scenario is a directly outcome of the development assumptions (Table 4). Note that, due to mine longevity, mines from the previous decade may still be in operation, older mines may be in reclamation stage and new mines may be in development (e.g. in the *SingleReg* scenario, a new mine is started each decade, and the mine started in the previous decade is still in operation).

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[11] See Fall and Morgan 2013 for details.

Table 4. Summary of mine development for scenarios assessed

Scenario name	**Average annual ore concentrate produced (tones/year) by end of decade for first 50 years**				
	1st decade	**2nd decade**	**3rd decade**	**4th decade**	**5th decade**
MaxDev	2,000,000	4,000,000	N/A	N/A	N/A
NoDev	0	0	0	0	0
SingleReg	200,000	400,000	400,000	400,000	400,000
MultipleReg	400,000	800,000	800,000	800,000	800,000
Boom-bust	2,000,000	2,000,000	0	0	0

3.3. Gas production

The same base well and case placement scenario was used in all assessment scenarios, which applied a single play type for coal bed methane. This scenario applied parameters from the earlier Klappan CEA[12]. This resulted in 24 cases (exploration wells), 15 of which were successful. The successful cases had an average of 26 associated production leases of 4 directional wells each (104 wells/case and a total of 1564 production wells). Each well had an average production of 500 thousand cubic feet (mmf/day) and a total recoverable resource of 6.5 billion cubic feet (bcf), or 25.9 bcf per lease. Hence, on average, wells were assumed to have a productive longevity of about 35 years. Cases had an average total recoverable resource of 676 bcf. Total production from all production wells in this scenario would be about 10 trillion cubic feet[13].

All scenario developed cases in the same sequence, but differed in rate of development. Once all 24 cases were processed, no more cases were developed (which occurs in the *SingleReg* scenario after 240 years, in the *MultipleReg* scenario after 120 years, and in the *Boom-bust* scenario after 110 years).

The estimated gas production by decade (Table 5) shows the effect of overlap between case developments, while length of pipeline built (Table 6) is an up-front cost. Note that the pipeline length built only refers to connections between wells within a case. Pipelines to connected cases to a main pipeline to transport gas out of the study area is not included here.

Table 5. Summary of coal bed methane production for scenarios assessed

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[12] Cortex Consultants Ltd.

[13] Somewhat higher than the 8 trillion cubic feet estimated in the Cortex analysis.

Scenario name	**Average annual gas produced (bcf/year) by end of decade for first 50 years**				
	1st decade	**2nd decade**	**3rd decade**	**4th decade**	**5th decade**
MaxDev	1.9	5.2	N/A	N/A	N/A
NoDev	0	0	0	0	0
SingleReg	0	0.7	0.7	1.2	1.4
MultipleReg	0.35	0.95	2.0	2.8	2.6
Boom-bust	1.9	3.3	3.3	2.9	0.2

Table 6. Summary of gas pipeline development for scenarios assessed

Scenario name	**Average pipeline developed (km) in each decade for first 50 years**				
	1st decade	**2nd decade**	**3rd decade**	**4th decade**	**5th decade**
MaxDev	11,180	11,950	N/A	N/A	N/A
NoDev	0	0	0	0	0
SingleReg	0	2,300	0	1,810	1,580
MultipleReg	2,300	1,810	3,700	2,310	1,060
Boom-bust	11,180	0	0	0	0

3.4. Roads developed

The length of road developed increases with resource development rate and lack of coordination (Table 7). Note that the roads reported here do not include roads associated with pipelines. If each pipeline segment is assumed to have an associated road, then total roads would add in pipeline length (Table 6).

Table 7. Summary of roads developed for scenarios assessed

Scenario name	Average road developed (km) in each decade for first 50 years				
	1st decade	2nd decade	3rd decade	4th decade	5th decade
MaxDev	2,067	181	N/A	N/A	N/A
NoDev	0	0	0	0	0
SingleReg	538	606	373	376	358
MultipleReg	572	604	434	442	373
Boom-bust	535	828	448	425	397

3.5. Moose winter habitat

Winter habitat at year 0 is 612,500 ha, and changes depending on management and natural processes (Table 8). Note that wildfire and logging reduces shelter habitat, but may increase feeding habitat, and roads reduce both, but that overall habitat depends on the proximity of both types of habitat.

Table 8. Summary of moose winter habitat for scenarios assessed

Scenario name	Amount of moose winter habitat (thousands of ha) in each decade for first 50 years				
	1st decade	2nd decade	3rd decade	4th decade	5th decade
MaxDev	555,600	532,300	N/A	N/A	N/A
NoDev	547,700	595,700	582,900	586,800	547.100
SingleReg	604,700	587,500	584,000	567,200	551,500
MultipleReg	576,400	564,700	569,700	543,100	494,900
Boom-bust	530,800	542,000	512.100	504,700	479,300

3.6. Grizzly bear secure habitat

Secure habitat at year 0 is 1,814,500 ha, and changes depending on management and natural processes (Table 9). Note that road building reduces secure habitat.

Table 9. Summary of grizzly bear secure habitat for scenarios assessed

Scenario name	**Amount of secure grizzly bear habitat (thousands of ha) in each decade for first 50 years**				
	1st decade	**2nd decade**	**3rd decade**	**4th decade**	**5th decade**
MaxDev	1,485,600	1,345,500	N/A	N/A	N/A
NoDev	1,814,500	1,812,100	1,811,500	1,811,400	1,809,400
SingleReg	1,782,000	1,720,100	1,703,500	1,631,400	1,550,600
MultipleReg	1,772,400	1,711,300	1,679,000	1,621,100	1,526,100
Boom-bust	1,745,400	1,589,500	1,536,900	1,513,900	1,487,800

3.7. Water quantity: water balance

For this assessment, the water balance and glacier mass balance component was run for 20 years (on a monthly time step) for all scenarios using the ClimateBC normal temperature and precipitation for 1961 to 1990. Each month, a climate variance (increment/decrement of temperature and precipitation) was stochastically selected, based on variance between 1990 to 2010. To keep results comparable among scenarios, the same sequence of precipitation and temperature variances were applied. In a more complete assessment, multiple replicates would be run on different climate streams.

Ideally, changes in water quantity would assess changes to low flow and peak flow in each watershed. However, these attributes are of a fine temporal resolution, in particular peak flow, which can occur over a period of hours as the largest volume of rain or melt water flows. ClimateBC data is available in month time steps, which is a lower feasible limit for long-term projection scenarios using the toolkit on this large area. We compare the lowest and highest water flows by month with estimated flows in the absence of development (roads and pipelines, which may affect flows), and report the proportion of watersheds (scaled by area) for which minimum and maximum monthly flow increased or decreased over 20 years by class (± 5%, 10%).

The results for lowest monthly flow (

Table 10) and highest monthly flow (Table 11) show that over a 20 year time frame, this water flows in the study area are insensitive (less than 1% change) to development. The primary effect of development on water balance is to increase open areas from logging, which increases potential evaporation. This component does not yet account for effects of roads, pipelines, well sites or mines.

Table 10. Summary of changes to water runoff for monthly lowest flow for scenarios assessed. Each assessment watershed is classified based on percent change in average lowest monthly flow between scenario and historical conditions (natural processes but ignore existing roads). Area of assessment watershed within each class is summed in table.

Scenario name	**Area of assessment watershed ('000s ha) based on percentage change in lowest month flow (mean lowest flow for scenario / historical). Negative values indicate drop in monthly low.**						
	≤ -5%	**-5 to -2%**	**-2 to -1%**	**-1 to 1%**	**1 to 2%**	**2 to 5%**	**> 5%**
MaxDev	0	0	0	6,917	0	0	0
NoDev	0	0	0	6,917	0	0	0
SingleReg	0	0	0	6,917	0	0	0
MultipleReg	0	0	0	6,917	0	0	0
Boom-bust	0	0	0	6,917	0	0	0

Table 11. Summary of changes to water runoff for monthly highest flow for scenarios assessed. Each assessment watershed is classified based on percent change in average highest monthly flow between scenario and historical conditions (natural processes but ignore existing roads). Area of assessment watershed within each class is summed in table.

Scenario name	**Area of assessment watershed ('000s ha) based on percentage change in highest month flow (mean highest flow for scenario / historical). Negative values indicate drop in monthly high.**						
	≤ -5%	**-5 to -2%**	**-2 to -1%**	**-1 to 1%**	**1 to 2%**	**2 to 5%**	**> 5%**
MaxDev	0	0	0	6,917	0	0	0
NoDev	0	0	0	6,917	0	0	0
SingleReg	0	0	0	6,917	0	0	0
MultipleReg	0	0	0	6,917	0	0	0
Boom-bust	0	0	0	6,917	0	0	0

3.8. Water quality: coarse sedimentation

A primary determinant coarse sedimentation hazard is "stream coupling"[14]; that is the flow paths of unstable terrain (class IV and V terrain) paths into streams may be direct (*coupled*), partially blocked by relatively narrow lower slope barriers *(partially coupled)* or more fully blocked by relatively wide lower

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[14] See Utzig 2009, Fall and Morgan 2013 and Utzig and Carver 2013 for details

slope barriers (*decoupled)*. Unstable terrain has expected long-term levels of landslides that may result in sediment loading in downslope streams. This inherent base level of sediment loading is assumed to continue (i.e. there are not projects to stabilize steep slopes on a broad scale in the study area). In addition to base sediment hazard, areas upslope from unstable terrain may also influence sedimentation, as roads built within and above unstable terrain are assumed to increase likelihood of landslide (and hence long-term expected sedimentation loading). The main effect of different scenarios on sediment hazard is thus assumed to be different locations and density of road construction.

Sediment load was defined as average sediment load into creeks due to landslides per year, 50% of which Is assumed to be coarse sediment, and the remainder fine sediment and organic material. Base sediment load over the whole study area was estimated to capture natural levels that would be expected (Table 12). The sediment load over time for each scenario shows a slight increase in sedimentation as development pressure increases (Table 12). The increase in sediment load is concentrated in a subset of drainages (

Table 13), with some exceeding 10% increased load.

Table 12. Summary of changes to sediment load into streams (in '000s of m^3/year) for scenarios assessed. The "*Base*" row represents an estimate of natural levels of sediment loading.

Scenario name	**Mean sediment load (thousands of m^3/year)**		
	Years 1 – 20	**Years 21 – 51**	**Years 101 – 250**
Base	1,774	N/A	N/A
MaxDev	1,784	N/A	N/A
NoDev	1,781	1,781	1,781
SingleReg	1,782	1,784	1,798
MultipleReg	1,782	1,784	1,800
Boom-bust	1,782	1,785	1,801

Table 13. Summary of changes to sedimentation loading in streams for scenarios assessed. Each assessment watershed is classified based on percent increase in loading due to roads and pipelines over historical conditions. Percentage of assessment watersheds within each class is summed in table.

Scenario name	**Percentage of assessment watersheds (out of 1567 in total) classed by percentage change in sedimentation loading (load for scenario / historical).**							
	Year 20				**Year 50**			
	≤ 2%	**2 to 5%**	**5 to 10%**	**> 10%**	**≤ 2%**	**2 to 5%**	**5 to 10%**	**> 10%**
MaxDev	88%	6%	4%	2%	N/A	N/A	N/A	N/A
NoDev	95%	3%	2%	1%	95%	3%	2%	1%
SingleReg	93%	4%	2%	1%	92%	4%	3%	1%
MultipleReg	93%	4%	2%	1%	91%	5%	3%	1%
Boom-bust	93%	4%	2%	1%	91%	4%	3%	2%

4. Discussion and Conclusions

This document presented a scenario analysis for the Upper Nass/Iskut-Stikine CEA project. It applied the toolkit developed for the study area to examine several key scenarios developed to increase understanding of some tradeoffs regarding management choices. Scenarios were used to define parameter settings for process model components in the toolkit. The process model components were run to generate dynamic projections of landscape conditions driven by natural disturbance, succession, and resource development. The dynamic landscape projections were represented as spatial time series (decadal output of spatial variables, such as stand age, road state, pipeline state, etc). The dynamic landscape projections were then used as input to value indicator models for wildlife habitat (moose and grizzly bear) and water quality and quantity assessments. Output from the process models was also used to produce economic indicators such as timber supply.

The main goal of this assessment was to demonstrate the functionality of the CEA toolkit and explore a broad range of scenarios that represent distinct management direction. As such, the value indicator outputs were presented in this report as scenario summaries. Value indicator outputs are also provided as inputs to the next step of a cumulative effects analysis, risk assessment. In this case, the value indicator outputs are generally more detailed than the summary information presented herein (e.g. area of moose winter habitat is output in decade steps, stratified by assessment watershed, wildlife management unit, ungulate winter range, major watershed, ecosection, landscape units and BEC variant).

5. Literature Cited

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