Development & Application of NorWeST Stream Temperature Scenarios for PNW Streams

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U.S. Forest Service
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⁴USGS
General outline:
1) Background & stream temperature trends
2) NorWeST model & scenarios
3) Uses of NorWeST scenarios
4) Future expansion of NorWeST
Stream Temperature is “Climate” in Streams

Master variable for ectotherms

Stream Temperature (°C)

TMDL limit

Too Hot!

Time

Growth

Temperature
Temperature Trends In Northwest Rivers

Fraser River - Annual
\[ \Delta = 0.18^\circ \text{C/decade} \]

Snake River, ID - Summer
\[ \Delta = 0.27^\circ \text{C/decade} \]

Columbia River - Summer
\[ \Delta = 0.40^\circ \text{C/decade} \]

Missouri River, MT - Summer
\[ \Delta = 0.33^\circ \text{C/decade} \]
Stream Temperature Trends Track Air Trends at Local Weather Stations 1980-2009

Streams change at ~60% air warming rate

Stream Temperature Trends Track
Air Trends at Local Weather Stations

Seasonal Climate Variability and Change in the Pacific Northwest of the United States

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Department of Geography, University of Idaho, Moscow, Idaho

DAVID E. RUPP AND PHILIP W. MOTE

Weather Station Data

PDO Is Buying us Time...

“but I’ll be Back...”
PDO Is Buying us Time...

2014 Set a New Global Record

“but I’ll be Back...”
There’s A Lot on the Line...

Climate Boogeyman

Tribal & Recreational Fisheries

Land Use & Water Development

ESA Listed Species
Good News! Lots of Things we Can do to Improve Stream Habitat Resilience

- Maintaining/restoring flow...
- Maintaining/restoring riparian...
- Restoring channel form/function...
- Prescribed burns limit wildfire risks...
- Non-native species control...
- Improve/impede fish passage...

Where to do them?
Is there a grand strategy?
Many Climate Models & Scenarios for Air Temperature & Precipitation Exist...
... but None for Stream Temperature

**Air Temp ≠ Stream Temp**

$r^2 = 0.26$
A Need for Regional Stream Scenarios

Taking Climate into the Water Where Fish Live...
A Need for Regional Stream Scenarios

Climate model (air temp & precip) → Regional patterns

Stream temperature & flow

Stream reach
Lots of Data Exist...

>50,000,000 hourly records
>15,000 unique stream sites
>80 resource agencies

$10,000,000
BIG DATA are often Autocorrelated
Spatial Statistical Network Models

Advantages:
- flexible & valid autocovariance structures that accommodate network topology & non-independence among observations
- improved predictive ability & parameter estimates relative to non-spatial models

Ver Hoef et al. 2006; Ver Hoef & Peterson 2010; Peterson & Ver Hoef 2013

Valid interpolation on networks

Let’s us connect the dots…

... & aggregate databases
NorWeST Temperature Model for the Mid-Columbia
NorWeST Temperature Model for the Mid-Columbia

9,521 August means
2,760 stream sites
19 summers (1993-2011)

60,099 stream kilometers

• Temperature site
Climatic Variability in Historical Record

Extreme years encompass mid-Century averages

Air Temperature (°C)

Discharge (m³/s)

Δ = 4°C

3x change
Mid-Columbia Temperature Model

\( n = 9,521 \)

**Covariate Predictors**

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)
9. Glacier (%)

10. Discharge (m³/s)  
**USGS gage data**
11. Air Temperature (°C)  
**RegCM3 NCEP reanalysis**  
Hostetler et al. 2011

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**Mean August Temperature**

- **Spatial Model**
  \( r^2 = 0.94; \) RMSE = 0.91°C

- **Non-spatial Model**
  \( r^2 = 0.60; \) RMSE = 2.26°C

More details: [NorWeST website](#)  
“Means” vs Short-Term Maxima...

- Short-term metrics are difficult to model
  - More variable/less stable than means
  - Occur at different times each year (GCM linkage)

- Summer metrics are strongly correlated

<table>
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<tr>
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<th>Summer mn</th>
<th>Mwmt</th>
<th>Mwat</th>
<th>awat mn</th>
<th>awmt mn</th>
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<td>August Mean</td>
<td><strong>0.99</strong></td>
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<td><strong>0.95</strong></td>
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<tr>
<td>August MWMT</td>
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<td>0.92</td>
<td>0.92</td>
<td>0.98</td>
<td><strong>0.92</strong></td>
</tr>
</tbody>
</table>
It’s the Same “Information”  
So Metric Conversions are Easy...

\[ y = 1.39x + 0.095 \]
\[ R^2 = 0.87 \]
Relative Effects of Predictors

Mid-Columbia River Basin Model

**Spatial covariates**

- Elevation
- Stream slope
- Lake
- Annual precip
- Latitude
- Baseflow index
- Drainage area
- Riparian canopy
- Air temperature
- Discharge

**Temporal covariates**

- Cooling
- Warming

* = statistically significant at p < 0.01

Standardized parameters vary across predictors, with some showing significant effects (indicated by asterisks) at p < 0.01.
Relative Effects of Predictors
Northwest Montana Model

- **Spatial covariates**
  - Elevation
  - Annual precip
  - Latitude

- **Temporal covariates**
  - Stream slope
  - Lake
  - Baseflow index
  - Drainage area
  - Riparian canopy
  - Air temperature
  - Discharge

- **Standardized parameter**

- **Manage?**
  - * = statistically significant at p < 0.01
Riparian Canopy Predictor

%Canopy variable from 2001 NLCD

%Canopy adjusted by MTBS through 2008

Ways of teasing out 'management effects''black box'' of autocovariance

New covariates & refit model

Geostats block-kriging for treatment/ref conditions

Talk about at EPA webinar in few weeks
Models Enable Climate Scenario Maps

Many possibilities exist...

Adjust...
- Air
- Discharge
- %Canopy

...values to create scenarios
## NorWeST Historical Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
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<tbody>
<tr>
<td>S1_93_11</td>
<td>Historical scenario representing 19 year average August mean stream temperatures for 1993-2011</td>
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<tr>
<td>S2_02_11</td>
<td>Historical scenario representing 10 year average August mean stream temperatures for 2002-2011</td>
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<td>S3_1993</td>
<td>Historical scenario representing August mean stream temperatures for 1993</td>
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<tr>
<td>S4_1994</td>
<td>Historical scenario representing August mean stream temperatures for 1994</td>
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<tr>
<td>Etc…</td>
<td><em>2012 &amp; 2013 starting with Washington</em></td>
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<tr>
<td>S21_2011</td>
<td>Historical scenario representing August mean stream temperatures for 2011</td>
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</table>

*Extensive metadata on website*
Historical Year Sequence (1993-2011)

<table>
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<th>Year</th>
<th>$r^2$</th>
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<td>1998</td>
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<td>2001</td>
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<td>2002</td>
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<td>2003</td>
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<td>2004</td>
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<td>2005</td>
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<td>2006</td>
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<td>2007</td>
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<td>2008</td>
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<td>2009</td>
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<td>2010</td>
<td>0.93</td>
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<tr>
<td>2011</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Historical Year Sequence (1993-2011)
Mean August Temperature - Clearwater Basin

2011

Observed
Predicted

2011
$\text{r}^2 = 0.95$

Temperature ($^\circ\text{C}$)
- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0

Air Temp (C) Discharge (m3/s)

Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

August Discharge ($m^3/s$) vs. August Air Temperature ($ºC$)

$S1 =$ baseline

$R^2 = 0.9587$

2001
Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

August Discharge ($m^3/s$) vs. August Air Temperature ($ºC$)

$S_1 =$ baseline

$R^2 = 0.9514$

2006
Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

August Discharge (m$^3$/s) vs. August Air Temperature ($^\circ$C)

$S_1 = $ baseline

$R^2 = 0.9487$

2011
Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

- August Discharge ($m^3/s$)
- August Air Temperature ($^\circ C$)

$S_1 =$ baseline

- 2040
- 2080
High-Resolution Stream Temp Scenarios

R² = 0.91; RMSE = 1.0°C; 1-km resolution

The BLOB... it just keeps growing...

- 46,674 summers of data swallowed
- 467,000 stream kilometers of thermal ooze
State Stream Temperature Maps...

A Thermal Map for all Idaho Streams
Future Scenarios – Which to Choose?

The Specifics are an “Unknowable Unknown”

Just plan on it gradually getting warmer...
# 10 NorWeST Future Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
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<tbody>
<tr>
<td>S23_1C</td>
<td>Future scenario adds 1°C to S1_93-11</td>
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<tr>
<td>S24_1C_D</td>
<td>Future scenario adds 1°C to S1_93-11 &amp; incorporates differential stream sensitivity</td>
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<tr>
<td>Etc…</td>
<td>For +2°C &amp; +3°C</td>
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<tr>
<td>S29_2040</td>
<td>Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble.</td>
</tr>
<tr>
<td>S30_2040_D</td>
<td>Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble. Adjustment applied for differential sensitivity.</td>
</tr>
<tr>
<td>S31_2080</td>
<td>Etc…</td>
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</tbody>
</table>

*Extensive metadata on website*
Cold Streams Less Sensitive to Climate Forcing

MaxWAT = $b_1(\text{air}) + b_2(\text{discharge})$


*Variation within basins +/-50% from sensitivity adjustment*
Reality Check: Past August Warming Rates
Reconstructions for 44 Year Period (1968 – 2011)

Streams ~0.1°C / decade

Warming rate (°C / decade)

Salmon, Clearwater, Spokoot, Missouri, SnakeBear, MidSnake, MidColumbia, OR Coast, South OR, Lahontan, East WA, West WA
Website Distributes BLOB Scenarios & Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios

2) GIS shapefiles of stream temperature model prediction precision

3) Temperature data summaries

Google “NorWeST” or go here...

http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml
Web-Surf the Blob from Your Desktop!

Interactive Online Mapping Tool

Click on any stream location to query the database...
Data feeds All Models...

Mechanistic & Statistical

Examples...
• QUAL2Kw
• SSTEMP/SNTEMP
• BasinTemp
• Heat Source
• WET-Temp

\[ Y = b_0 + b_1 x \]
Lots of Annual Data Coming…

>3,000 sites in Pacific Northwest

>200 new sites last year
Correlations Among Monthly Means

**Strong Correlations Except for Winter**

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<tr>
<th></th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>March</th>
<th>April</th>
<th>May</th>
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<td>Nov</td>
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<td>Dec</td>
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<td>Feb</td>
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<td>March</td>
<td>0.89</td>
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<td>May</td>
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<td>0.87</td>
<td>0.88</td>
<td>0.84</td>
<td>0.93</td>
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</table>

- **Non-winter months** \( r = 0.87 \)
- **Winter months (DJF)** \( r = 0.47 \)
The Reasons Temperature Matters...
How NorWeST data are Being Used…

**Monitoring & Temperature Standards**
- Interagency coordination & less redundancy
- Annual, long-term data instead of summer, short-term
- Oregon DEQ macroinvertebrate habitat indices & riparian conditions
- Total Maximum Daily Loads & site potential

**Salmon & Resident Fish Research**
- Hatchery stray rates (Westerley & Dittman, U Washington)
- Pre-spawn mortality rates in Chinook salmon (Bowerman, Keefer, & Caudill, U Idaho)
- Descriptions of historical species distribution shifts (Lemoine Ph.D., U Montana)

**Climate Vulnerability Assessments & Land Management Planning**
- Blue Mountains Adaptation Partnership, Northern Rockies Adaptation Partnership, Clearwater – EcoAdapt, etc.
- Forest Plan revisions (30 - 50 national forests) in Regions 1, 2, 4, & 6
- Southwest Crown of the Continent initiative
- Regional bull trout & cutthroat trout vulnerability assessments
NorWeST Temperature & Prespawn Mortality in Salmon

Bowerman, Keefer, & Caudill (U. Idaho)
NorWeST Temperature & Prespawn Mortality in Salmon

Bowerman, Keefer, & Caudill (U. Idaho)
Field-Based Temperature Standards using BIG FISH Databases

Stream temperature maps

Regional fish survey databases (n ~ 13,000)

Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*
A Generalizable Approach...

Just need georeferenced biological survey data

Too warm... Too cold... Just right
Thermal Niches in Batch Mode...

NorWeST Stream Temperature ($S_1$)

Frequency of Occurrence

~20,000 fish surveys

Wenger et al., In Preparation
Climate Effects on Rainbow Thermal Habitat

Historic (1993-2011 Average August)
Climate Effects on Rainbow Thermal Habitat

+1.56°C Stream Temp (~2040s)

Too Hot

Suitable

Too Cold

<17.0°C & >11.0°C
Climate Effects on Rainbow Thermal Habitat
+2.83°C Stream Temp (~2080s)

- Too Hot
- suitable
- Too Cold

<17.0°C & >11.0°C
Climate Effects on Bull Trout Thermal Habitat

Historic (1993-2011 Average August)

< 11.0°C
Climate Effects on Bull Trout Thermal Habitat

+1.56°C Stream Temp (A1B, 2040s)

Clearwater R., Lochsa R., Selway R., Salmon R.

< 11.0°C

Suitable

Unsuitable
Climate Effects on Bull Trout Thermal Habitat

+2.83°C Stream Temp (A1B, 2080s)

< 11.0°C

Suitable
Unsuitable
Precise & Accurate Models
Empower Local Decision Makers

High-resolution landscape models

Coarse model

I’m going to invest here...

... instead of here

Debris flow susceptible channel
Thermally suitable - occupied
Thermally suitable - unoccupied
Projected habitat loss
Road culvert fish barrier
NorWeST User Community...

Website launched 2.5 Years Ago
• 18,046 visits
• 1,146 downloads last 6 months

Last week – site visits
NorWeST User Community...

Website launched 2.5 Years Ago
• 18,046 visits
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NorWeST Status & Future Prospects
NorWeST Status & Future Prospects
Nationally consistent geospatial stream database

NHDPlus Streams

Reach
Descriptors:
• Elevation
• Slope
• %Landuse
• Precipitation

100’s more...


Nationally consistent geospatial stream database

**NHDPlus Streams**


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Needed, but not currently available

NorWeST Stream Temp
Thank You!

80+ agencies & counting...

- State
- Federal
- Tribal
- Private
- Municipal
- County
Inspiring the Next Generation of Stream Climatologists...

Some school kids in 4,500 classrooms may be monitoring stream temperatures soon...