The effects of projected climate change on stream temperatures in the Stillaguamish River

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South Fork of the Stillaguamish – Lake 22 trail

Collaborators

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Research Sponsors

STILLAGUAMISH Tribe of Indians

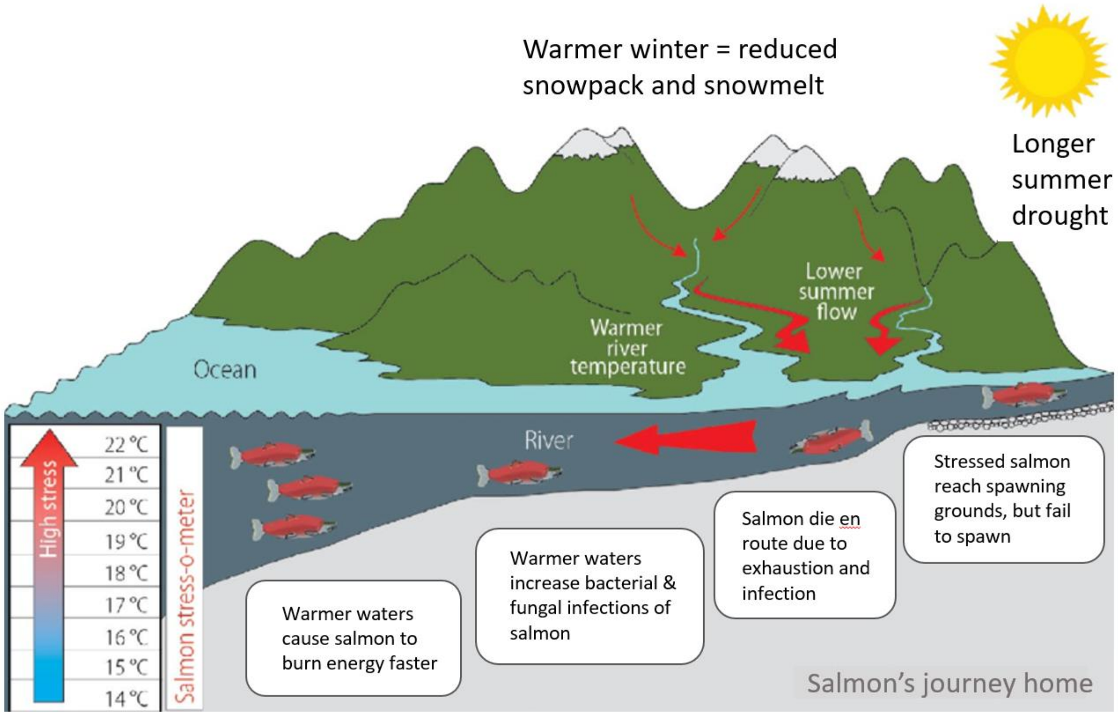
NORTHWEST Climate Adaptation Science Center Research Fellowship

Freeman, Kyra, "Modeling the Effects of Climate Variability on Hydrology and Stream Temperatures in the North Fork of the Stillaguamish River" (2019). WWU Graduate School Collection. 855. https://cedar.wwu.edu/wwuet/855

Clarke, Katherine, "Modeling the effects of climate change on streamflow and stream temperature in the South Fork of the Stillaguamish River" (2020). WWU Graduate School Collection. 983. https://cedar.wwu.edu/wwuet/983

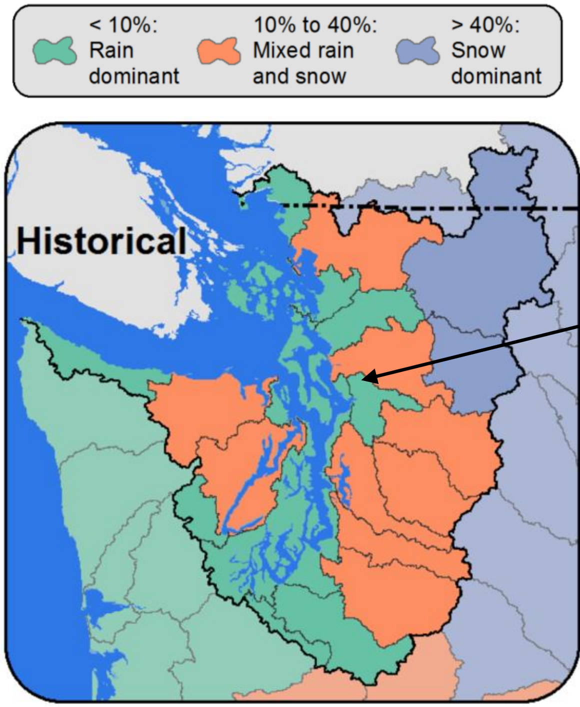
Motivation

- The Stillaguamish River is subject to a temperature TMDL
- The Stillaguamish Tribe of Indians are concerned about how climate warming will further jeopardize salmon habitat (Chinook)



Modified from Campbell et al., 2014

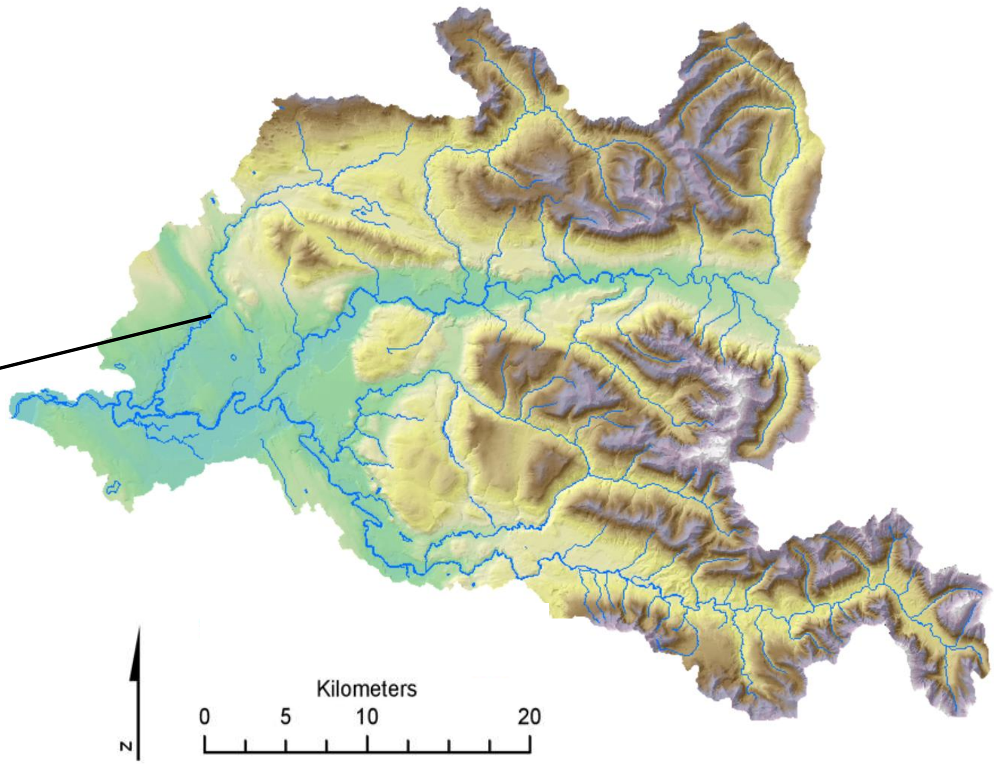
Puget Sound Region Watersheds



NW Washington State

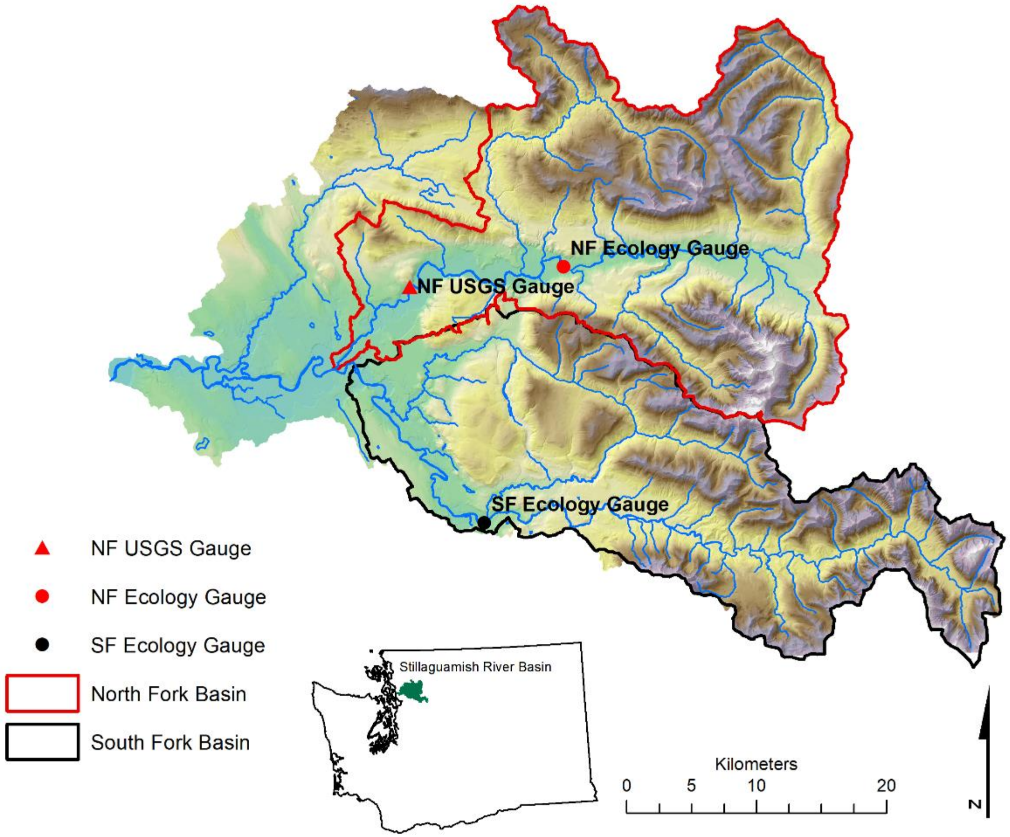
Figure from Mauger et al, 2015 / Hamlet et al., 2013

Stillaguamish Watershed



About 1700 km^2, with relief ranging from sea level to about 2,050 m [6800 ft], heavily forested, historically logged. About 20% of the basin > 1000 m.

Stillaguamish Watershed



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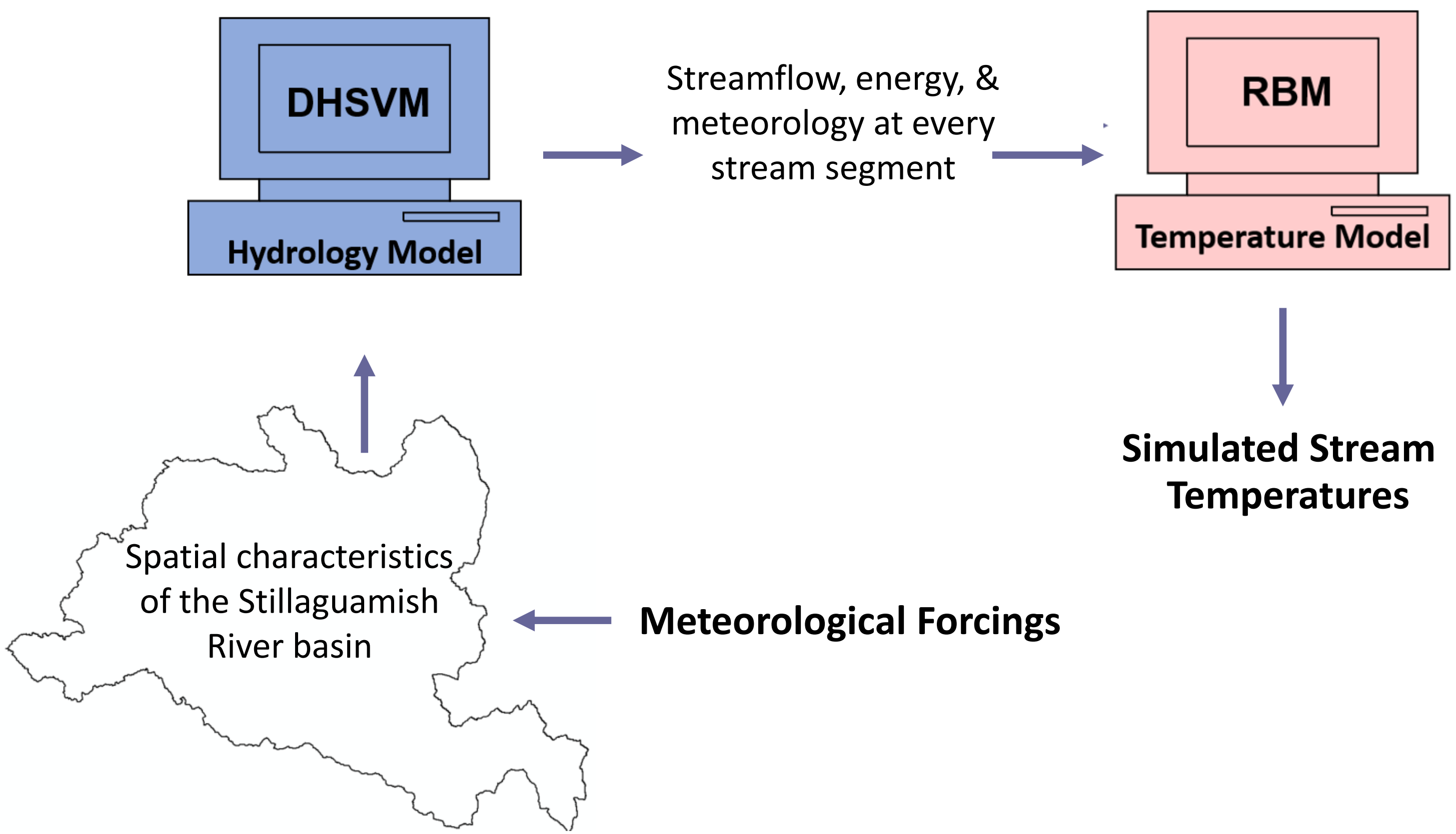
We simulate **hydrology** and **stream temperatures** using numerical models and gridded meteorological data



Gridded Meteorological Forcings

Historical modeling used met inputs from **Livneh** et al. (2013)

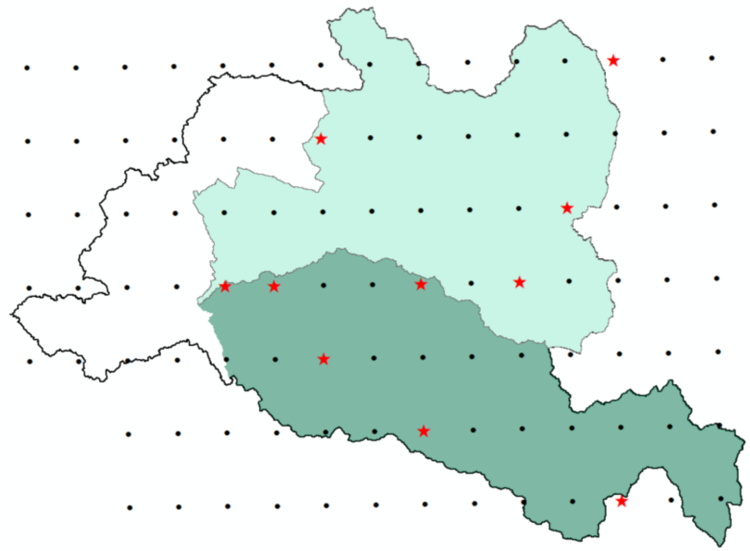
Projected scenarios were based on statistically downscaled global climate models (**MACA**) produce by Abatzoglou and Brown (2012)

Daily Data
Max temperature
Min temperature
Precipitation
Wind speed

Processed and disaggregated

3-hr DHSVM Met Inputs
Temperature
Precipitation
Wind speed
Humidity
Shortwave radiation
Longwave radiation

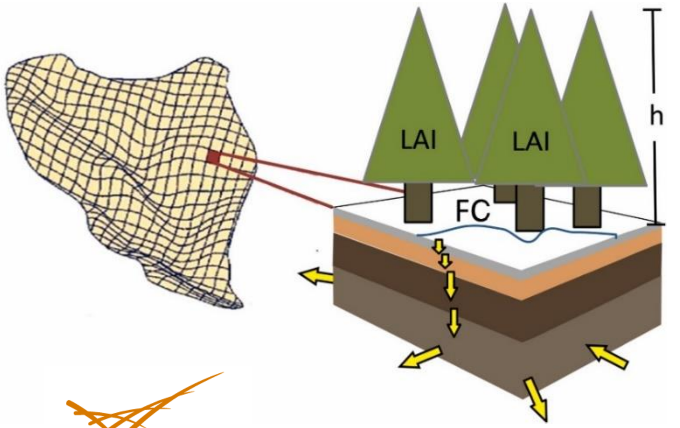
Stillaguamish Watershed



★ nodes used in the modeling

The Distributed Hydrology Soil Vegetation Model (**DHSVM**) was used to simulate hydrology in the basin.

Spatially distributed, physically-based model that explicitly represents the effects of local climate, topography, soil, and vegetation on snow accumulation and melt along with overland and subsurface hydrological processes within watersheds.



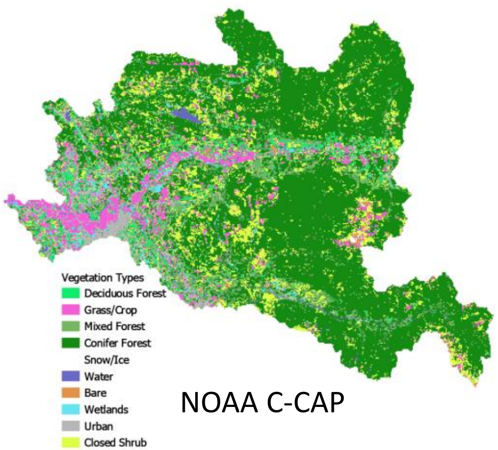
Pacific Northwest NATIONAL LABORATORY

Wigmosta et al., 1994 & 2002

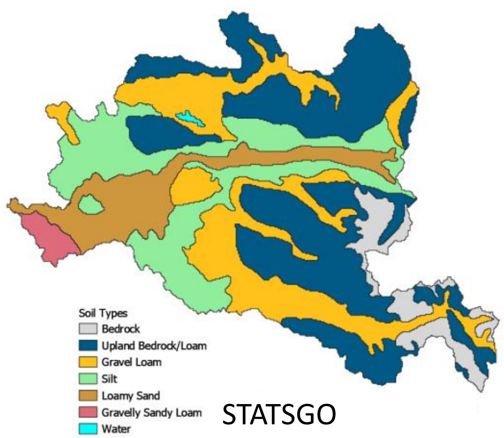
https://www.pnnl.gov/projects/distributed-hydrology-soil-vegetation-model

DHSVM Spatial Inputs

Raster-Grid-Based Stillaguamish Watershed

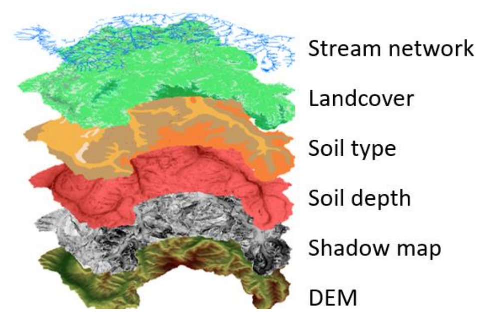


NOAA C-CAP



STATSGO

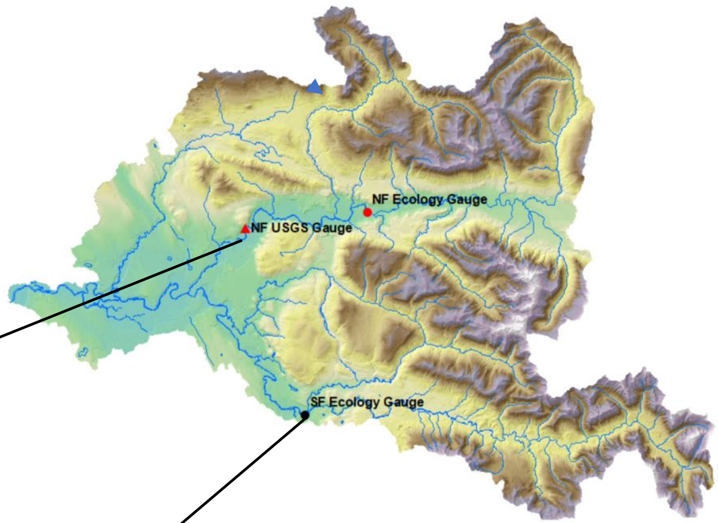
Spatial Inputs (50 m grid cells)



DHSVM Model Calibration

Adjust model parameters (temperature lapse rates, rain and snow temperature thresholds, soil conductivities and porosities, etc.) to achieve reasonable simulated streamflow comparable to observed streamflow.

Stillaguamish Watershed



North Fork Water years 2003-2012

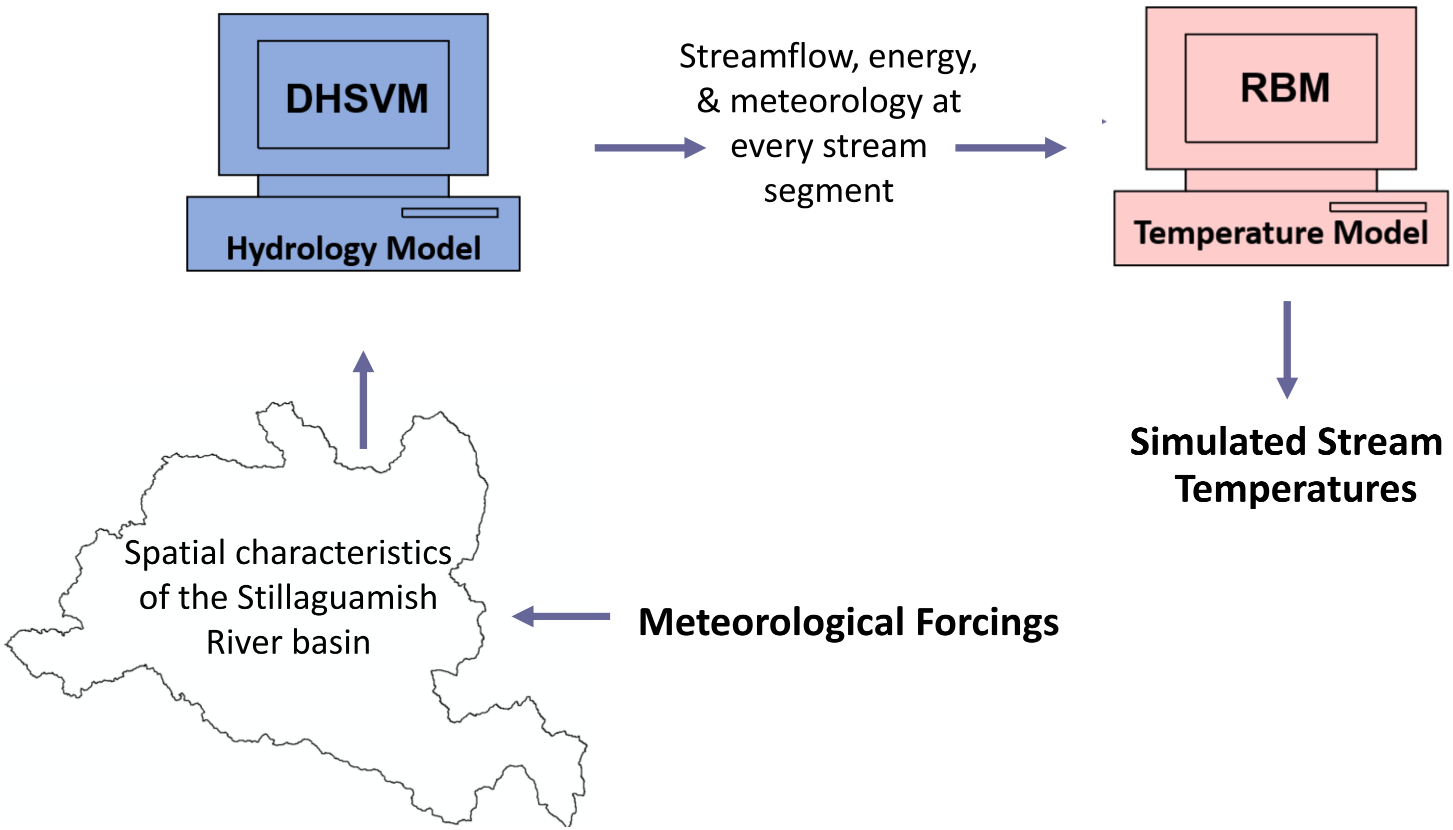
	All data		May – September only	
	Daily mean	Monthly mean	Daily mean	Monthly mean
NSE	0.813	0.88	0.547	0.634
R^2	0.842	0.905	0.649	0.731
RSR	0.431	0.346	0.673	0.604
PBIAS	3.947	3.967	1.029	1.032

South Fork Water years 2004 to 2009

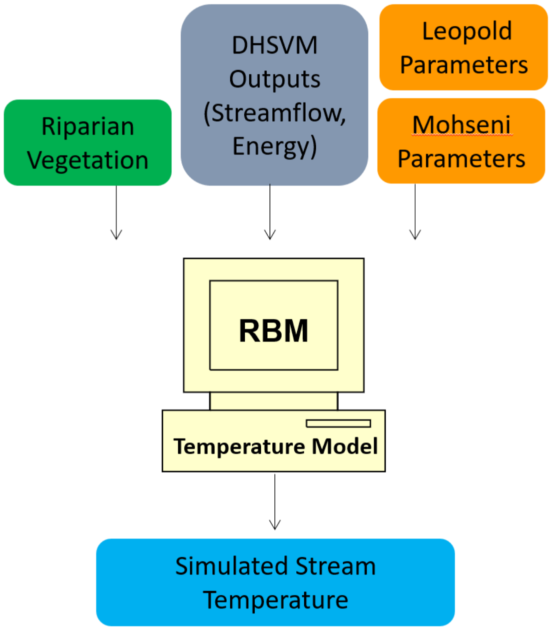
	All data		May – September only	
	Daily mean	Monthly mean	Daily mean	Monthly mean
NSE	0.464	0.854	0.618	0.807
R^2	0.477	0.895	0.686	0.945
RSR	0.732	0.378	0.617	0.43
PBIAS	-13.4	-13.3	-24.1	-24.1

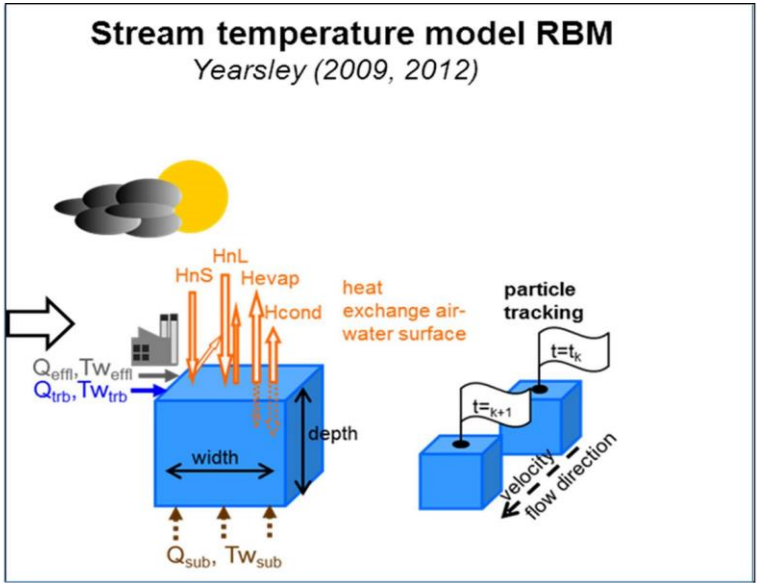
NSE = Nash–Sutcliffe model efficiency coefficient

Use the calibrated DHSVM to simulate inputs required for the RBM



RBM – River Basin Model





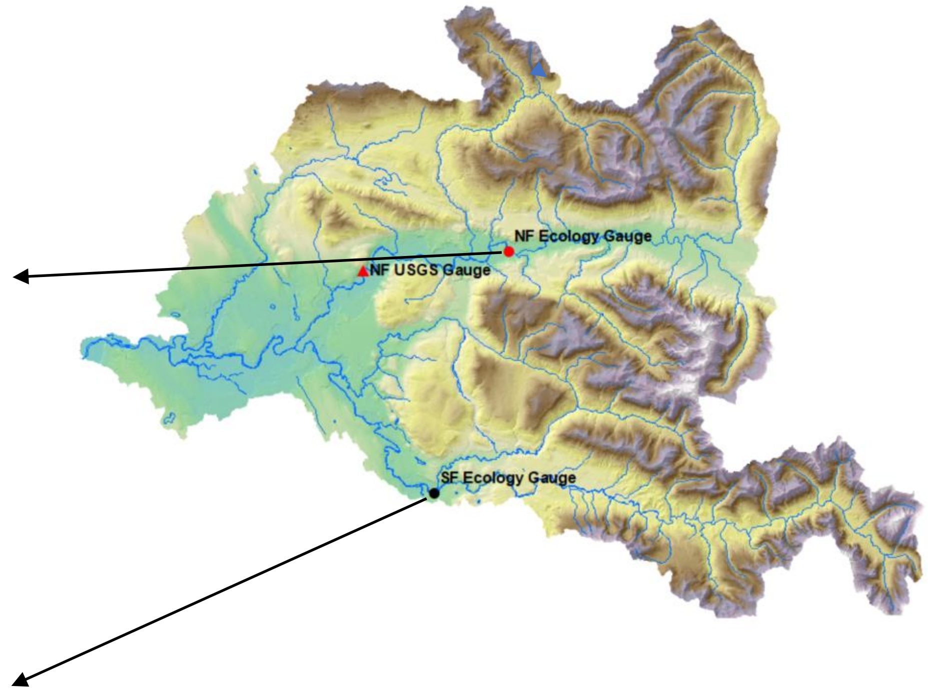
About 2500 stream segments in the two forks.

Sun Ning, J Yearsley, N Voisin, DP Lettenmaier. 2015. “A spatially distributed model for the assessment of land use impacts on stream temperature in small urban watersheds.” Hydrological Processes 29 (10): 2331–2345 DOI: 10.1002/hyp.10363

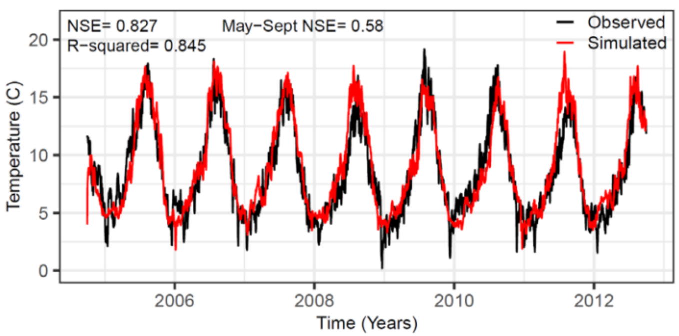
RBM Model Calibration

Calibration of the RBM requires the manipulation of eleven variables until the simulated stream temperatures match observed stream temperatures within statistical thresholds.

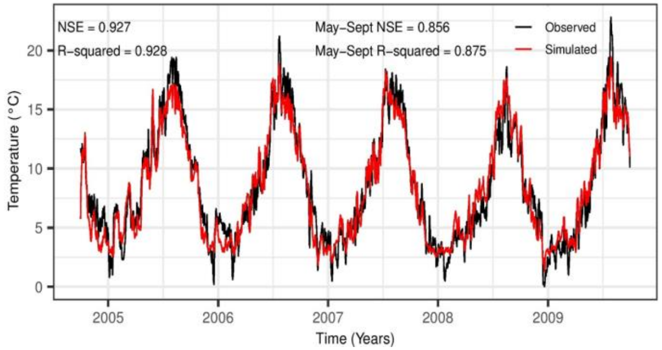
Stillaguamish Watershed



NF Ecology gauge water years 2005-2012

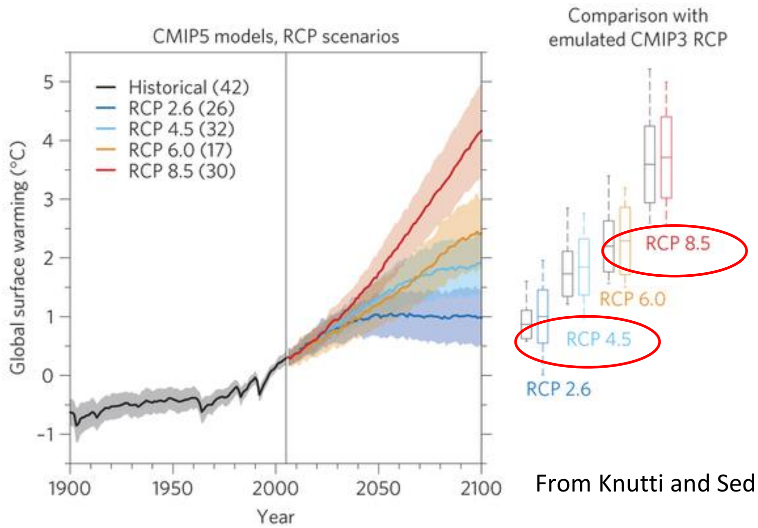


SF Ecology gauge water years 2005-2009



NSE = Nash–Sutcliffe model efficiency coefficient

Climate Projections



From Knutti and Sedlacek, 2013

CMIP5 – Coupled Model Intercomparison Project Phase 5, March 2013 includes 20 Climate Modeling groups from around the world.

GCM – global climate model

RCP – Representative Concentration Pathways (future greenhouse gas emission narrative)

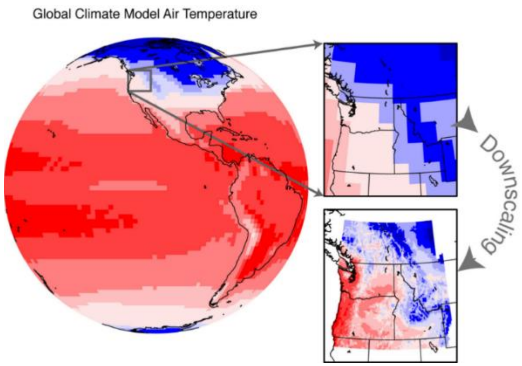
- RCP 4.5 – moderate emission narrative
- RCP 8.5 – severe emission narrative

Projected Climate Data

Model	Center
BCC-CSM1-1-M	Beijing Climate Center, China Meteorological Administration
CanESM2	Canadian Centre for Climate Modeling and Analysis
CCSM4	National Center of Atmospheric Research, USA
CNRM-CM5	National Centre of Meteorological Research, France
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization/ Queensland Climate Change Centre of Excellence, Australia
HadGEM2-ES	Met Office Hadley Center, UK
HadGEM2-CC	Met Office Hadley Center, UK
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France
MICROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
NorESM1-M	Norwegian Climate Center

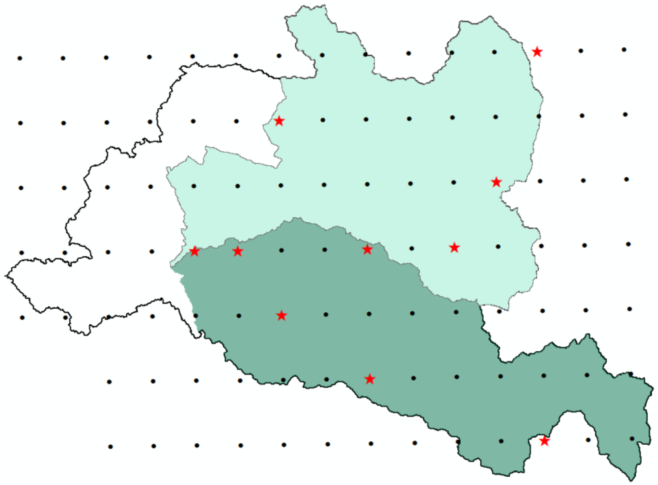
median

Projected scenarios were based on statistically downscaled GCMs produce by Abatzoglou and Brown (2012; **MACA**)



Based in Rupp et al. (2013) we used 10 GCMs each with a RCP4.5 and 8.5 scenarios

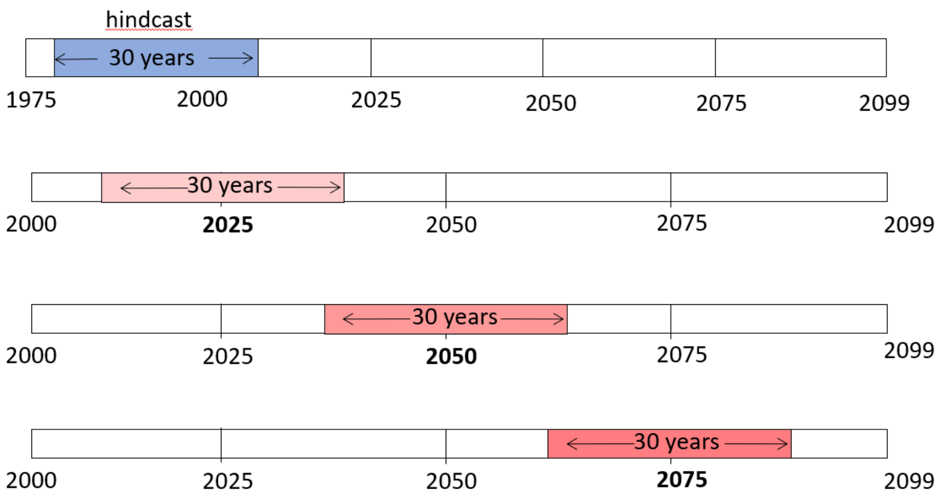
<u>**3-hr DHSVM Met Inputs**</u>
Temperature
Precipitation
Wind speed
Humidity
Shortwave radiation
Longwave radiation



★ nodes used in the modeling

Data Analysis

Climate data are analyzed in 30-year climate normals to account for natural variance in climate systems



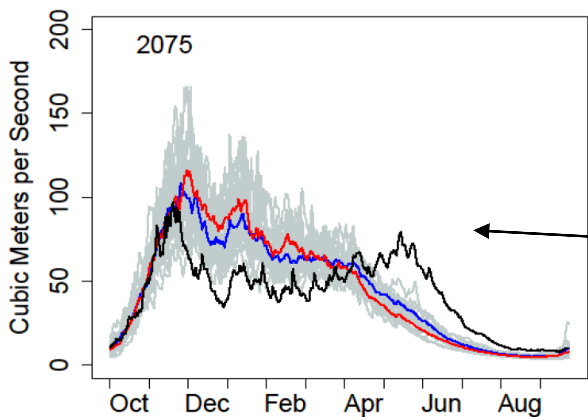
WESTERN
WASHINGTON UNIVERSITY

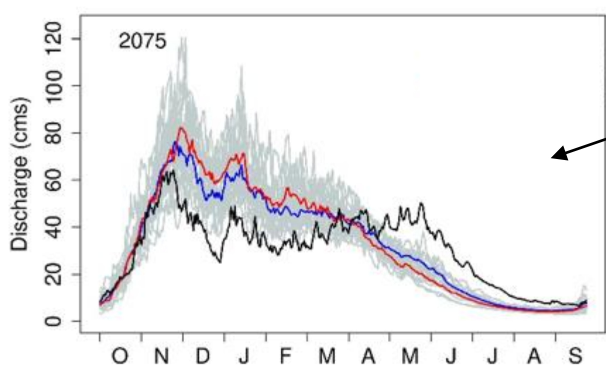
Computer cluster

Projected changes in hydrology

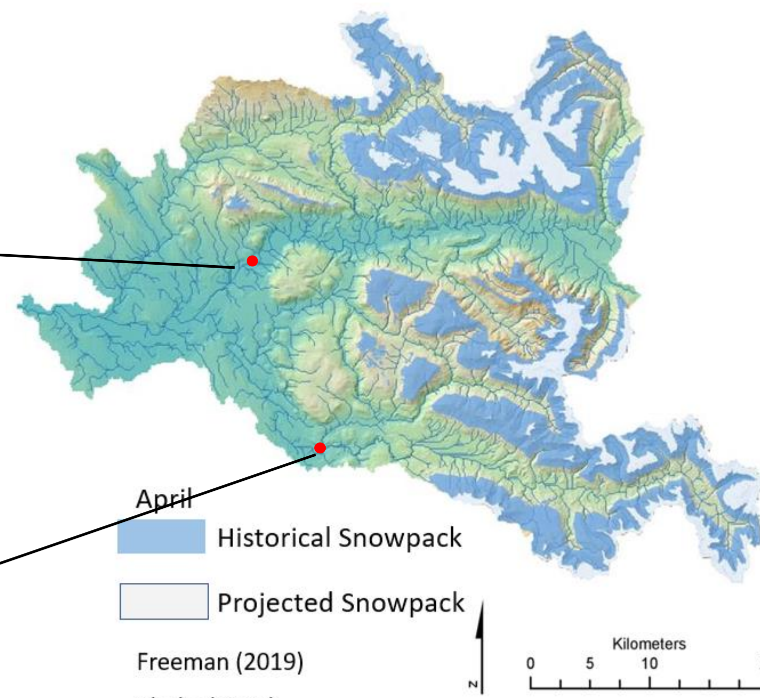
Each point on the plots represents a daily average over 30 years

Hindcast (1981-2011)
Individual GCM (20 total)
Median of 10 GCMs with RCP 4.5 scenario
Median of 10 GCMs with RCP 8.5 scenario





Stillaguamish Watershed



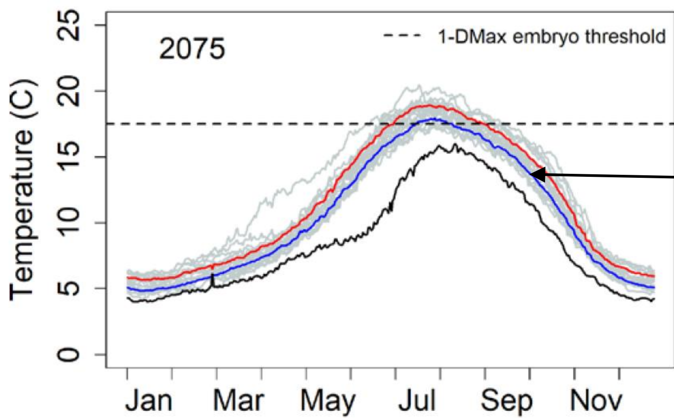
Freeman (2019)

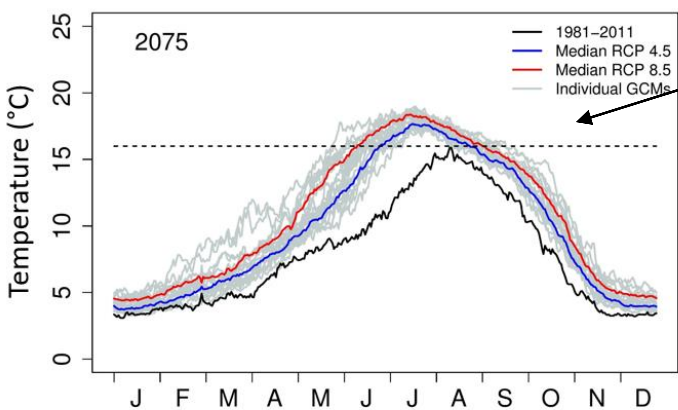
Clarke (2020)

Projected changes in stream temperature

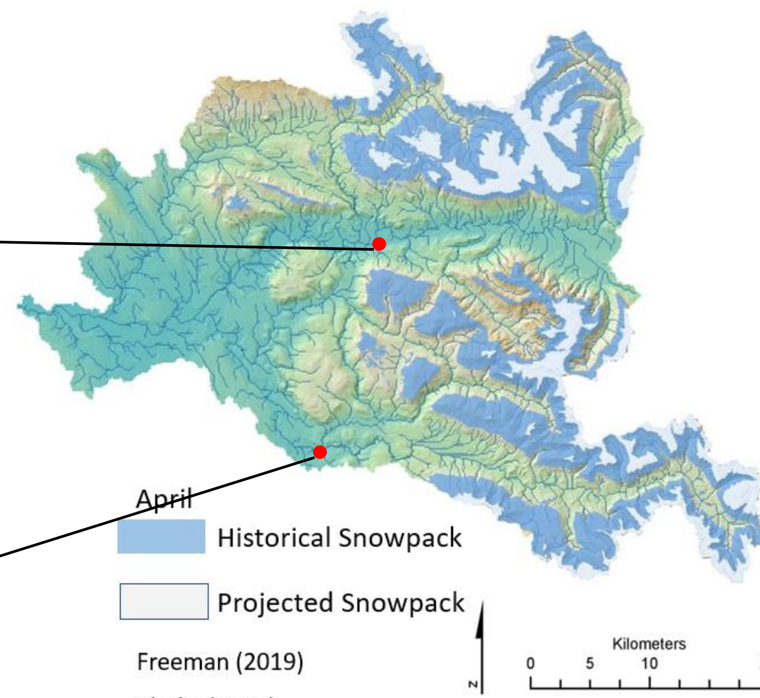
Each point on the plots represents a daily average over 30 years

- Hindcast (1981-2011)
- Individual GCM (20 total)
- Median of 10 GCMs with RCP 4.5 scenario
- Median of 10 GCMs with RCP 8.5 scenario





Stillaguamish Watershed



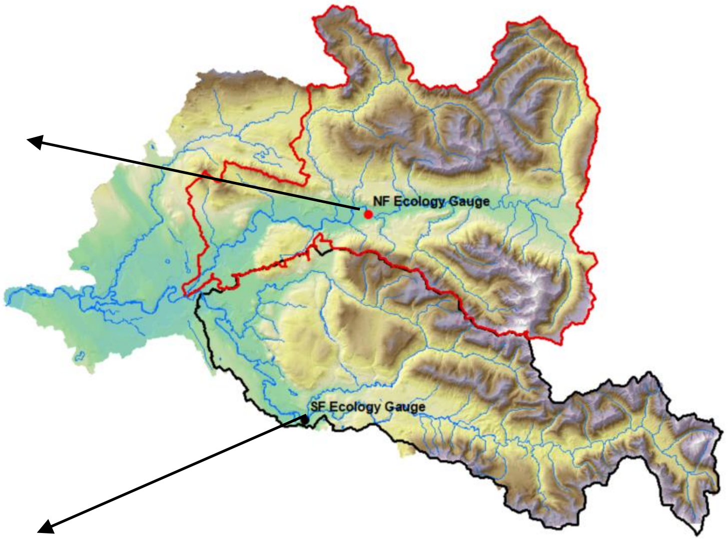
Freeman (2019)

Clarke (2020)

Modeled monthly median stream temperature for the median GCM results for 30-years surrounding 2025, 2050, 2075, and the historic (hindcast) period.

Month	Historic °C	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
		2025		2050		2075	
January	4.2	4.4	4.5	4.7	5.0	5.0	5.8
February	4.8	5.0	4.9	5.3	5.4	5.6	6.3
March	5.5	5.8	5.8	6.2	6.2	6.7	7.2
April	6.8	7.4	7.3	7.7	7.8	8.1	8.6
May	8.1	8.7	8.9	9.5	9.8	10.6	11.8
June	9.4	11.7	11.7	13.3	13.8	14.6	15.8
July	13.8	15.4	15.5	16.6	17.0	17.4	18.4
August	15.2	16.2	16.2	16.9	17.2	17.4	18.3
September	13.7	14.5	14.5	15.3	15.6	15.7	16.7
October	10.1	11.1	11.3	12.1	12.5	12.5	13.8
November	6.1	6.7	6.8	7.2	7.6	7.7	8.6
December	4.4	4.7	4.9	5.2	5.6	5.5	6.4

Stillaguamish Watershed



Month	Historic °C	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
		2025		2050		2075	
January	3.3	3.4	3.4	3.6	3.7	3.8	4.4
February	3.8	4.0	3.9	4.3	4.4	4.6	5.5
March	4.5	4.7	4.9	5.3	5.4	5.9	6.7
April	6.1	6.9	6.9	7.3	7.5	7.9	9.1
May	8.2	9.1	9.2	10.0	10.5	11.0	13.1
June	10.1	12.0	12.2	13.8	14.6	14.9	16.5
July	14.1	16.0	16.2	16.8	17.2	17.3	18.1
August	15.3	15.9	16.0	16.3	16.5	16.6	17.1
September	13.0	13.8	13.8	14.3	14.6	14.6	15.2
October	8.9	9.7	10.0	10.6	11.2	11.1	12.3
November	4.4	4.9	5.0	5.5	6.0	6.0	7.0
December	3.1	3.4	3.5	3.8	3.9	4.0	4.7

Stream Temperature Impact on Salmon

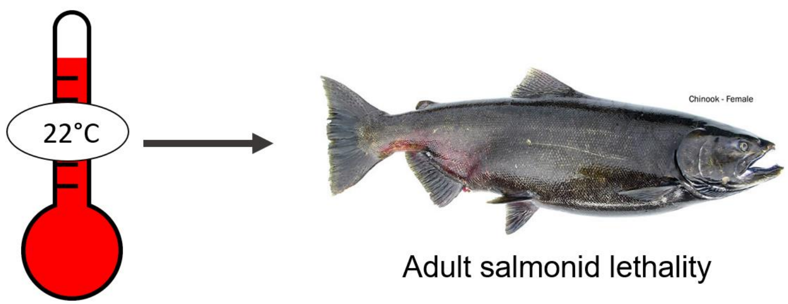
<u>WA Department of Ecology Standards:</u>

"**7-DADMax**" = Seven-day average of the daily maximum temperatures

16.0 ^{o}C - Core Summer Salmonid Habitat Standard

17.5 ^{o}C - Lethality to developing salmon embryos can be expected

> 22.0 ^{o}C – Adult lethality



Adult salmonid lethality

Stream Temperature Impact on Salmon

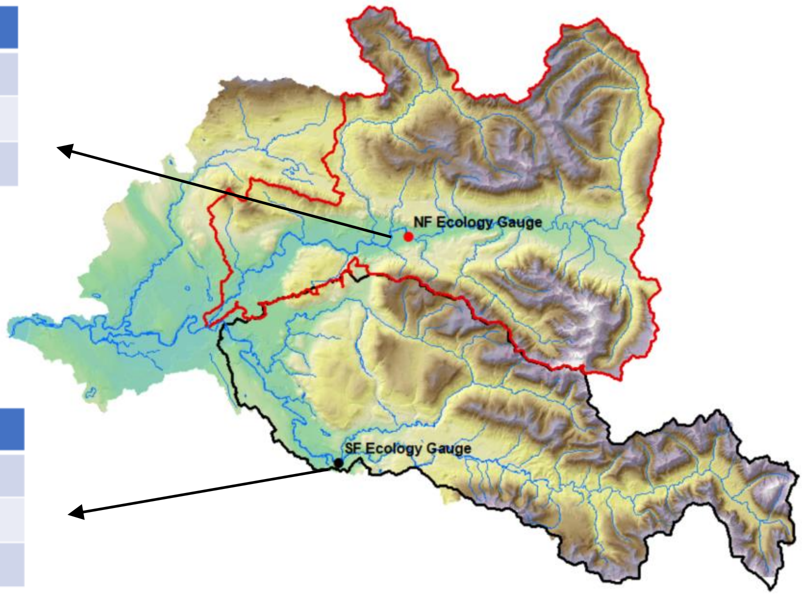
Average days per year exceeding the 16°C threshold:

Emission Scenario	Historic	2025	2050	2075
Moderate (RCP 4.5)	32	58	79	95
Severe (RCP 8.5)	32	59	88	117
Most Severe (HadGEM2-ES, RCP 8.5)	32	68	97	136

Average days per year exceeding the 16°C threshold:

Emission Scenario	Historic	2025	2050	2075
Moderate (RCP 4.5)	40	59	74	85
Severe (RCP 8.5)	40	60	83	110
Most Severe (HadGEM2-ES, RCP 8.5)	40	65	90	124

Stillaguamish Watershed



Summary

Observations	Inferences
Decrease in basin-wide SWE	Warmer winter air temperatures result in more precipitation falling as rain rather than snow
Shift of peak SWE to earlier in the winter	Warming air temperatures causes the snowpack to melt earlier
Increase in winter flow	More precipitation falling as rain results in a more rapid runoff to streams (loss of snowpack buffer)
Decrease in spring freshet	A smaller snowpack produces a smaller freshet
Decrease in summer flow	A smaller freshet and projected warmer drier summers produce lower steamflows
Increase in stream temperatures in every month	Warmer air temperature transfers more heat to streams
Greatest stream temperature increases in June	Loss of cool meltwater from the reduced freshet
Highest stream temperatures in July/August	Warmer air temperature transfers more heat to streams with a lower discharge.