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Hydrological modelling as an improvement on ECA-based methods for informing risk-based forest management

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Introduction

- Forest disturbance can affect the runoff regime of a watershed
  - Magnitude and timing of peak flows and duration of low flows
- In snowmelt-dominated watersheds, forest removal:
  - Less shading → earlier/more rapid snowmelt
  - Less forest canopy → less snow (and rain) interception
  - Higher exposure, regenerating plants → higher evapotranspiration
- The effect of forest removal on streamflow depends on where the disturbance is situated in the watershed
  - Elevation and Slope-Aspect: synchronization of spring freshet
  - Elevation and Climate Gradients: Greater effect in higher precipitation areas

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Risk-Based Forest Management

- Risk-based management decision frameworks are now commonly used by resource managers to guide forest management decisions (e.g., ABCPF and EGBC, 2020).
- Proponent must consider and evaluate the possible hydrologic effects of existing or proposed forestry activities
- Assess of the change in the likelihood of a harmful hydrological response:
    - Frequency and/or magnitude of a damaging flood (risk to infrastructure, water quality)
    - Duration or magnitude of a low flow event (risk to water users, water quality, aquatic habitat)
- Requires knowledge of how forest disturbance could alter the timing and magnitude of streamflow in a watershed.

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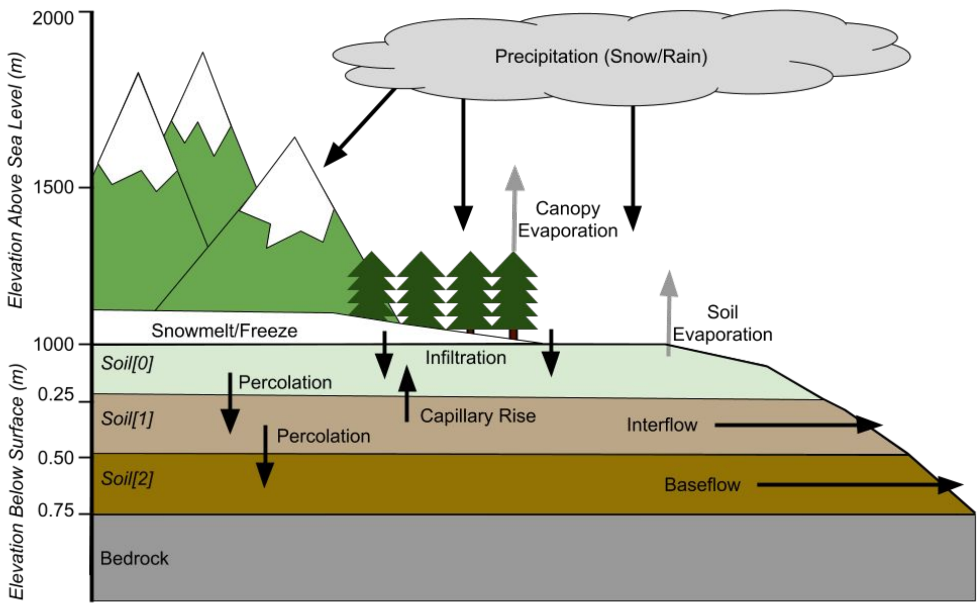
Equivalent Clearcut Area (ECA)

- ECA is a proxy-type indicator that relates a single calculated value to the hydrological response of the watershed
  - Can be adjusted for forest recovery, and, at times weighted by elevation
- Relies on knowing rate of hydrological recovery post-disturbance
  - “Hydrological recovery” results from the interaction of several processes, including vegetation interception, snowmelt, and evapotranspiration, each of which may have variable recovery rates
- Few studies that have attempted to relate a ECA to a level of hydrological response; existing studies show inconsistent outcomes
- Results in an uncertain and somewhat subjective output that is difficult to integrate into risk-based forest management

Process-Based Hydrological Modelling



- Simulates streamflow and other hydroclimatic variables
- Explicitly accounts for the hydrologic processes driving streamflow
  - Including interception, snowmelt, evapotranspiration
- Incorporates climate/weather and land cover (HRUs)
  - Can be used to evaluate land cover and climate scenarios
- Can be regionally calibrated and applied to ungauged watersheds

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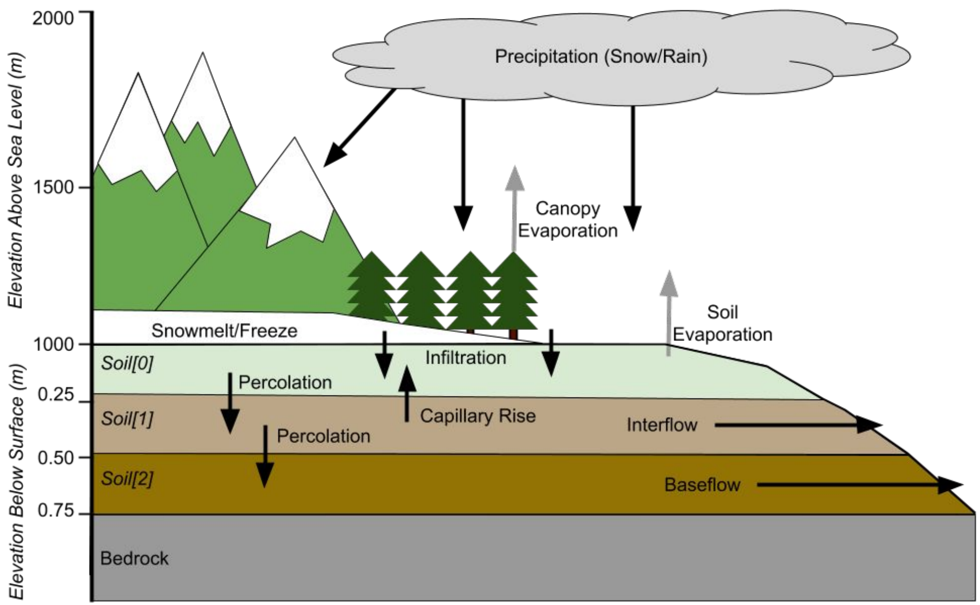
Process-Based Hydrological Modelling



- Adapted HBV-EC hydrological model emulated with Raven
  - Have applied this model setup widely across western Canada
- Snowmelt
  - Temperature Index Model corrected for slope-aspect, daylength, and vegetation
- Vegetation Interception
  - Function of leaf area index, forest cover, and canopy storage capacity
  - Varies by vegetation type and season
- Evapotranspiration
  - Priestley-Taylor; varies by vegetation type

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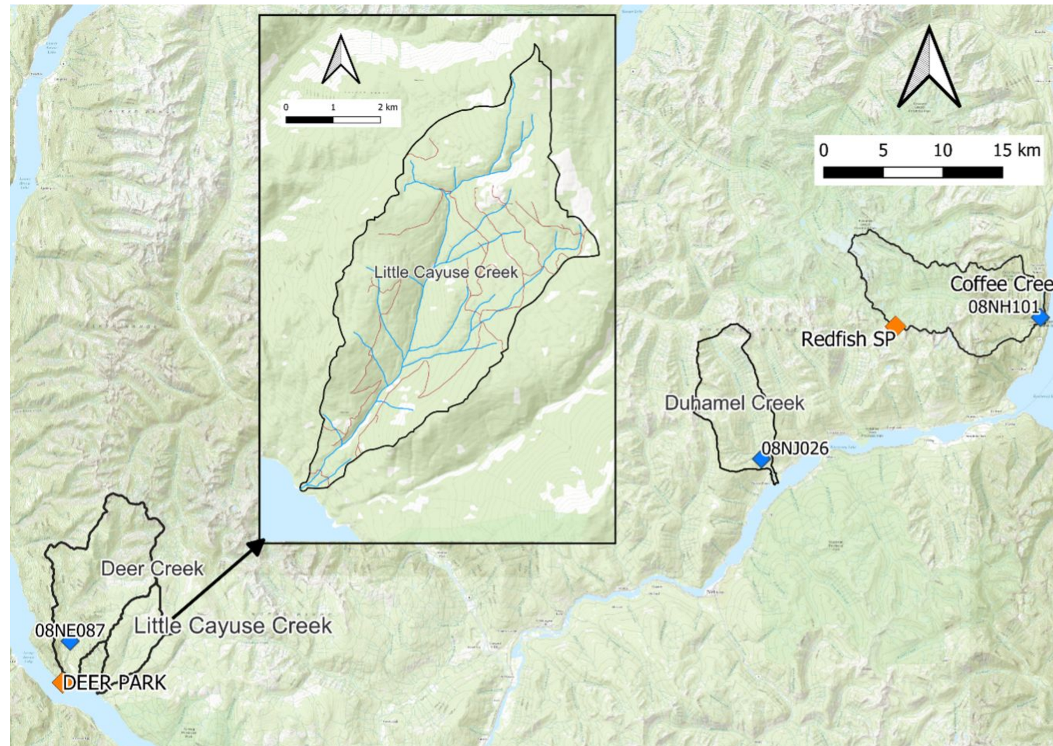
South Selkirk Region

- Steep, forested mountain watersheds
- Humid continental climate, deep winter snowpacks
- Contains three long-term regional hydrometric gauges used to calibrate model
- Modelling workflow is applied to ungauged Little Cayuse Creek



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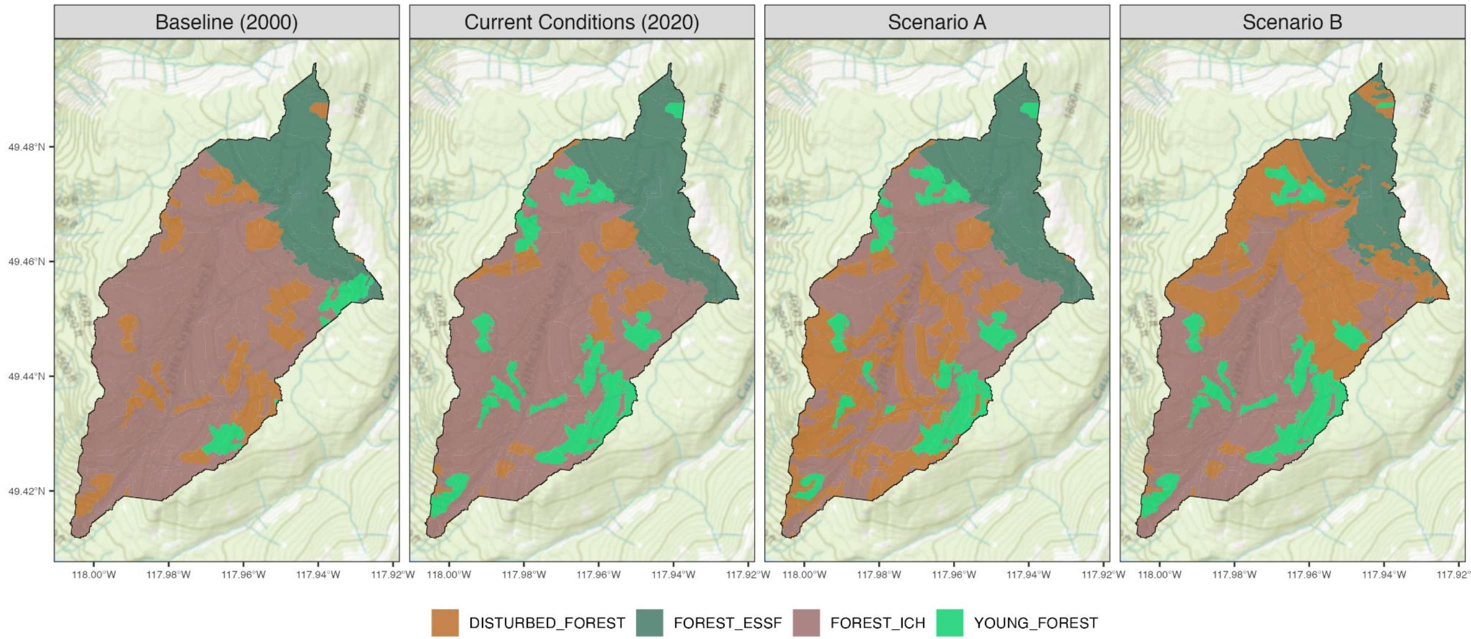
Land Cover Scenarios



- *Two historical land cover configurations (2000, and 2020)*
- *Two conceptual scenarios with a high level of disturbance at low (A) and high (B) elevation*
- *Could also apply actual harvest plans, wildfire perimeters, etc.*

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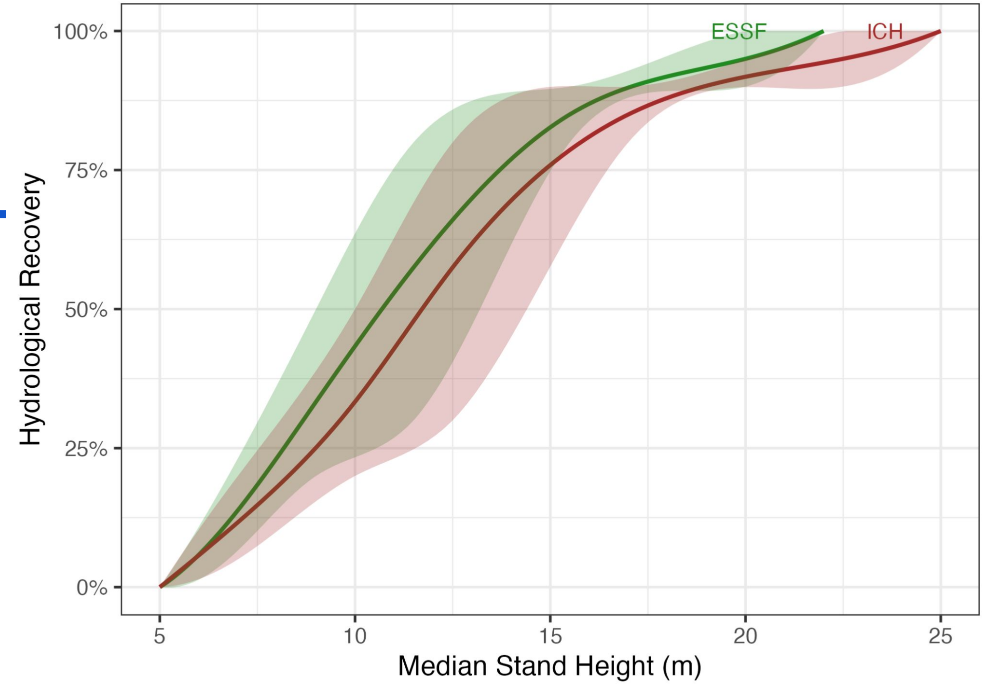
ECA Evaluation

- Used a 2018 LiDAR canopy height model and BC's 2021-Vegetation Resource Inventory (VRI)
- GIS exercise based on recovery rate specific to each biogeoclimatic (BEC) zone
- Outputs are an ECA value for each scenario



	Baseline (2000)		**Current Conditions**		**Scenario A**		**Scenario B**	
	Little Cayuse	above 1250m H60	Little Cayuse	above 1250m H60	Little Cayuse	above 1250m H60	Little Cayuse	above 1250m H60
ECA (ha)	621	427	485	363	989	408	1075	951
ECA (%)	**24**	**27**	**19**	**23**	**38**	**26**	**41**	**61**

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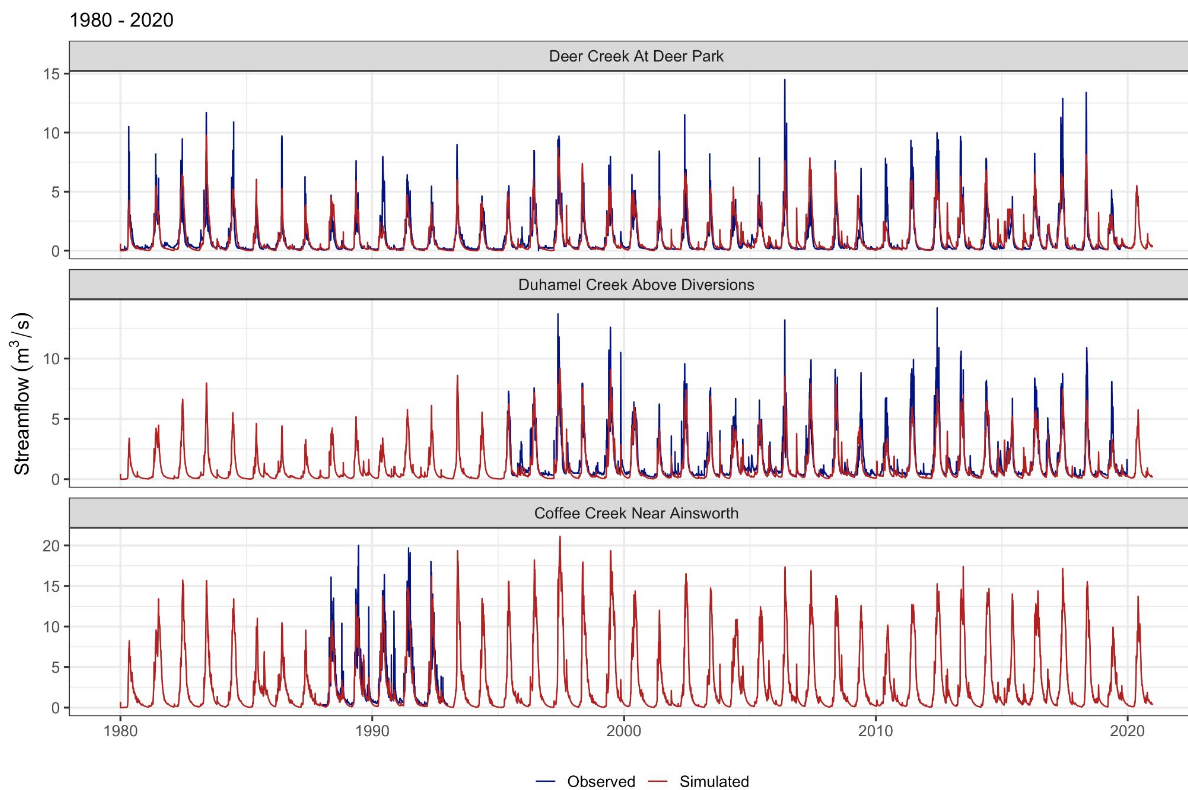
Hydrological Model Evaluation

- Model parameters calibrated to regional datasets, including weather stations, snow pillows, and hydrometric gauges
- Vegetation parameters can also be informed from field studies, remotely sensed products



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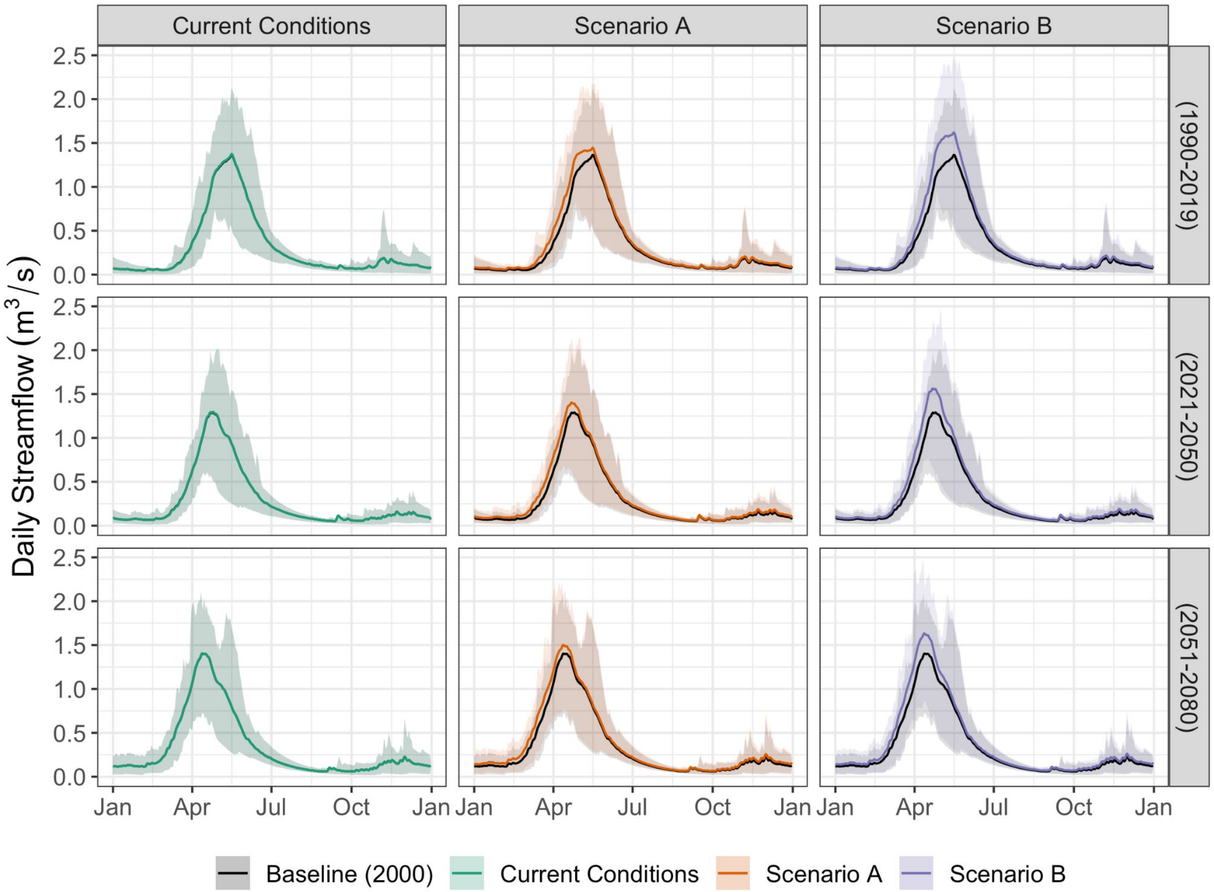
Hydrological Model Evaluation



- Model streamflow outputs can be used to identify changes in hydrologic conditions
- Can evaluate the cumulative effects of land cover and climate change

Hydrological Model Evaluation

Little Cayuse Creek Near Deer Park

Land Cover Scenario	Mean Annual Flow	Aug-Sept Low Flow	2-year Peak Flow	20-year Peak Flow	Peak Flow Timing
1990-2019					
Current Conditions	−0%	−0%	1%	1%	0.0 days
Scenario A	13%	9%	7%	5%	-0.9 days
Scenario B	18%	12%	22%	16%	-2.5 days
2021-2050					
Baseline (2000)	−7%	−25%	−13%	6%	-14.9 days
Current Conditions	−7%	−25%	−13%	6%	-14.9 days
Scenario A	5%	−18%	−7%	10%	-17.0 days
Scenario B	10%	−14%	5%	19%	-18.0 days
2051-2080					
Baseline (2000)	9%	−25%	−3%	1%	-16.2 days
Current Conditions	9%	−26%	−2%	1%	-16.3 days
Scenario A	22%	−19%	3%	4%	-19.2 days
Scenario B	27%	−16%	13%	12%	-19.2 days

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Some Advantages of a Hydrological Model

- Gives a quantitative estimate of the change in a specific harmful event of concern which can be integrated into a risk management framework
    - i.e. Change in 20-year Peak Flow
- Accounts for the location of the disturbance
    - Some areas are more hydrologically sensitive than others
- Accounts for differing recovery rates for different processes
    - i.e. Evapotranspiration may recover faster than the forest canopy
- A heuristic tool to better understand the hydrologic regime
    - Identify which areas can have disproportionate impacts on hydrologic indicators of concern
- Incorporate changing climatic conditions into evaluation
    - Climate change may lead to changes in the spatial pattern of hydrologic sensitivity

Limitations and Future Work

- Model performance and process representation
  - Model fidelity, especially performance for hydrologic indicators of interest
  - Parameterizing forest regrowth and change
- Selection of a "baseline" condition
  - What do we evaluate change against?
  - Range of natural variability in forest disturbance is itself dynamic
  - Changes in forest species composition due to disturbance and/or climate change
- Establish thresholds of change for hydrologic indicators of concern
  - Further conceptual work is needed to link percent change in an indicator with known physical impacts to aquatic values

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Conclusions

- The hydrological modelling workflow presented here is an improvement over ECA methods
    - Accounts for the hydrologic processes driving streamflow and impacting recovery
    - Gives a direct evaluation of hydrologic alteration for an indicator of concern
    - Geographically scalable
    - Can be integrated by into a risk decision framework to guide forest management decisions
- Forest managers must be able to plan under future hydroclimatic conditions
- In addition to the amount of forest disturbance, the location and elevation of the disturbance are important considerations
- Model outputs can be used to identify which areas have disproportionate impacts on hydrologic indicators of concern
    - Can be used to minimize forest development in hydrologically sensitive areas

Acknowledgements

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