Climate Change Alters Future Hydrologic Regimes in an Alaskan Salmon Stronghold

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Cameron Wobus[1], Robert Prucha[2], David Albert[3], Russell Jones[1]

[1]Stratus Consulting, Boulder, CO [2]Integrated Hydro Systems, Golden, CO [3]The Nature Conservancy, Juneau, AK

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Overview

- The headwaters of streams feeding into Bristol Bay, Alaska are part of the world's most productive wild sockeye salmon fishery. The region also hosts the world's largest undeveloped copper deposit.
- The ecological impacts of mine development would be superimposed on a changing climate, which is likely to alter stream temperatures and flow regimes.
- We use the integrated hydrologic code MIKE SHE/MIKE 11 to simulate changes in streamflow under climate change scenarios.
- These altered flow regimes should be considered as the new baseline from which mine development scenarios can be evaluated.

1. Site Description

The model is focused on the headwaters of the North and South Forks of the Koktuli River, and Upper Talarik Creek. The copper deposit sits at the junction of these three river systems.

The physiography is characterized by low topographic relief and thick, coarse-grained outwash deposits. The combination of subdued topography and permeable deposits creates stream reaches with strong groundwater upwelling and downwelling.

These hydrologic conditions create ideal salmon habitat throughout these rivers.

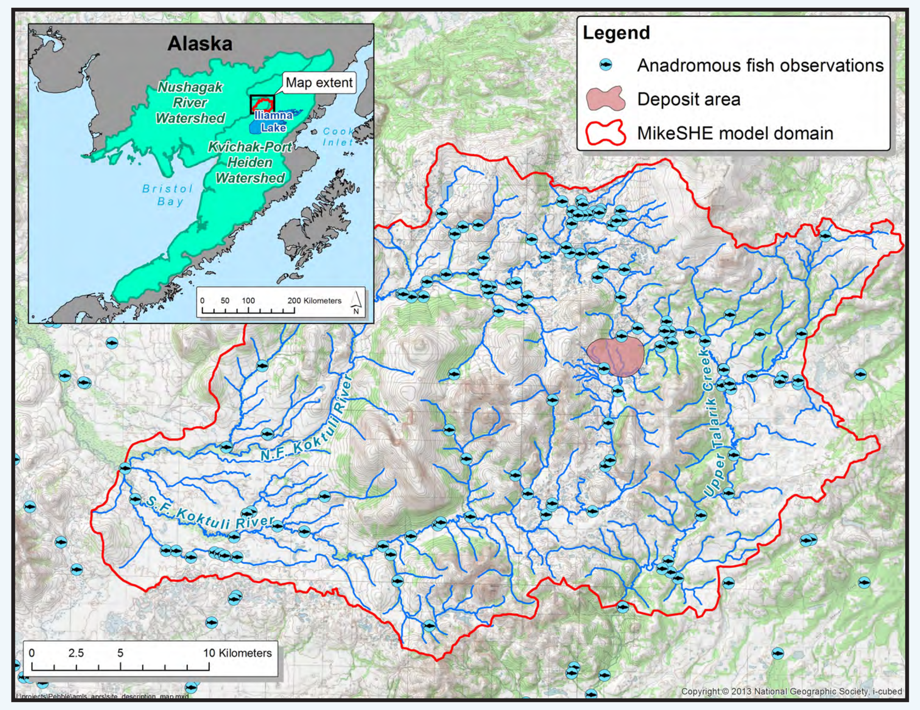

Figure 1. Site location and model domain. Pink shading is approximate location of the Pebble copper deposit. Blue dots are locations where anadromous fish have been observed (primarily sockeye, coho and chinook salmon).

2. Model Description

We selected the fully coupled hydrologic code MIKE SHE/MIKE 11 for our simulations. Model selection was based on the following criteria:

- The system is characterized by strong coupling between surface water and groundwater systems under baseline conditions, necessitating an integrated code.
- Climate change impacts will include changes in snowpack, precipitation, and evapotranspiration, all of which can be tracked within the MIKE SHE/MIKE 11 framework.
- Mining impacts would include development and dewatering of an open pit nearly 2 miles wide, affecting both surface water and groundwater. Mine impact evaluations will require a fully coupled code.

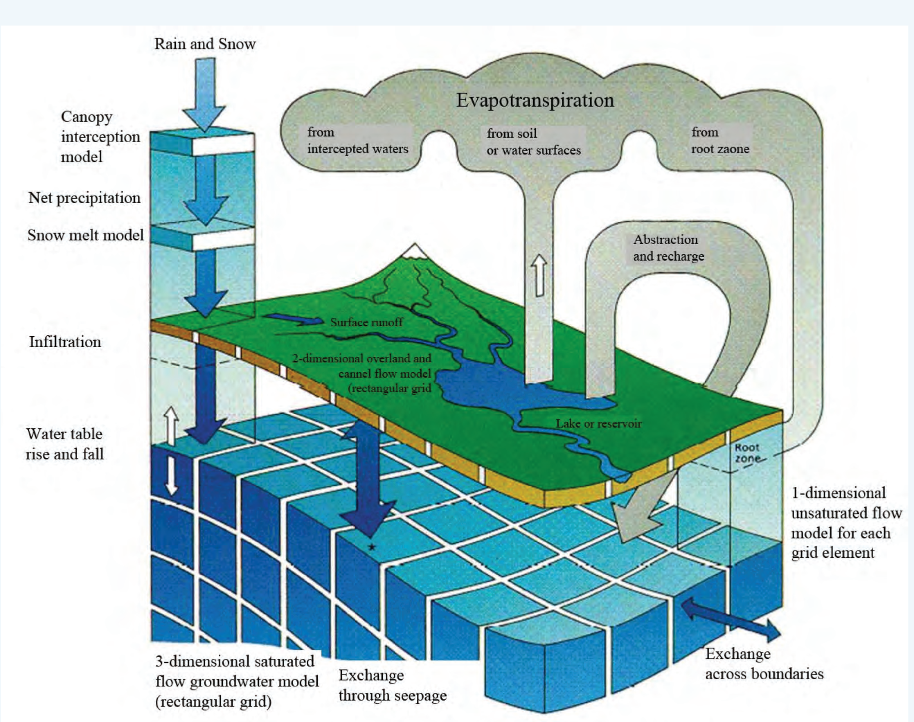

Figure 2. Schematic of processes simulated in MIKE SHE/MIKE 11 (Graham and Butts, 2005).

MIKE SHE/MIKE 11 setup

3-hour timestep.

250 x 250 m grid cells track soil moisture, snowpack, evapotranspiration, and hydraulic heads for each timestep.

Four subsurface layers:
- Soil (2–5 meters thick)
- Overburden/outwash (see map above)
- Weathered bedrock (15-m thick)
- Competent bedrock.

Open channel flow dynamically linked to MIKE SHE and simulated in higher temporal and spatial resolution submodel (MIKE 11).

3. Model Inputs

Climate: Baseline climate data were derived from the North American Regional Reanalysis (NARR) product (ESRL, 2012; Mesinger et al., 2006). NARR includes estimates of precipitation, temperature, relative humidity, wind speed, and insolation every 3 hours.

Topography and Land Cover: Topography came from 1-arc second (~ 30 m) SRTM DEM. We used soil types from the NRCS STATSGO database, a broad-based inventory of soil types. Leaf area index and root depths, which control transpiration from plants, were estimated from vegetation cover compiled in the national land cover database (NLCD).

Hydrogeology: Subsurface geology and hydraulic conductivity were compiled from data publicly released by the Pebble Limited Partnership (Schlumberger Water Services, 2011).

Climate Change: Climate change simulations were based on the delta method (Mantua et al., 2010), using the MIROC and CCCM models (Walsh et al., 2008). Climate futures were bracketed using high emissions (A2) and low emissions (B1) paths.

4. Calibration

- Model captures dynamics of the hydrologic system, including snowmelt timing, baseflows, and groundwater-surface water interactions.
- Peak flows not well simulated: NARR dataset under-estimates precipitation, particularly in the fall.

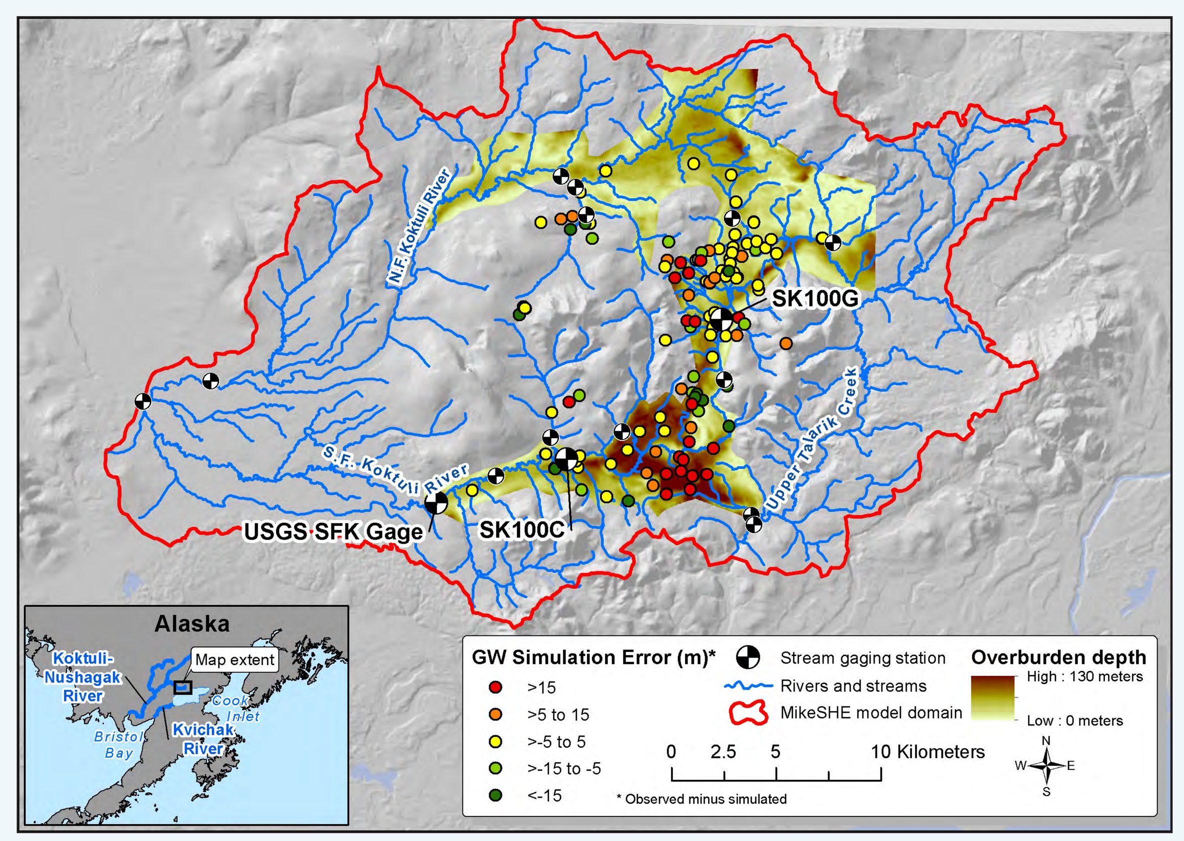

Figure 3. Overview of calibration results. Colored dots are groundwater calibration points colored by mean error. Brown shading is thickness of overburden (Schlumberger Water Services, 2011).

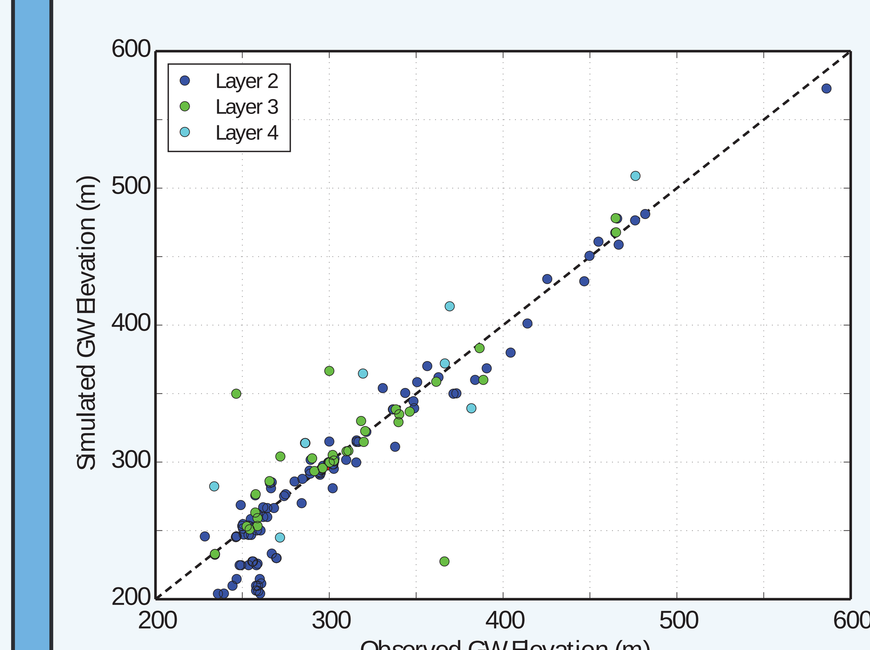

Figure 4. Groundwater calibration results. Best fit is for upper model layers higher in catchment.

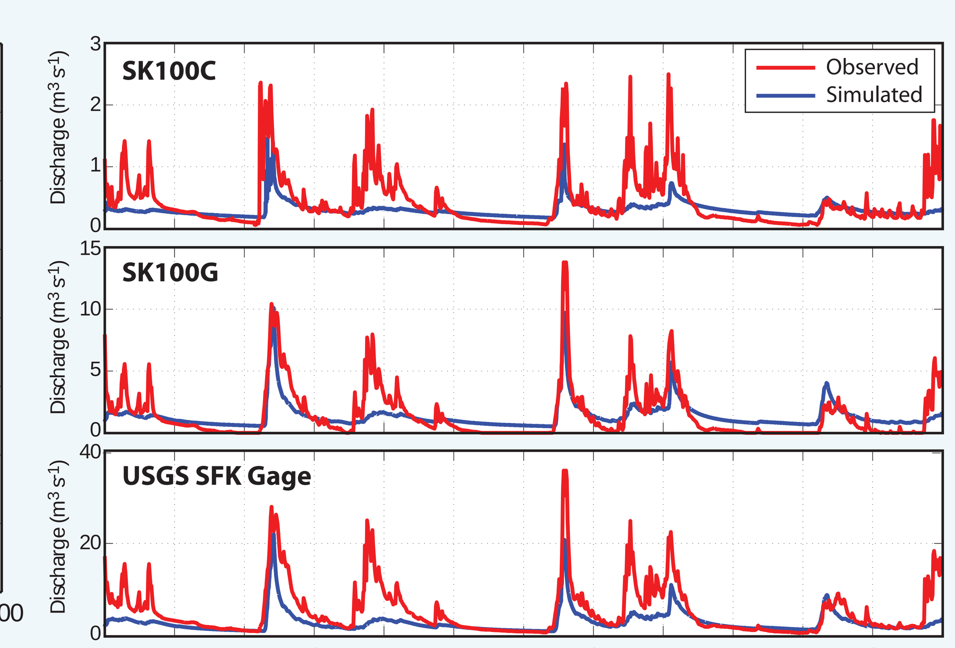

Figure 5. Surface water calibration results. Model matches timing of peak spring runoff to within 3–5 days of observed for all gages.

5. Climate Change Results

A. Temperature and precipitation

- Winter temperatures increases by 1.5–3ºC by 2050, and 2.5–8ºC by 2100.
- All models project an increase in winter liquid precipitation and decreased snowpack by 2100.

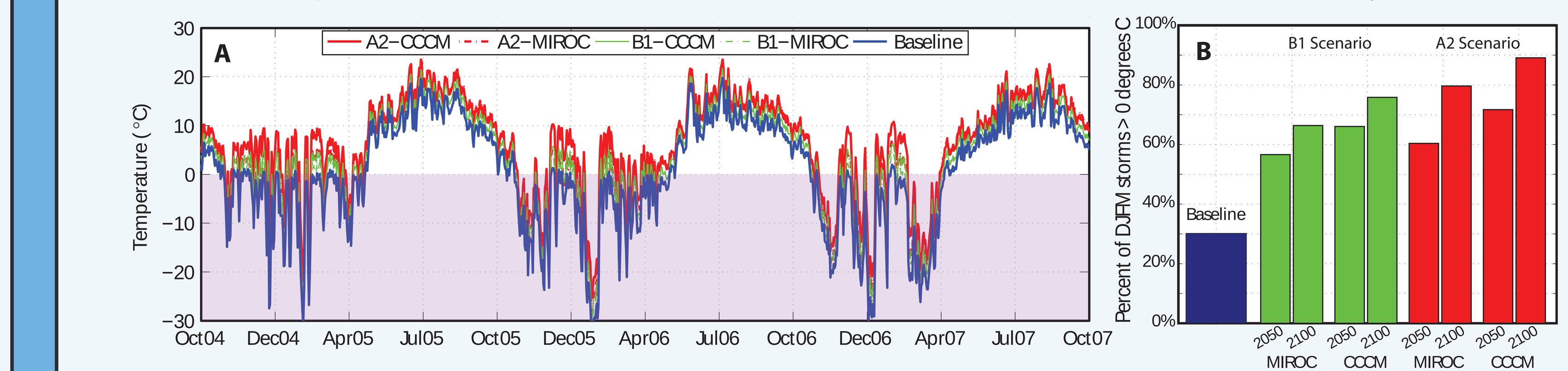

Figure 6. Baseline and future climate conditions. A) NARR 2004–2007 temperature timeseries (blue) and projected changes from A2 (red) and B1 scenarios (blue). B) Fraction of winter storms above freezing for baseline vs. climate change scenarios.

B. Hydrology

- Spring freshet is substantially reduced by 2050 in all models, and completely lost by 2100.
- Winter runoff events become significant as winter storms fall as rain.

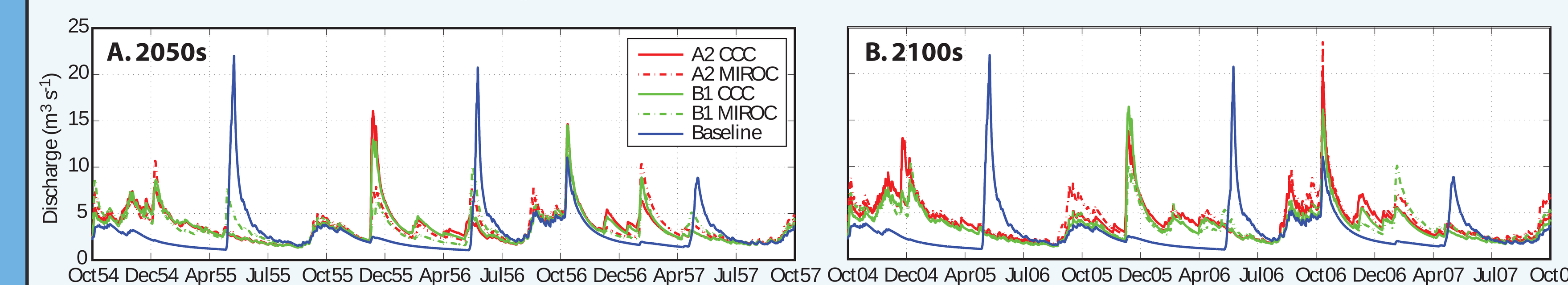

Figure 7. Baseline and future hydrologic conditions for USGS SFK gage for A) 2050s, and B) 2100s. In each case, blue is baseline flows for 2004–2007; red and green are A2 and B1 scenarios, respectively.

6. Implications for Salmon

A. Potential for scour of redds

- Winter rainstorms create new runoff events during egg incubation.
- These changes create the potential for winter scour events that do not occur under baseline conditions.

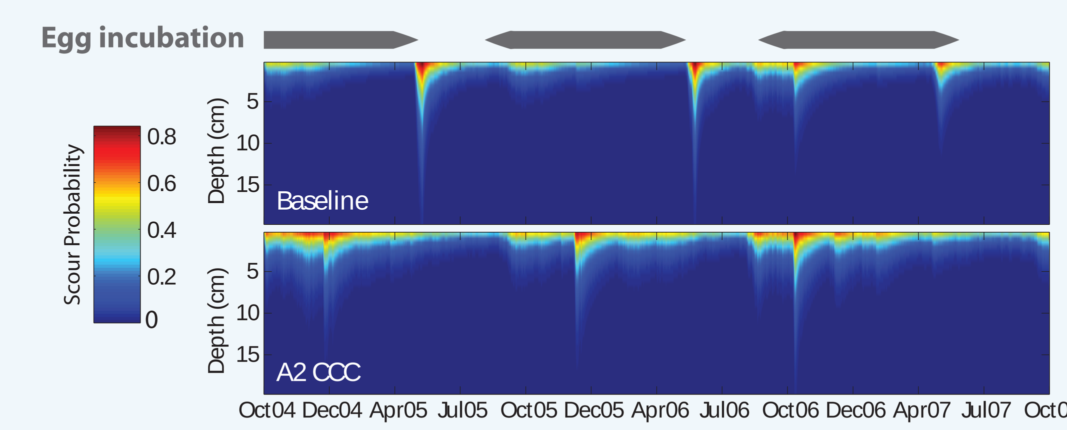

Figure 8. Example calculations of scour probability for 2100 CCCM A2 scenario, assuming D50 of 15 mm (e.g., Haschenberger, 1999).

B. Stream temperature effects

- Return to baseflows earlier in summer coupled with warmer summer air temperatures will create warmer summer stream temperatures, which can reduce suitable habitat.
- Thermal modeling is a focus of future research.

7. Summary

- Salmon in Bristol Bay have adapted to a predictable pattern of seasonal flows, including a reliable spring runoff.
- A range of climate change scenarios all suggest fundamental changes to the hydrology of this system.
- Ecological impacts of climate change must be considered in conjunction with potential effects of hard rock mining, including pit dewatering, changes in stream temperature, and changes in water quality downstream from wastewater effluent.

Future work will focus on evaluating compounding effects of climate change and hard rock mining.

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