Stream temperature data in support of river ecosystem science in the Klamath River

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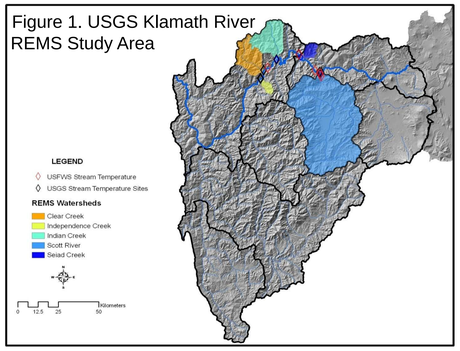
Introduction

The USGS is engaged in an integrated science program studying physical processes that create mainstem thermal patchiness and cold-water refugia at tributary confluences within the Klamath River watershed. This project was designed as part of a River Ecosystems Models and Science (REMS) framework that uses multi-scale, multi-disciplinary approaches to address hydrologic and ecologic issues in river systems. Basin-scale hydrologic models provide boundary conditions for current and future climate scenarios and coupled physical and bio-energetic models at the reach and habitat-scale will be used to evaluate the effects of temperature regimes on key fish species. To support these efforts, in-situ stream temperatures and thermal remote sensing (TIR) imagery were collected at low flow conditions during the summer of 2010 along an 80 km mainstem reach and at five tributary confluences. This assessed the spatial and temporal variability of surface stream temperatures throughout the study area.

Figure 1. USGS Klamath River REMS Study Area



Background

Stressful stream temperatures are normal for the Klamath River, which lies on an "ecological edge" with respect to water temperatures for coldwater fish species. Elevated stream temperatures along the Klamath River occur more frequently and for longer durations than in adjacent anadromous streams. Analysis of historic stream temperature data show an increase of ~ 1.0º C since 1962 and stream temperature modeling indicates the cumulative exposure to stressful temperatures has been increasing in frequency and duration (Bartholow, 2005). Atypical low-flows during September 2002 coupled with an above average salmonid run and warm water temperatures, which are not unusual in the Klamath River during September, created ideal conditions for pathogens to infect salmonids resulting in an unprecedented fish-kill of over 33,000 adult salmon and steelhead (DFG, 2004). The fish-kill of 2002, FERC relicensing of a series of dams, and proposed dam removal initiated renewed stream temperature monitoring and numerous reviews of conditions required for ameliorating detrimental temperatures.

Methods

We collected spatial and temporal datasets to assess lateral, longitudinal, and vertical stream temperature variability. Thermal remote sensing (TIR) provided a synoptic longitudinal view of surface stream temperatures at the reach and confluence scale and insitu data were used to assess temporal and vertical variations at the confluence and habitat unit scale. Five confluence sites (Fig.1) were targeted for data collection and during the summer of 2010 we deployed 30 insitu temperature probes throughout the REMS study area to supplement an existing array of USFWS probes that are part of a long-term monitoring program. The objective for the TIR was to collect a diurnal set of imagery during an afternoon (8/25/10) and morning (8/26/10) at each of the 5 tributary confluences and along the 80km study reach. Variability was assessed using statistical measures of dispersion (max, min, range, std dev, variance, kurtosis).

Results

Water temperatures and measures of variability are shown at the reach, confluence, habitat unit scale. TIR data (Fig.2 & 3 and Table 1) from 8/26/10 indicate the highest stream temperatures occurred downstream of IGD. Progressive downstream cooling began near the Shasta River confluence and become more pronounced near the Scott River confluence. In the vicinity of Seiad Creek stream temperatures and variability increased. Further downstream mainstem cool patches occur between Indian and Independence creeks. Along the 80km study reach median surface temps were > 20ºC at 92% of the sampled locations and temperatures ranged from 19.2 to 23.7ºC. Reach scale data show ~ 4.5ºC variability and confluence scale data show <1.0 ºC variability. Diurnal variations based on TIR data at the Scott and Seiad confluences was ~8ºC.

Figures 2 & 3. TIR reach and confluence scale data (1 pixel = 0.8m^2)

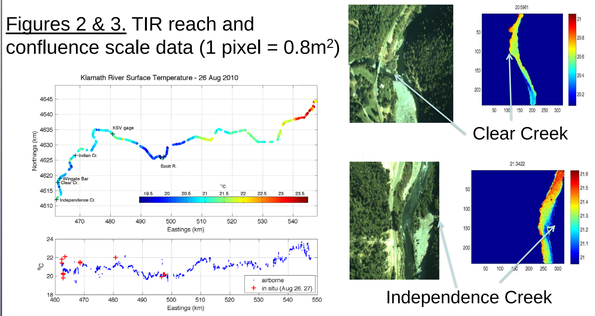


Table 1. Spatial analysis of calibrated TIR surface stream temperatures

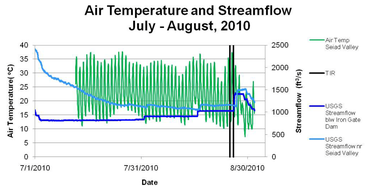
Site	LP	SR	SR	SR	SC	SC	SC	IC	IC	CC	CC	IndC	IndC
Date	8/26	8/25	8/26	8/26	8/25	8/26	8/26	8/26	8/26	8/26	8/26	8/26	8/26
Time	1002	1721	0857	1101	1741	0915	1116	0929	1128	0940	1143	0952	1158
N=	1390	129	165	155	213	180	208	163	226	181	260	148	103
Max	23.70	28.65	20.58	21.78	29.80	21.80	23.36	21.09	23.08	21.70	23.07	21.30	21.19
Min	19.26	27.72	19.38	21.37	27.02	19.45	21.41	20.34	21.18	20.11	21.66	20.77	20.52
Range	4.44	0.93	1.20	0.41	2.78	2.35	1.95	0.75	1.90	1.59	1.41	0.53	0.67
Std Dev	0.84	0.17	0.22	0.10	1.05	0.44	0.65	0.12	0.61	0.30	0.36	0.10	0.14
Variance	0.70	0.03	0.05	0.01	1.10	0.19	0.42	0.01	0.37	0.09	0.13	0.01	0.02
Kurtosis	0.67	-0.06	0.16	-0.94	-1.61	1.74	-0.91	5.31	-0.33	0.55	-0.31	1.69	1.08

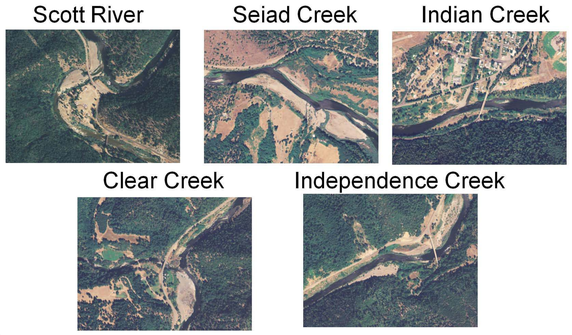
Insitu data (Fig. 4 to 9) were analyzed for lateral, vertical and temporal variability at the confluence and habitat unit scale. Mean seasonal diurnal variations were ~ 2 to 3ºC at the Scott, Seiad, and Independence confluences and ~ 4 to 6ºC within Seiad Creek and the Scott River. Thermal stratification was measured at Seiad and Independence confluences where mean seasonal vertical variations were ~0.5 to 1.0ºC. A 2 ºC thermocline was measured within a 1m deep pool near the Seiad Creek mouth but was destroyed by mixing and/or loss of riparian shade by 3pm.

Figures 4 to 9. Insitu seasonal and diurnal data collected at the confluence and habitat unit scale.

Discussion

TIR and insitu data reveal significant variability at all scales. Longitudinal variability at the reach scale was 4.5 ºC. Seasonal diurnal and vertical variability at the confluence scale were ~0.5 to 3ºC and ~0.5 to 1.0ºC respectively. Mainstem thermal patchiness and poorly-mixed flows at tributary confluences provide habitat for salmonids existing at the margin of their environmental tolerances. Spatial and temporal variability may be generated by addition of cooler tributary flows, topographic shading, thermal stratification, or hyporheic flow.





Conclusions

Reach scale TIR data show ~ 4.5ºC variability and confluence scale TIR data show <1.0 ºC variability. Precision is typically better than accuracy for radiometers thus we have higher confidence in the relative temperature differences whereas the TIR may not accurately represent absolute temperatures. Insitu data indicate poorly-mixed flows at stream confluences which may be problematic for TIR calibration. Continued monitoring, analysis of confluence channel hydraulics, and basin-scale solar radiation, topographic shading, and air temperature modeling will help explain some of the observed complexities. Geologic evidence indicates that the REMS study reach may occupy an underfit paleodrainage with the mainstem flowing through an unusually wide valley with low slopes and a lack of riparian cover. Underfit channel morphology and confluence morphodynamics likely play key roles in temperature variability.

Future Work

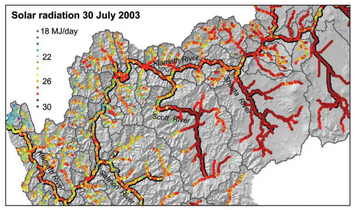
Future work will focus on determining how climate and geomorphology influence physical processes that create mainstem thermal patchiness and cold-water refugia at tributary confluences and development of basin, reach and habitat scale physical models.

TIR and insitu temperature data
- integrate with climate and topographic models

TIR calibration
- channel topography using bathymetric lidar survey

Distributed temperature sensing (DTS)
- investigate variability, thermal patchiness, hyporheic flow

Monitor effects of dam removal
- sediment, stream temperature, channel changes



* from Flint and Flint, 2008

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Acknowledgements

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