# High Resolution Geospatial Stream Temperature Data for the Northwest U.S.

# A User's Guide for the NorWeST Regional Database and Model

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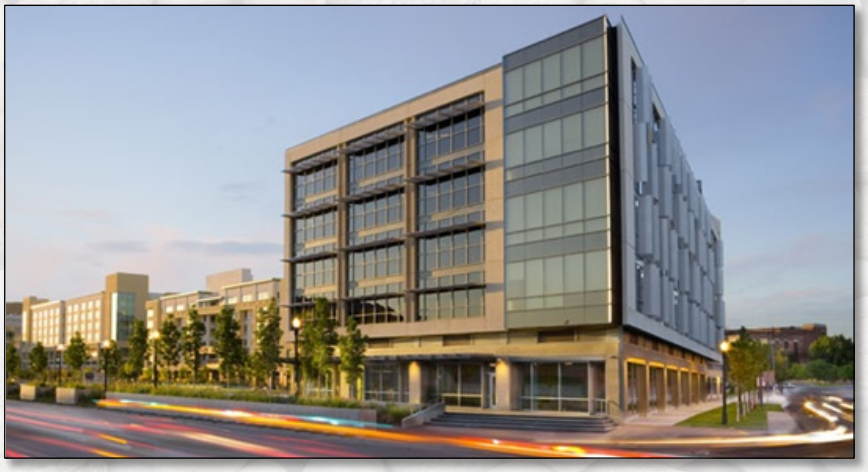
**Jason Dunham and David Hockman-Wert**

U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center

# INTRODUCTION

# Boise Aquatic Sciences Lab



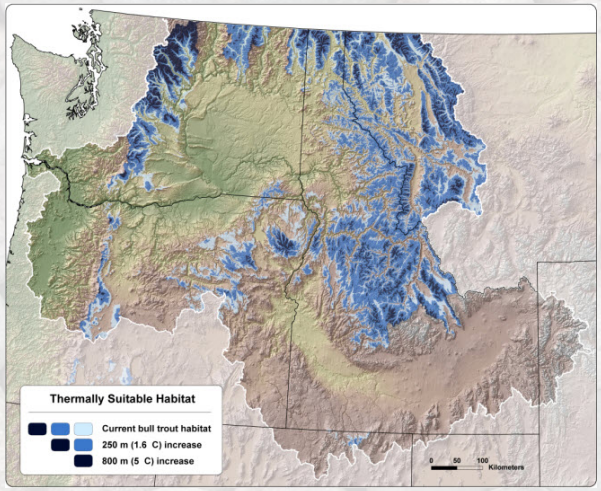
Idaho Water Center

Fish and watershed research

# Acknowledgements

## Dan Isaak, Bruce Rieman, Charlie Luce, Jason Dunham, Seth Wenger

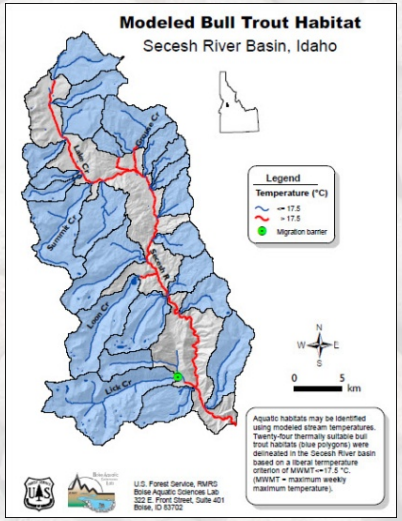
# Boise Lab Stream Temperature History




## 1) Air temperature based model

**Generated using sampled bull trout lower limit locations, air temperature, elevation, latitude, and longitude**

***Rieman et al. 2007***

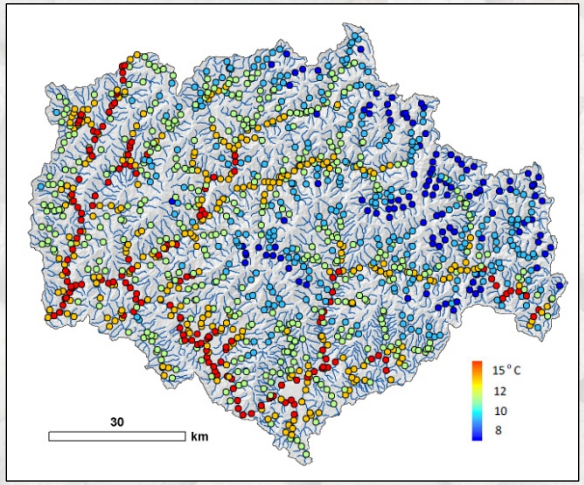



## 2) Multiple regression model

**Based on observed stream temperature data and elevation, catchment area, slope, lake presence, and burn history**

***Isaak et al. 2009***

# Boise Lab Stream Temperature History and NorWeST




## 3) Spatial statistical model

**Used STARS geospatial tools and SSN statistical package with observed stream temperatures and spatial and climate covariates**

***Isaak et al. 2010***

## 4) NorWeST regional model

**Uses the spatial statistical approach with a massive temperature sensor network and processing at a landscape scale**

***http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html***

NorWeST Stream Temp

# Funding and Partners

Great Northern
LANDSCAPE CONSERVATION COOPERATIVE

TROUT UNLIMITED

CSIRO

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

USGS Forest and Rangeland Ecosystem Science Center

# NorWeST OVERVIEW

# NorWeST

1) Regional Temperature Database

2) Modeled Stream Temperatures

**Purpose: Conduct climate vulnerability assessments for aquatic species**

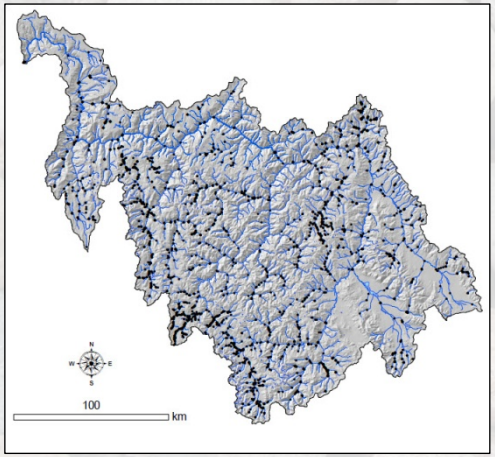
**Extent: Northwest U.S.**
**350,000 stream km**

# Products

## 1) Summarized stream temperature observation data (database)

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | OBSPRED_ID | Date | DailyMinimum | DailyMean | DailyMaximum | Nobs | Status |
| 2 | 1 | 8/1/2008 | 10.60 | 12.11 | 14.10 | 10 | P |
| 3 | 1 | 8/2/2008 | 10.90 | 12.26 | 13.70 | 10 | P |
| 4 | 1 | 8/3/2008 | 10.60 | 11.84 | 12.90 | 10 | P |
| 5 | 1 | 8/4/2008 | 10.60 | 11.91 | 12.90 | 10 | P |
| 6 | 1 | 8/5/2008 | 10.60 | 12.00 | 13.70 | 10 | P |
| 7 | 1 | 8/6/2008 | 10.90 | 12.61 | 14.40 | 10 | P |
| 8 | 1 | 8/7/2008 | 12.10 | 13.18 | 14.10 | 10 | P |
| 9 | 1 | 8/8/2008 | 12.50 | 13.17 | 14.40 | 10 | P |
| 10 | 1 | 8/9/2008 | 12.10 | 12.94 | 14.10 | 10 | P |
| 11 | 1 | 8/10/2008 | 10.60 | 12.07 | 13.30 | 10 | P |

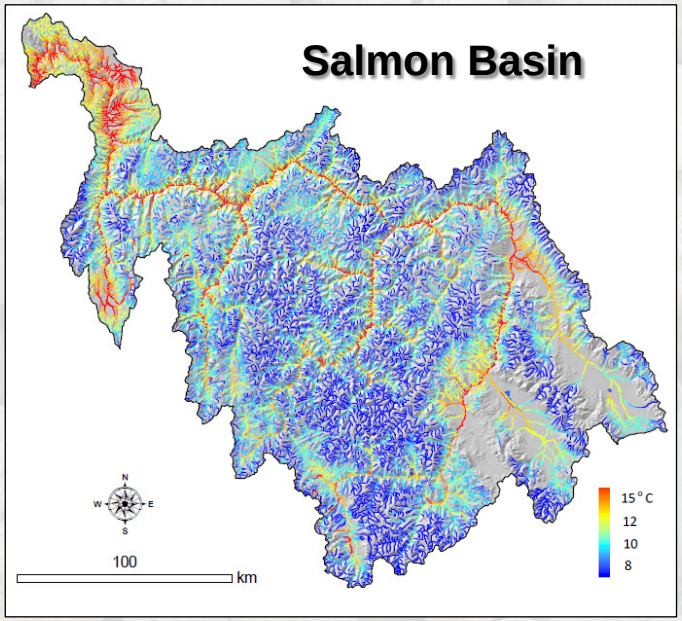
AugustDailySummary




**Excel and ESRI GIS format**

***Daily metrics***

## 2) Modeled stream temperature scenarios

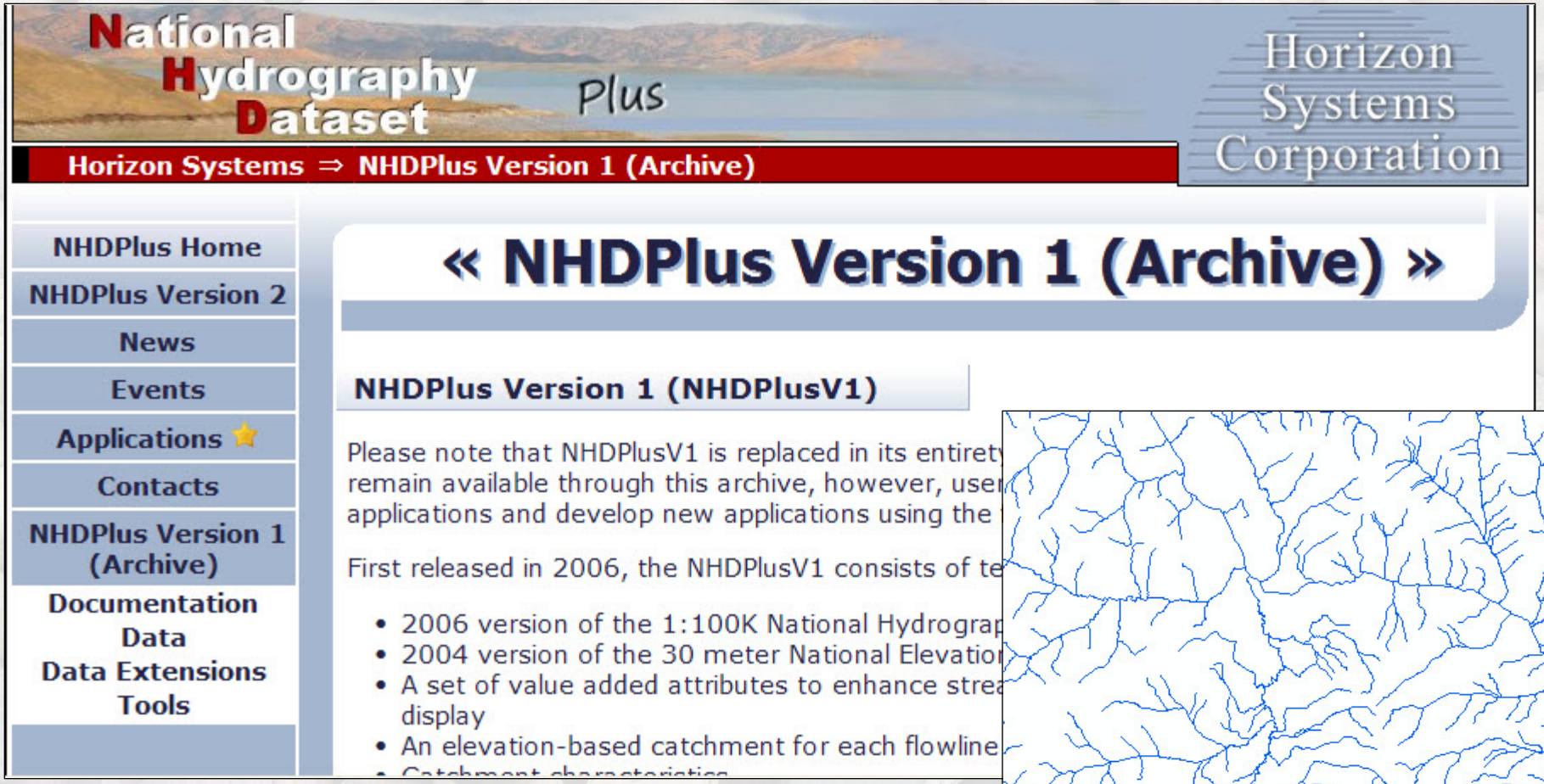



**ESRI GIS format**

***Annual August means***

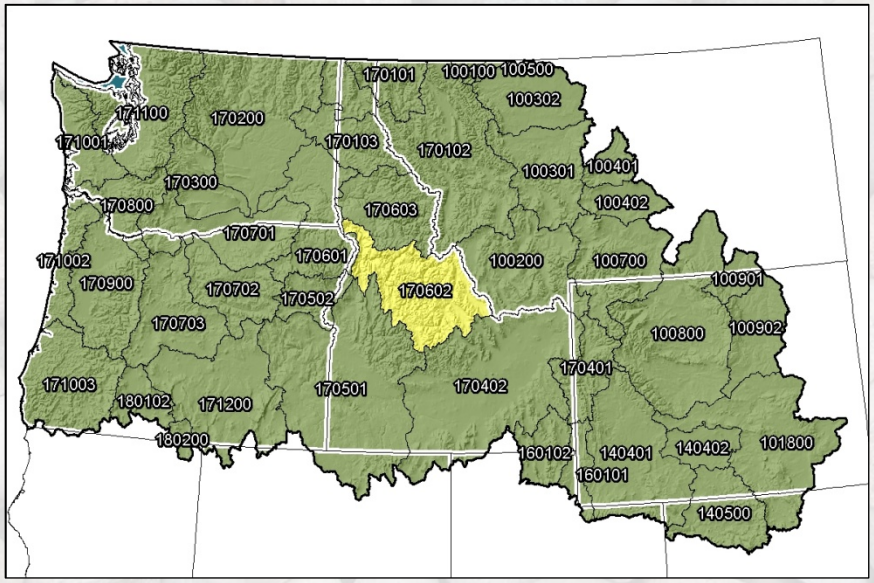
# GIS Base Layer

- NHDPlus Version 1
- 1:100,000 scale stream lines

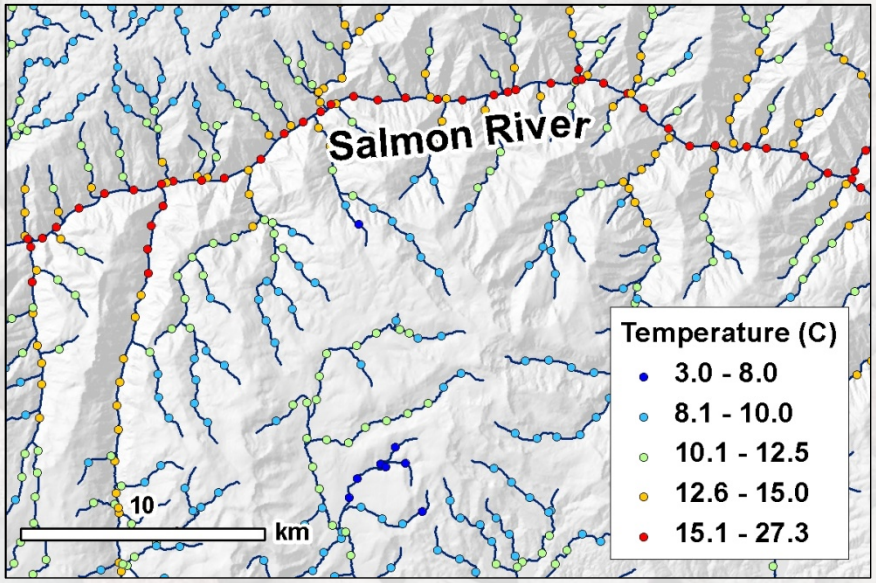


# Modeling Scale

## Models are fit and run at the HUC 3 watershed scale




## Results are generated at approximately 1 km resolution



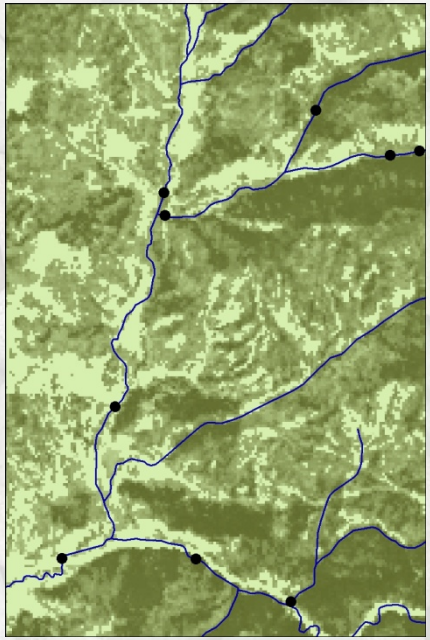
# Modeling Approach – Step 1
# Collect/Generate Input Data

## At every observation location obtain:

**1) Stream temperature (dependent)**

**Data aggregated from contributors**

**2) Nine spatial variables (GIS) (predictors)**



**e.g. elevation, canopy cover, etc.**

**3) Two climate variables (predictors)**

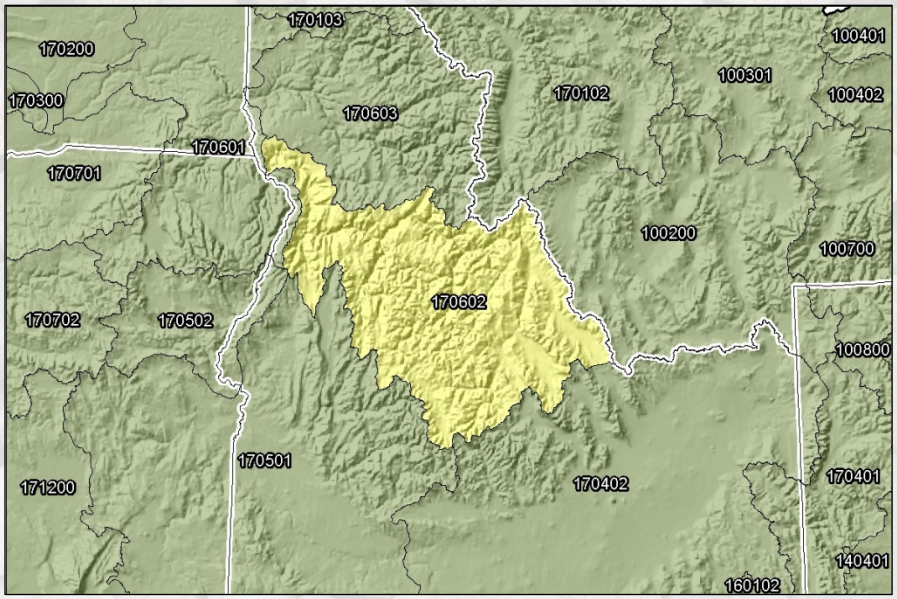
**Air temperature**

**Stream flow**

# Modeling Approach – Step 2
# Fit the Model Using the Input Data

**At the basin scale, correlate stream temperature with the predictors**

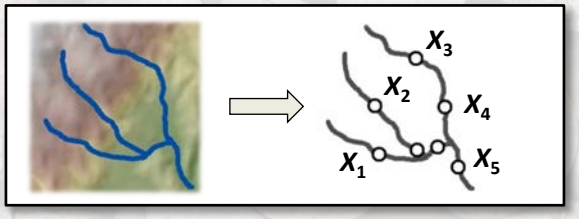
**Fit the model with:**




1) **Stream temperature**
2) **Spatial variables**
3) **Climate variables**

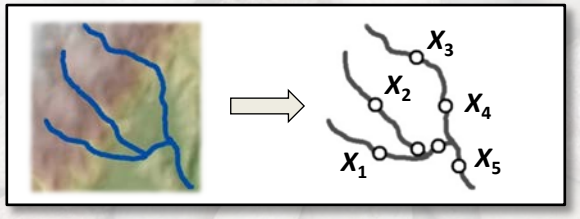
**using**

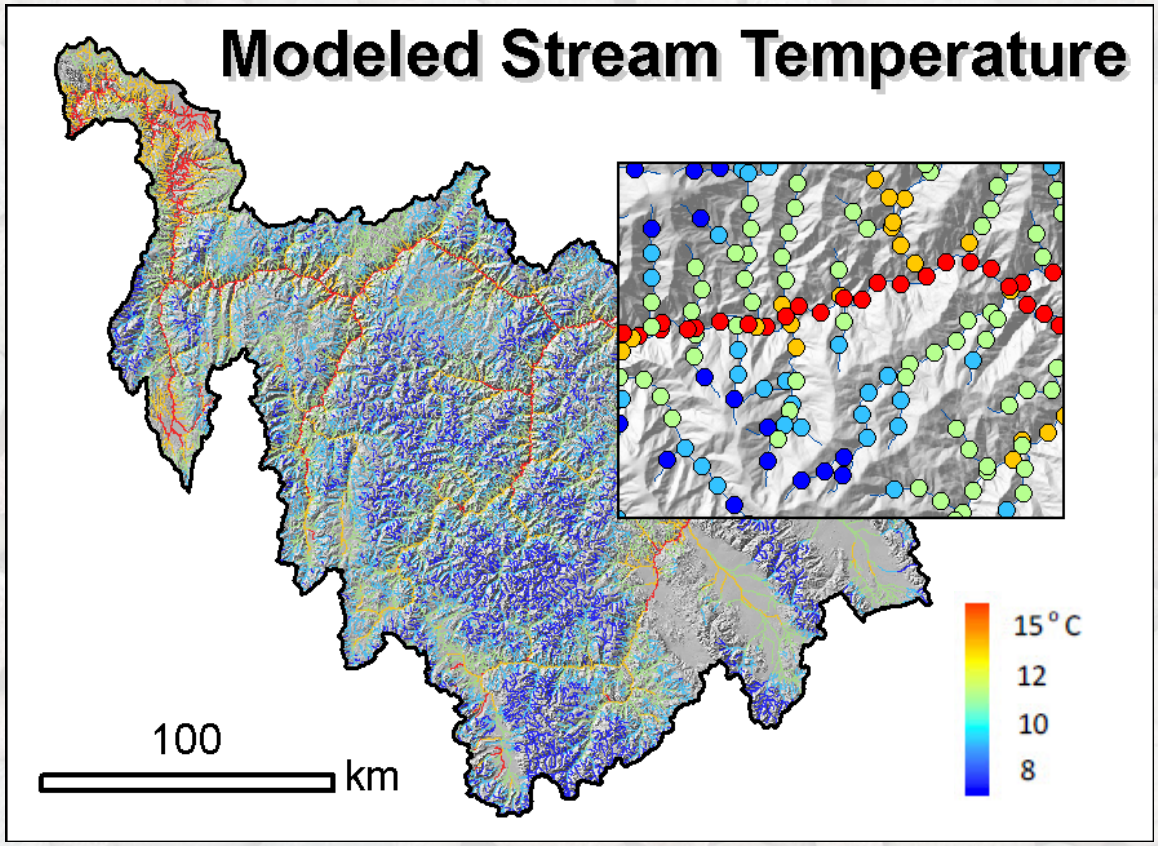
**Spatial statistical tools**



# Modeling Approach – Step 3
# Generate Modeled Temperatures

**Generate modeled stream temperature output at 1 km interval**



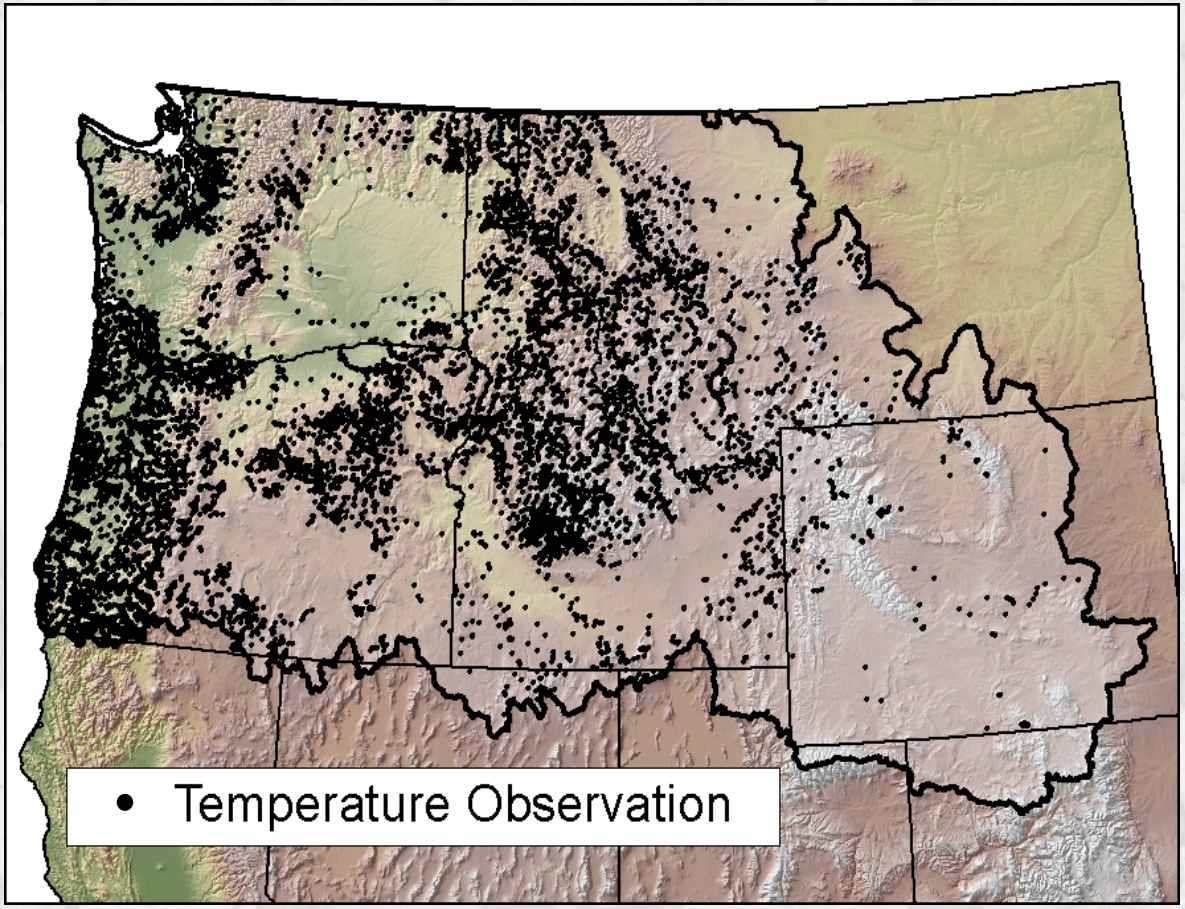



# DATA DETAILS

# Temperature Sensor Network

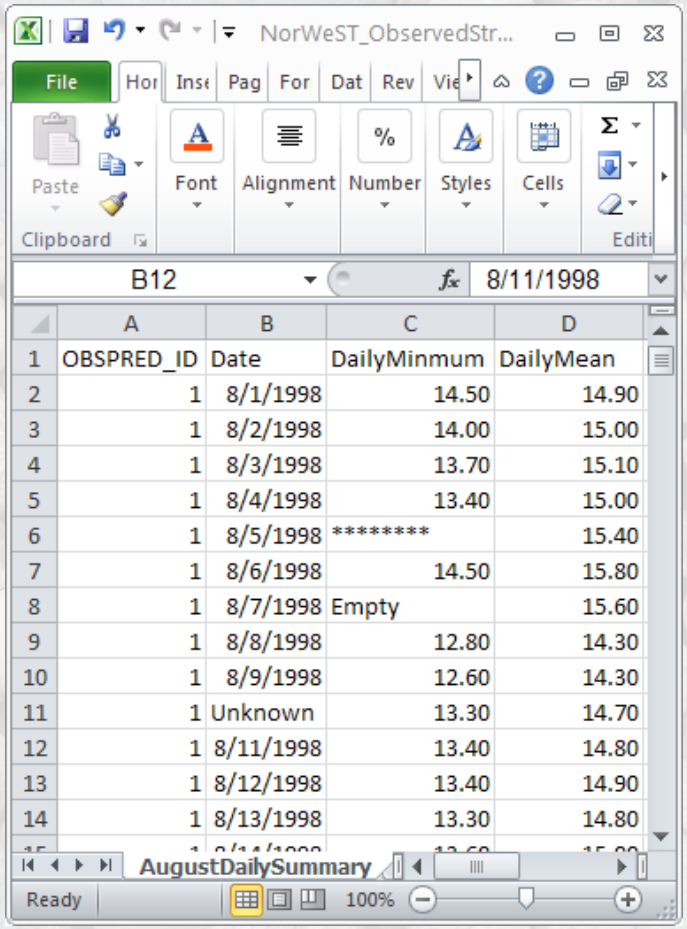
## Observed Temperatures for Modeling and Distribution

- About 15,000 unique stream sites
- 45,000,000 hourly observations
- Over 50 contributors



# Preprocessing

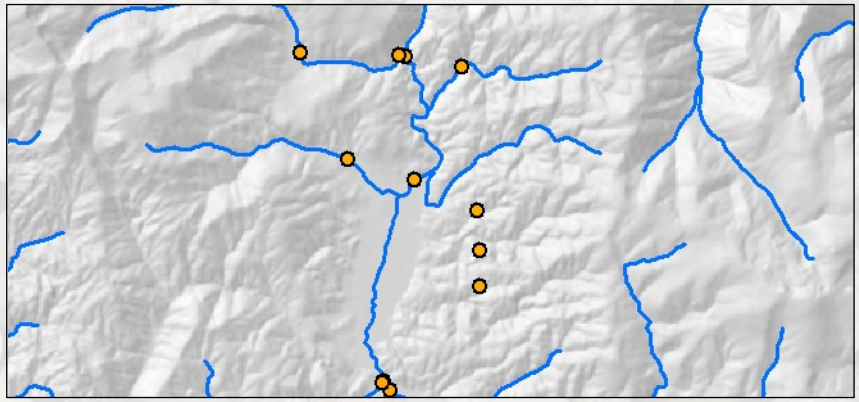
## Observed Temperature Database




| | A | B | C | D |
|---|---|---|---|---|
| 1 | OBSPRED_ID | Date | DailyMinmum | DailyMean |
| 2 | 1 | 8/1/1998 | 14.50 | 14.90 |
| 3 | 1 | 8/2/1998 | 14.00 | 15.00 |
| 4 | 1 | 8/3/1998 | 13.70 | 15.10 |
| 5 | 1 | 8/4/1998 | 13.40 | 15.00 |
| 6 | 1 | 8/5/1998 | ******** | 15.40 |
| 7 | 1 | 8/6/1998 | 14.50 | 15.80 |
| 8 | 1 | 8/7/1998 | Empty | 15.60 |
| 9 | 1 | 8/8/1998 | 12.80 | 14.30 |
| 10 | 1 | 8/9/1998 | 12.60 | 14.30 |
| 11 | 1 | Unknown | 13.30 | 14.70 |
| 12 | 1 | 8/11/1998 | 13.40 | 14.80 |
| 13 | 1 | 8/12/1998 | 13.40 | 14.90 |
| 14 | 1 | 8/13/1998 | 13.30 | 14.80 |

**Challenge: Ensure consistent formatting**

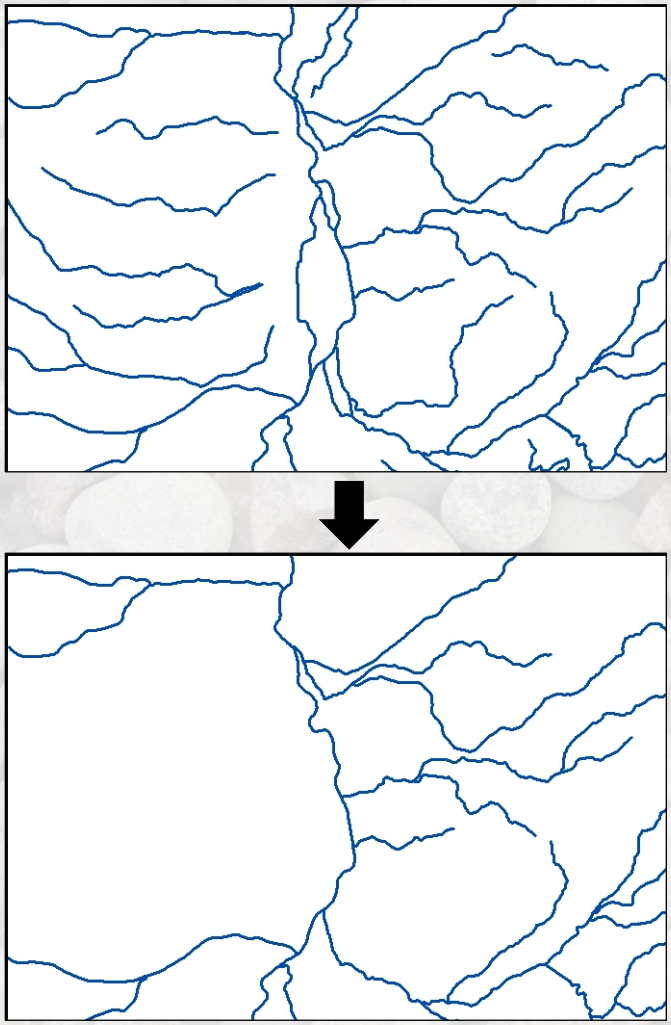
- Many thousands of records
- Thousands of errors and inconsistencies
- Errors: formatting, temperature, location



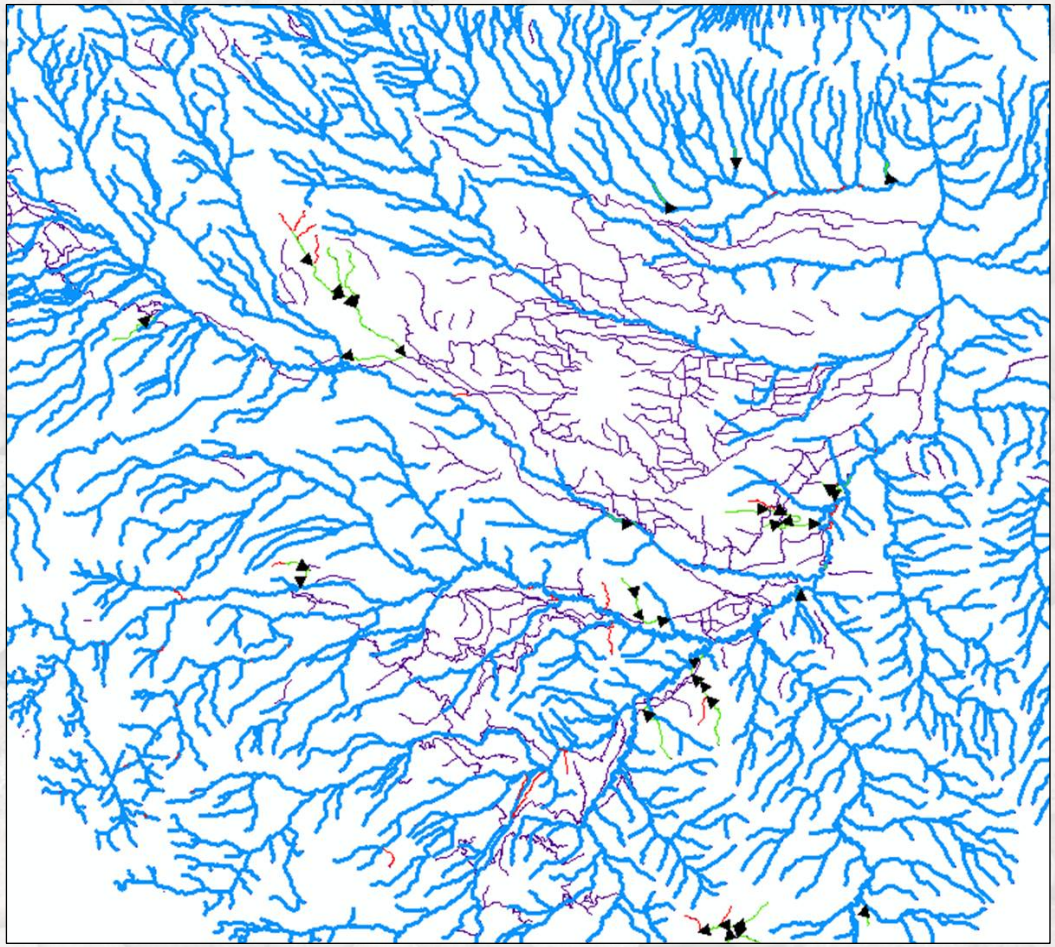
# Preprocessing

## NHDPlus Stream Lines

### Braids and sinks

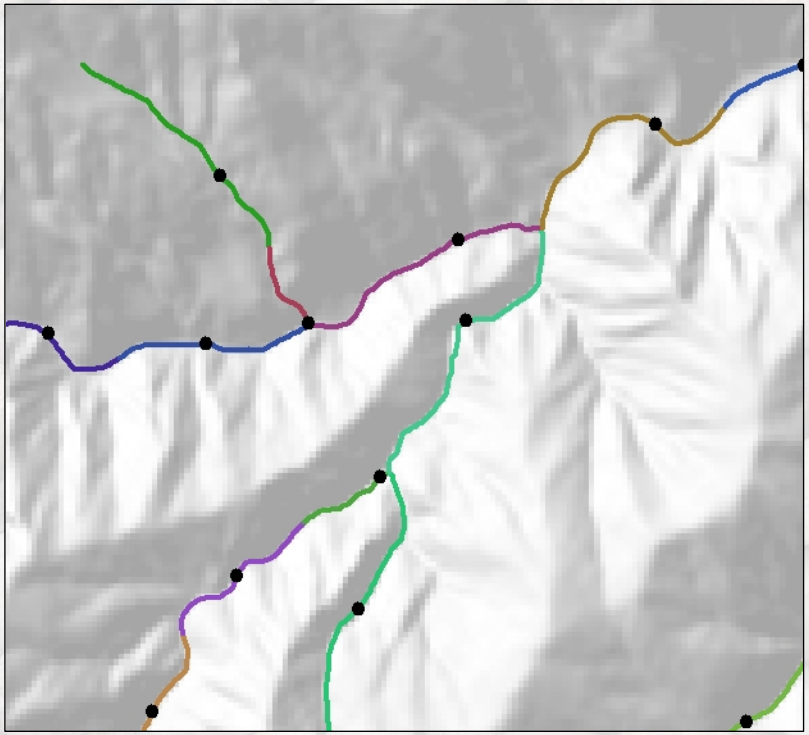


### Diversions and inconsistent flow

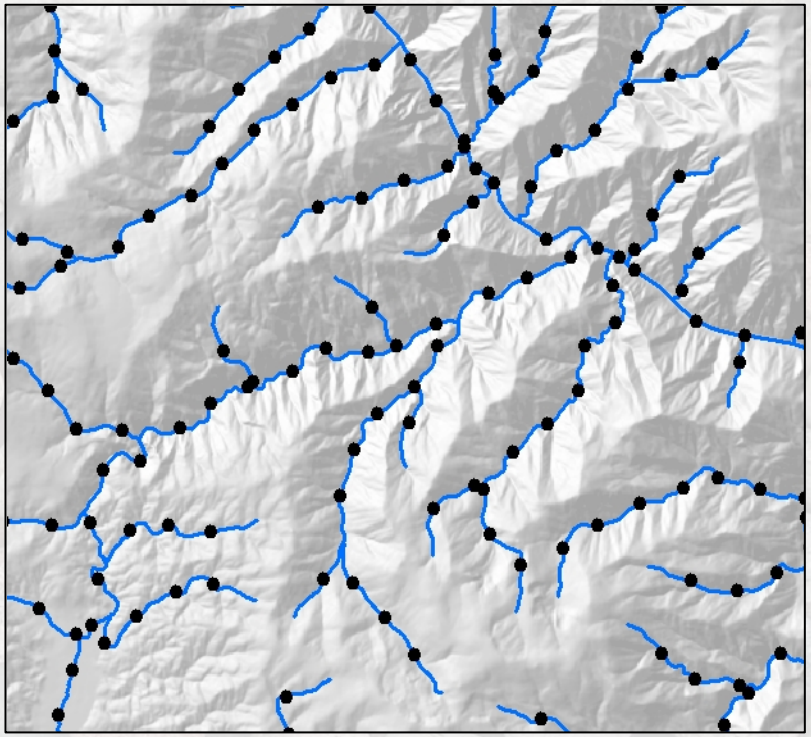


# 1 Kilometer Data Model

**Stream network divided into 1 km segments**



**Each segment is assigned a point (prediction point)**



- Temperature predictions for every line and point
- Facilitates habitat patching
- Points provide spatial bridge to other stream layer sources

# MODELING

1) Spatial variables

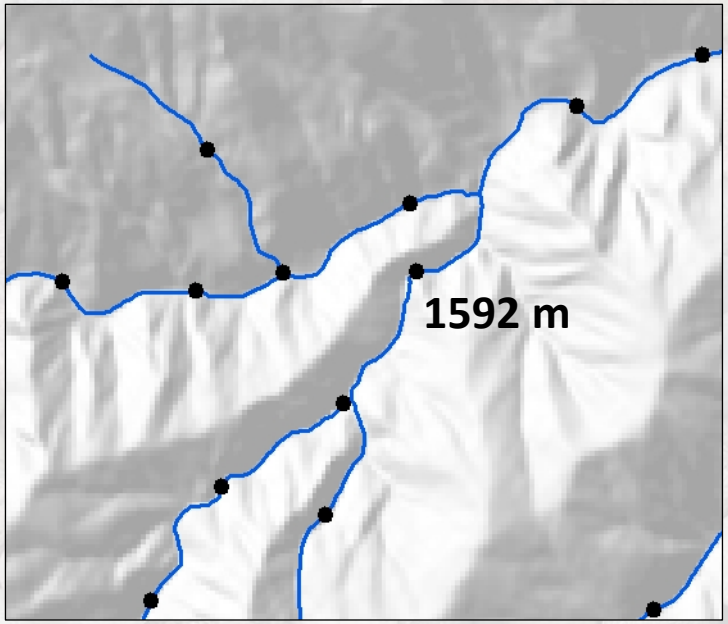
2) Climate variables

# Spatial Variables

## GIS Predictors

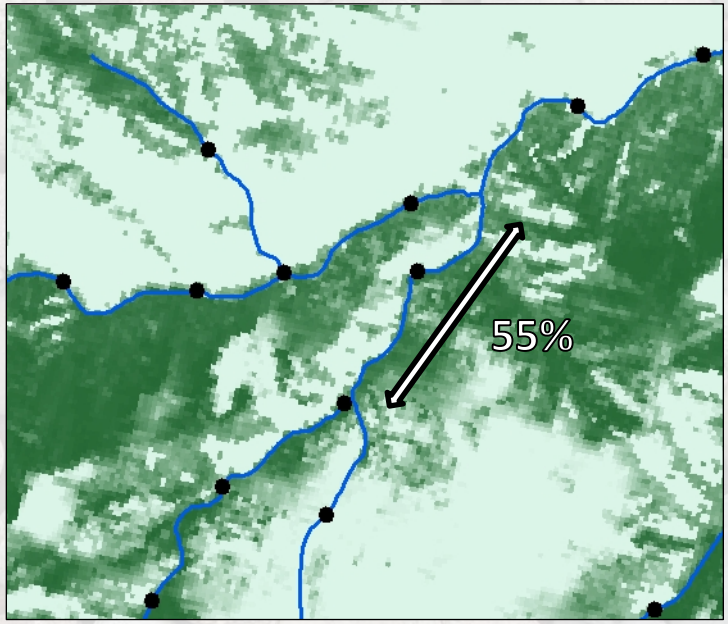
- Elevation
- Canopy percent
- Stream gradient
- Precipitation
- Catchment area
- Latitude
- Lake influence
- Base flow index
- Tailwater flag

# Elevation




- Source: 30 m DEM
- Elevation extracted at points
- Effect: Negative

# Canopy percent




- Source: National Land Cover Dataset
- Summarized by 1 km segment
- Effect: Negative

# Stream Gradient

Attributes of flowlineattributesflow

| MINELEVRAW | MAXELEVSMO | MINELEVSMO | SLOPE |
|---|---|---|---|
| 548.13 | 553.84 | 553.84 | 0 |
| 551.36 | 553.84 | 553.84 | 0 |
| 552.85 | 721.34 | 553.84 | 0.08379 |
| 721.34 | 763.07 | 721.34 | 0.04406 |
| 763.07 | 814.88 | 763.07 | 0.04339 |
| 816.41 | 862.38 | 814.88 | 0.03871 |
| 862.38 | 999.58 | 862.38 | 0.05597 |
| 999.58 | 1774.91 | 999.58 | 0.13585 |
| 541.97 | 553.84 | 553.84 | 0 |
| 554.7 | 555.42 | 553.84 | 0.0188 |
| 551.91 | 553.84 | 553.84 | 0 |
| 553.88 | 565.4 | 553.84 | 0.2028 |
| 547.98 | 553.84 | 553.84 | 0 |
| 558.97 | 562.75 | 553.84 | 0.08567 |

Record: 0 Show: All Selected Records (0 out

# Precipitation

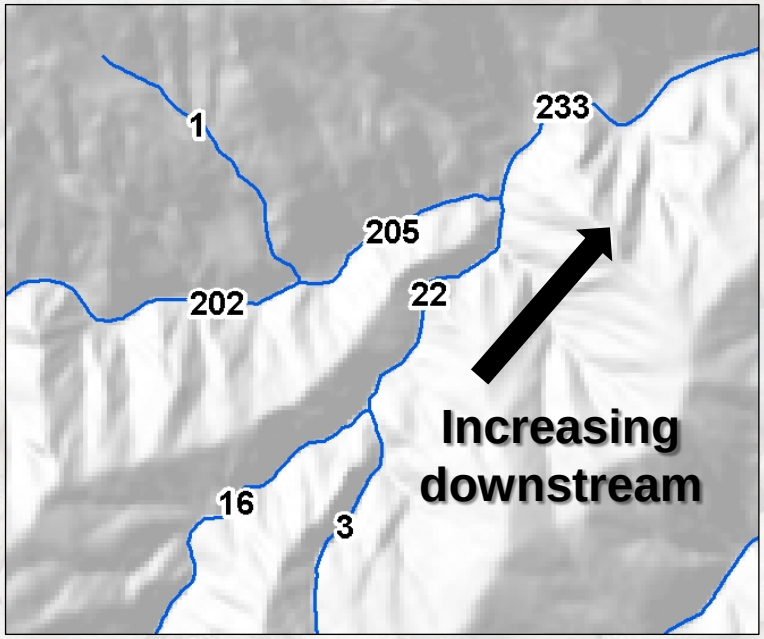
Attributes of catchmentattributestempprecip

| OID | COMID * | GRID_CODE | PRECIP | TEMP |
|---|---|---|---|---|
| 0 | 23574570 | 480163 | 904.15 | 34.9 |
| 1 | 23574572 | 480164 | 840.5867 | 51.9583 |
| 2 | 23574574 | 480165 | 880.348 | 47.2266 |
| 3 | 23574576 | 480166 | 904.15 | 34.9 |
| 4 | 23574578 | 480167 | 803.9309 | 53.93316 |
| 5 | 23574580 | 480168 | 756.75 | 56.9 |
| 6 | 23574582 | 480169 | 1164.823 | 30.26687 |
| 7 | 23574584 | 480170 | 1254.997 | 23.1752 |
| 8 | 23574586 | 480171 | 1151.356 | 24.89498 |
| 9 | 23574588 | 480172 | 909.5464 | 42.85244 |
| 10 | 23574590 | 480173 | 1005.988 | 34.20018 |
| 11 | 23574592 | 480174 | 763.26 | 36.3 |
| 12 | 23574594 | 480175 | 1038.085 | 34.92178 |
| 13 | 23574596 | 480176 | 977.8203 | 37.1352 |
| 14 | 23574598 | 480177 | 904.15 | 34.9 |

Record: 0 Show: All Selected Records (0

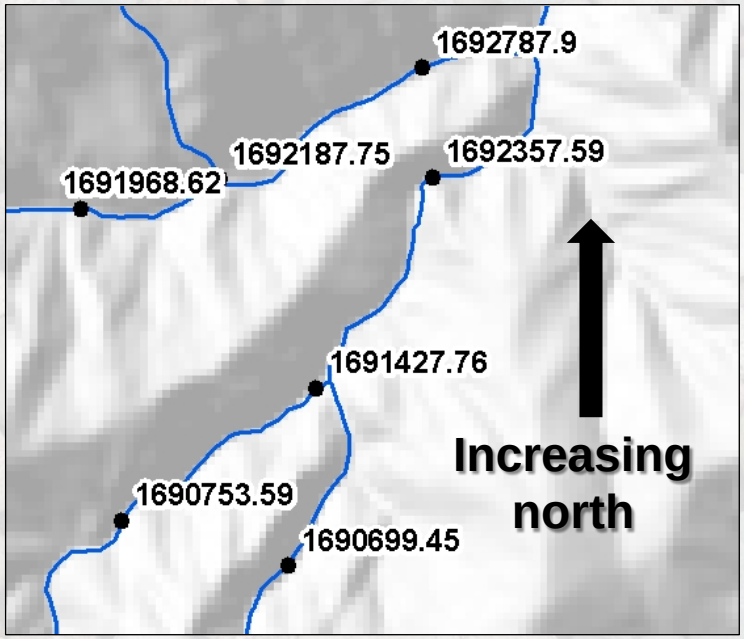
- **Source: NHDPlus tables**
- **Reach scale**
- **Effect: Negative**

# Catchment Area
## ($km^2$)



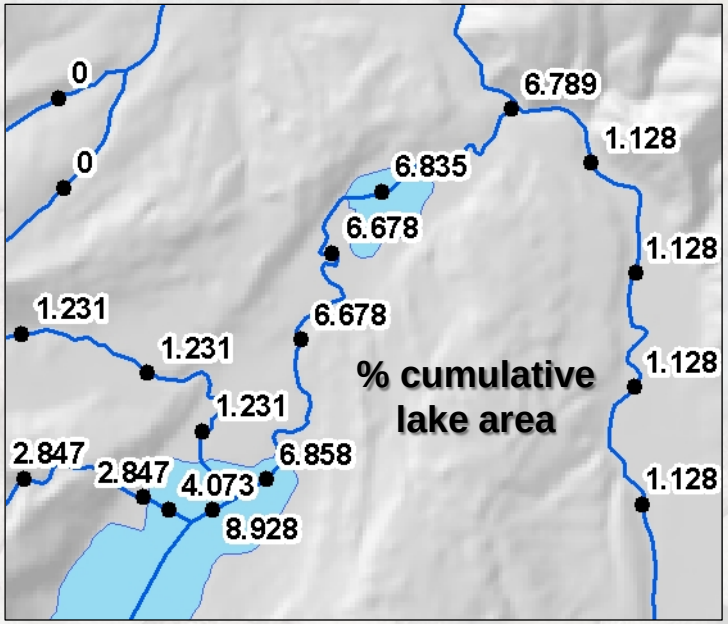

- NHDPlus reach scale
- Effect: Positive

# Latitude (m)



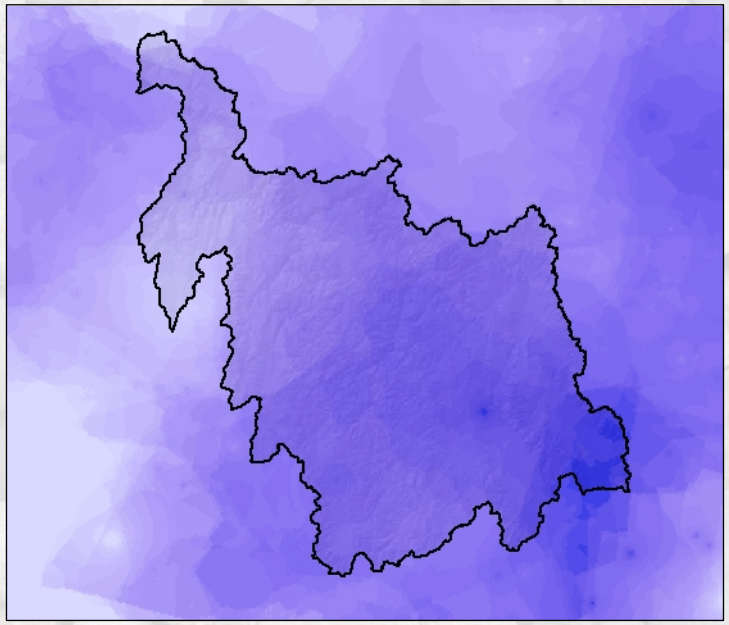

- Computed for each prediction point
- Effect: Negative

# Lake Influence



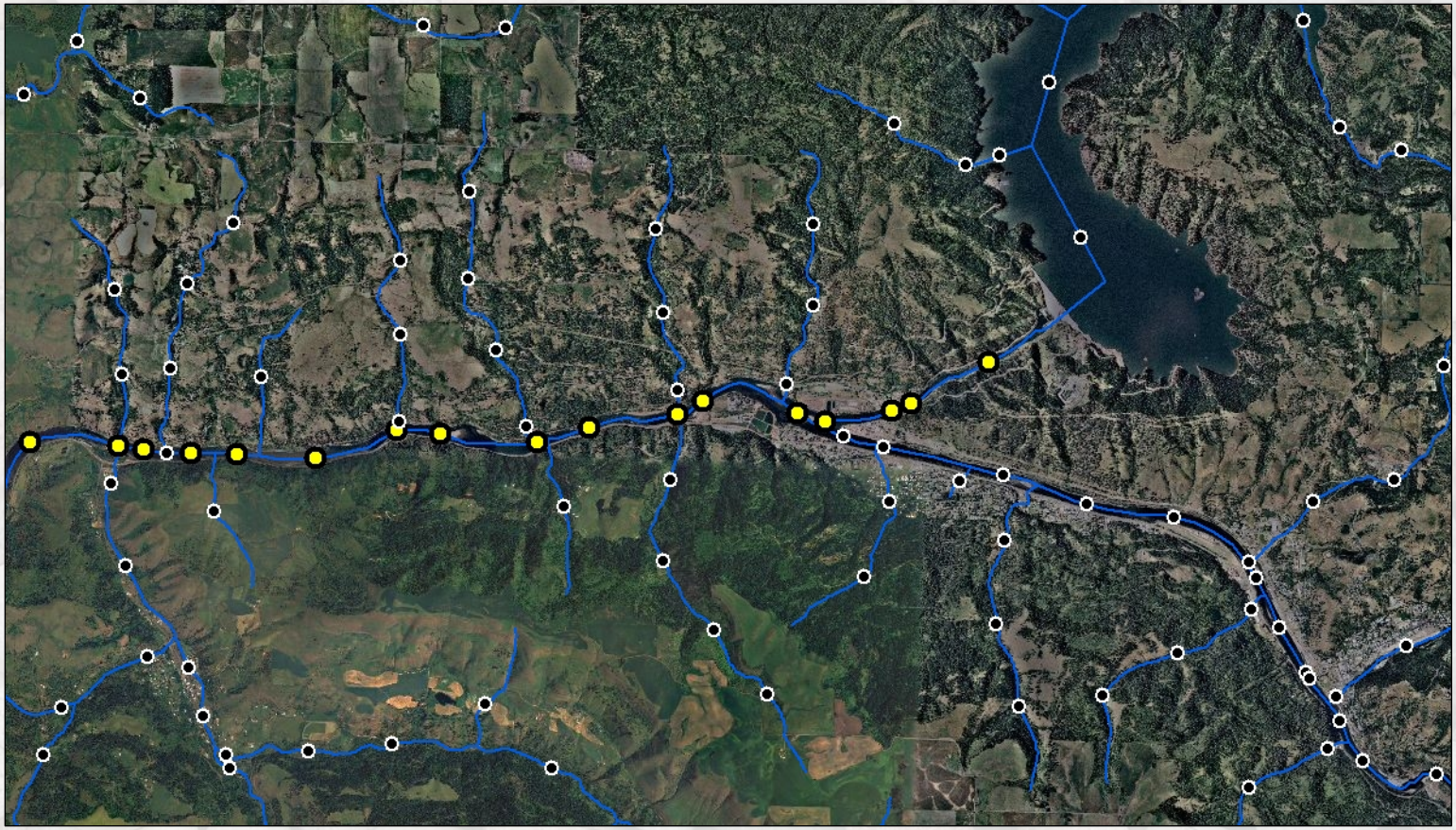

- Source: NHDPlus table derived from NLCD
- NHDPlus reach scale
- Effect: Positive

# Base Flow Index



- Source: USGS, Wolock (2003)
- Acquired for each prediction point
- Effect: Negative

# Tailwater Flag



- Hand coded for each prediction point down to the watershed outlet

# Climate Variables

## Predictors used to estimate interannual stream temperature

**Air temperature**

- Source: USGS modeled regional climate data. Hostetler (2011)
- Effect: Positive

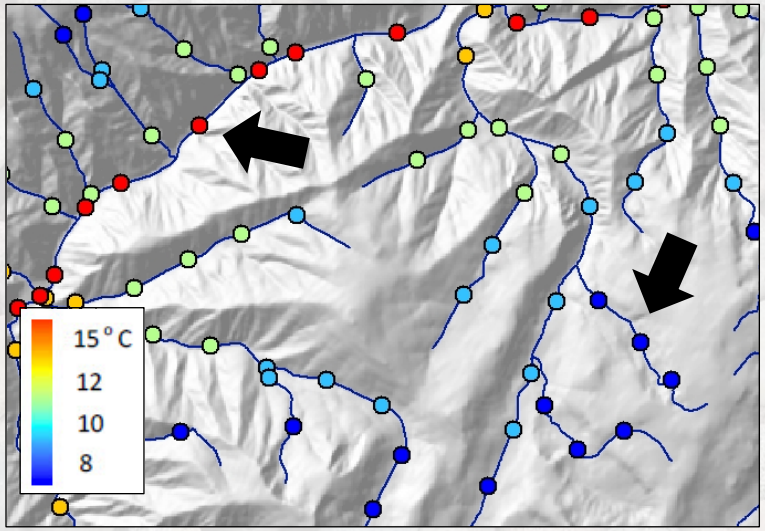
**Stream flow**

- Source: USGS gaging stations
- Effect: Negative

**Varies by year**

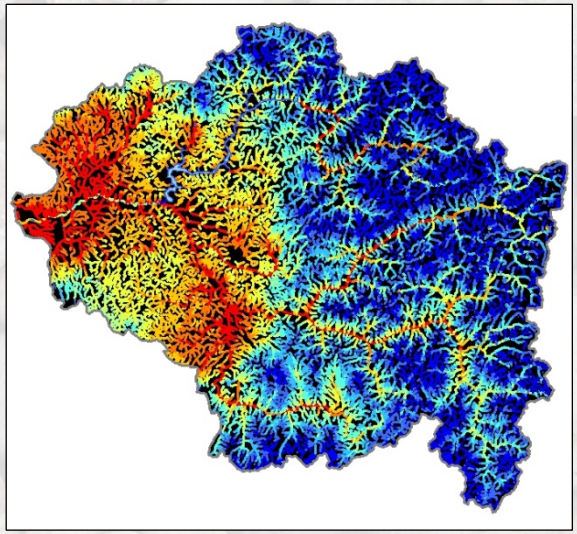
# Spatial and Climate Variables

**Spatial variables enable predictions to vary by location**

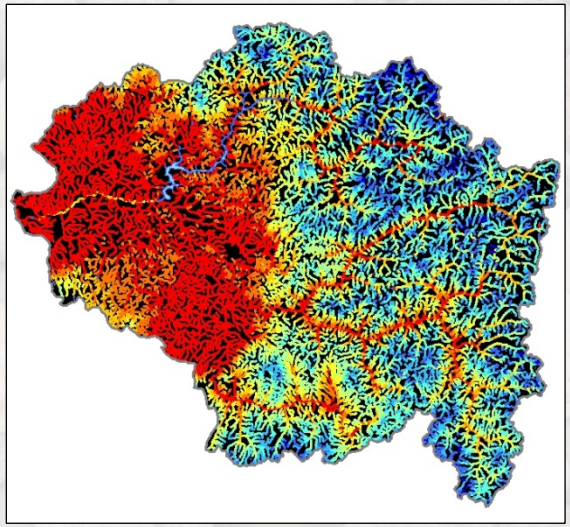



**Climate variables enable predictions to vary by year**

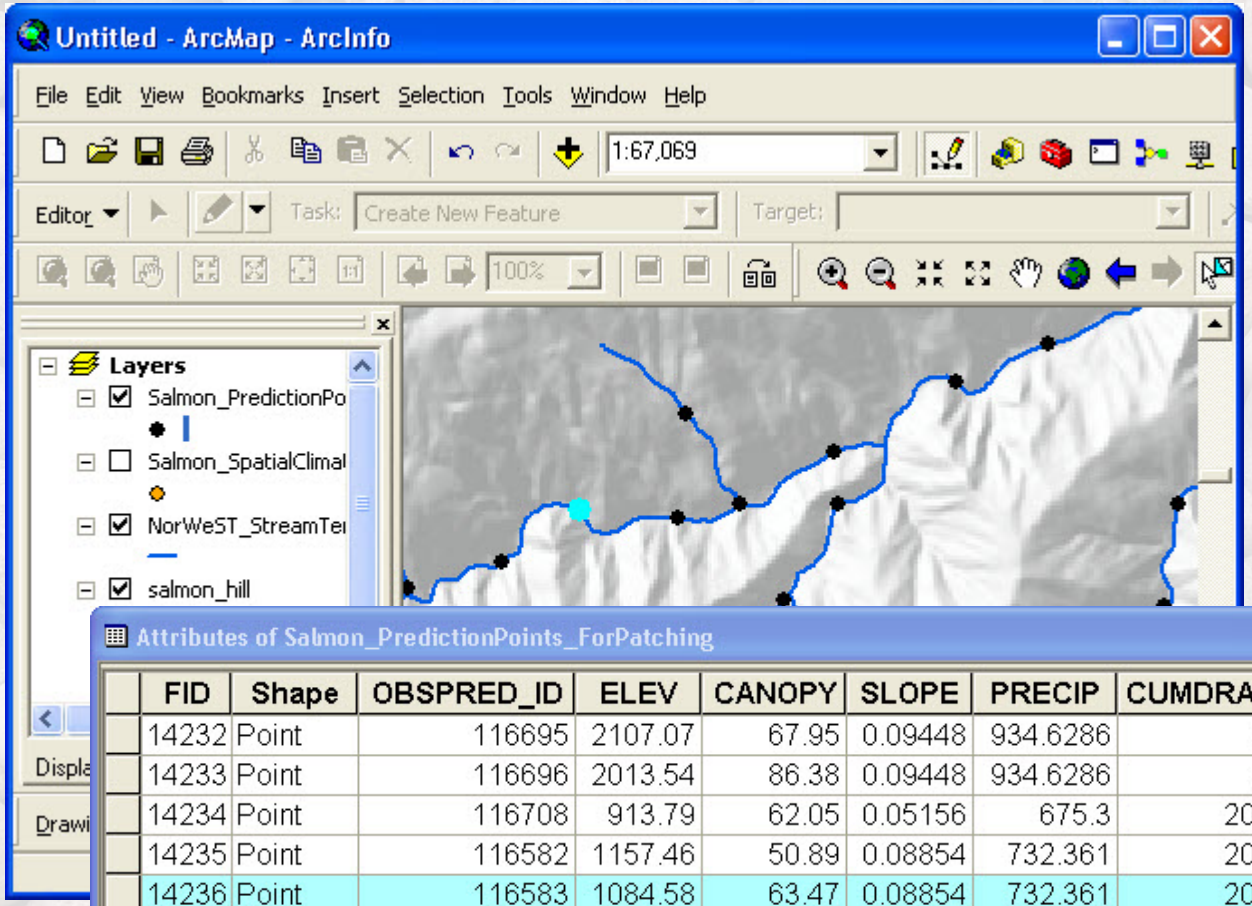
**1993**



**2003**



# Prediction Points with Spatial and Climate Variables




Attributes of Salmon_PredictionPoints_ForPatching

| FID | Shape | OBSPRED_ID | ELEV | CANOPY | SLOPE | PRECIP | CUMDRAINAG | Y_COORD | NLCD11PC | BFI |
|---|---|---|---|---|---|---|---|---|---|---|
| 14232 | Point | 116695 | 2107.07 | 67.95 | 0.09448 | 934.6286 | 3.396 | 1691927.63 | 0 | 68 |
| 14233 | Point | 116696 | 2013.54 | 86.38 | 0.09448 | 934.6286 | 3.396 | 1692528.85 | 0 | 68 |
| 14234 | Point | 116708 | 913.79 | 62.05 | 0.05156 | 675.3 | 205.321 | 1692787.9 | 0.025 | 69 |
| 14235 | Point | 116582 | 1157.46 | 50.89 | 0.08854 | 732.361 | 202.112 | 1691294.81 | 0.025 | 68 |
| 14236 | Point | 116583 | 1084.58 | 63.47 | 0.08854 | 732.361 | 202.112 | 1691864.52 | 0.025 | 68 |
| 14237 | Point | 116584 | 1004.41 | 71.21 | 0.08854 | 732.361 | 202.112 | 1691968.62 | 0.025 | 68 |
| 14238 | Point | 116415 | 1485.95 | 39.86 | 0.09897 | 797.6306 | 190.842 | 1689702.3 | 0.026 | 68 |
| 14239 | Point | 116416 | 1401.4 | 79.15 | 0.09897 | 797.6306 | 190.842 | 1690310.74 | 0.026 | 68 |
| 14240 | Point | 116417 | 1318.57 | 72.86 | 0.09897 | 797.6306 | 190.842 | 1690786.76 | 0.026 | 68 |

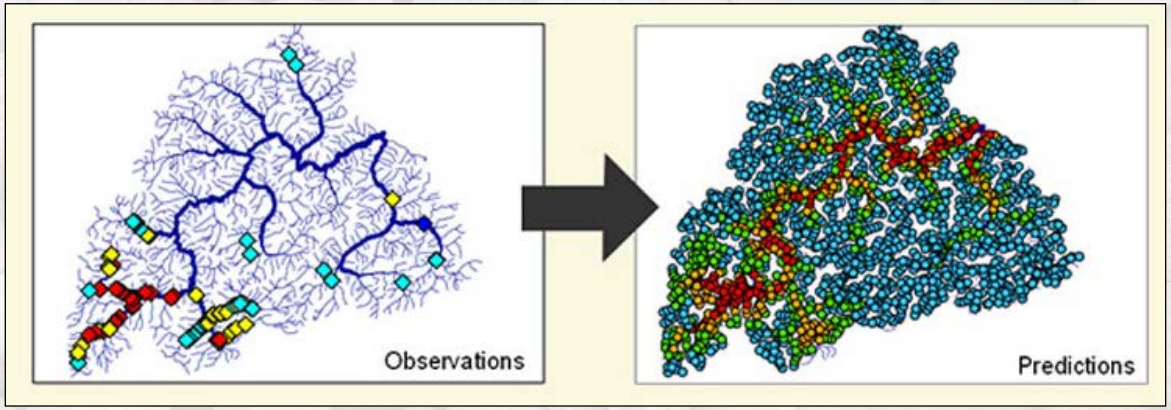
Record: 1 Show: All Selected Records (1 out of 21909 Selected) Options

# Spatial Statistical Tools

**Functional Linkage of Waterbasins and Streams (FLoWS)**
**Spatial Tools for the Analysis of River Systems (STARS)**
Developed for ArcGIS 9.3

**Spatial Stream Network package (SSN)**
Developed for R statistical software

***Erin Peterson and Jay Ver Hoef***




**Multiple regression with spatial network awareness**

CSIRO

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

***Google search: spatial stream networks***

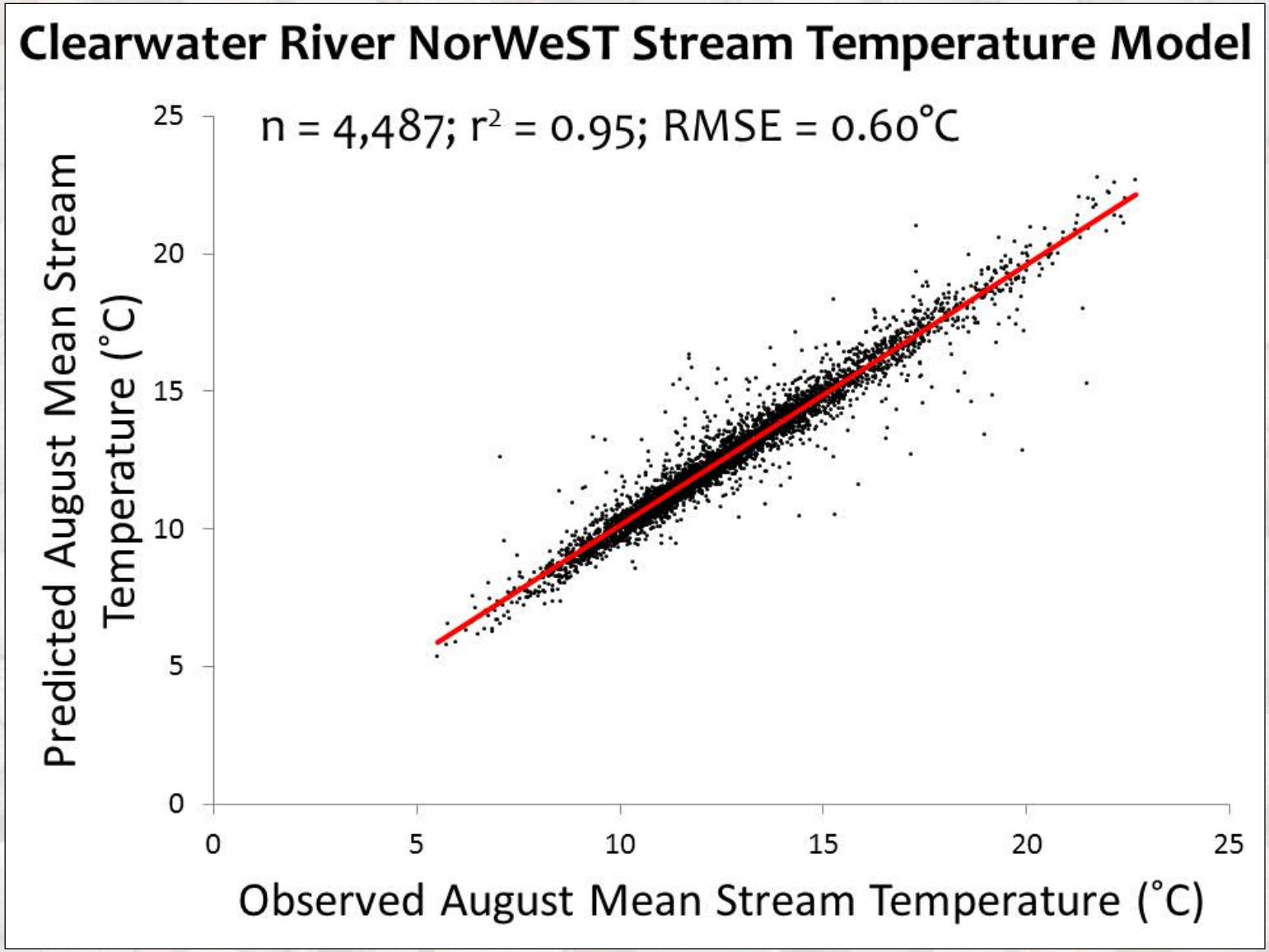
# RESULTS

# Clearwater Basin Model Results

| Parameter | Standard Estimate | p value |
|---|---|---|
| Tailwater | -13.27 | 0.000 |
| Elevation | -2.81 | 0.000 |
| Drainage area | 1.56 | 0.000 |
| Air temperature | 1.03 | 0.000 |
| Latitude | -0.83 | 0.004 |
| Slope | -0.75 | 0.000 |
| Base flow index | -0.73 | 0.005 |
| Precipitation | -0.55 | 0.013 |
| Canopy | -0.42 | 0.000 |
| Lake | 0.27 | 0.002 |
| Stream flow | -0.05 | 0.757 |

**Models explain about 90% of the variance in temperature**

# Clearwater Basin Model Results



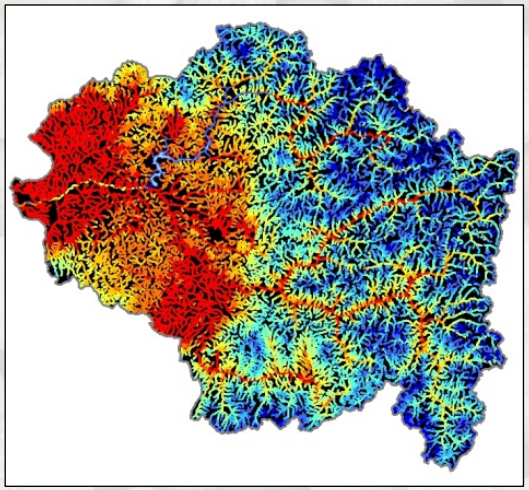
# Output Scenarios

## Mean August

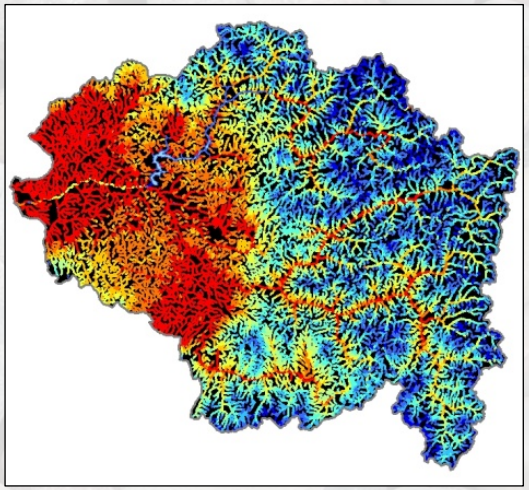
**Historical 10 year and 19 year averages**

*2 scenarios*

2002-2011

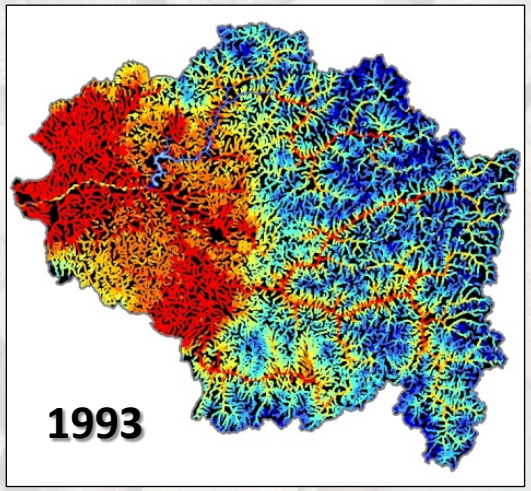


1993-2011



**Annuals 1993 – 2011**

*19 scenarios*

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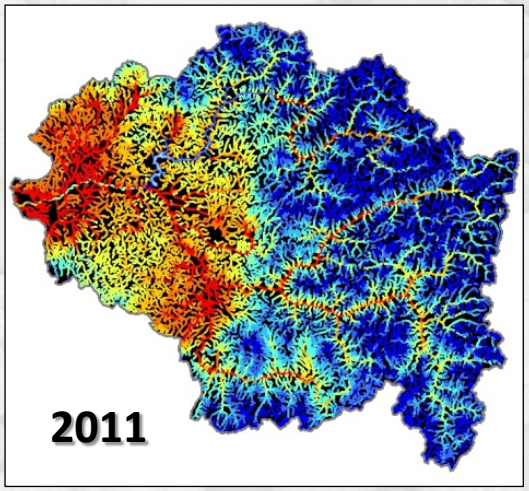
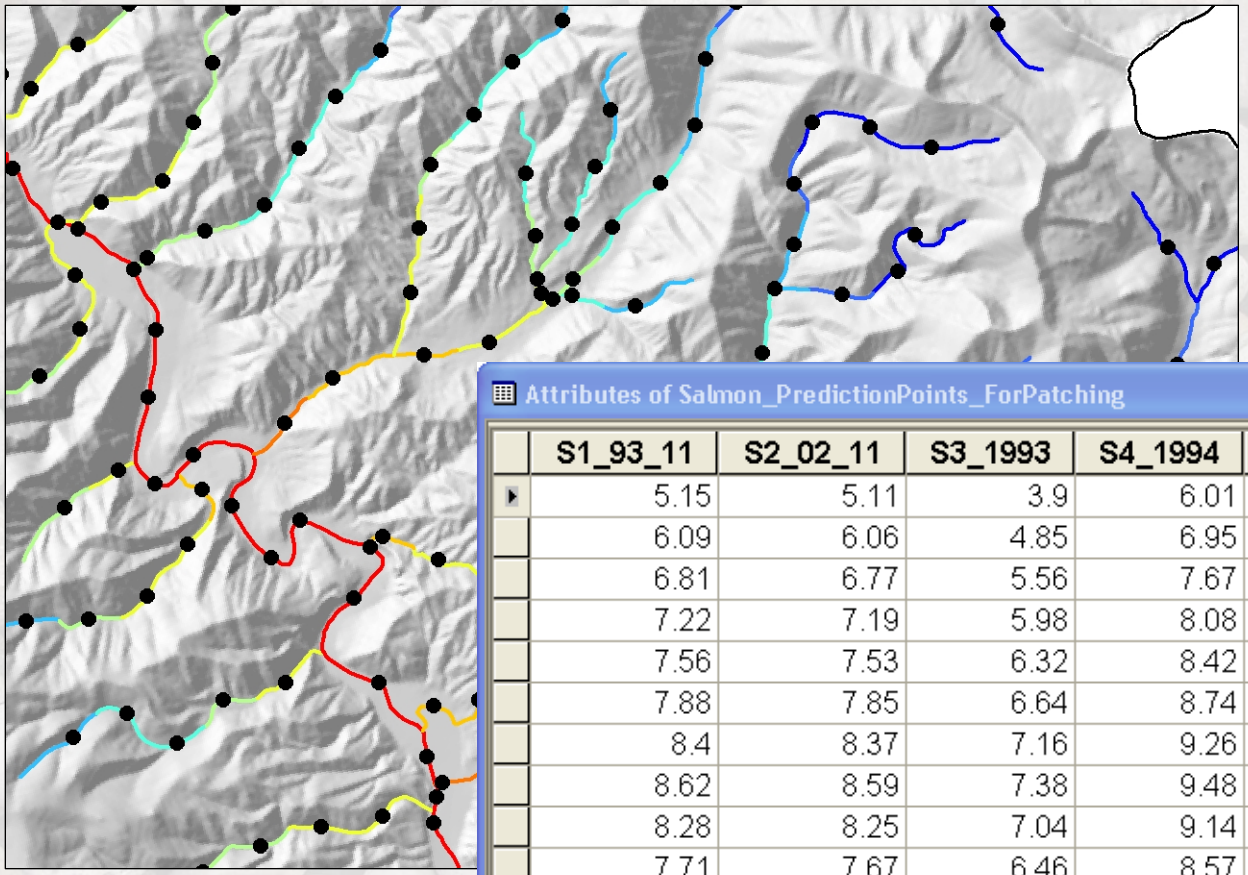


# Output Scenarios Attribute Table



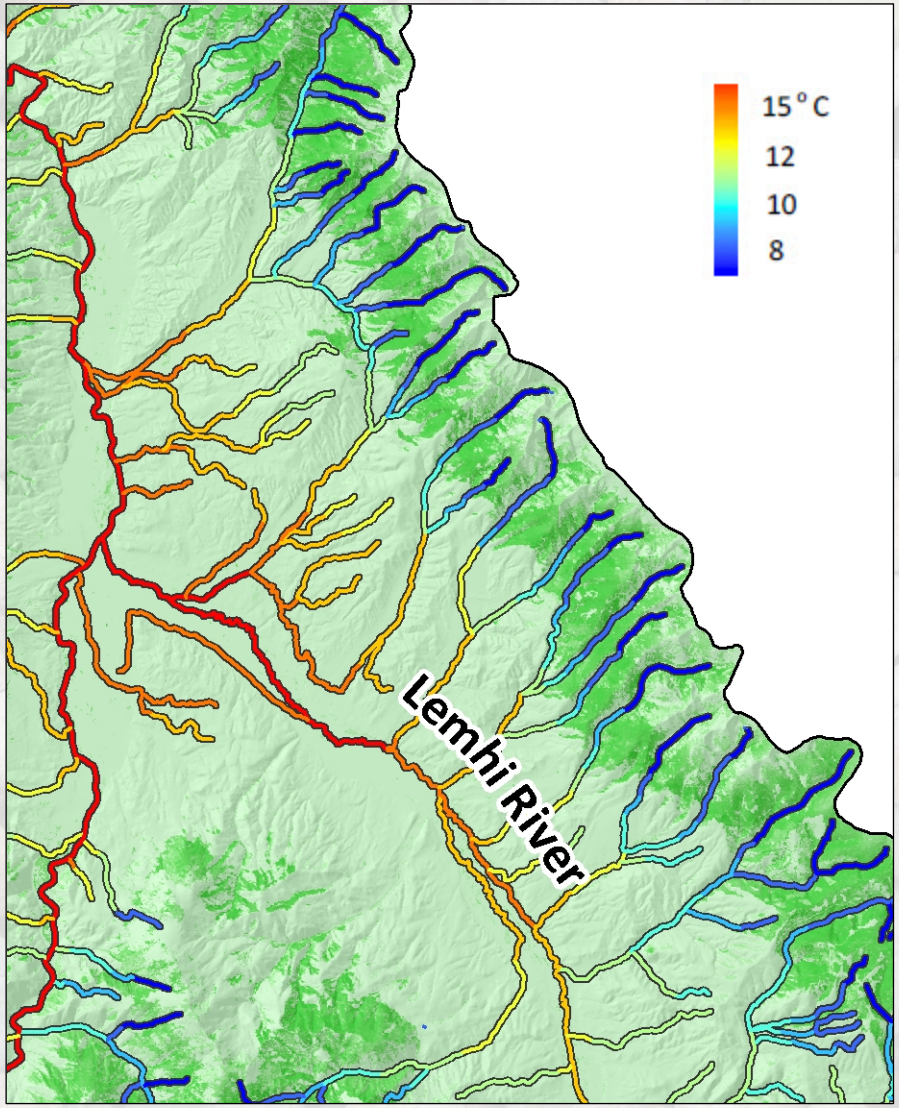
$^{0}$ C

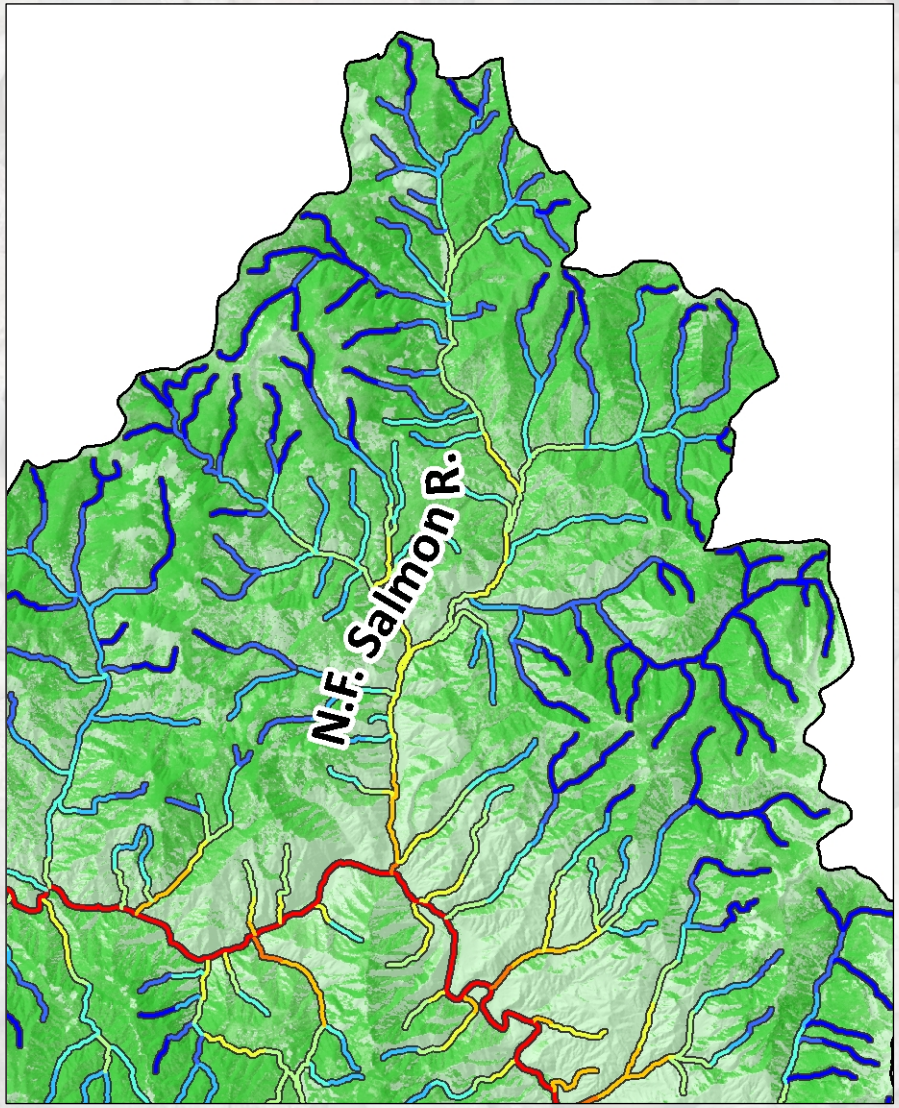
Attributes of Salmon_PredictionPoints_ForPatching

| S1_93_11 | S2_02_11 | S3_1993 | S4_1994 | S5_1995 | S6_1996 | S7_1997 |
|---|---|---|---|---|---|---|
| 5.15 | 5.11 | 3.9 | 6.01 | 4.56 | 5 | 4.73 |
| 6.09 | 6.06 | 4.85 | 6.95 | 5.5 | 5.95 | 5.68 |
| 6.81 | 6.77 | 5.56 | 7.67 | 6.22 | 6.66 | 6.39 |
| 7.22 | 7.19 | 5.98 | 8.08 | 6.63 | 7.08 | 6.81 |
| 7.56 | 7.53 | 6.32 | 8.42 | 6.97 | 7.42 | 7.15 |
| 7.88 | 7.85 | 6.64 | 8.74 | 7.29 | 7.73 | 7.46 |
| 8.4 | 8.37 | 7.16 | 9.26 | 7.81 | 8.25 | 7.98 |
| 8.62 | 8.59 | 7.38 | 9.48 | 8.03 | 8.48 | 8.21 |
| 8.28 | 8.25 | 7.04 | 9.14 | 7.69 | 8.14 | 7.87 |
| 7.71 | 7.67 | 6.46 | 8.57 | 7.12 | 7.56 | 7.29 |
| 7.34 | 7.31 | 6.1 | 8.21 | 6.75 | 7.2 | 6.93 |
| 5.95 | 5.91 | 4.7 | 6.81 | 5.35 | 5.8 | 5.53 |
| 6.1 | 6.06 | 4.85 | 6.96 | 5.51 | 5.95 | 5.68 |

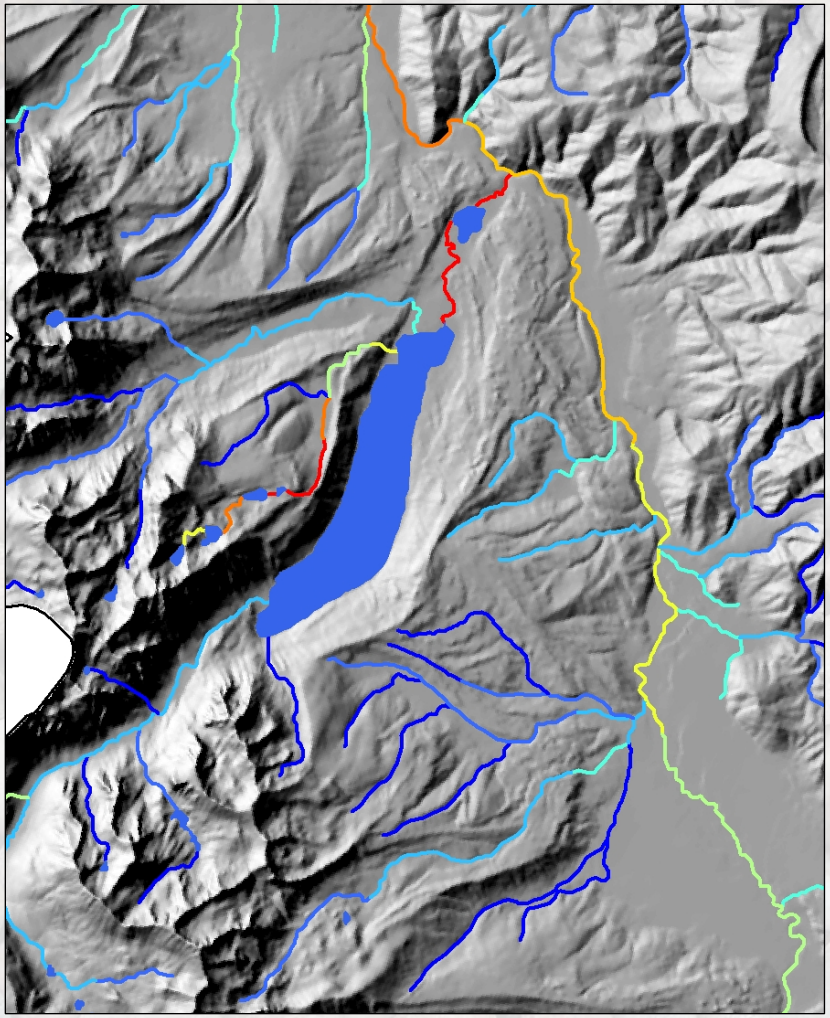
Record: 1 Show: All Selected Records (0 out of 21909 Selected) Options

# Example Results

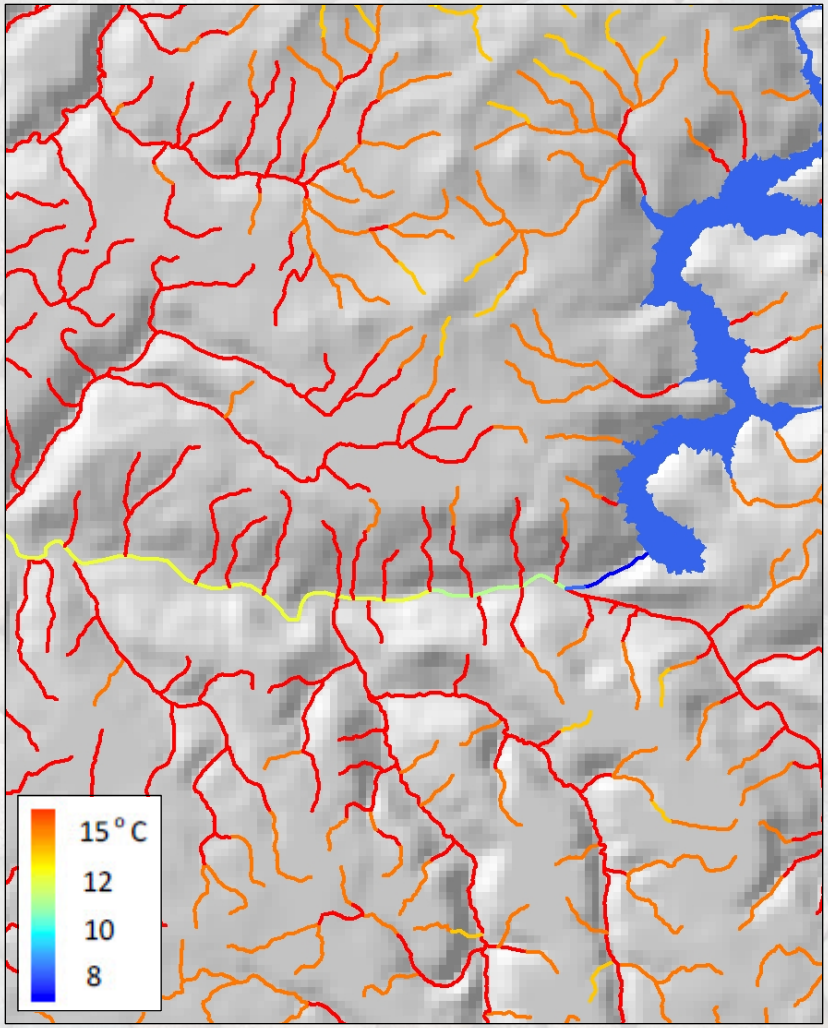


# Lake and Tailwater Examples



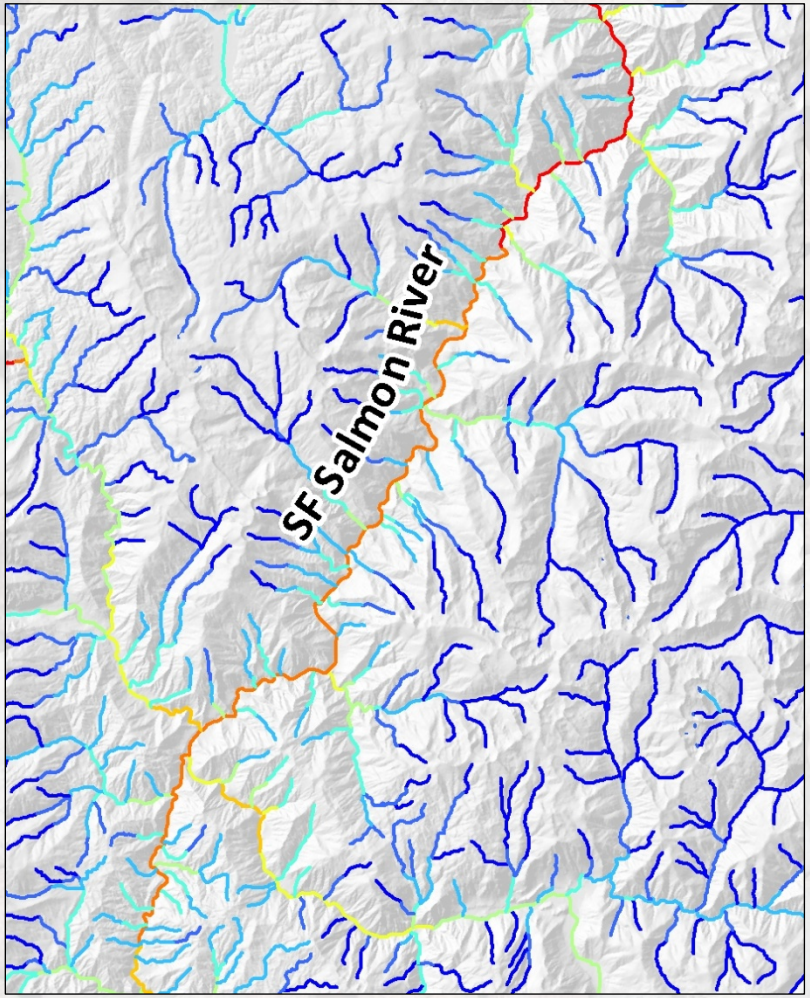
Redfish Lake




Dworshak Reservoir

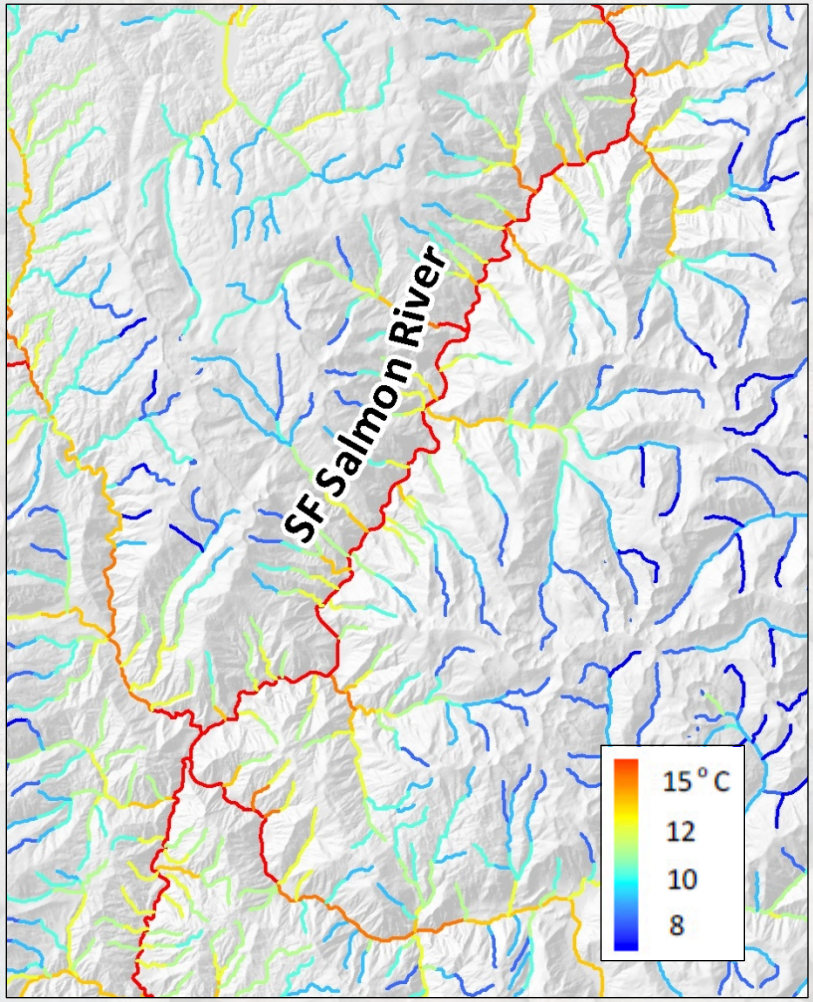
# Compare Years

## 1993




Air = 11.9 ºC  Flow = 50.1 cms

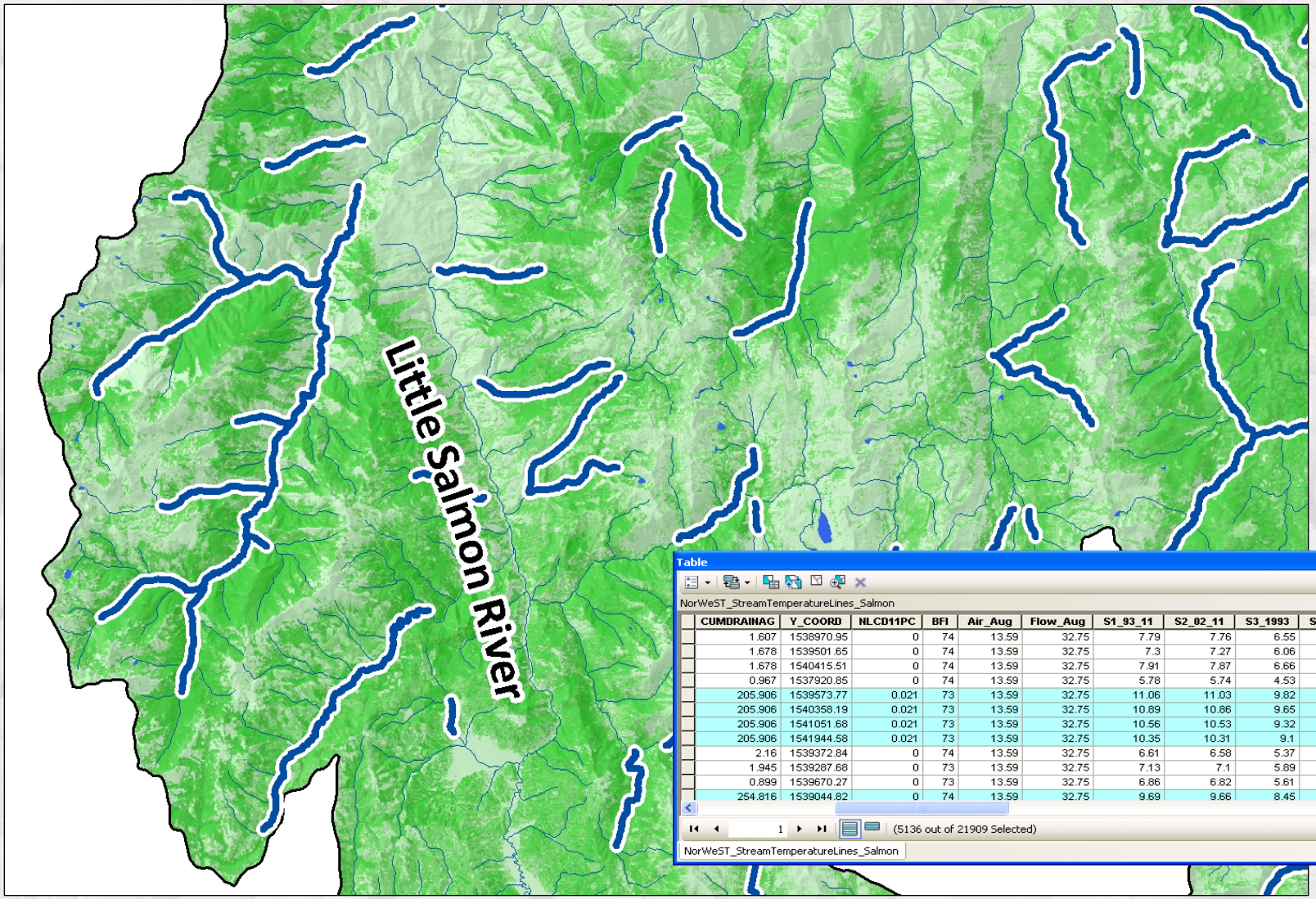
## 2003




Air = 15.8 ºC  Flow = 26.7 cms

# Queries

## Catchment > 10 km$^2$ and temperature < 12 º C




Table

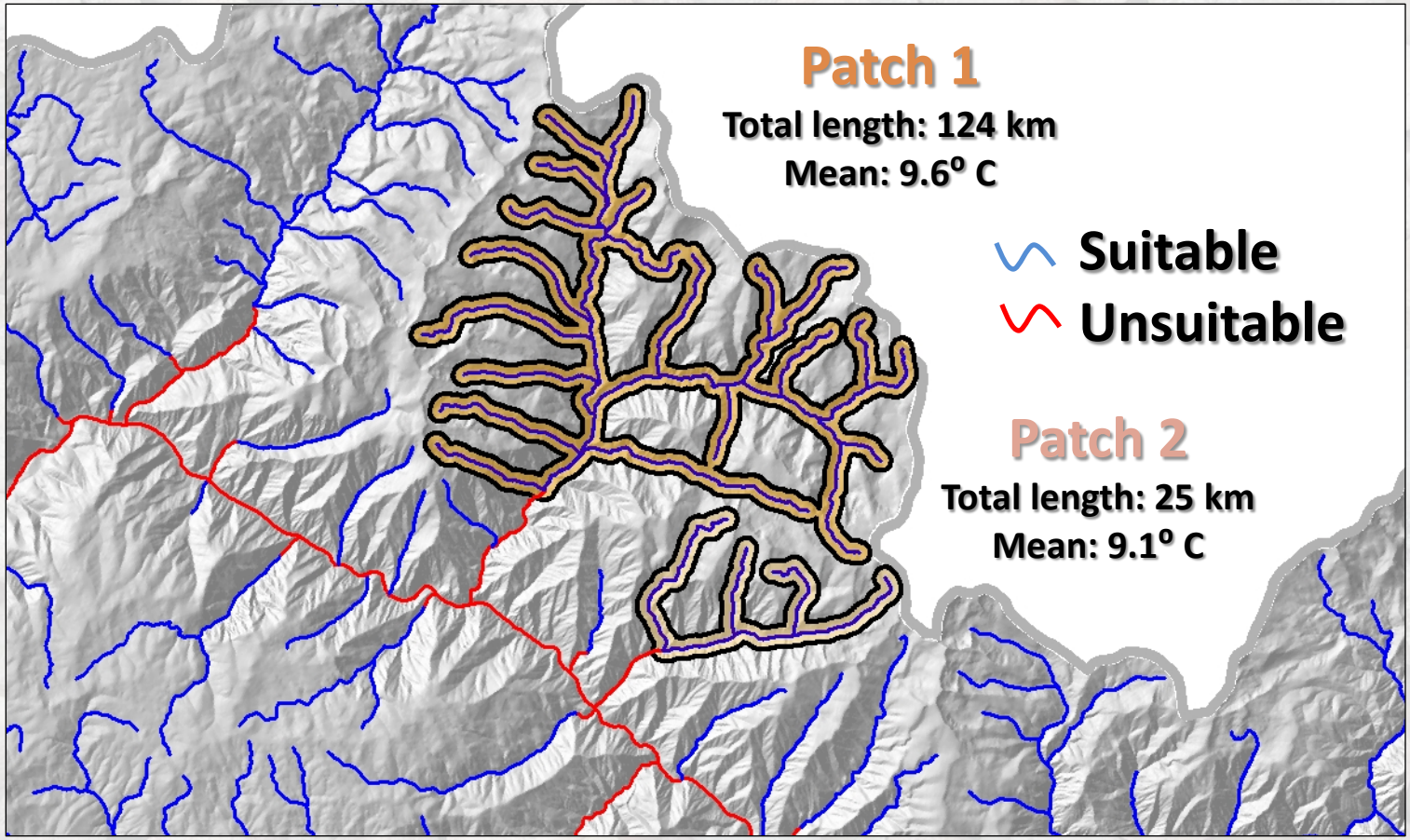
NorWeST_StreamTemperatureLines_Salmon

| CUMDRAINAG | Y_COORD | NLCD11PC | BFI | Air_Aug | Flow_Aug | S1_93_11 | S2_02_11 | S3_1993 | S4_1994 | S5_1995 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.607 | 1538970.95 | 0 | 74 | 13.59 | 32.75 | 7.79 | 7.76 | 6.55 | 8.65 | 7.2 |
| 1.678 | 1539501.65 | 0 | 74 | 13.59 | 32.75 | 7.3 | 7.27 | 6.06 | 8.16 | 6.71 |
| 1.678 | 1540415.51 | 0 | 74 | 13.59 | 32.75 | 7.91 | 7.87 | 6.66 | 8.77 | 7.32 |
| 0.967 | 1537920.85 | 0 | 74 | 13.59 | 32.75 | 5.78 | 5.74 | 4.53 | 6.64 | 5.18 |
| 205.906 | 1539573.77 | 0.021 | 73 | 13.59 | 32.75 | 11.06 | 11.03 | 9.82 | 11.92 | 10.47 |
| 205.906 | 1540358.19 | 0.021 | 73 | 13.59 | 32.75 | 10.89 | 10.86 | 9.65 | 11.75 | 10.3 |
| 205.906 | 1541051.68 | 0.021 | 73 | 13.59 | 32.75 | 10.56 | 10.53 | 9.32 | 11.42 | 9.97 |
| 205.906 | 1541944.58 | 0.021 | 73 | 13.59 | 32.75 | 10.35 | 10.31 | 9.1 | 11.21 | 9.76 |
| 2.16 | 1539372.84 | 0 | 74 | 13.59 | 32.75 | 6.61 | 6.58 | 5.37 | 7.47 | 6.02 |
| 1.945 | 1539287.68 | 0 | 73 | 13.59 | 32.75 | 7.13 | 7.1 | 5.89 | 7.99 | 6.54 |
| 0.899 | 1539670.27 | 0 | 73 | 13.59 | 32.75 | 6.86 | 6.82 | 5.61 | 7.72 | 6.27 |
| 254.816 | 1539044.82 | 0 | 74 | 13.59 | 32.75 | 9.69 | 9.66 | 8.45 | 10.55 | 9.1 |

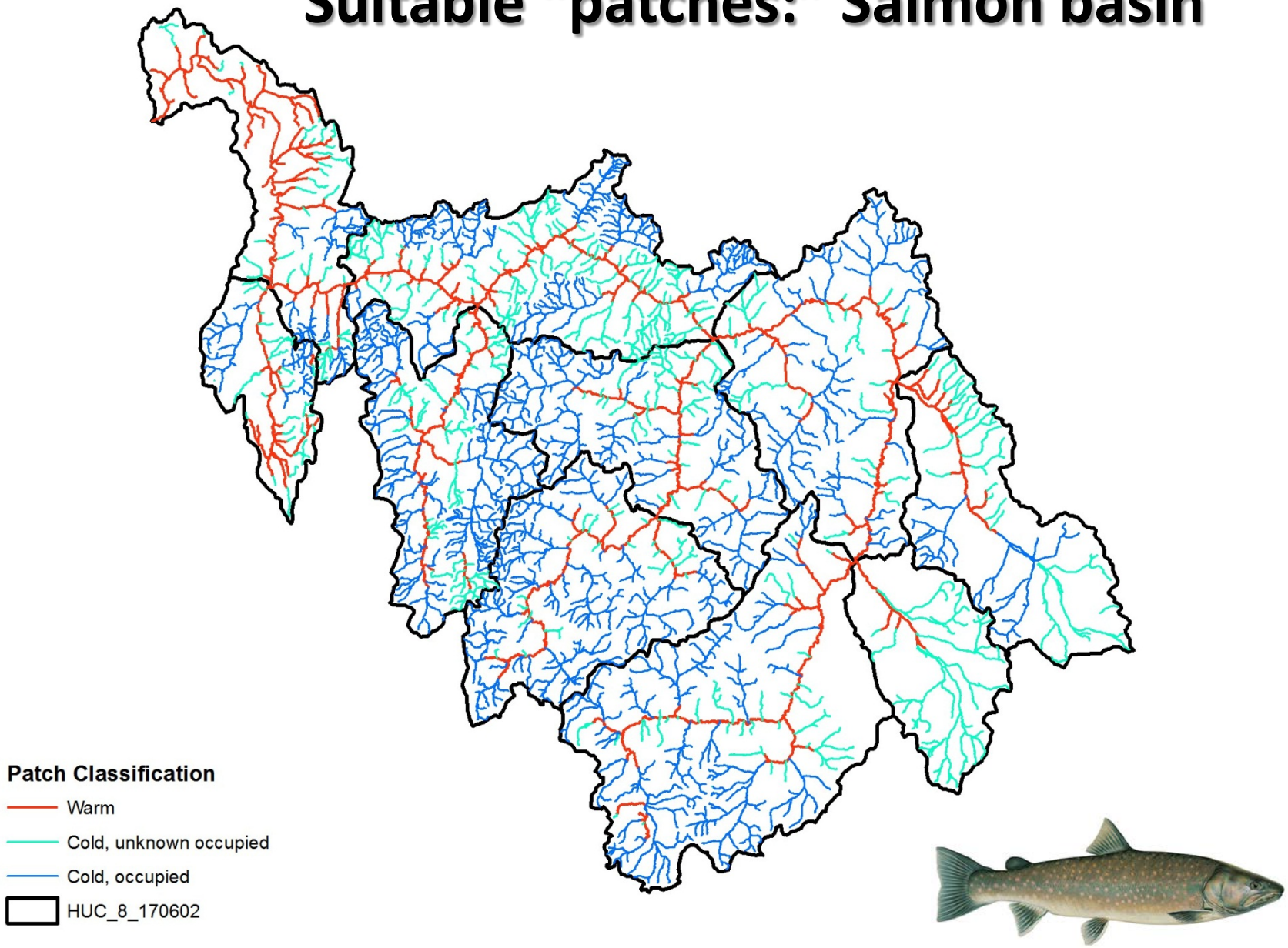
1 (5136 out of 21909 Selected)

NorWeST_StreamTemperatureLines_Salmon

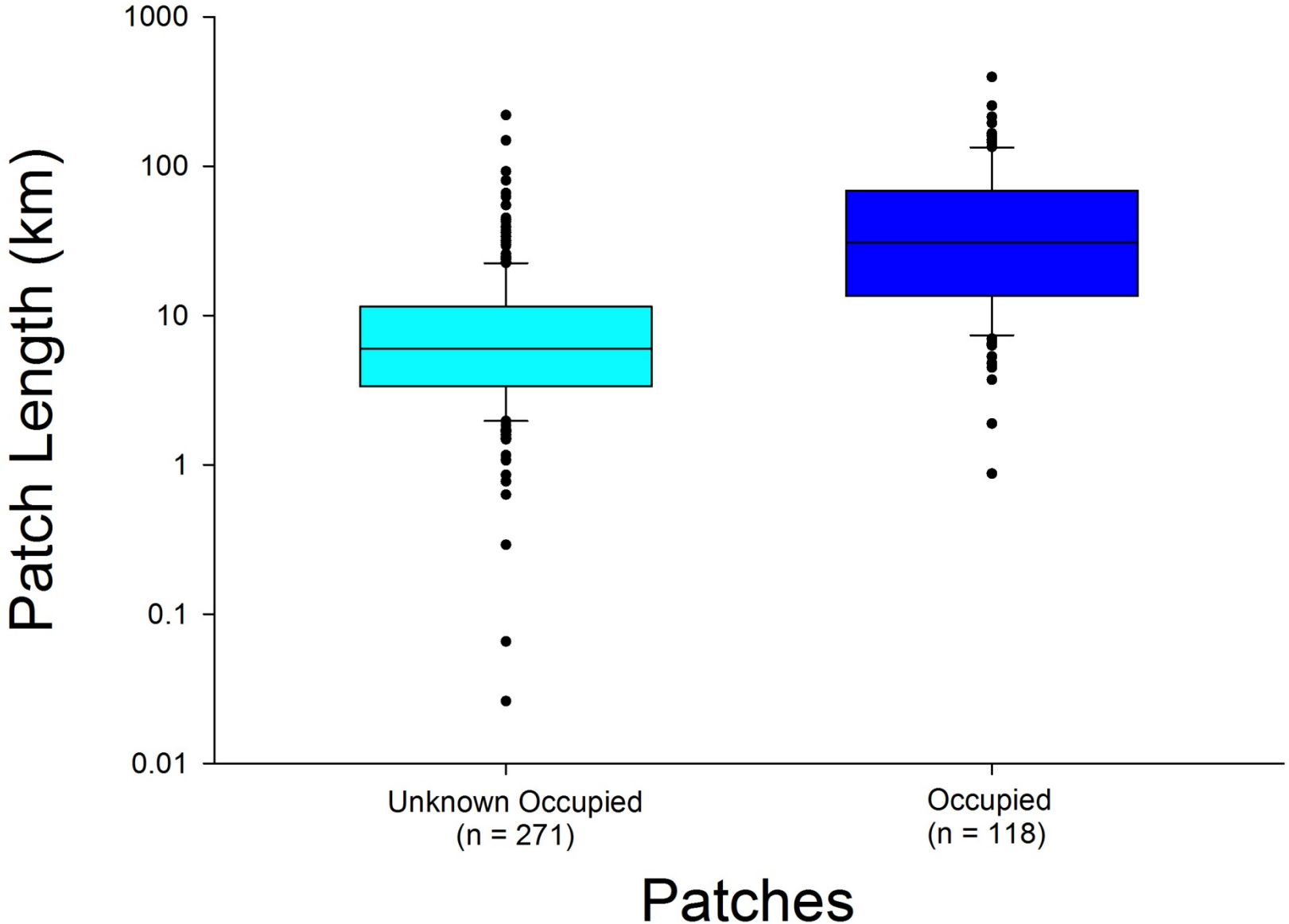
# Thermally Suitable Habitat Patches



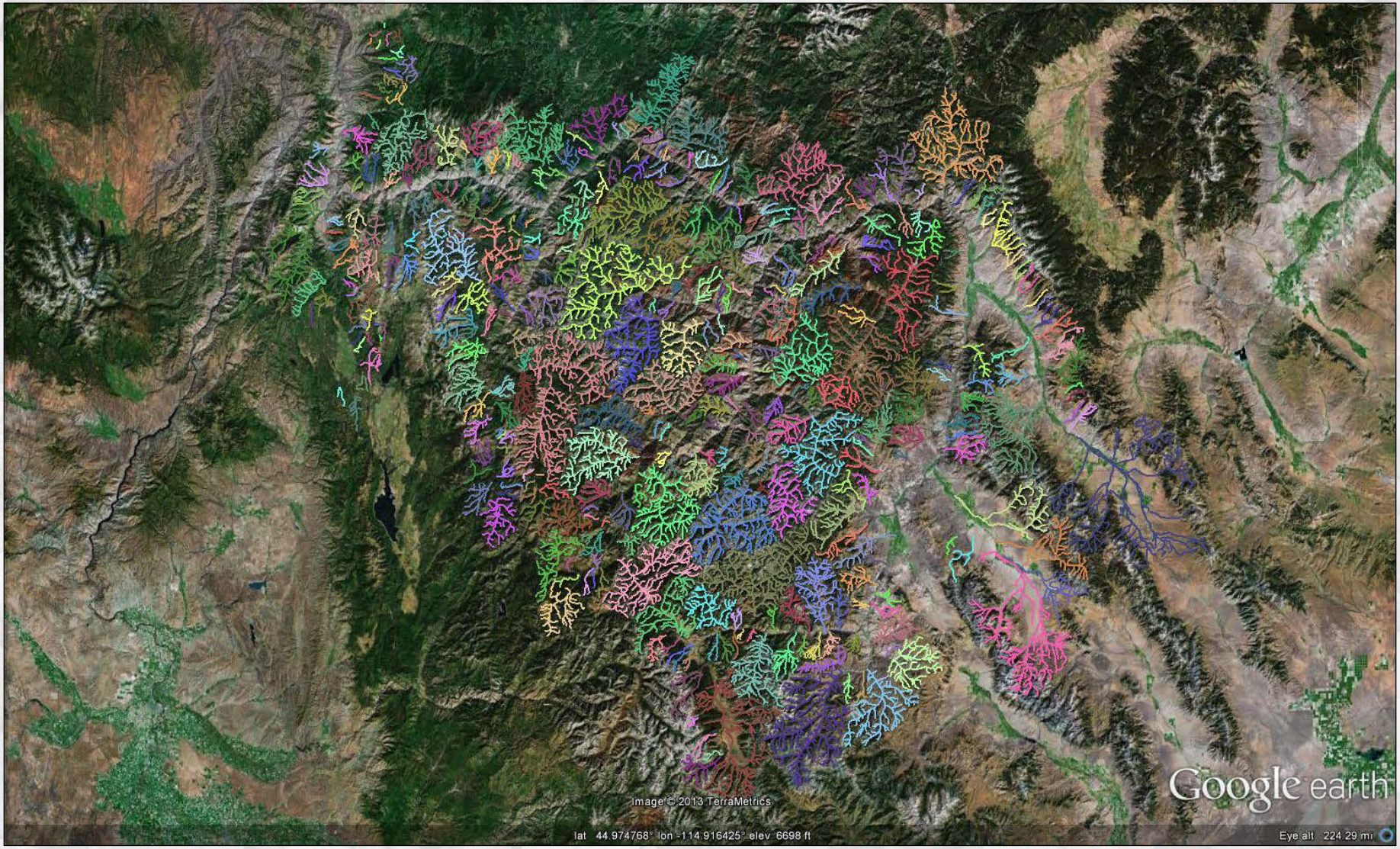
# Suitable "patches:" Salmon basin



# Patches and known presence



# Landscape Scale Patterns




From Dunham 2013

# DATA DISTRIBUTION

NorWest Stream Temperature - Regional Database and Model - Windows Internet Explorer provided by USDA Forest Service

http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

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# NorWeST Stream Temp Regional Database & Model

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NorWeST Stream Temp

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## Regional Database and Modeled Stream Temperatures

### NorWeST

The NorWeST webpage hosts stream temperature data and geospatial map outputs from a regional temperature model for the Northwest U.S. The temperature database was compiled from hundreds of biologists and hydrologists working for dozens of resource agencies and contains more than 45,000,000 hourly temperature recordings at more than 15,000 unique stream sites. These temperature data are being used with spatial statistical stream network models to develop an accurate and consistent set of climate scenarios for all streams.

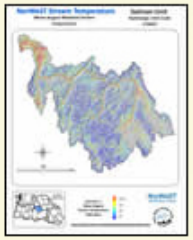
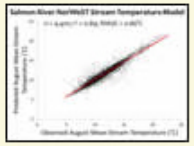
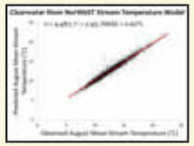
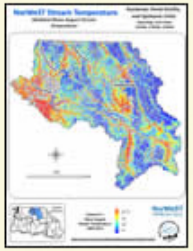
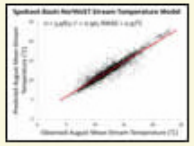
Temperature data and model outputs are posted to the website after QA/QC procedures and development of the final temperature model within a river basin. It is hoped that open access to the data and the availability of accurate stream temperature scenarios will foster new research and collaborative relationships that enhance management and conservation of aquatic resources.

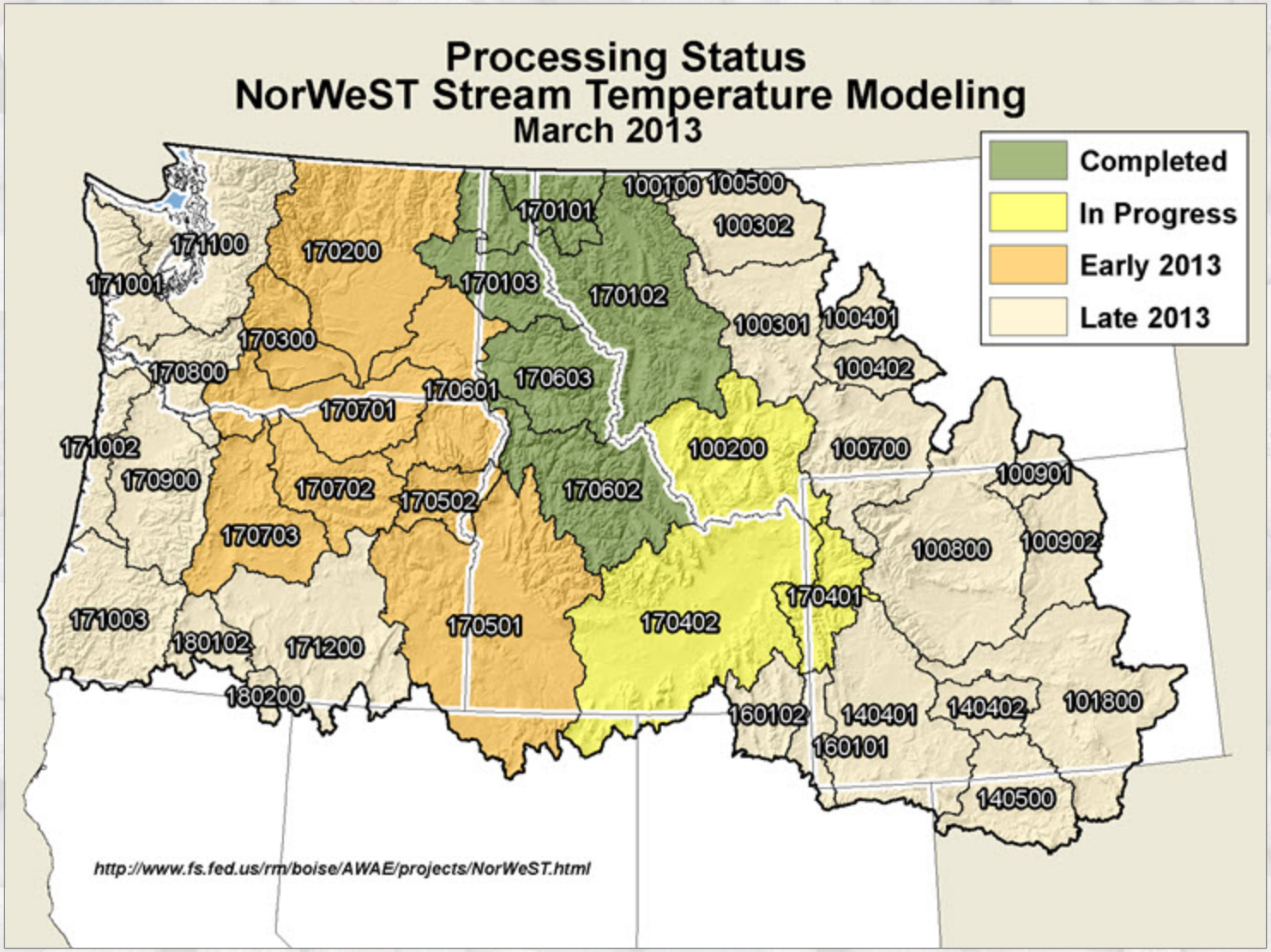
Funding for the project was provided by the GNLCC with additional funds and in-kind support from the USFS, USGS, and USFWS. Original grant proposal

Local intranet 100%

**Google search: norwest stream temperature**

# Maps and Data Downloads

| HUC 3s within Processing Units | Model Results | | GIS Downloads with Metadata |
|---|---|---|---|
| **Salmon River Basin - 170602** |  Stream Temperature Scenario Map |  Model Prediction Accuracy | 1-km Stream Segment Shapefile<br>1-km Stream Point Shapefile |
| **Clearwater River Basin - 170603** | Stream Temperature Scenario Map |  Model Prediction Accuracy | 1-km Stream Segment Shapefile<br>1-km Stream Point Shapefile |
| **"SpoKoot" Processing Unit**<br>**Kootenai - 170101**<br>**Pend Oreille - 170102**<br>**Spokane - 170103** |  Stream Temperature Scenario Map |  Model Prediction Accuracy | 1-km Stream Segment Shapefile<br>1-km Stream Point Shapefile |


Processing Status
NorWeST Stream Temperature Modeling
March 2013
Completed
In Progress
Early 2013
Late 2013
100100
100500
170101
100302
171100
170200
171001
170103
170102
100301
100401
170300
100402
170800
170601
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100700
170900
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170502
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100902
170401
171003
170501
170402
180102
171200
180200
160102
140401
140402
101800
160101
140500
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html

# Contributors

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The Nature Conservancy

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