Factors And Processes Determining Water Temperature in the Willamette River, Oregon

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U.S. Department of the Interior
U.S. Geological Survey

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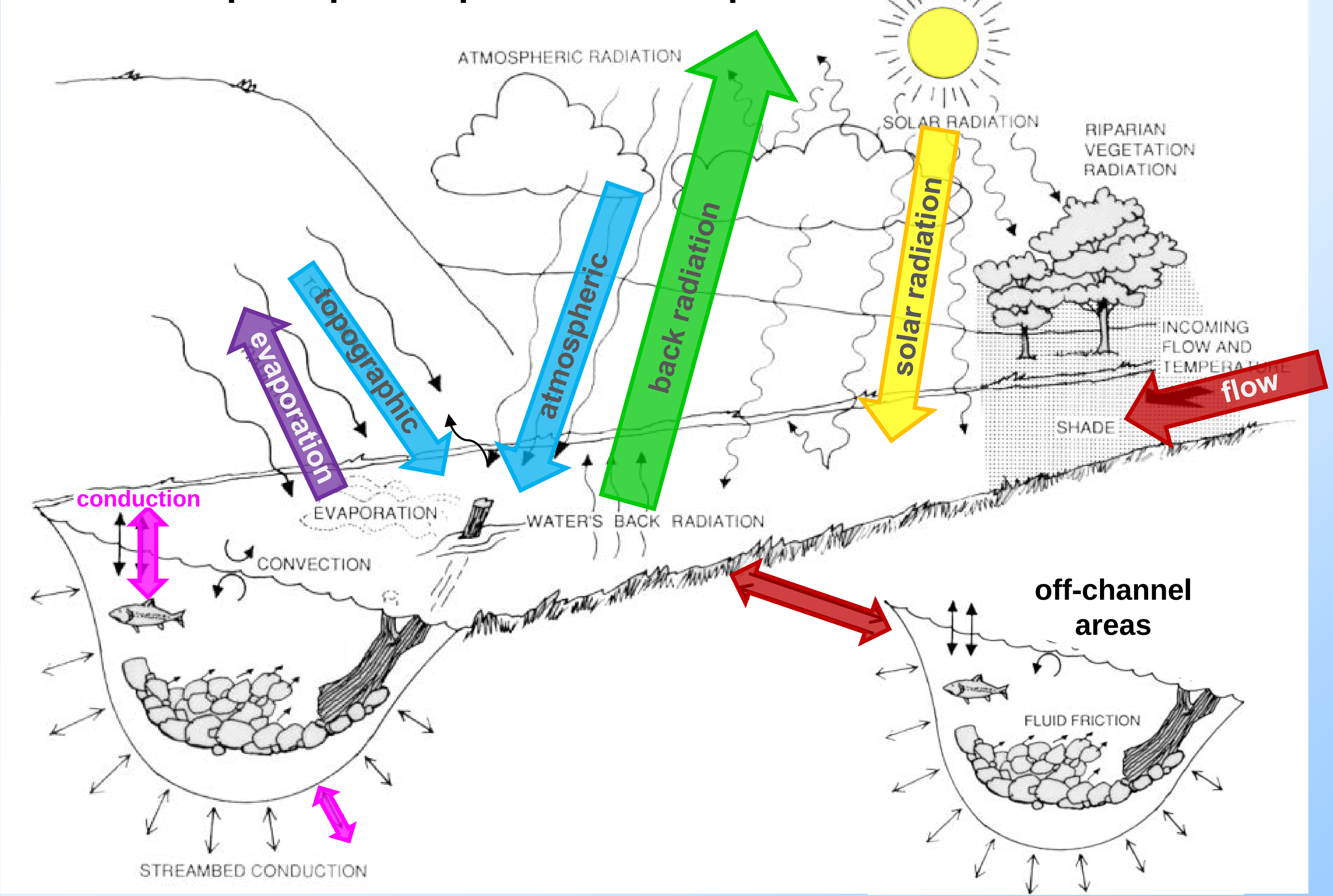
A Riverine Heat Budget

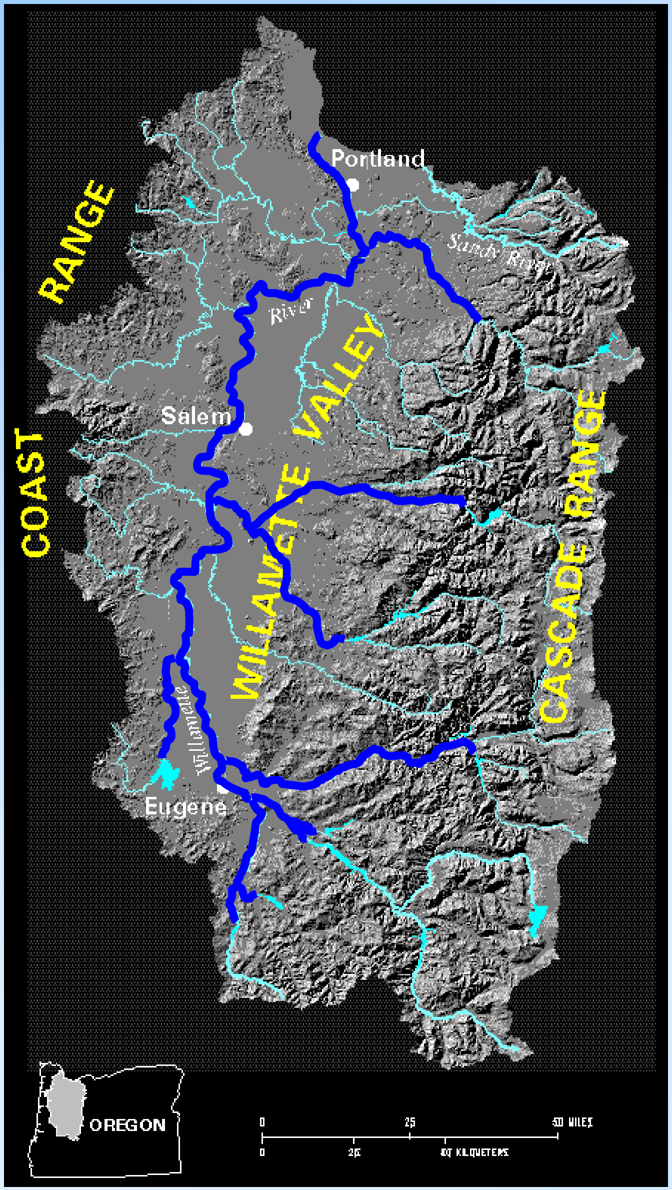
Net heat input equals inputs minus outputs.



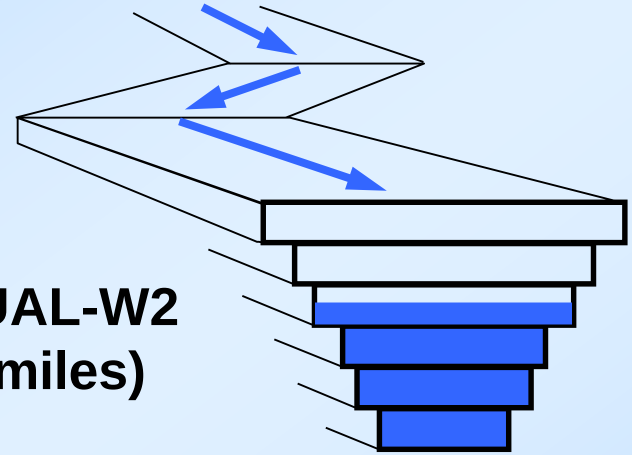
schematic from Bartholow (2000), USGS Open-File Report 99-112

USGS

Willamette River Models



map from USGS



CE-QUAL-W2 (444 miles)

- **Full heat budget**
- **Willamette River and tributary models constructed and calibrated for temperature TMDL (2001, 2002) (PSU, USGS, ODEQ efforts)**
- **Extended to simulate 2011 (cool/wet) and 2015 (hot/dry), 2016**
- **Evaluate effects of upstream dams and flow management, and provide context for off-channel conditions**

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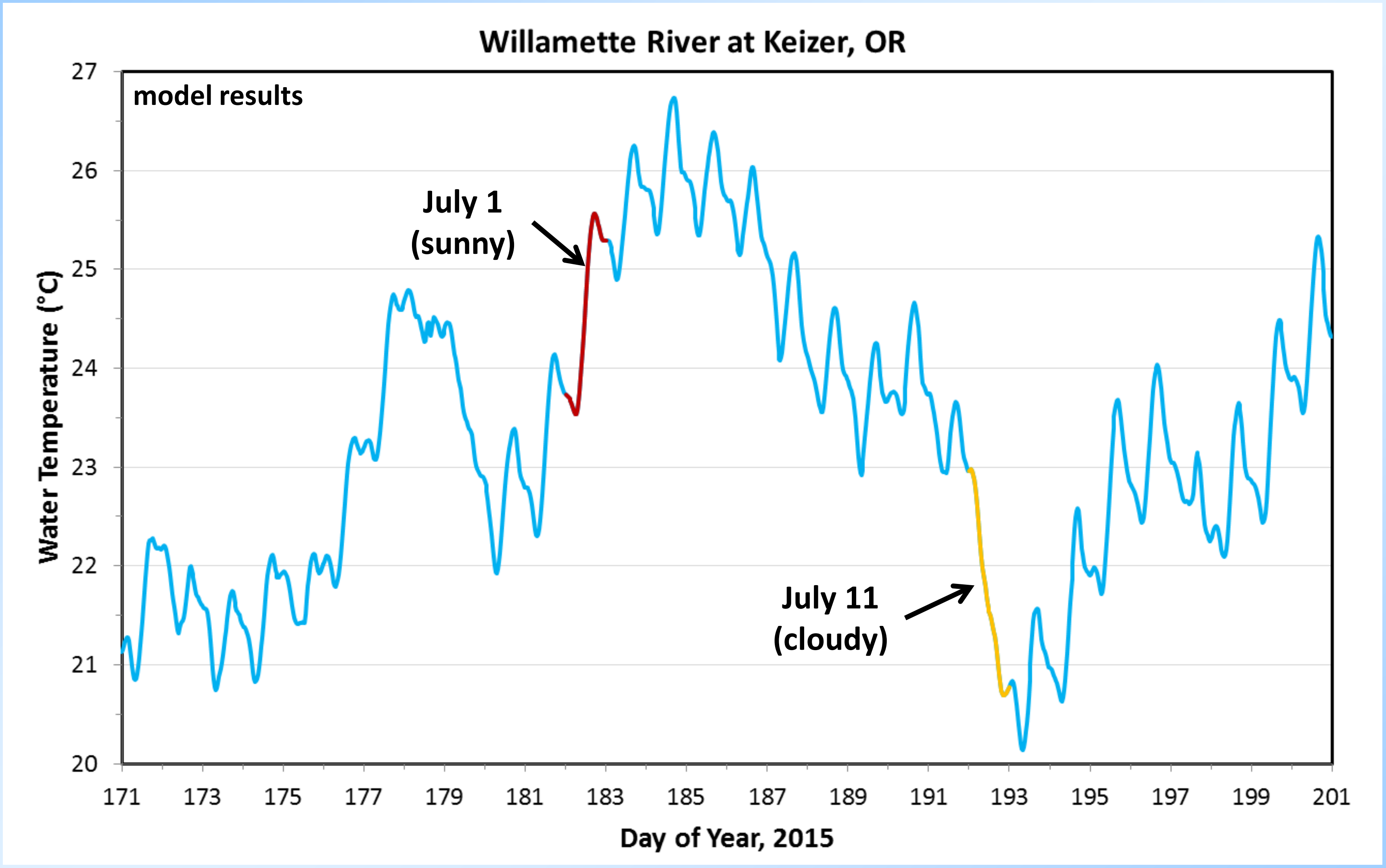
Willamette River Water Temperature



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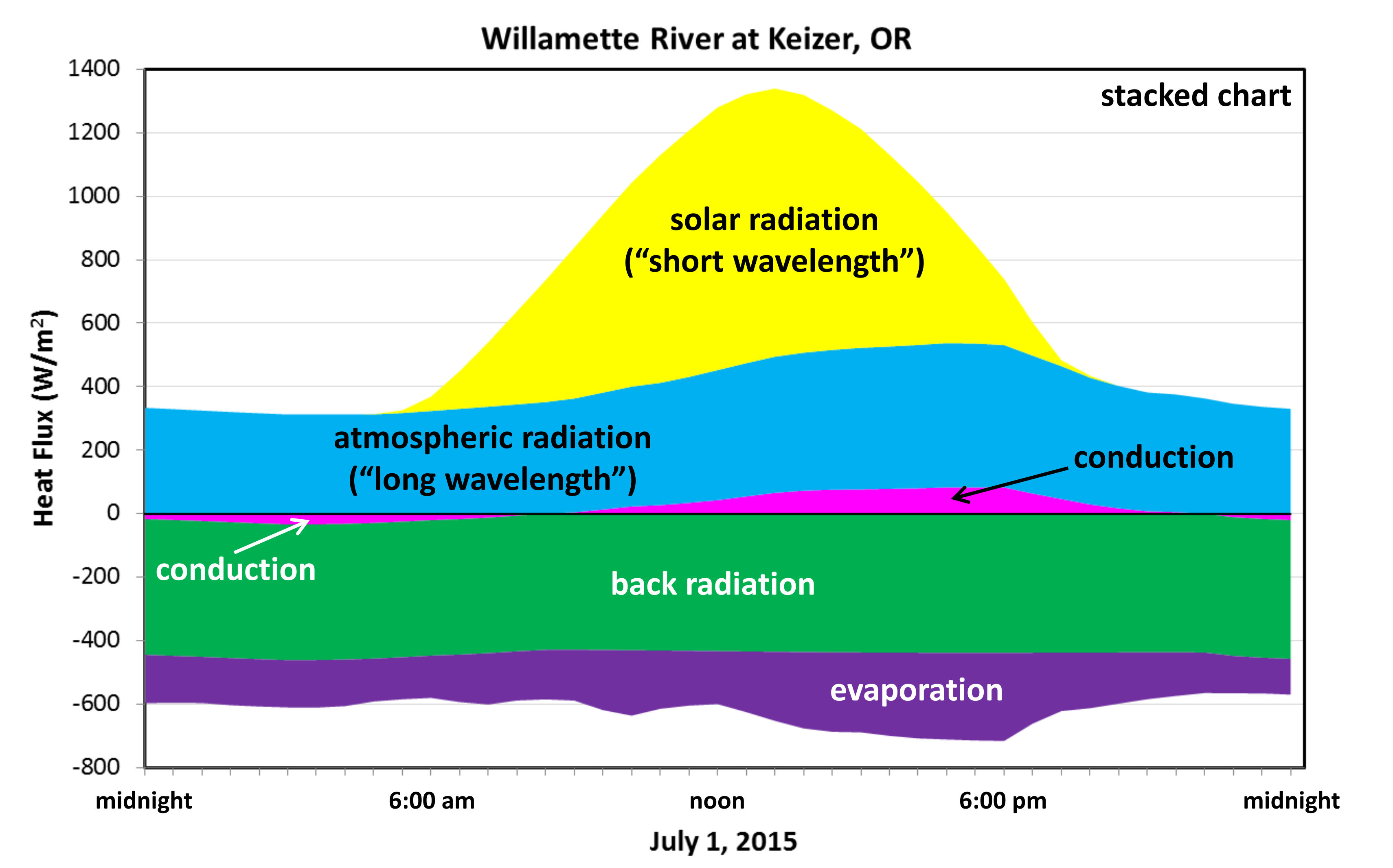
Willamette River Heat Budget on a Sunny, Hot Day



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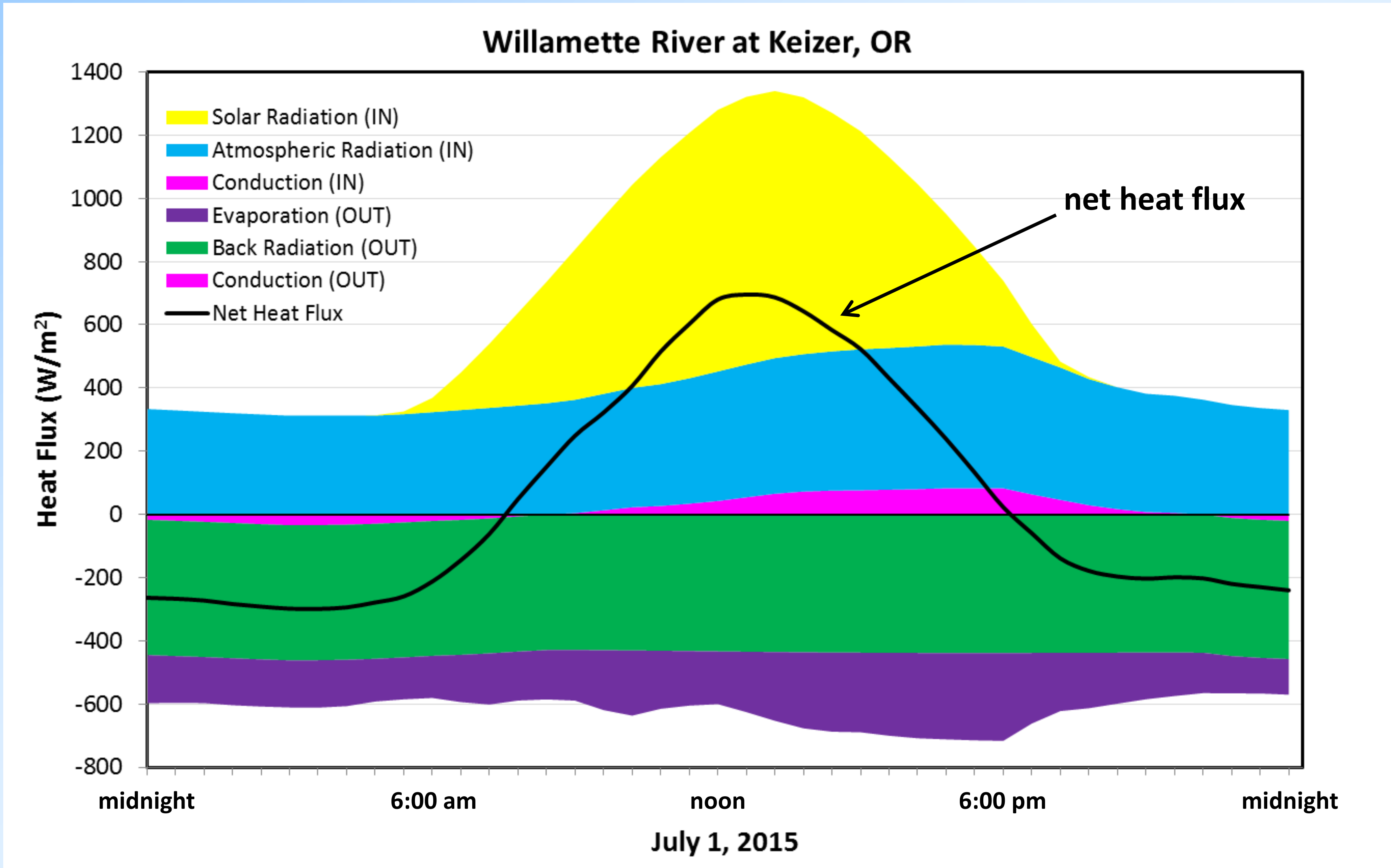
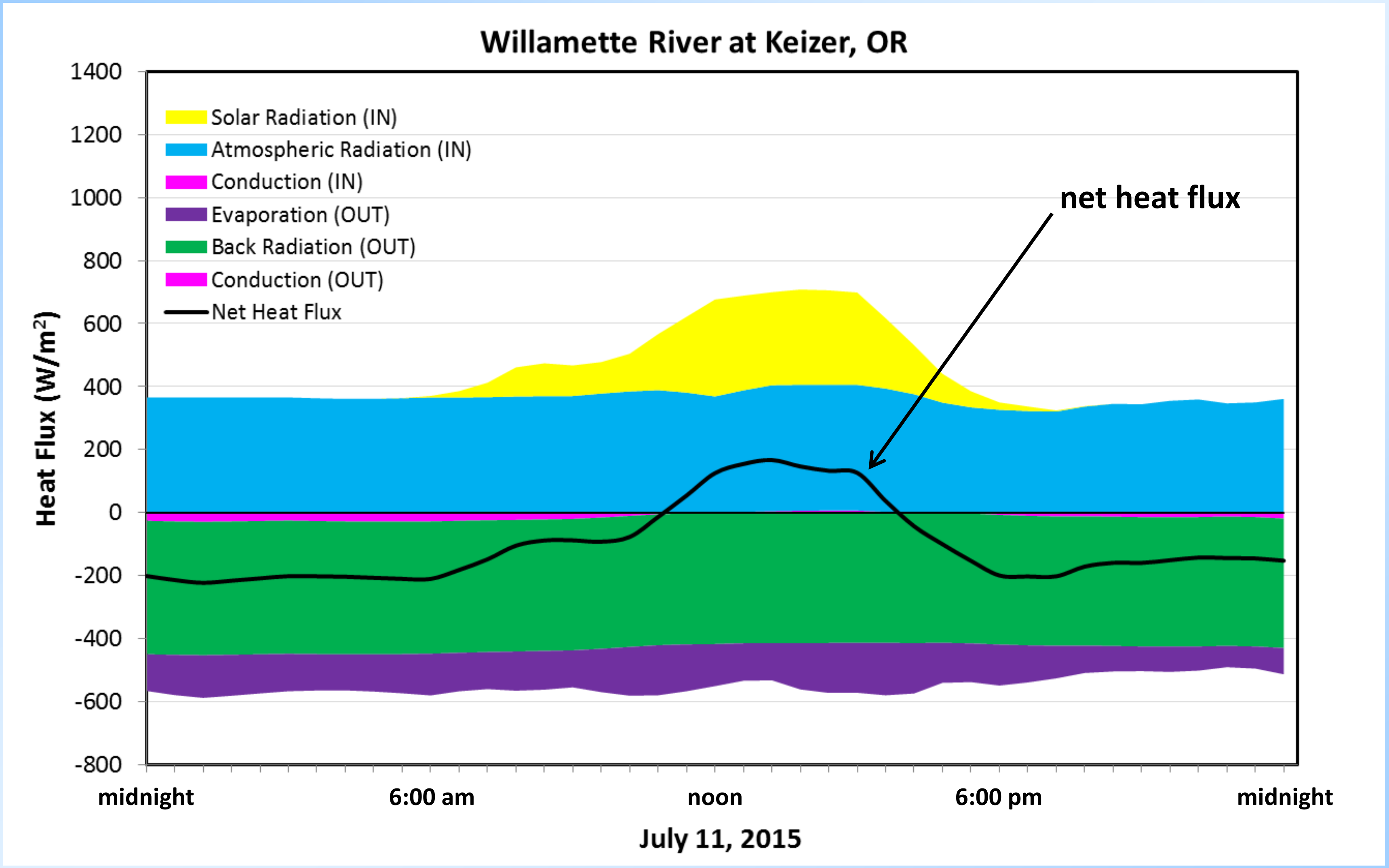
Willamette River Heat Budget on a Sunny, Hot Day



Willamette River Heat Budget on a Cloudy Day



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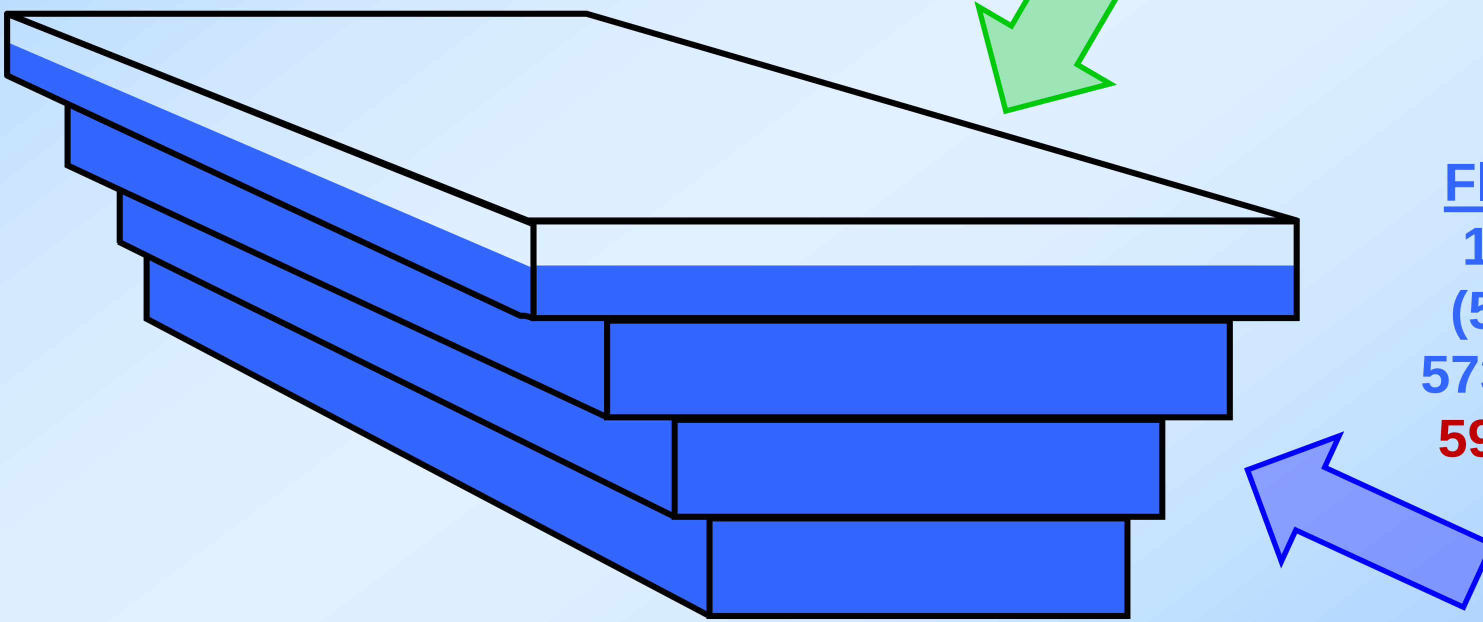
Willamette River at Keizer, July 1st, Noon

Heat content = $\rho V C_p T$
(let's use a reference temperature of 0°C)

<u>Model Segment</u>

Volume:	**56,273**	**m^3**
Length:	**250.2**	**m**
Width:	**184.4**	**m**
Depth:	**2.33**	**m**
Heat Content:	**5,814**	**gJ**

<u>Environmental Inputs</u>
212.7 gJ/hr



<u>Flow Inputs</u>
159.3 m^3/s
(5,626 ft^3/s)
573,600 m^3/hr
59,259 gJ/hr

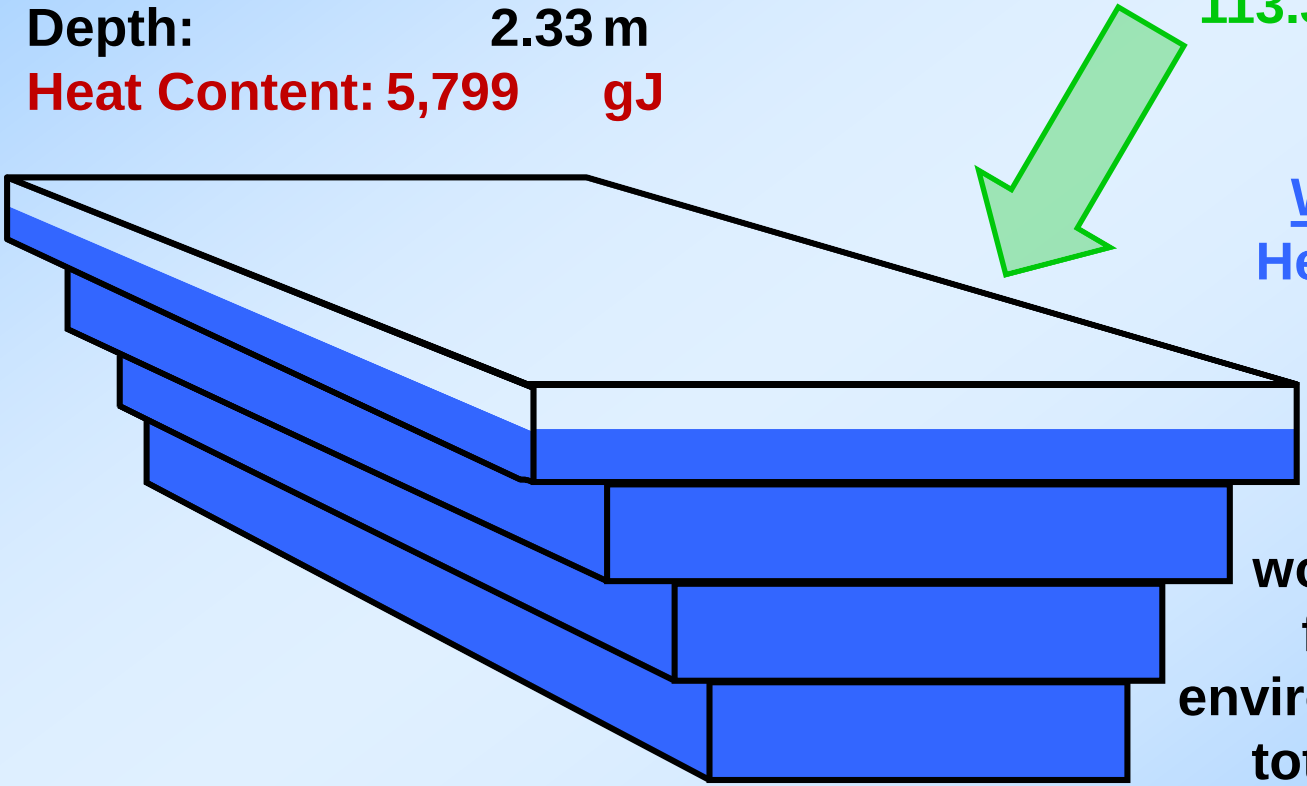
Willamette River at Keizer, July 1st

Sunny Day, Daily Mean

Model Segment

Volume:	56,428	m^3
Length:	250.2	m
Width:	184.4	m
Depth:	2.33	m
Heat Content:	5,799	gJ

Daily Mean
Environmental Inputs
113.3 gJ/hr



Warm Sunny Day
Heat Turnover Rate:
2.13 days

Tracking this parcel of water, it would take 2.13 days for weather-related environmental inputs to total the current heat content in that water parcel.

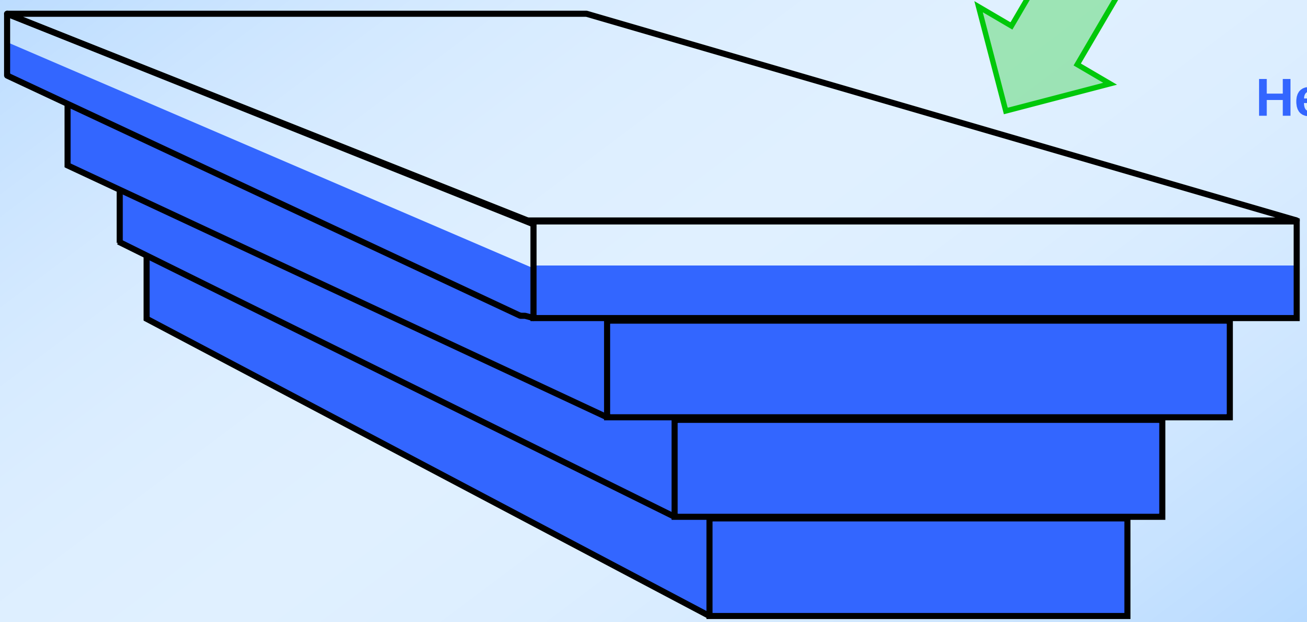
Willamette River at Keizer, July 11th

Cloudy Day, Daily Mean

Model Segment

Volume:	55,213	m^3
Length:	250.2	m
Width:	184.4	m
Depth:	2.31	m
Heat Content:	5,015	gJ

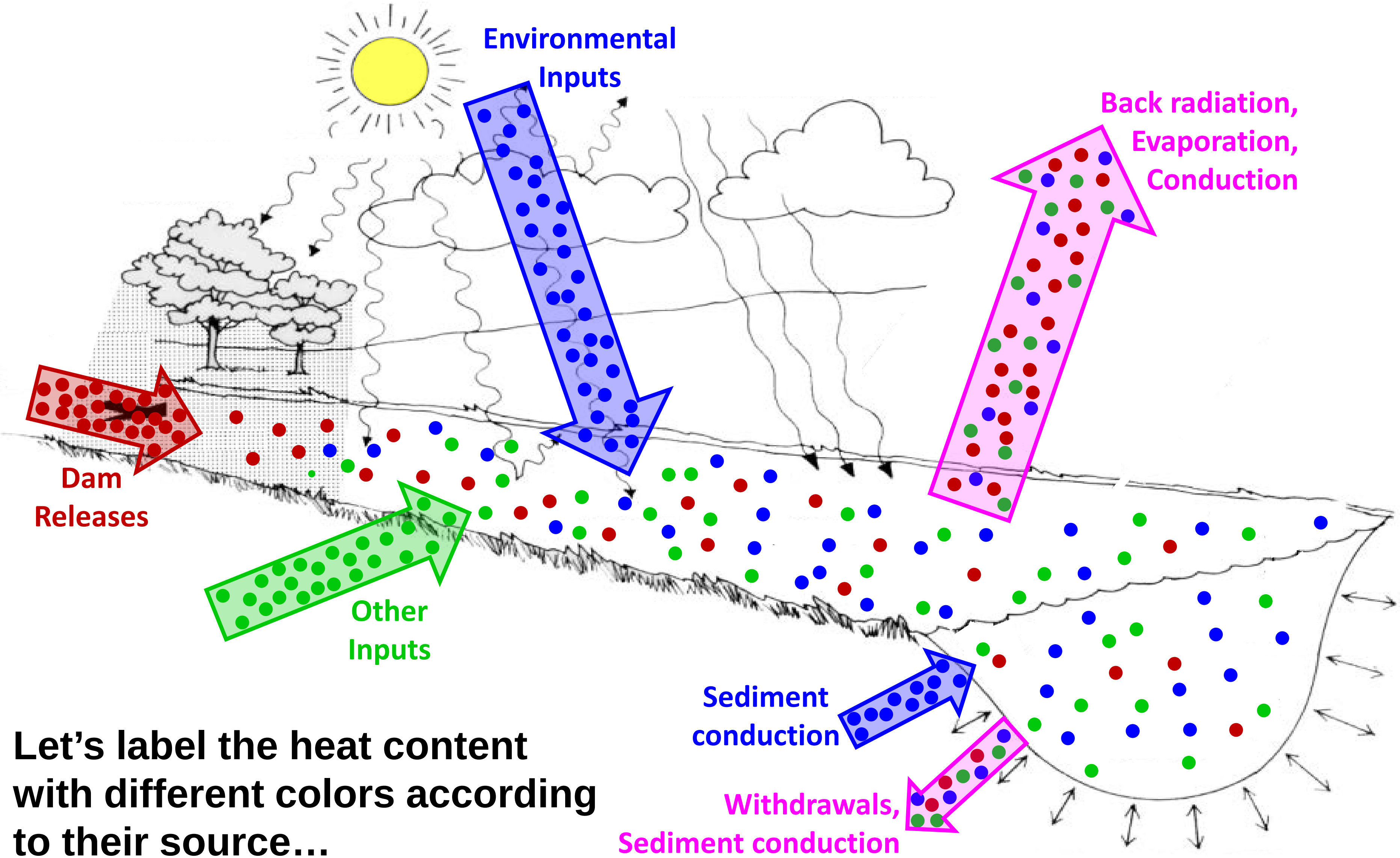
Daily Mean
Environmental Inputs
74.7 gJ/hr



Cloudy Day
Heat Turnover Rate:
2.80 days

What if the river were:
- Wider?
- Narrower?
- Deeper?
- Shallower?

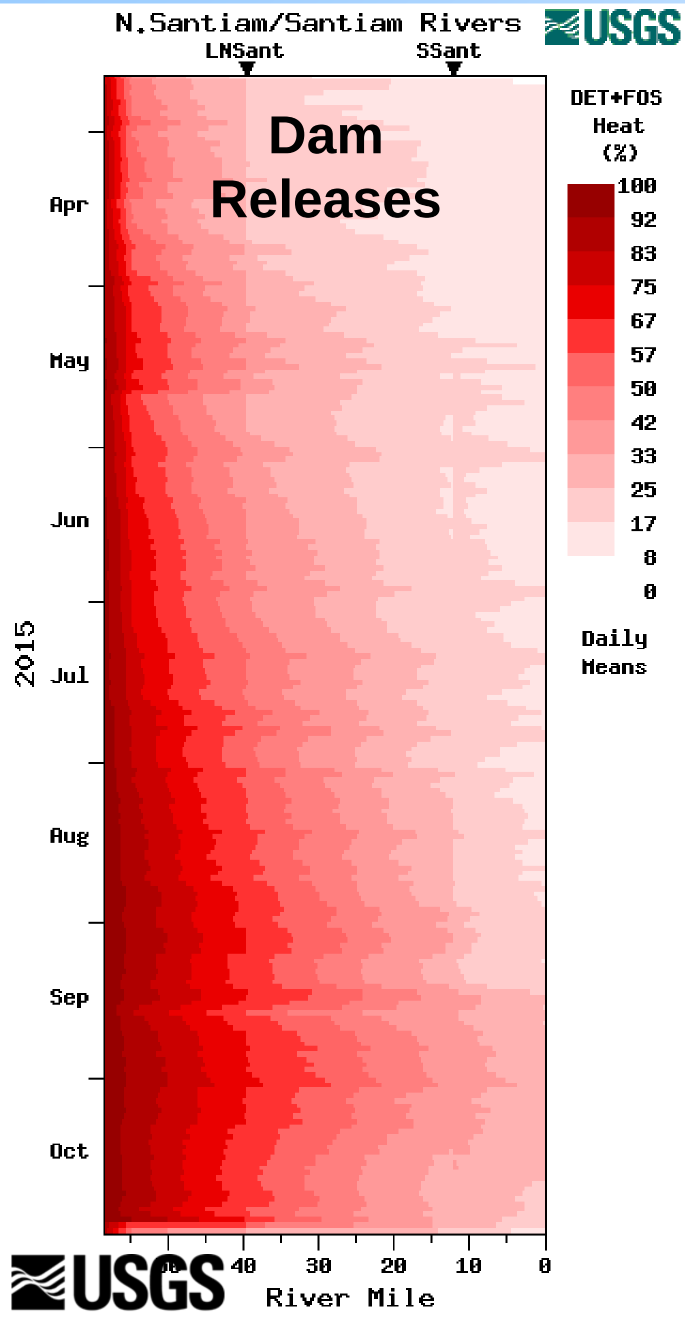
Heat Tracking



Let's label the heat content with different colors according to their source…

schematic modified from Bartholow (2000), USGS Open-File Report 99-112

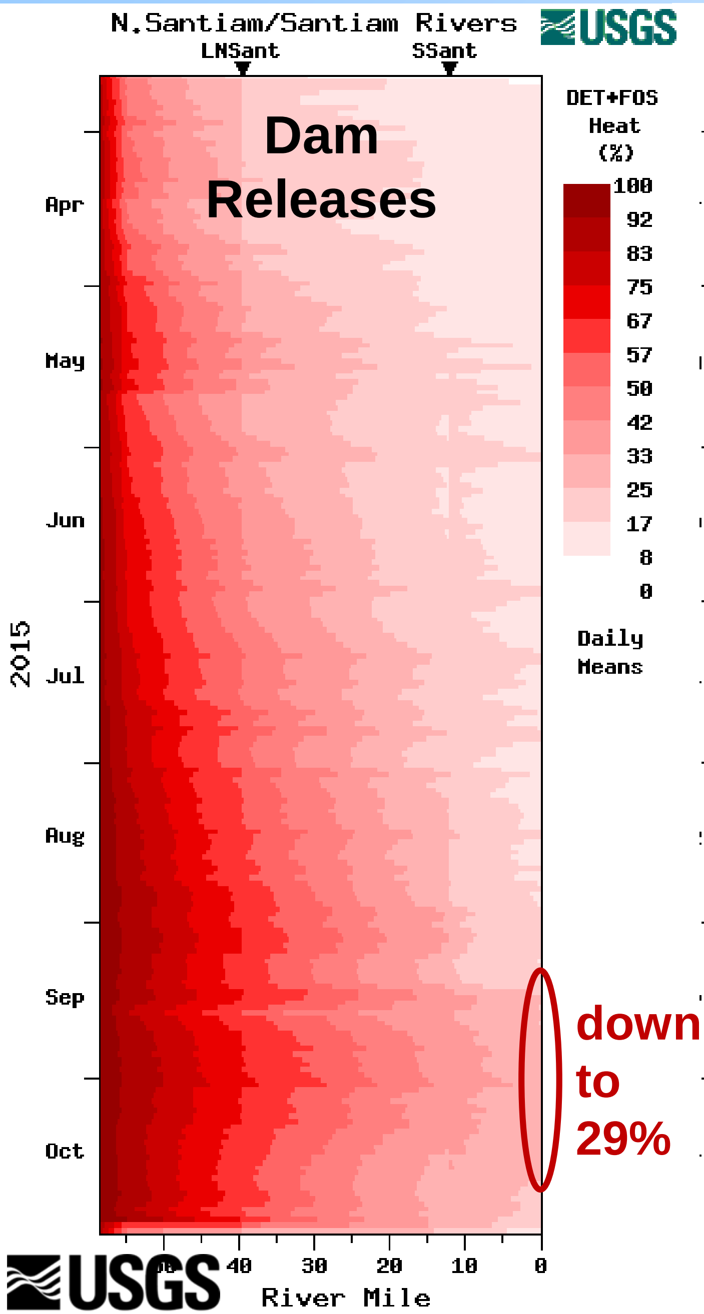
Heat Tracking – 2015 N. Santiam Model Results

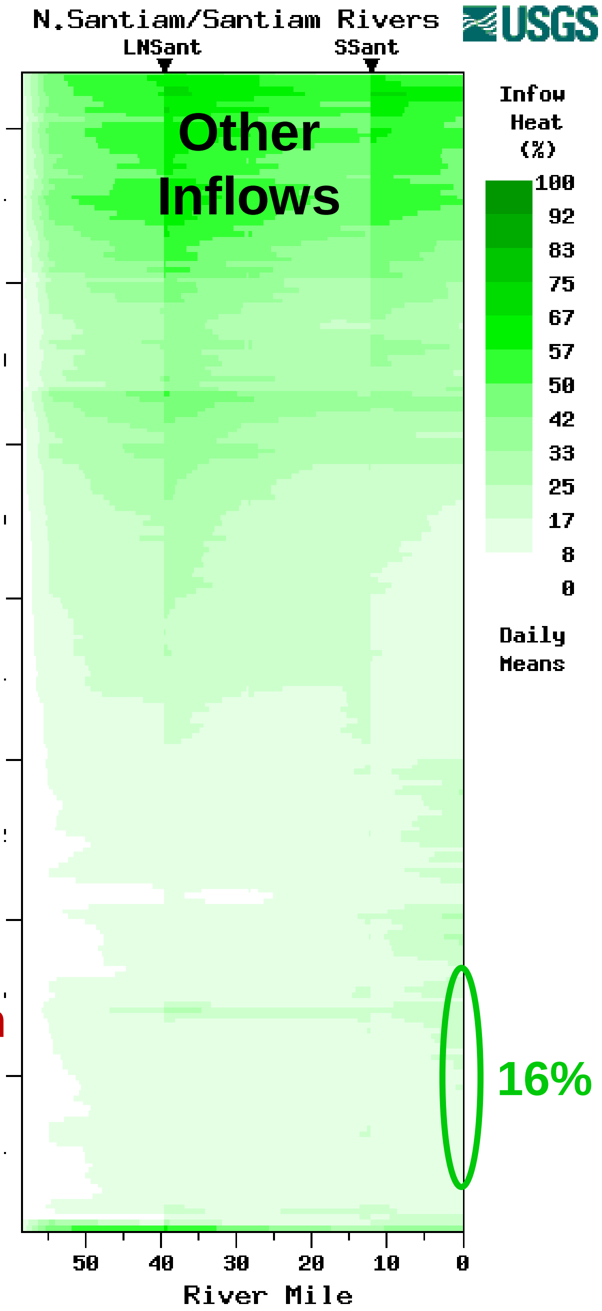


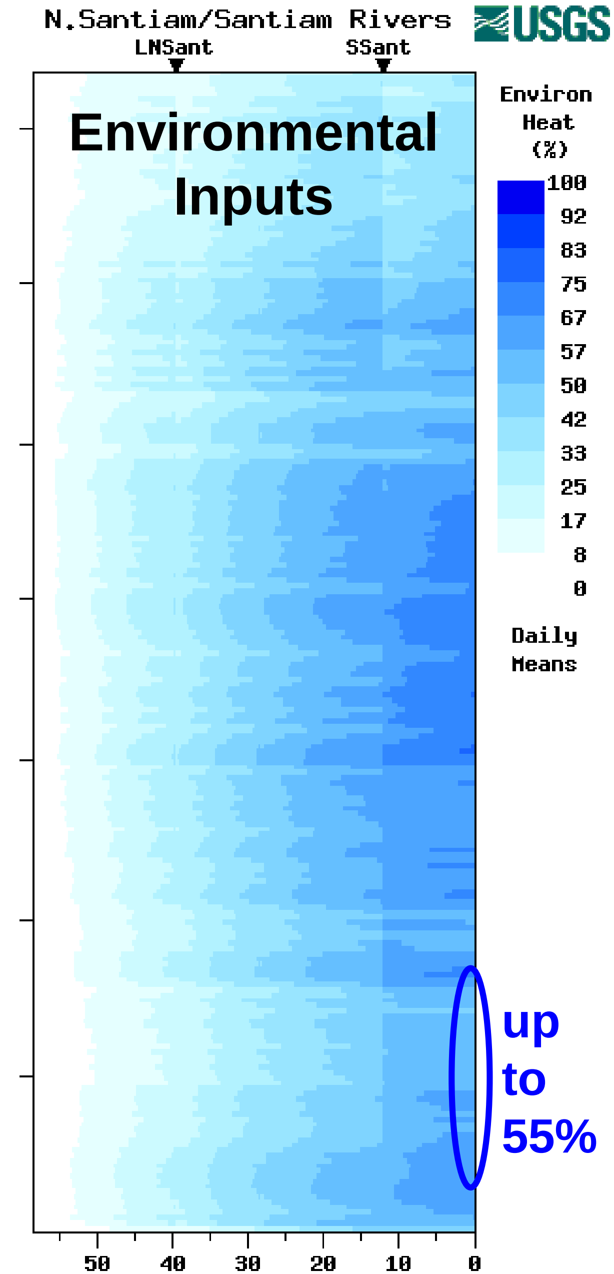
Modified version 4.1 of CE-QUAL-W2:

- **Customized generic constituents**
  - **- Heat: initial conditions**
  - **- Heat: specific dam releases**
  - **- Heat: all other flow inputs**
  - **- Heat: environmental inputs**
  - **- Flow: dam releases**
  - **- Age: heat**
- **Fixed evaporation code for tracking age and flow**

Heat Tracking – 2015 N. Santiam Model Results

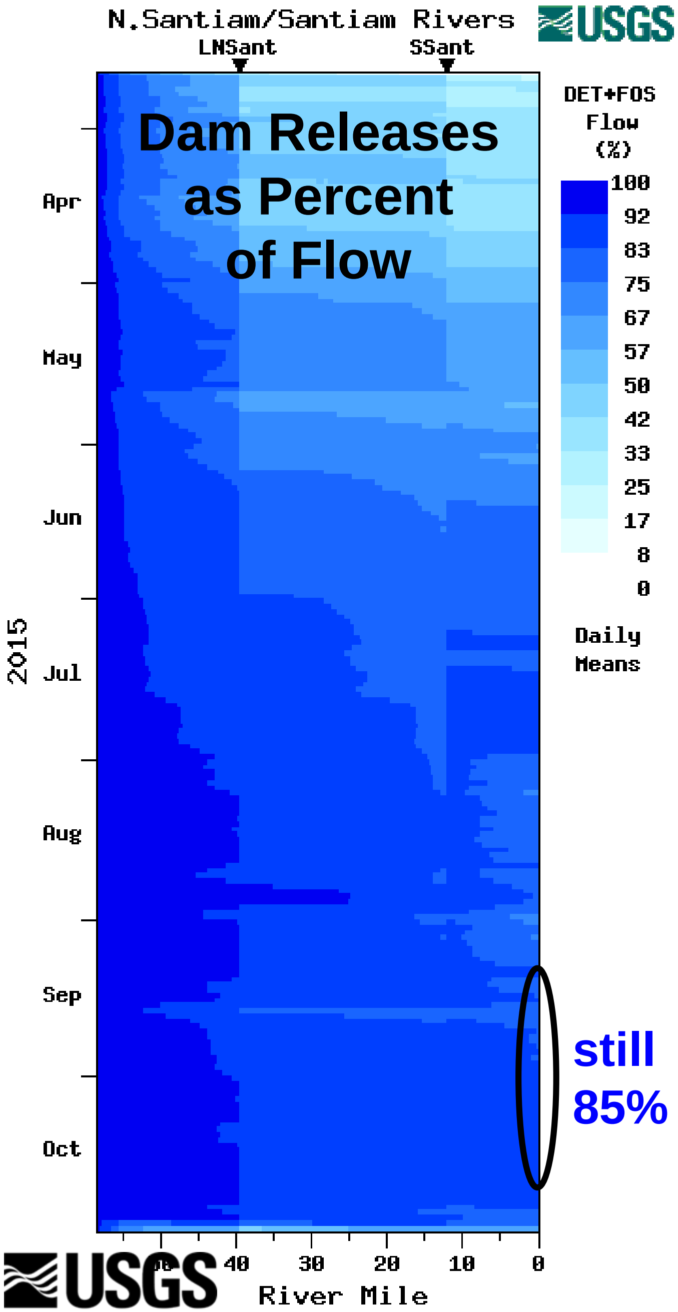


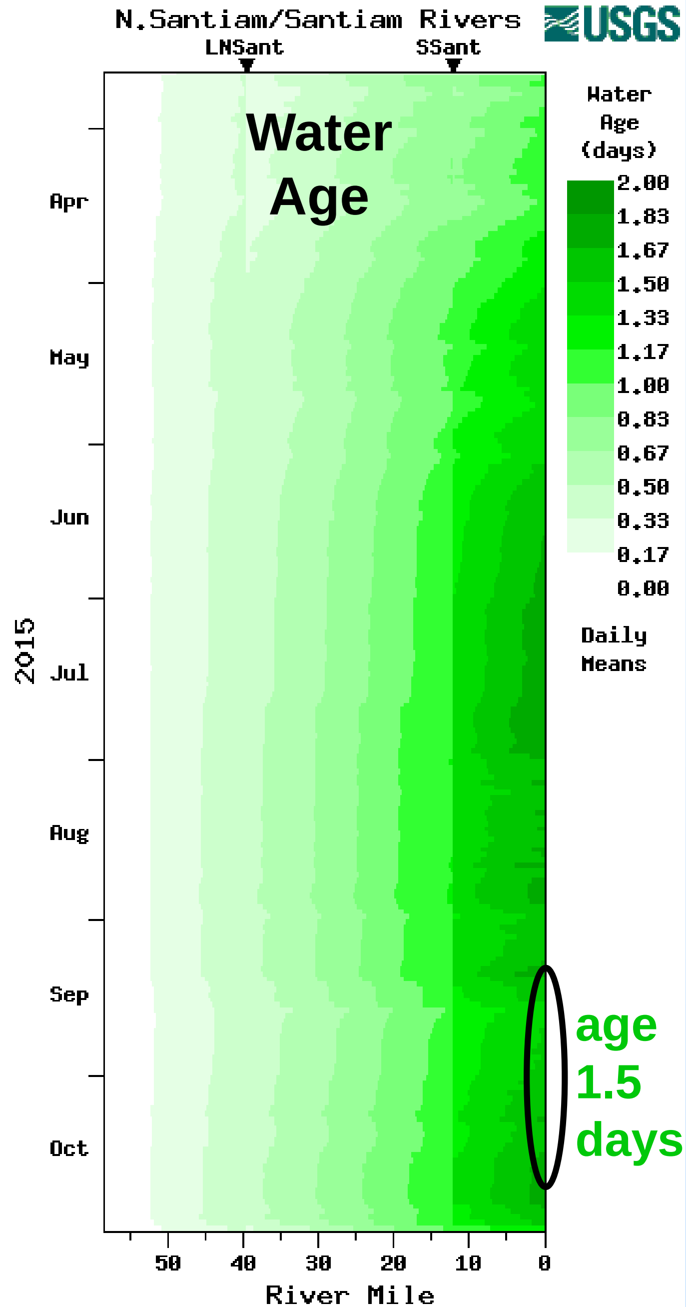




provisional results; subject to revision

Heat Tracking – 2015 N. Santiam Model Results



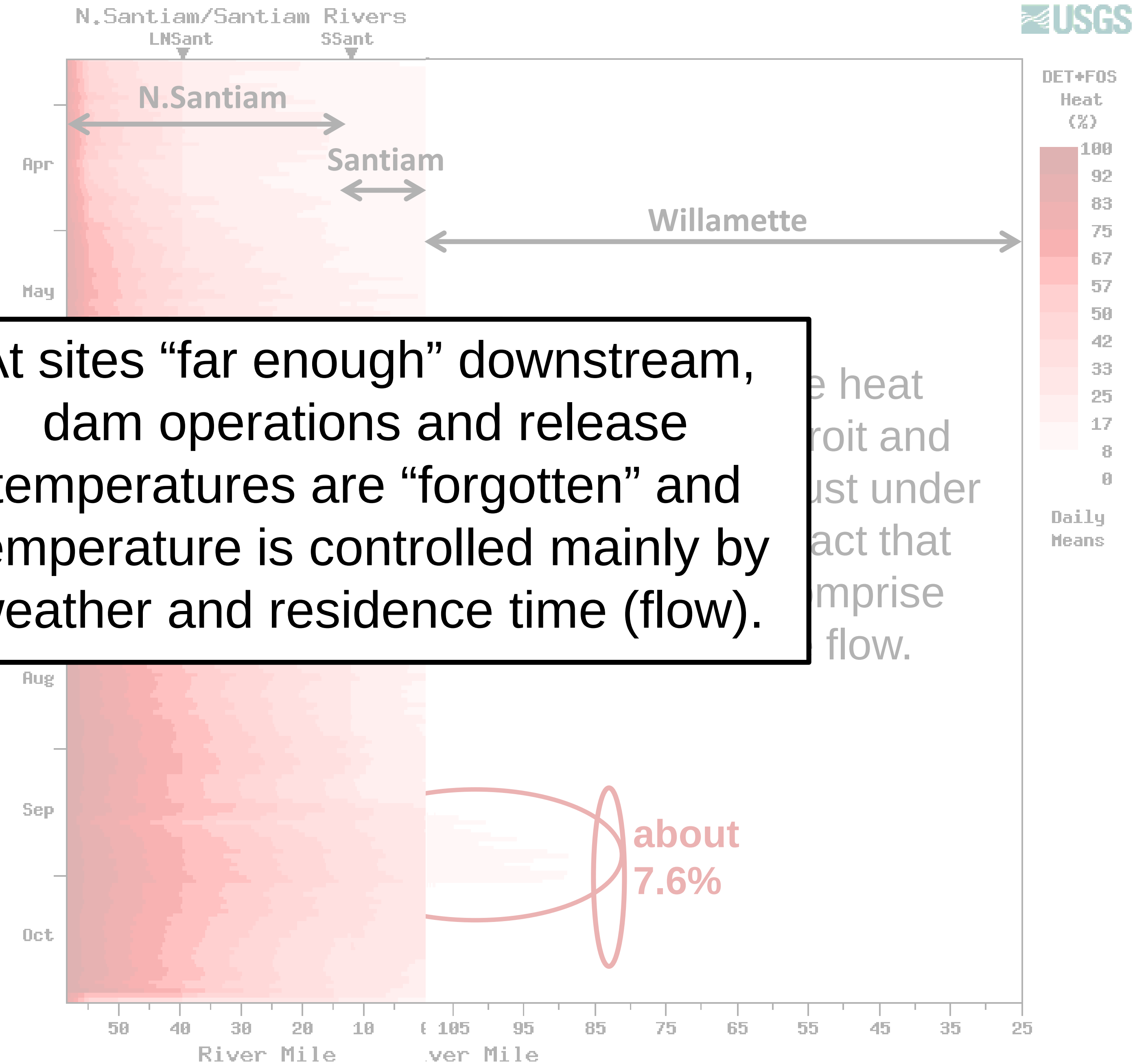


At the mouth of the Santiam River, dam releases from Foster and Detroit Dams still comprise **85% of the flow** in late September. The water has been in the system only about 1.5 days, but already **most of the heat content from the dam releases is gone**, replaced by environmental inputs and heat from other inflows.

provisional results; subject to revision

Heat Tracking – Downstream to the Willamette River

Dam Releases from Detroit and Foster Dams



At sites "far enough" downstream, dam operations and release temperatures are "forgotten" and temperature is controlled mainly by weather and residence time (flow).

provisional results; subject to revision

Regression Models

Objective: Predict 7-day water temperatures at Salem/Keiser, Albany, and Willamette Falls based on streamflow and air temperature. Use those models to evaluate the potential effects of several flow-management scenarios on water temperature.

Salem		
Period	**7-Day Mean**	**MAE (°C)**
April - May	7d WT = 0.4983*(7d AT) + 51584/(7d Q) + 3.536	0.50
June - August	7d WT = 0.4952*(7d AT) + 35849/(7d Q) + 5.479	0.62
September - October	7d WT = 0.5244*(7d AT) + 27064/(7d Q) + 4.782	0.62
November - March	7d WT = 0.5349*(7d AT) + 9209/(7d Q) + 4.036	0.77
Period	**7-Day Mean of Daily Max**	**MAE (°C)**
April - May	7dADM WT = 0.3651*(7dADM AT) + 56521/(7d Q) + 3.259	0.66
June - August	7dADM WT = 0.347*(7dADM AT) + 37854/(7d Q) + 6.355	0.69
September - October	7dADM WT = 0.3566*(7dADM AT) + 30185/(7d Q) + 5.153	0.89
November - March	7dADM WT = 0.4582*(7dADM AT) + 2725/(7d Q) + 3.305	0.87

where WT = water temperature
AT = air temperature at Salem airport
Q = streamflow at Salem
7d = 7-day mean
7dADM = 7-day mean of daily maximum, and
MAE = mean absolute error

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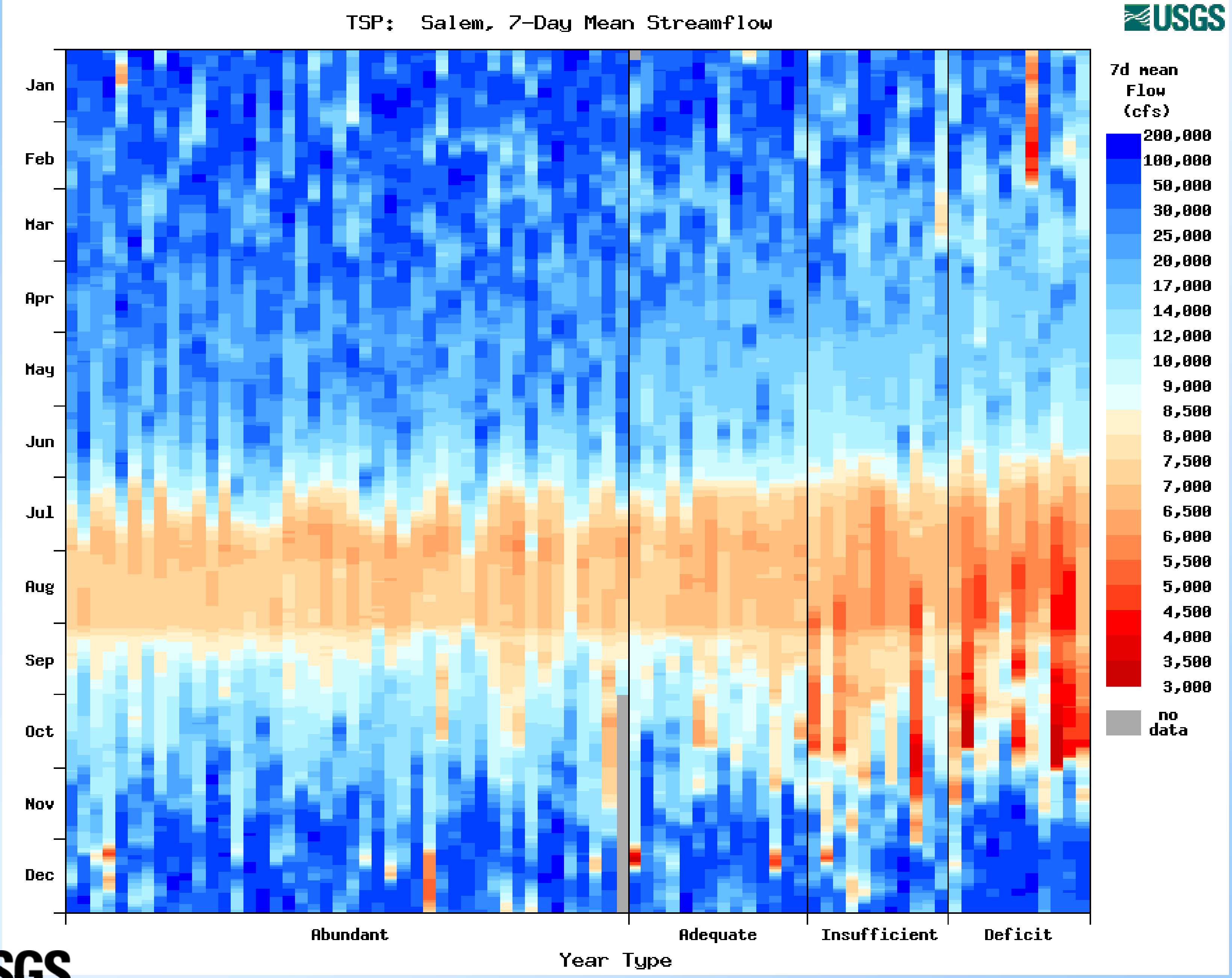
Streamflow Scenario: TSP, Salem, from RES-SIM



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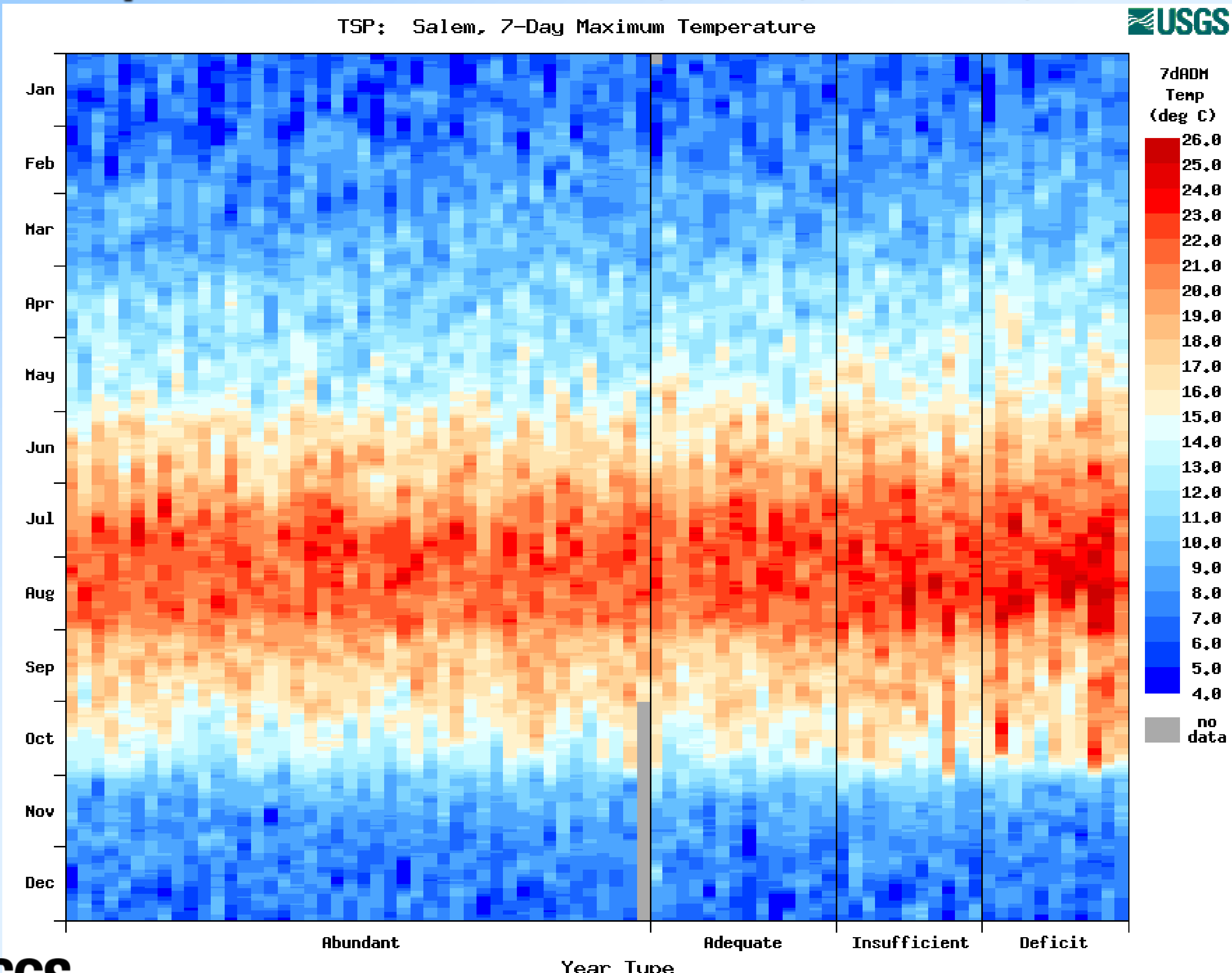
Temperature Conditions, TSP, 7dADM, Salem



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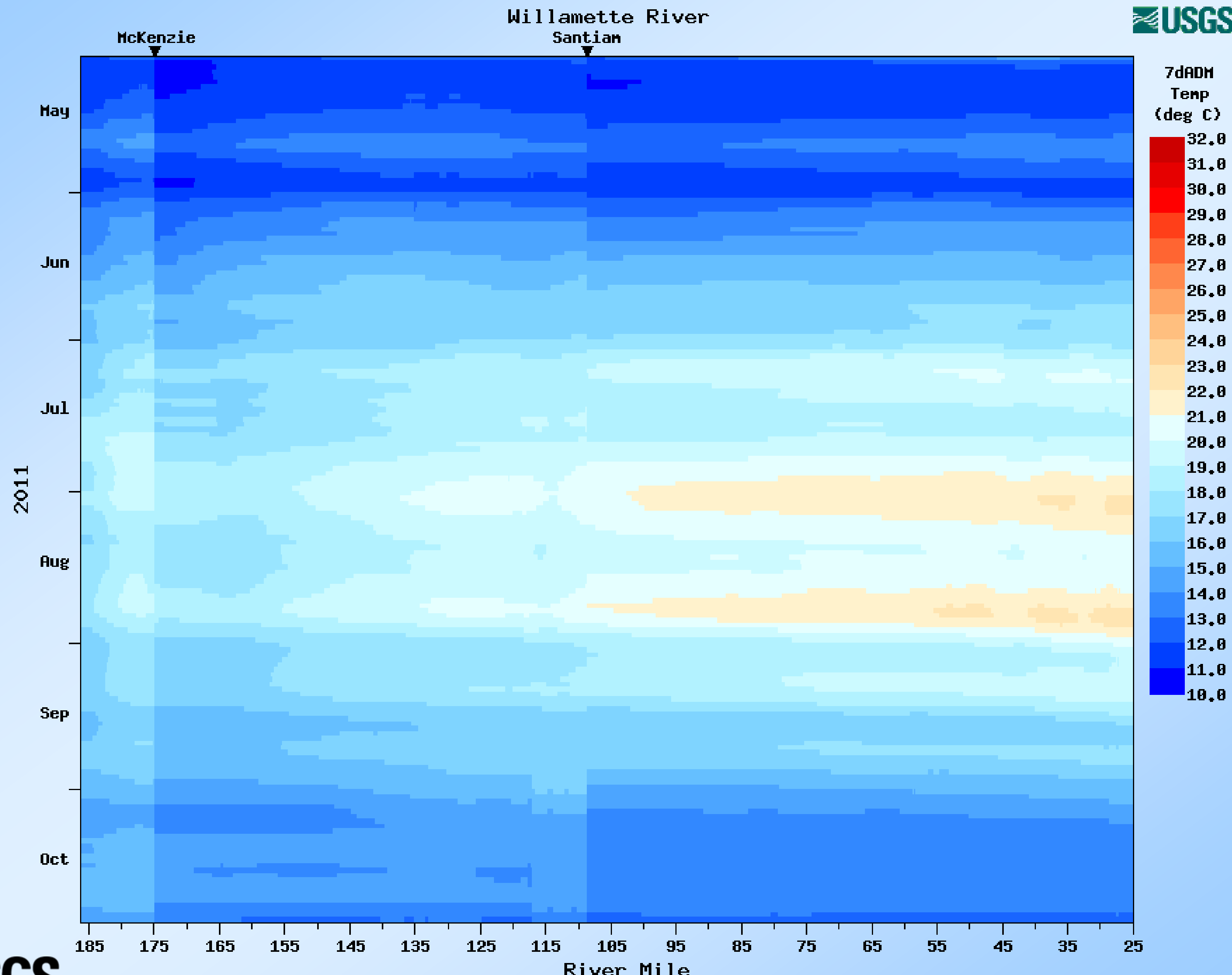
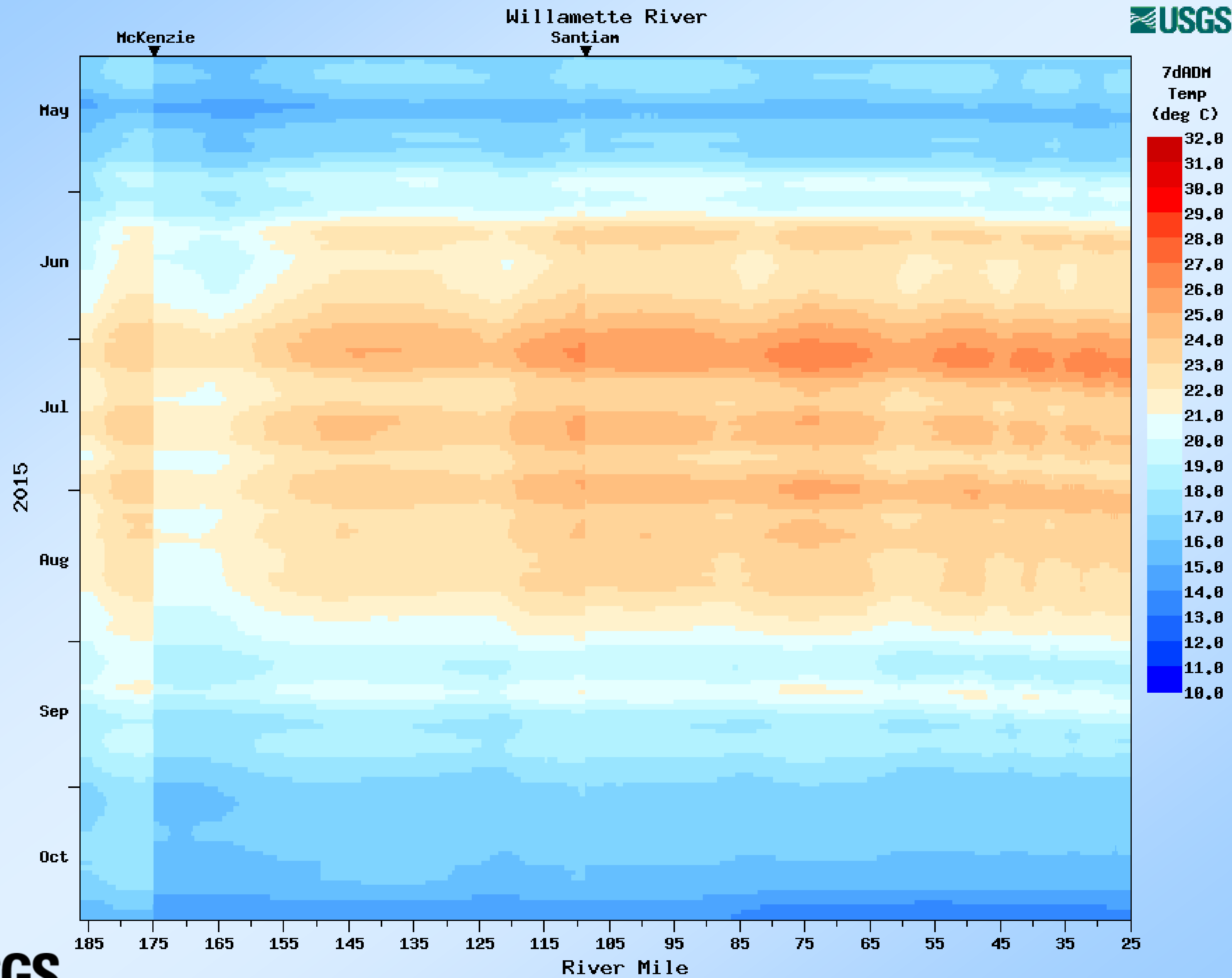
W2 Results Provide Main-Channel Context: 2011



provisional results; subject to revision

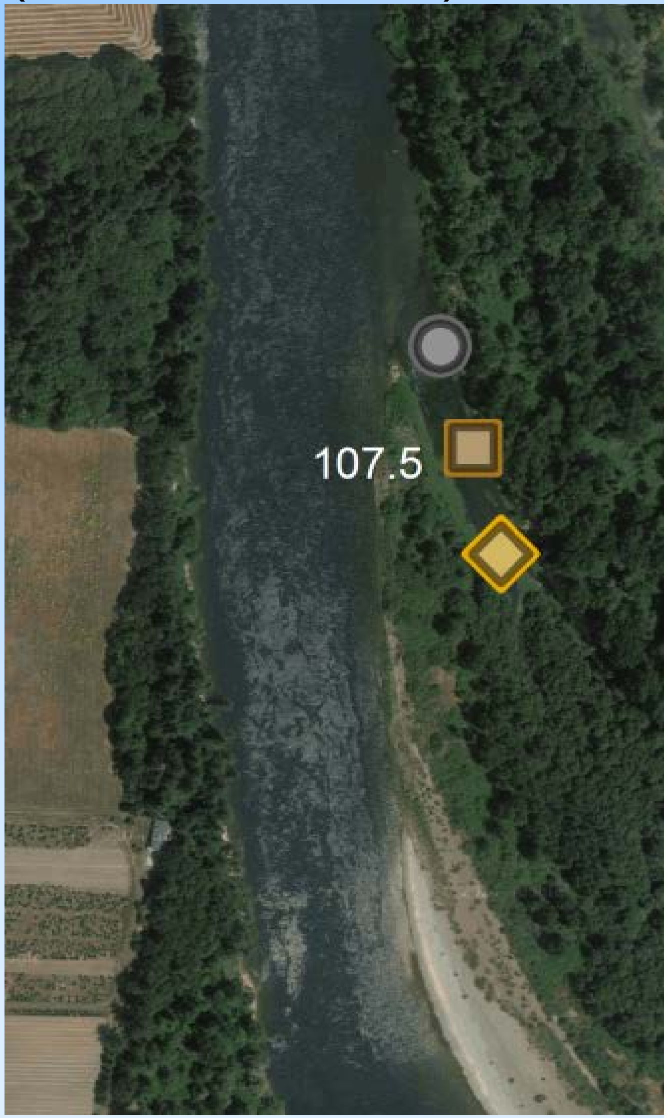
W2 Results Provide Main-Channel Context: 2015

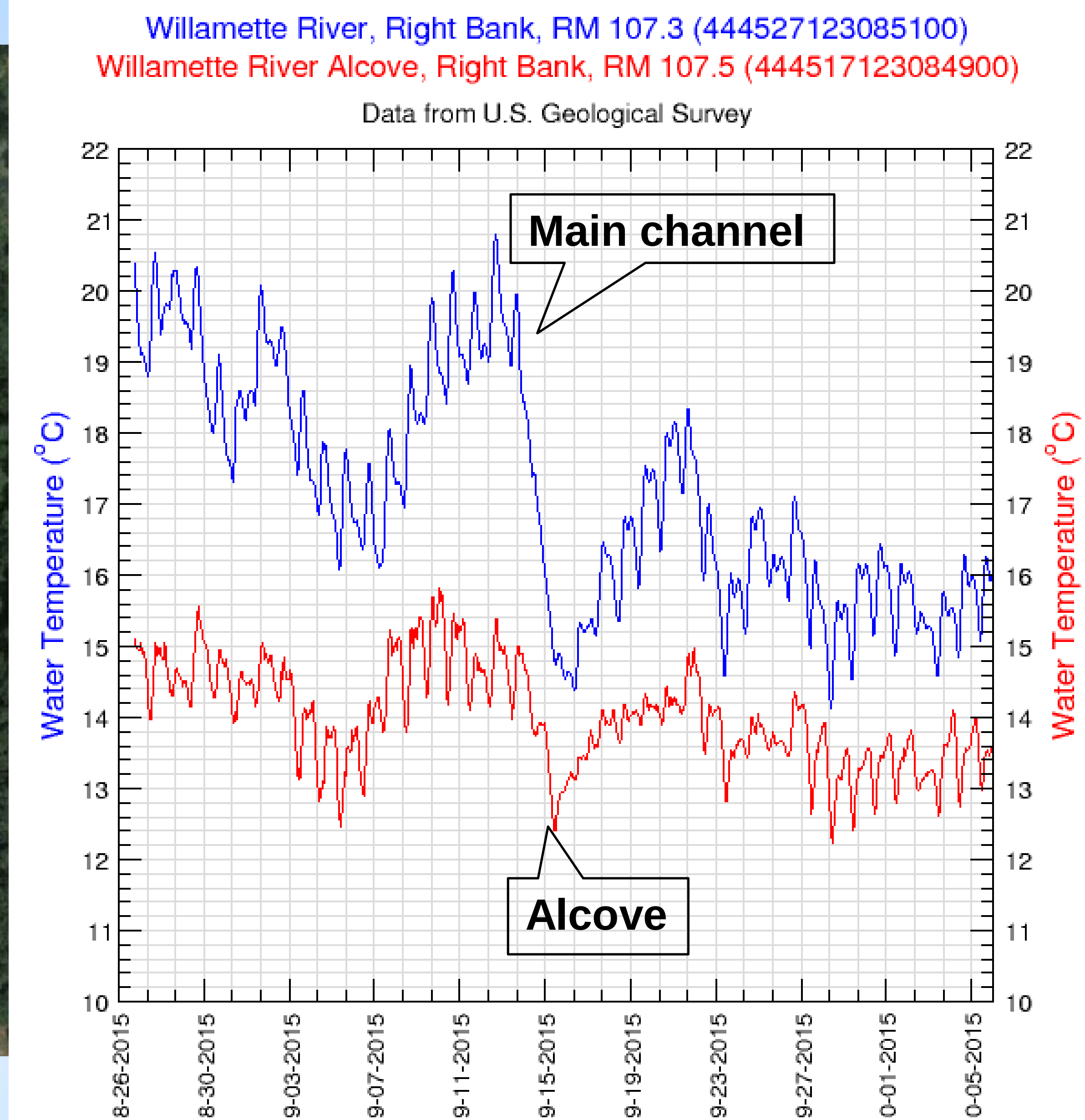


provisional results; subject to revision

Example Off-channel Temperature Comparison

(Alcove at RM 107.5)





https://or.water.usgs.gov/grapher/

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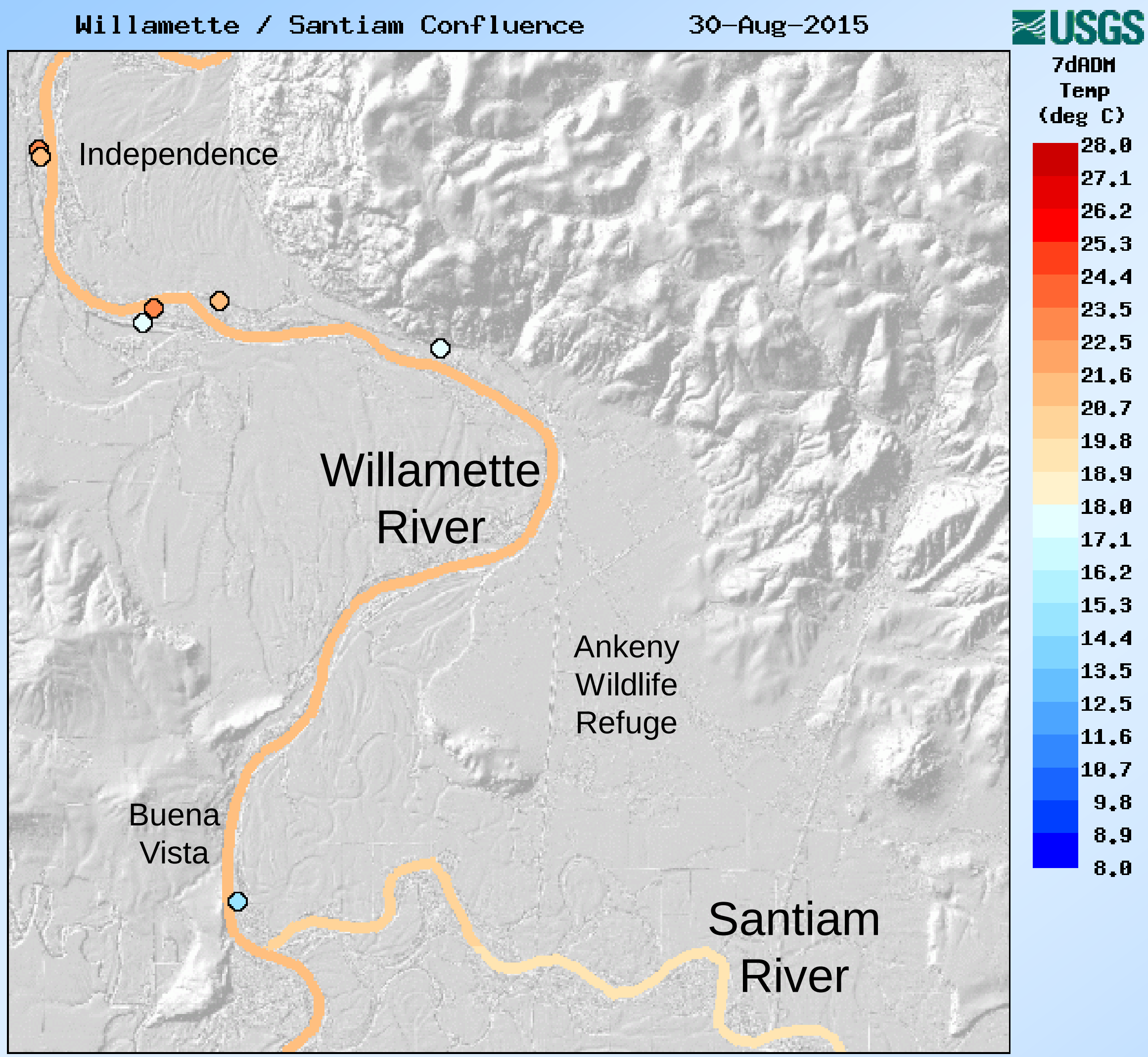
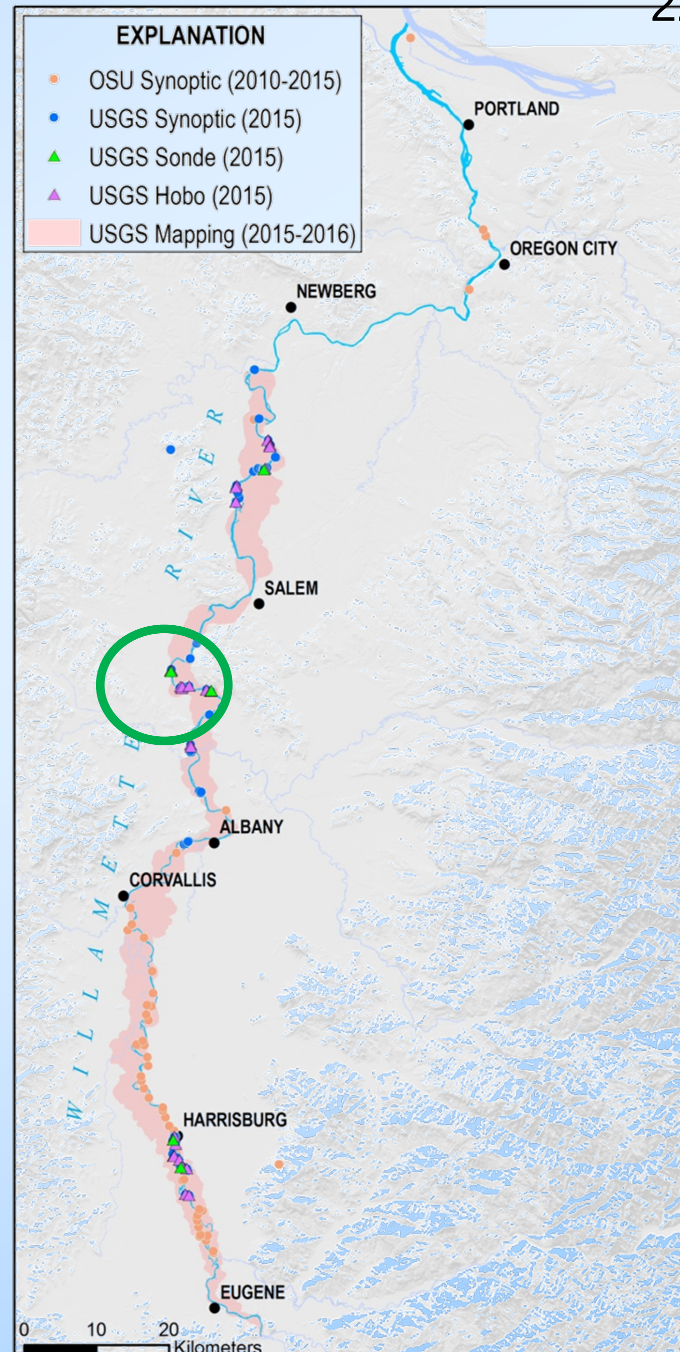
Independence/Santiam (RM 96-108)





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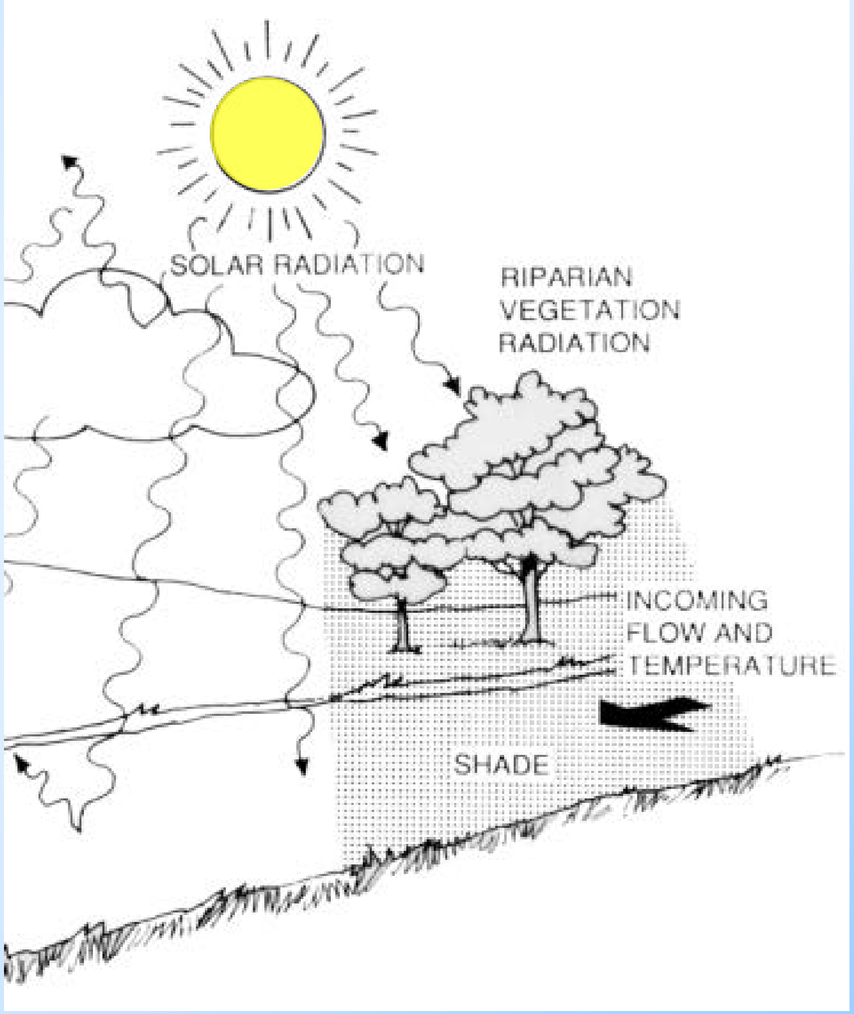
Factors Affecting Water Temperature

- **Shade**
  - **topographic and vegetative (not a huge effect for Willamette)**
- **Surface area**
  - **area is critical to the total energy flux (in and out)**
  - **width-to-depth ratio is important**
- **Dam operations**
- **Streamflow**
  - **affects "thermal mass" and residence time, replacement rate, downstream "effects" distance**
  - **need to track each water parcel to really track the heat sources**
- **Hyporheic flow**



- **It's not just air temperature!**

"*Even my dog knows it is cooler in the shade.*"

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Summary

- The most important heat fluxes across the air/water interface of streams are radiative.
- Weather and residence time are dominant controlling factors for stream temperature at downstream sites;
  close to dams, operations and release temps are dominant.
- The air/water heat flux is large enough to cause a water parcel to "forget" its thermal history after a number of days.
  - exact time scale varies; roughly 2-3 days in Willamette and larger tribs
- Regression models based on streamflow and air temp can predict downstream temperatures successfully.
  - at sites "far enough" downstream

photo by USGS

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Contacts and References

Contacts:

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References:

- Bartholow, J.M., 2000, The stream segment and stream network temperature models— A self-study course: U.S. Geological Survey Open-File Report 99-112, 276 p. (Available at https://pubs.er.usgs.gov/publication/ofr99112.)
- USGS Data Grapher: https://or.water.usgs.gov/grapher/

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