Assessing the impact of a warmer climate on stream water quality across the mountainous Western United States

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U.S. EPA STAR Grant No. RD-83419101-0

Consequences of Global Change for Water Quality

Santa Clara University

West: Warmer temperatures in past decades have led to streamflow timing changes and flow regime shifts

1948 - 2008

Fritze H, Stewart IT, Pebesma E, 2011, J Hydromet

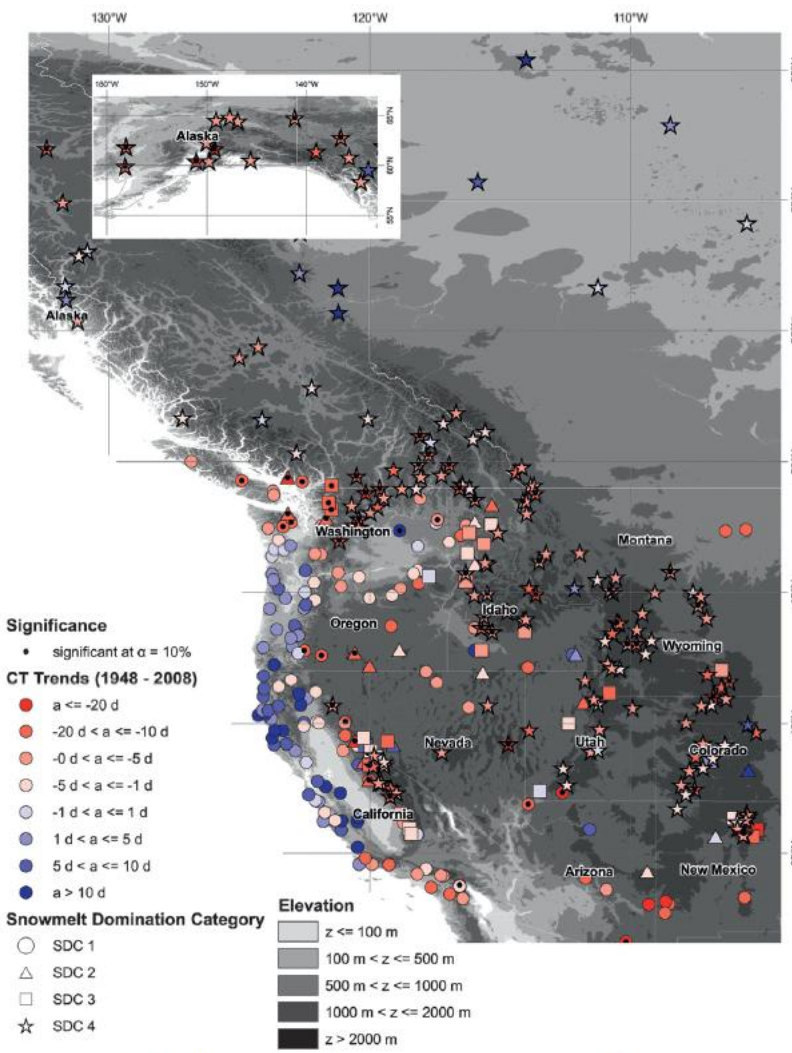


FIG. 3. Trends in CT for each SDC. Trend values are given in days over the 61-year period.

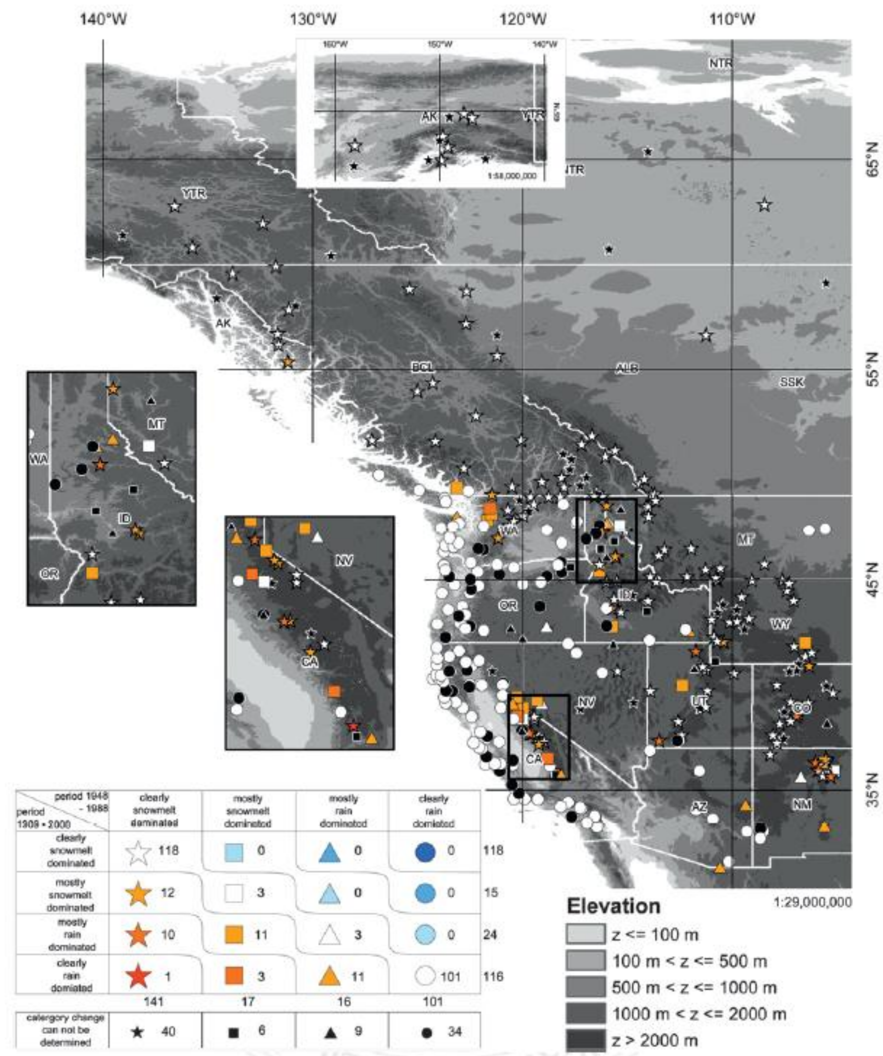
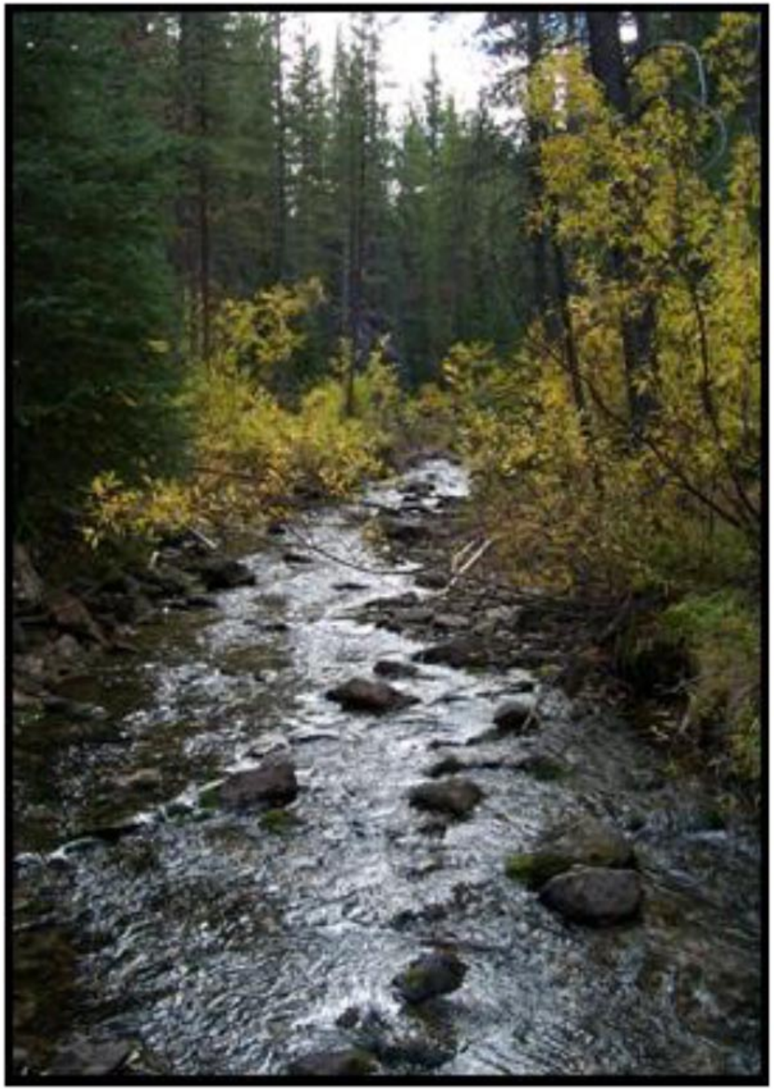


FIG. 12. Changes in SDCs between 1948–88 and 1989–2008. The main diagonal of the legend (row i =

Project Objectives

- How do future climatic changes impact the near-surface hydrology and water quality across mountainous western US unimpaired basins?
- Evaluate differences in impact on water quantity and quality different temporal and spatial scales, region-to-region
- Use ensemble of GCMs, 2 scenarios to assess uncertainties in predictions
- Assess impact on aquatic ecosystems



Hydrologic components (snowmelt, surface flow, ET, subsurface flow, soil storage, groundwater, streamflow)

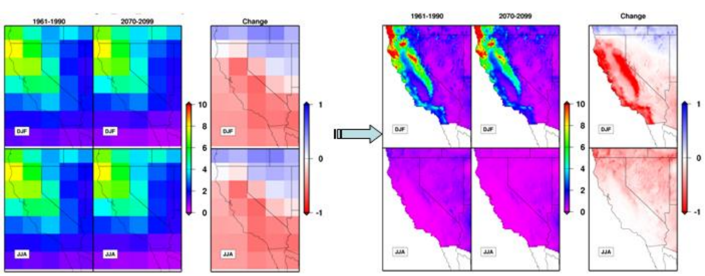
Water quality (stream temperature, dissolved oxygen, sediment)

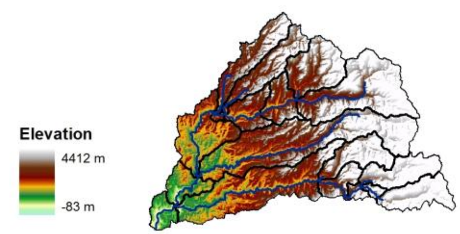
For 16 GCMs, 2 scenarios, subbasin scale, through 2100, uncertainties

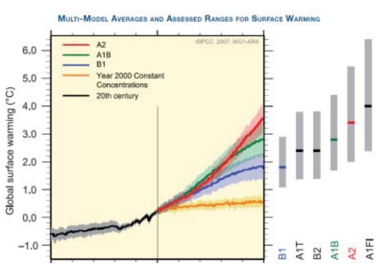
SWAT hydrologic simulations, water quality subbasin

New stream temperature model

Approach





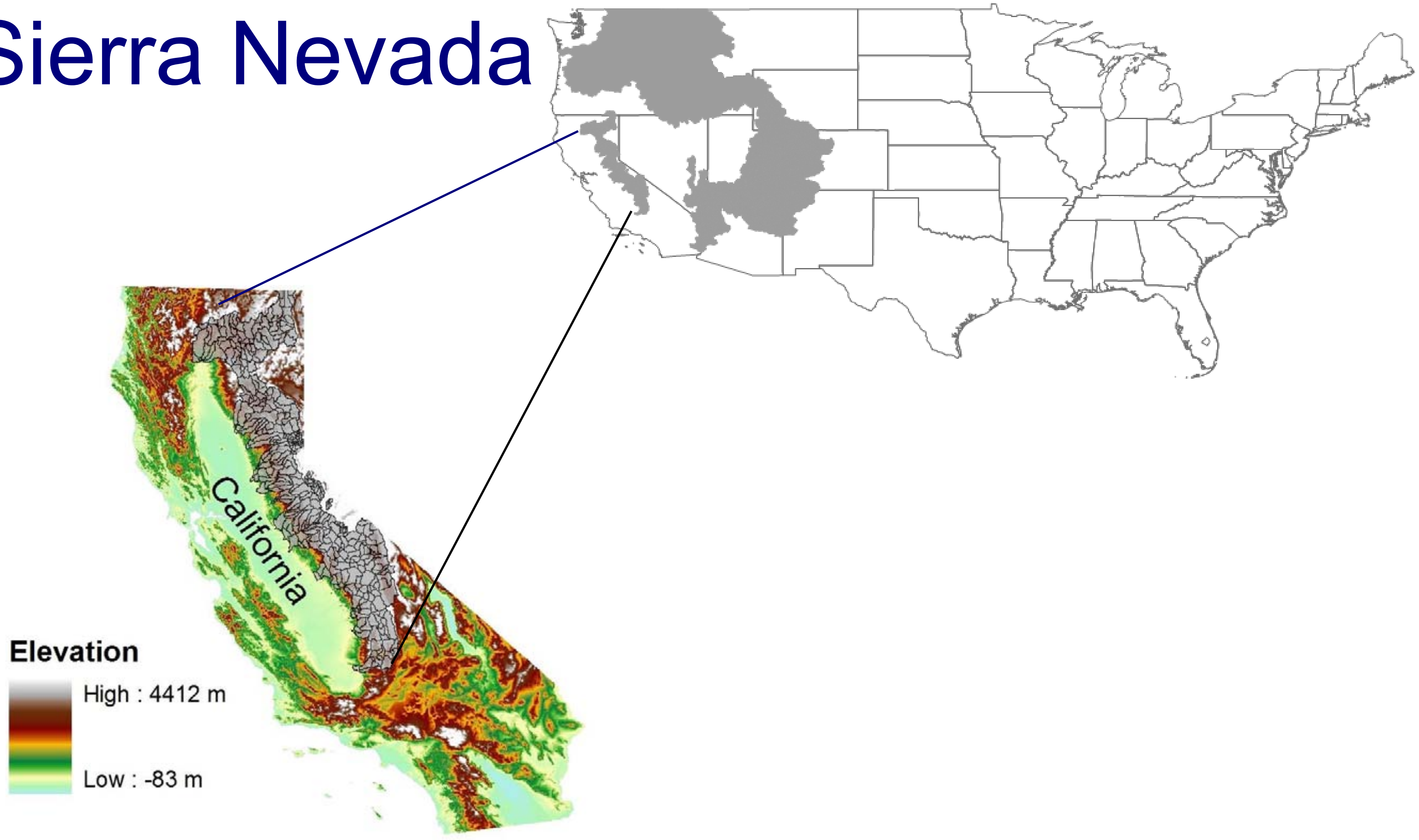


16 GCMs, statistically downscaled output (monthly)

2 emission Scenarios B1, A2

Watershed Delineations Topography Landuse Soil

Pilot:
Sierra Nevada



Commonly stream temperature is modeled solely as function of air temperatures

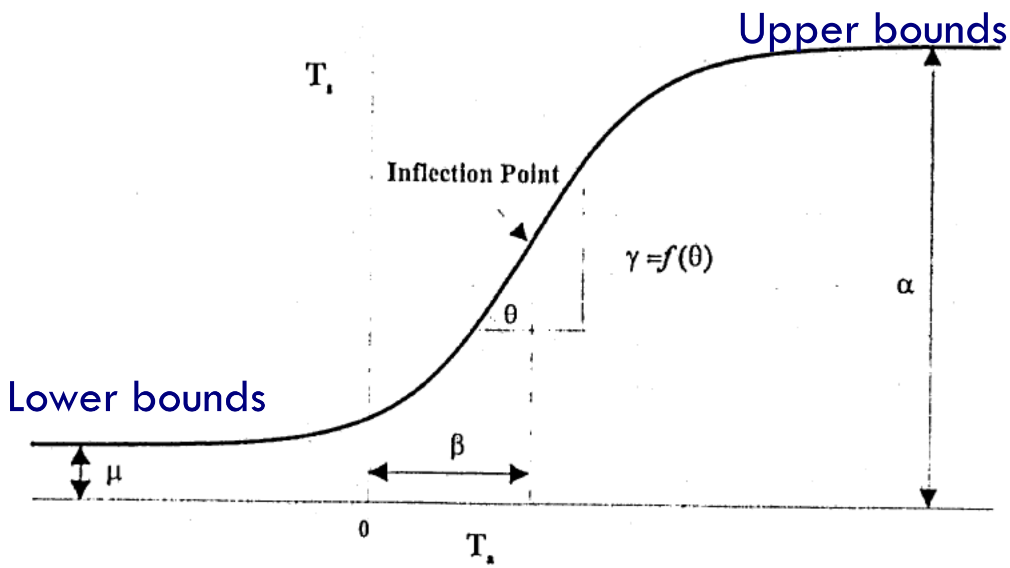
S-shaped function

- Missing: Influence of different hydrologic components and watershed
- SWAT: stream temp from air temp relationship by *Stefan and Prued'homme* [1993]

$T_{water} = 5.0 + 0.75 * T_{air}$

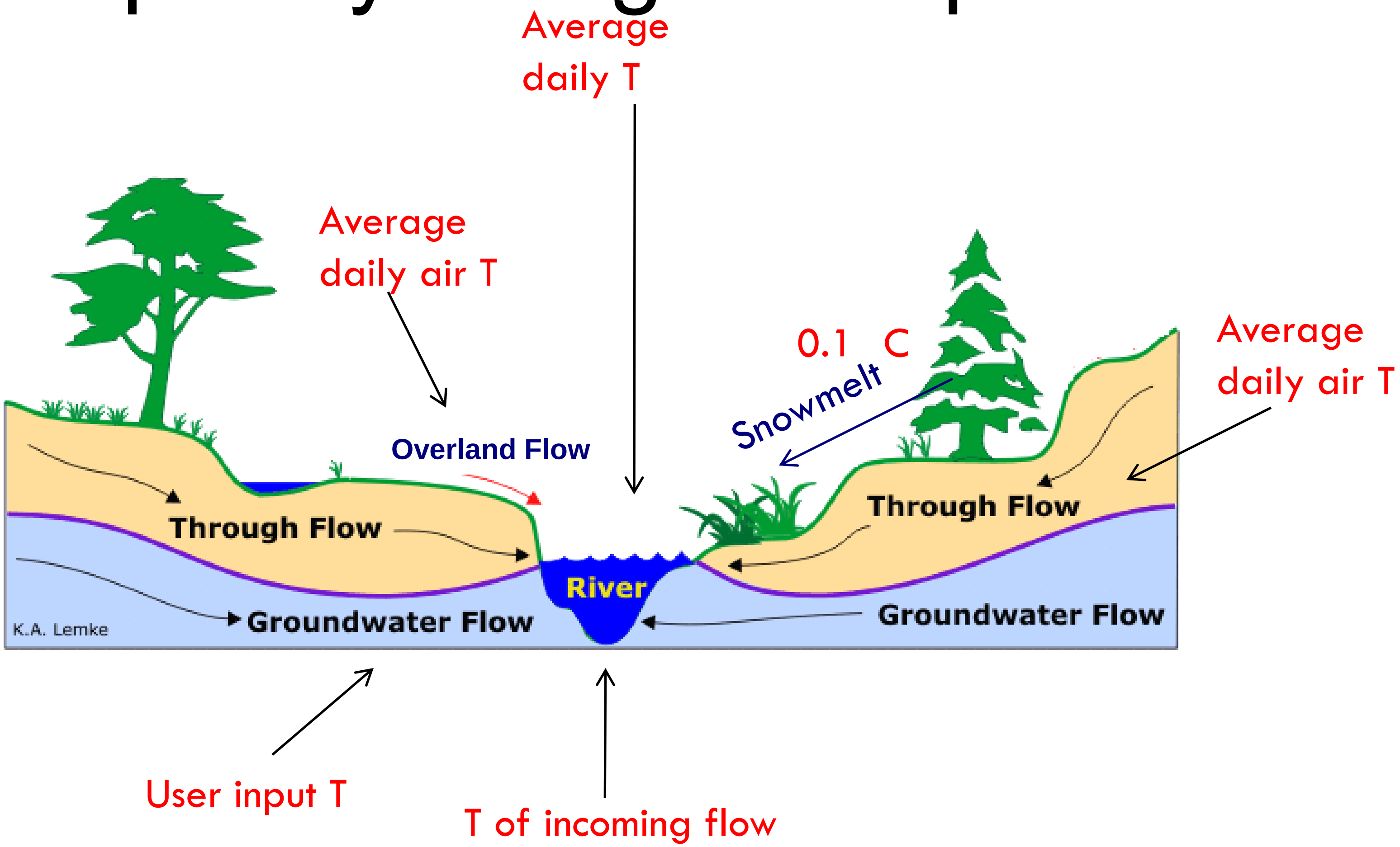
T_{water} = ave daily water temperature (°C)

T_{air} = ave daily air temperature (°C)

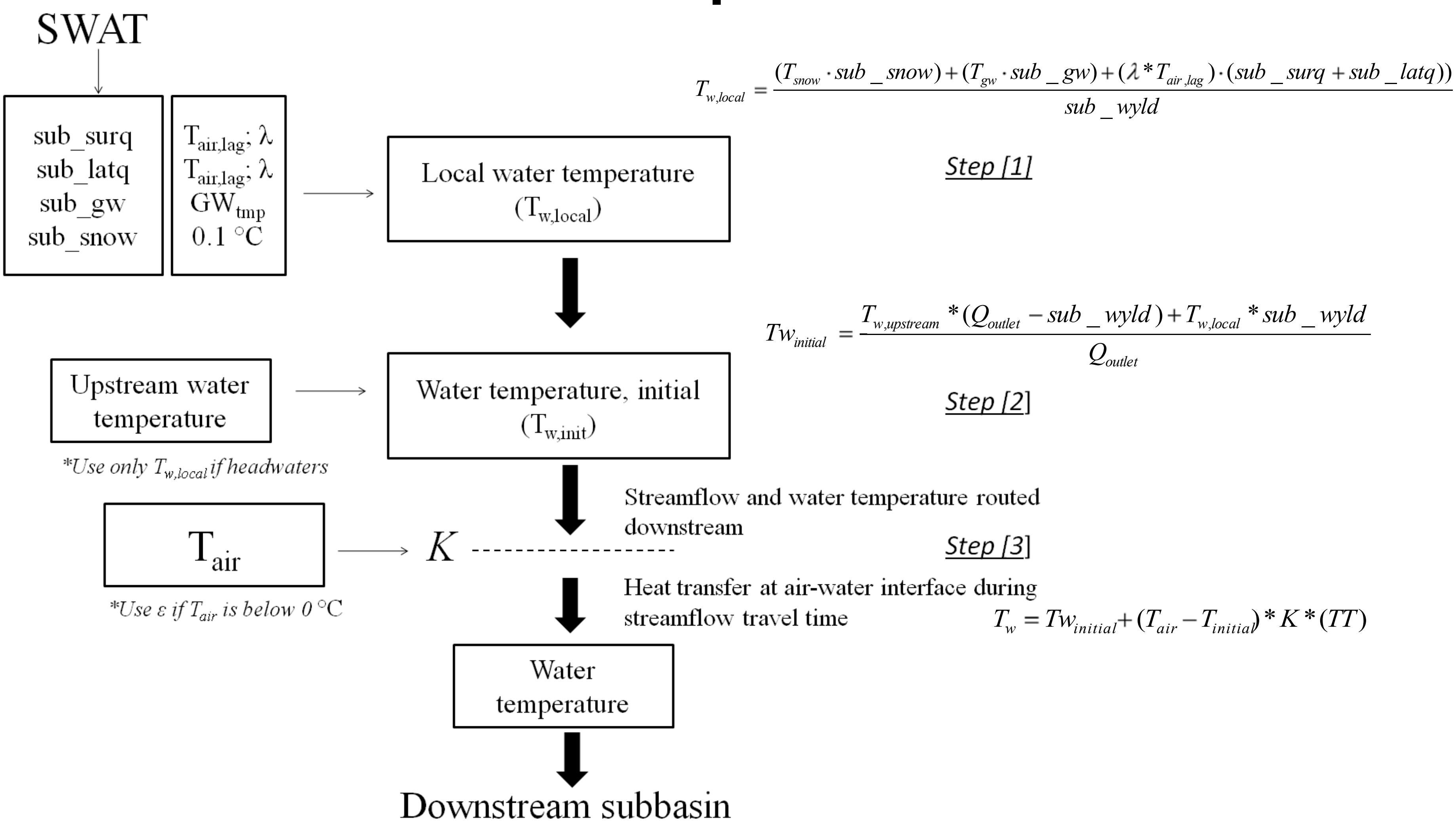


Mohseni et al., 1998

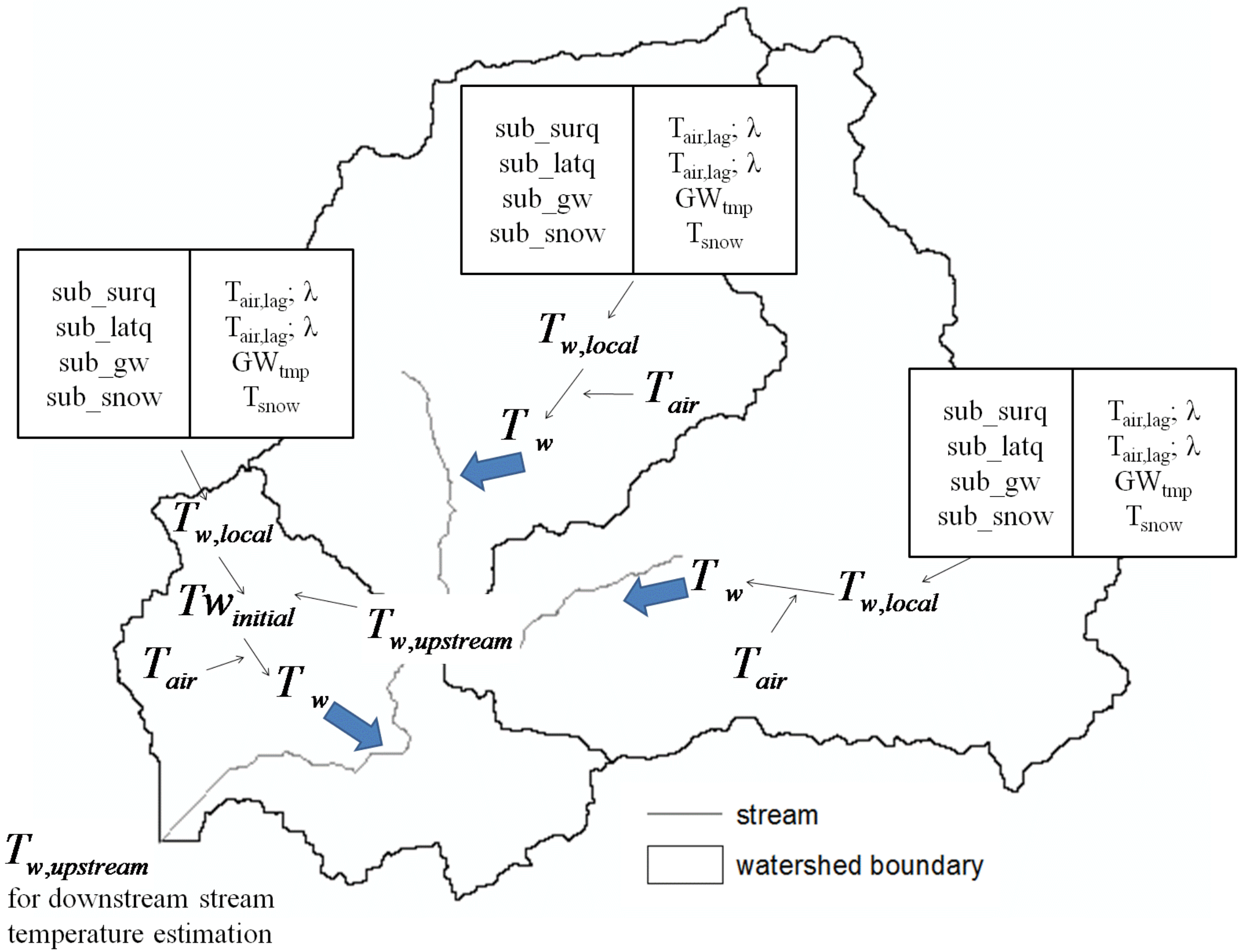
New stream temp model based on air temp & hydrologic components



New stream temperature model



Ficklin DL, Stewart IT, Maurer EP, 2011. *Development and application of a hydroclimatological stream temperature model within SWAT.* Submitted to Water Resour Res



sub_surq
sub_latq
sub_gw
sub_snow
$T_{air,lag}$; λ
$T_{air,lag}$; λ
GW_{tmp}
T_{snow}
sub_surq
sub_latq
sub_gw
sub_snow
$T_{air,lag}$; λ
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GW_{tmp}
T_{snow}
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T_{snow}
$T_{w,local}$
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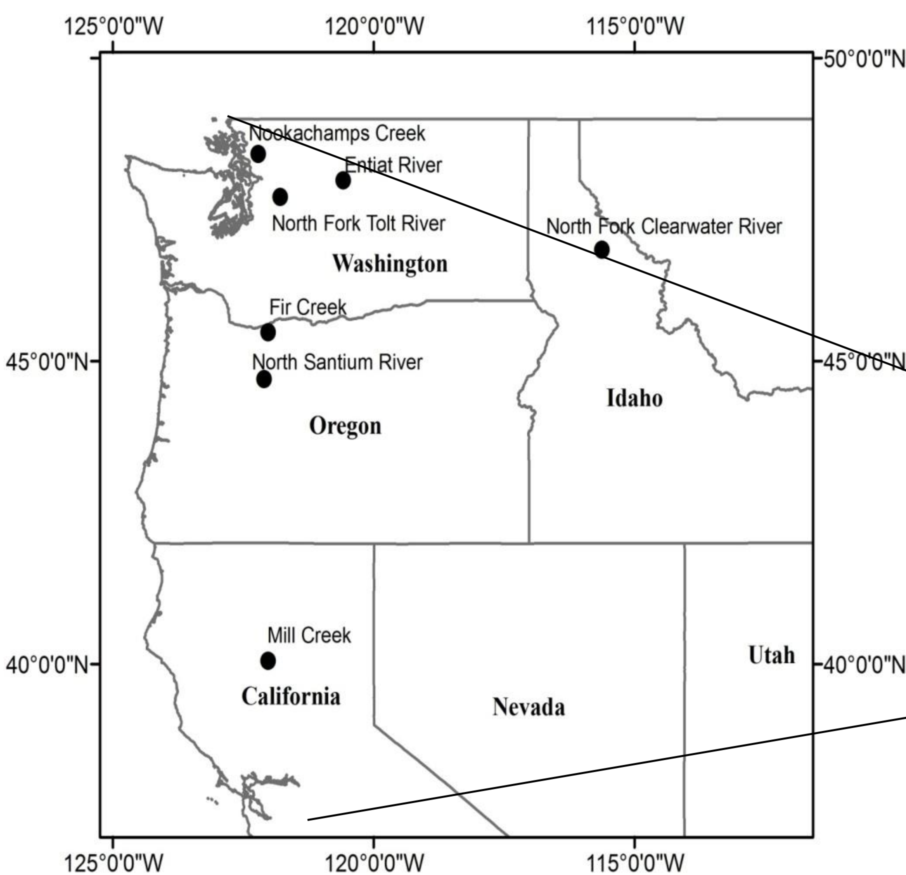
$T_{w,local}$
$Tw_{initial}$
$T_{w,upstream}$
T_{air}
T_w
T_w
$T_{w,local}$
T_{air}
stream
watershed boundary
$T_{w,upstream}$
for downstream stream temperature estimation

Model tested with 7 high quality sites in North American West



- 7 sites:
  - Snowmelt dominated
  - Differing elevations
    - 400 m to 1,400 m
  - High quality stream temp. data

Sensitivity analysis

- Assess effect of input parameter x on output parameter y (stream temperature mean and variance)

	K		*λ*		*Lag*	
Mean	-25%	25%	-25%	25%	-25%	25%
North Fork Clearwater River	-0.01	0.01	-0.09	0.09	-0.01	0.00
Fir Creek	-0.09	0.08	-0.12	0.12	0.00	0.00
Mill Creek	-0.12	0.10	-0.10	0.10	0.00	0.00
Nookachamps Creek	-0.03	0.02	-0.09	0.10	0.00	0.00
North Santium River	-0.05	0.04	-0.04	0.04	0.00	0.00
Entiat River	-0.08	0.08	-0.20	0.22	0.00	0.00
Tolt River	-0.08	0.07	-0.13	0.13	0.00	0.00
AVERAGE	-0.07	0.06	-0.11	0.11	0.00	0.00
STANDARD DEVIATION	0.05	0.04	0.05	0.06	0.00	0.00

	K		*λ*		*Lag*	
Variance	-25%	25%	-25%	25%	-25%	25%
North Fork Clearwater River	-0.03	0.02	-0.07	0.10	0.03	- 0.01
Fir Creek	-0.58	0.67	-0.06	0.18	0.02	- 0.01
Mill Creek	-0.19	0.14	-0.03	0.06	0.03	- 0.01
Nookachamps Creek	-0.14	0.12	0.11	- 0.02	0.03	- 0.01
North Santium River	-0.23	0.16	-0.02	0.03	0.04	- 0.02
Entiat River	-0.11	0.12	-0.43	0.52	0.01	0.00
Tolt River	-0.21	0.21	-0.28	0.35	0.05	- 0.03
AVERAGE	-0.21	0.21	-0.11	0.18	0.03	- 0.02
STANDARD DEVIATION	0.19	0.22	0.18	0.20	0.01	0.01

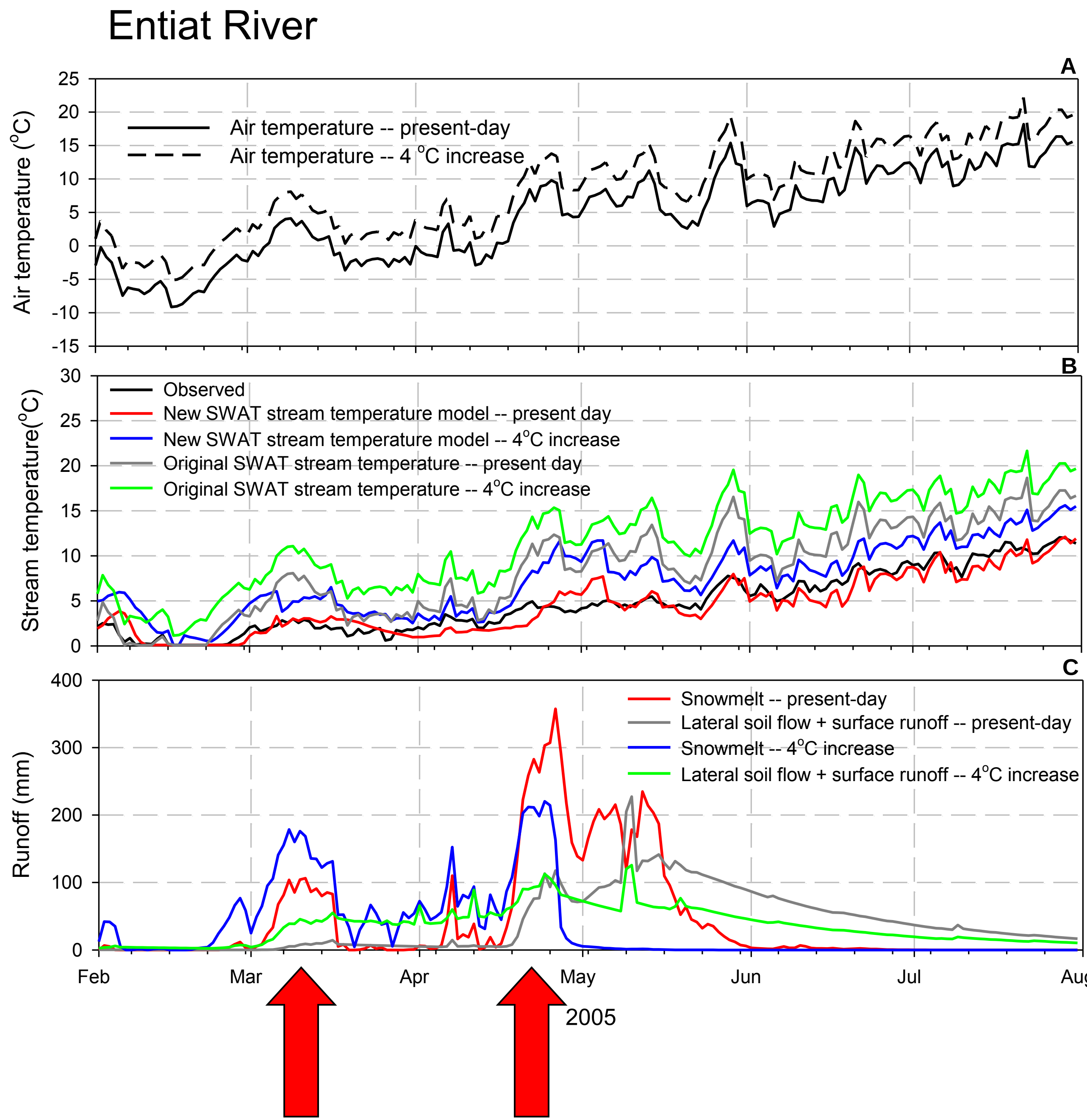
K and λ of high and medium sensitivity, lag and ε low sensitivity

New stream temperature model requires user to get the hydrology right

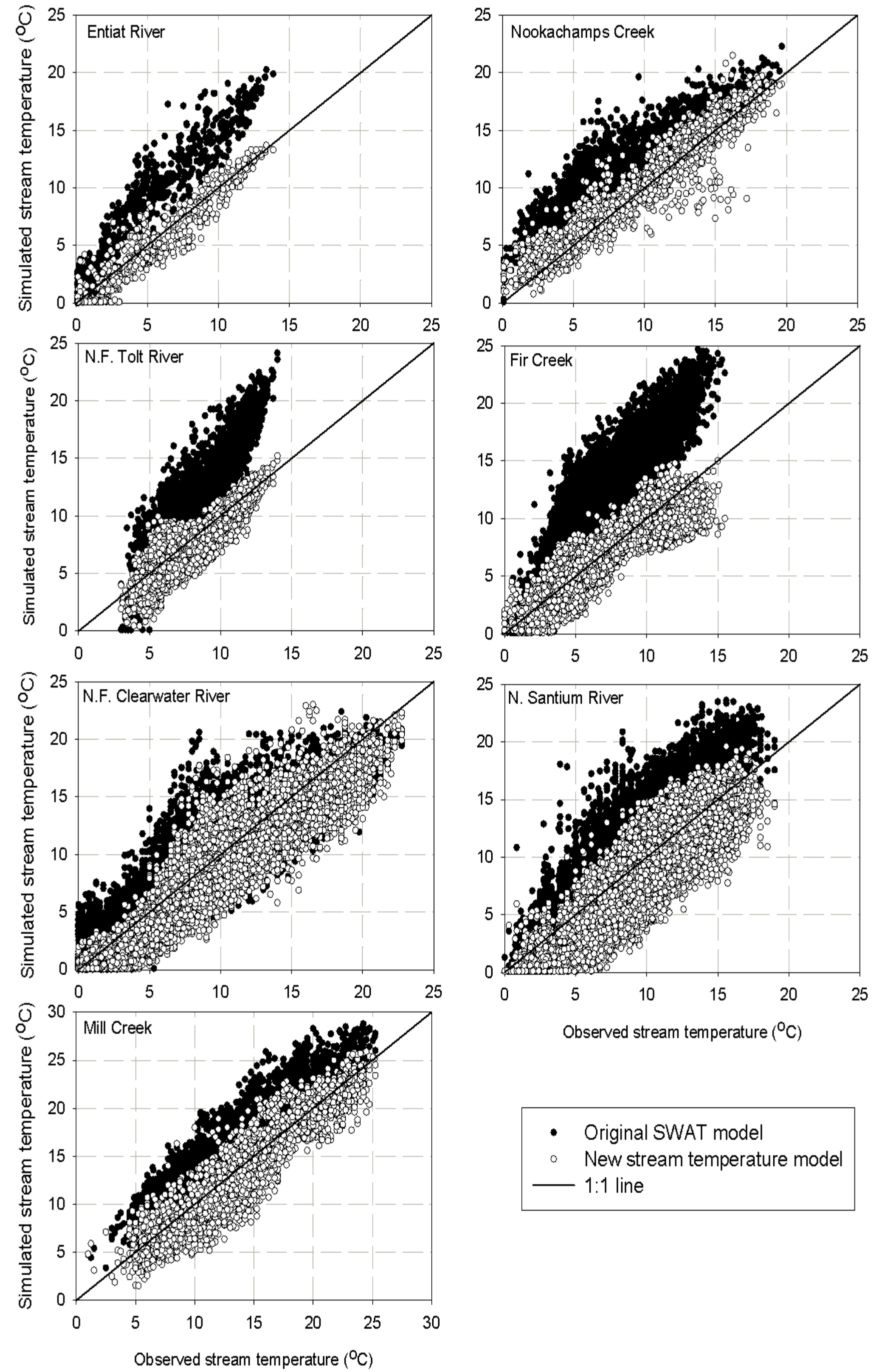
	Calibration			Validation		
Site	Years	NS	MSE	Years	NS	MSE
Entiat River	2003-2004	0.71	4.0	2005	0.60	2.9
Nookachamps Creek	2000-2003	0.68	1.2	2004-2005	0.64	1.5
North Fork Tolt River	1990-1998	0.65	6.4	1999-2005	0.57	6.4
Fir Creek	1980-1993	0.69	0.7	1994-2003	0.61	0.8
North Fork Clearwater River	1970-1990	0.64	69.3	1991-2005	0.69	60.0
North Santium River	1950-1980	0.59	15.5	1981-2005	0.64	14.1
Mill Creek	1990-1998	0.78	6.8	1999-2005	0.53	7.0

New stream temp model

allows a more realistic representation of changes in hydrologic components and their effects



New stream temperature model performs better compared to existing



Improved performance of new stream temp model

Calibration/Validation results

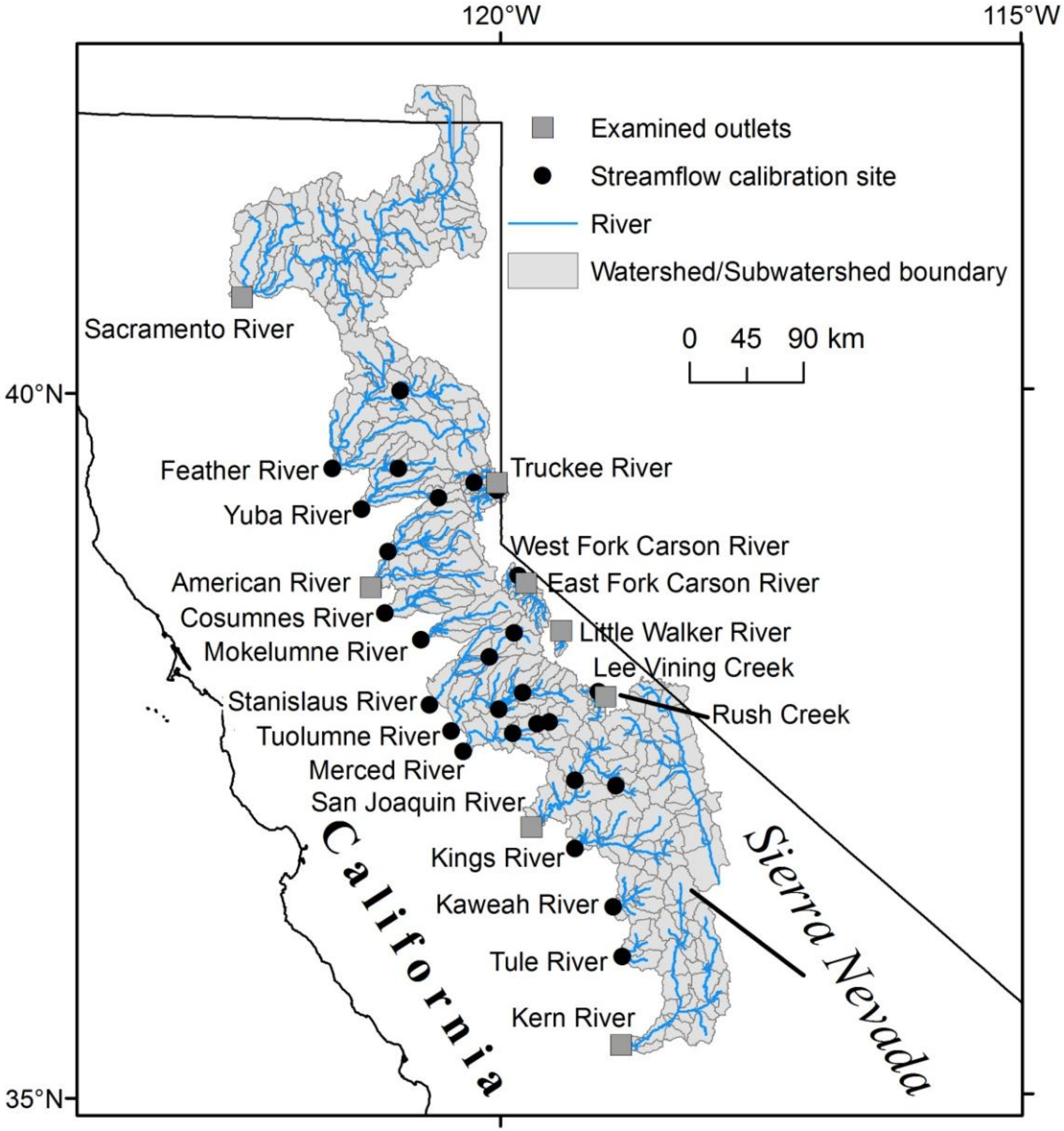
		Original SWAT stream temperature model						New SWAT stream temperature model				
	Calibration			Validation			Calibration			Validation		
River	**Years**	**NS**	**RMSE (^oC)**	**Years**	**NS**	**RMSE (^oC)**	**Years**	**NS**	**RMSE (^oC)**	**Years**	**NS**	**RMSE (^oC)**
Entiat River	2003-2004	-0.08	3.97	2005	-0.16	4.27	2003-2004	0.89	1.26	2005	0.89	1.33
Nookachamps Creek	2000-2003	0.24	3.96	2004-2005	0.31	3.81	2000-2003	0.86	1.67	2004-2005	0.91	1.33
North Fork Tolt River	1995-2000	-1.60	4.08	2001-2003	-1.54	3.99	1995-2000	0.70	1.38	2001-2003	0.77	1.21
Fir Creek	1980-1992	-2.27	5.44	1993-2003	-2.23	5.47	1980-1992	0.75	1.50	1993-2003	0.76	1.48
North Fork Clearwater River	1970-1990	0.80	2.72	1991-2005	0.83	2.54	1970-1990	0.87	2.19	1991-2005	0.84	2.61
North Santium River	1951-1980	0.49	2.53	1981-2005	0.59	2.58	1951-1980	0.73	2.14	1981-2005	0.70	2.24
Mill Creek	1998-2002	0.54	3.85	2003-2005	0.40	4.05	1998-2002	0.85	2.20	2003-2005	0.87	1.93

*Original SWAT stream temp: average NS of 0.27 and -0.26 for calibration and validation period

*New SWAT stream temp: average NS of 0.81 and 0.82 for calibration and validation period

Sierra Nevada results

Ficklin DL, Stewart IT, Maurer EP. *Projections of 21st century Sierra Nevada local hydrologic flow components using an ensemble of General Circulation Models*. In preparation.



Simulations of all sub-watersheds

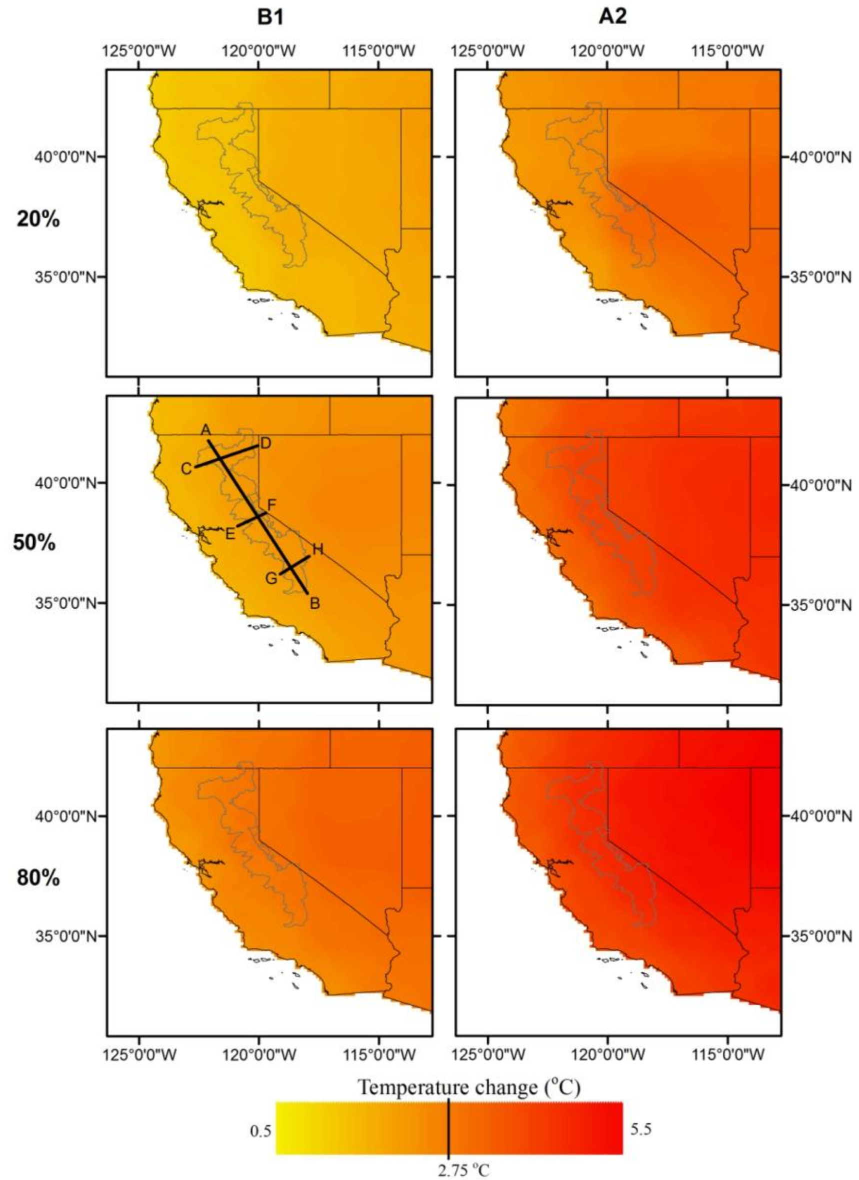
Multiple calibration sites

Automated calibration using SUFI-2

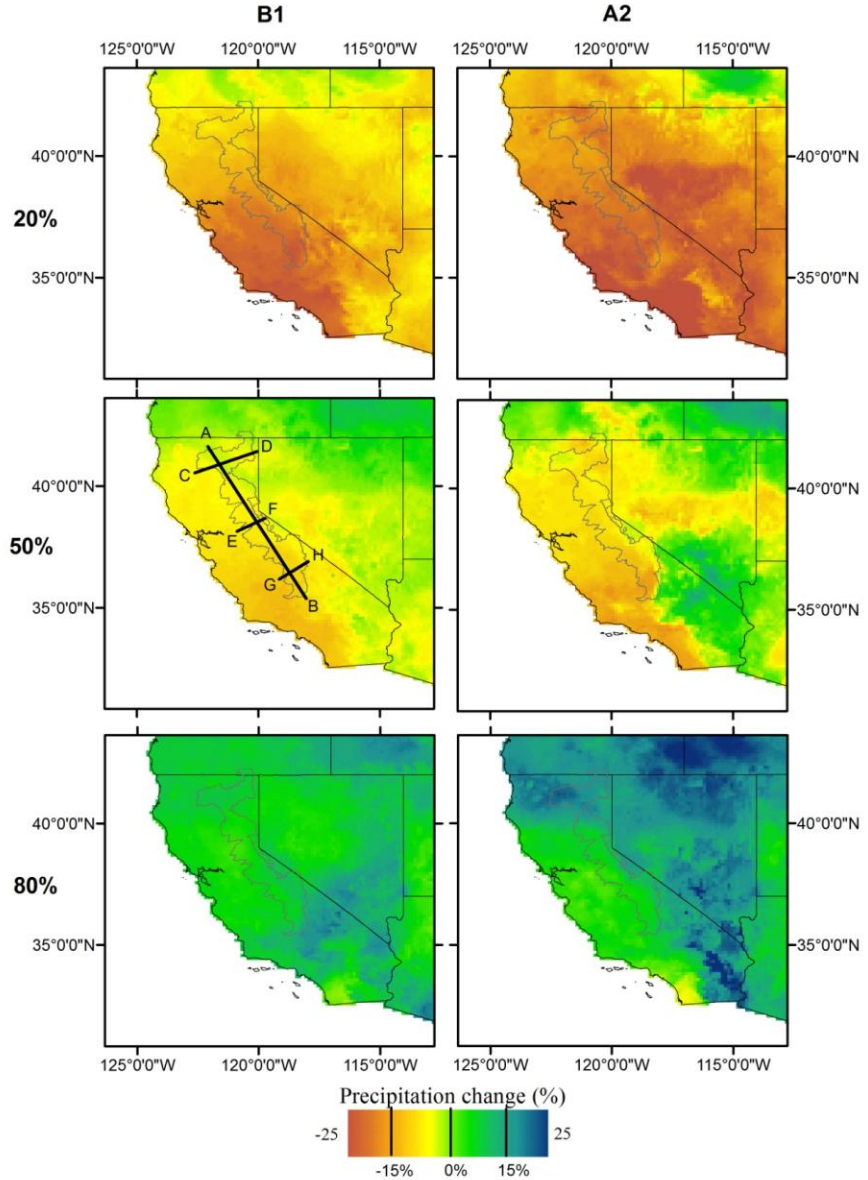
Split sample approach for calibration and validation

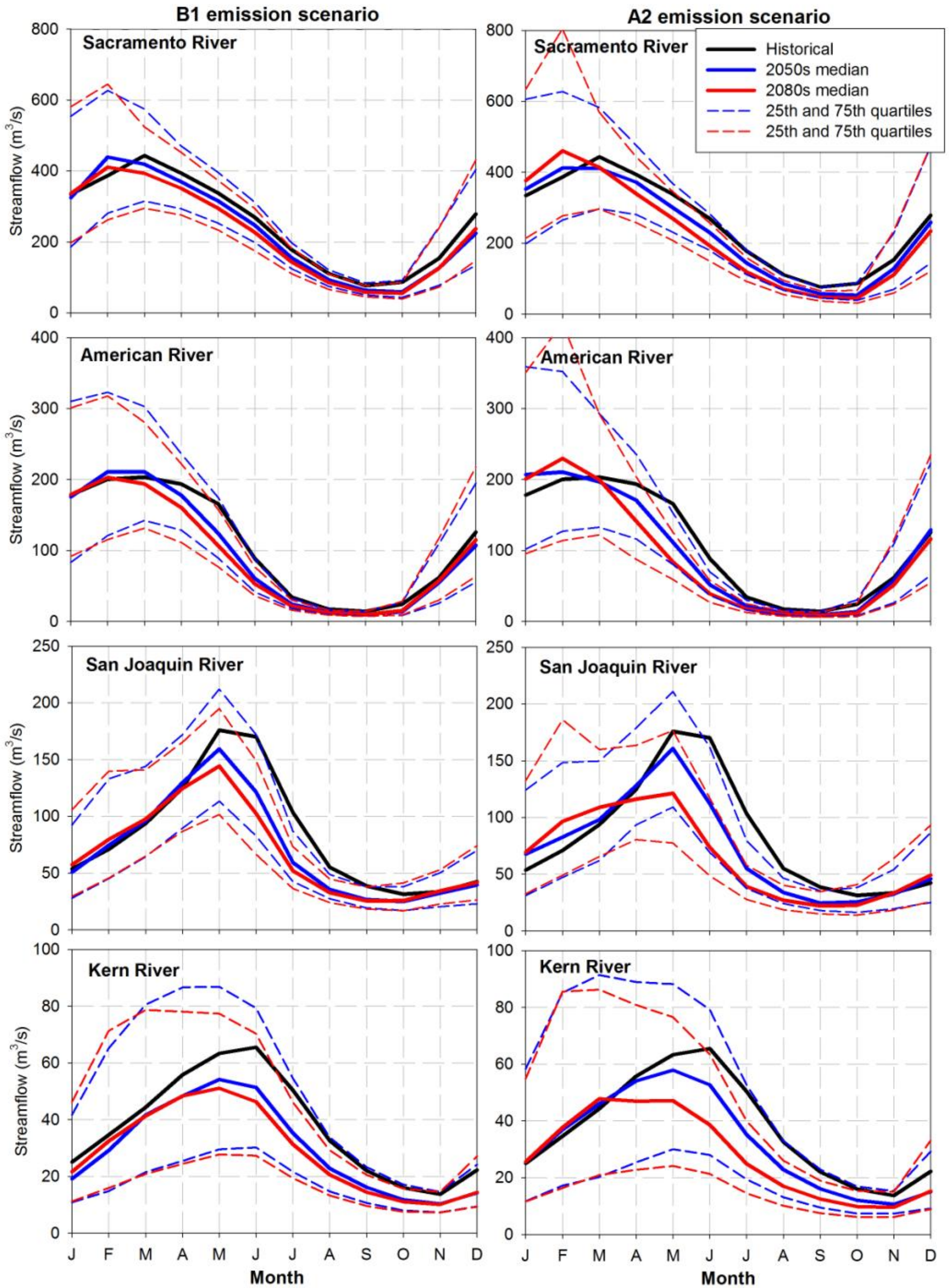
Air temperature changes:

Expect warming by 2-5 C

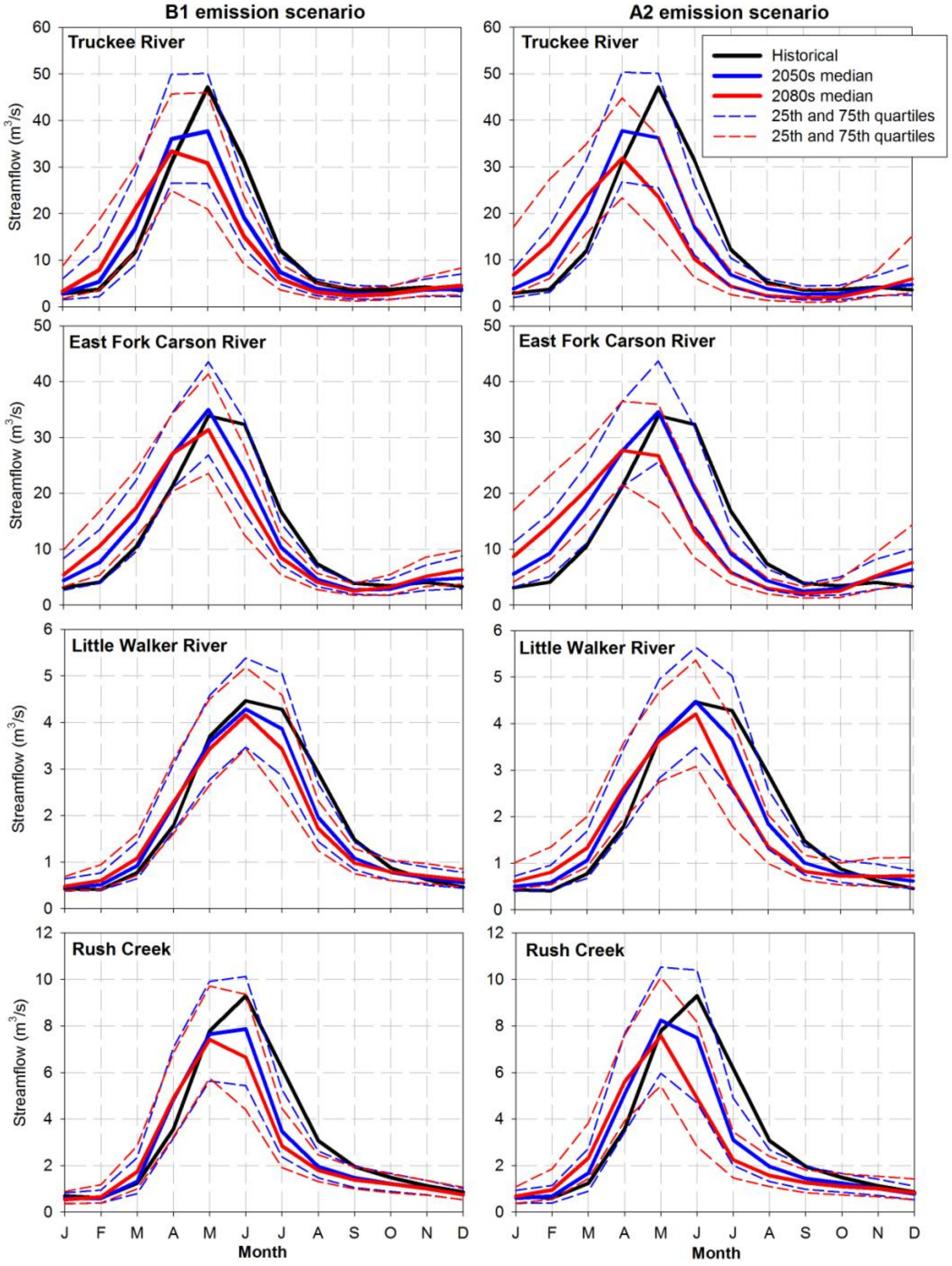


Precipitation changes more variable, generally drying





- 4 West side outflows
  - Lower Spring & Summer
  - Earlier peak



- 4 East side outflows
- Less effect in higher basins
  - Lower Spring & Summer
  - Earlier peak

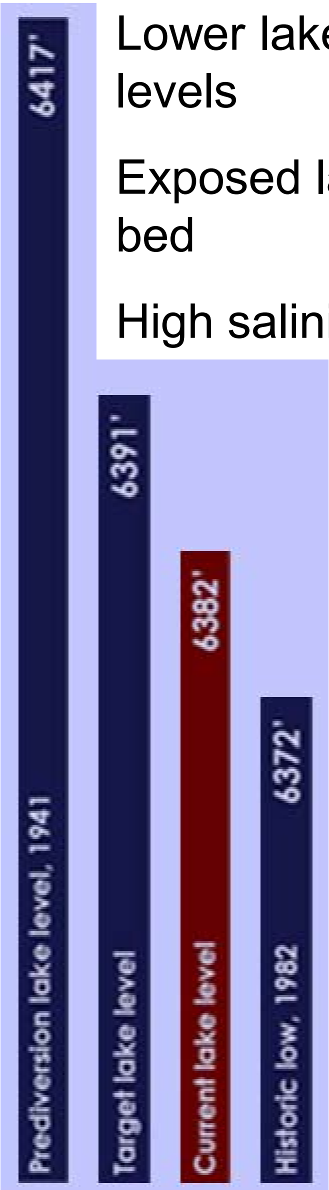
Used model to evaluate impacts of climate change on the inflows to Mono Lake

1941-82:

Lower lake levels

Exposed lake bed

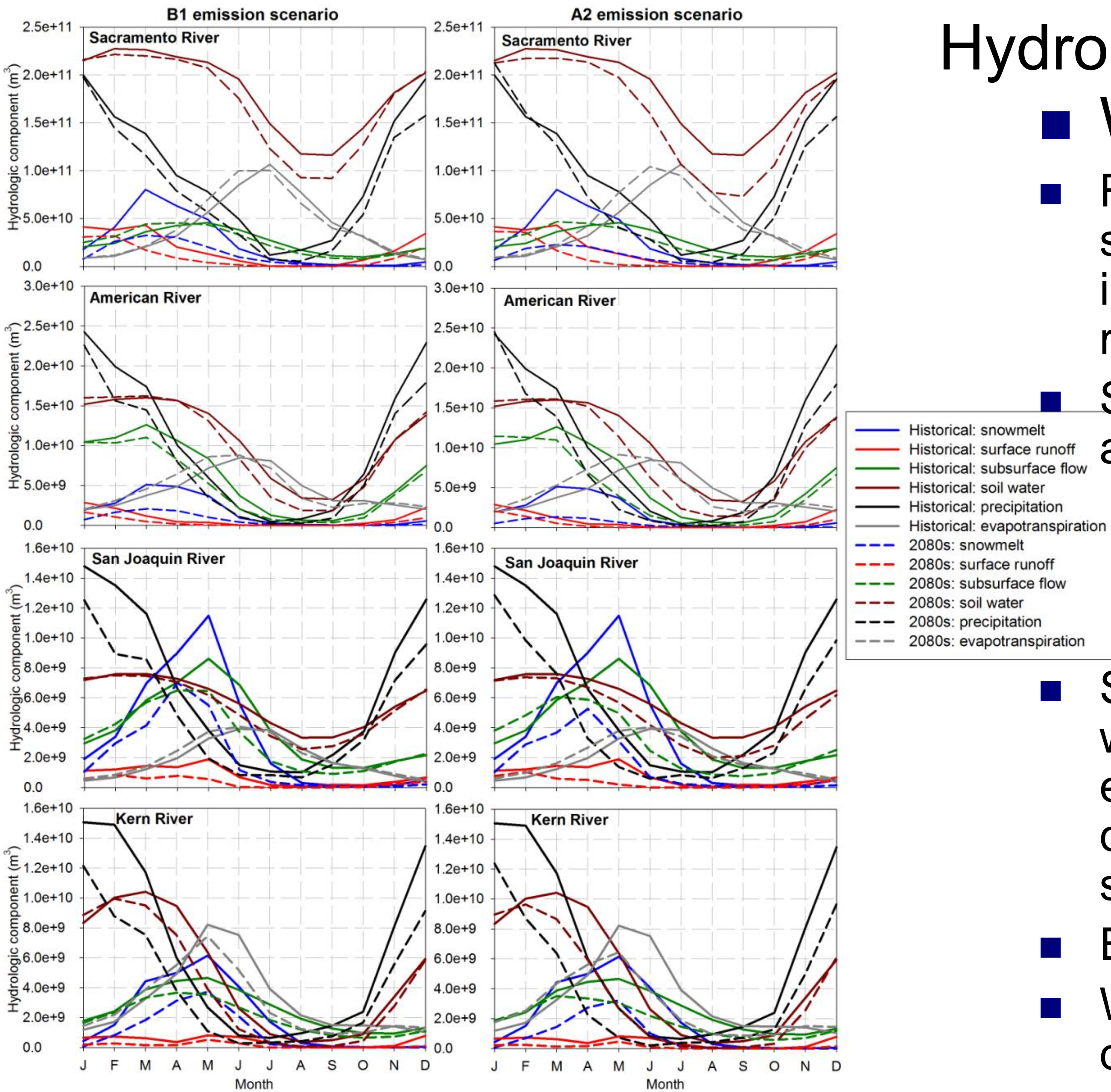
High saliniy



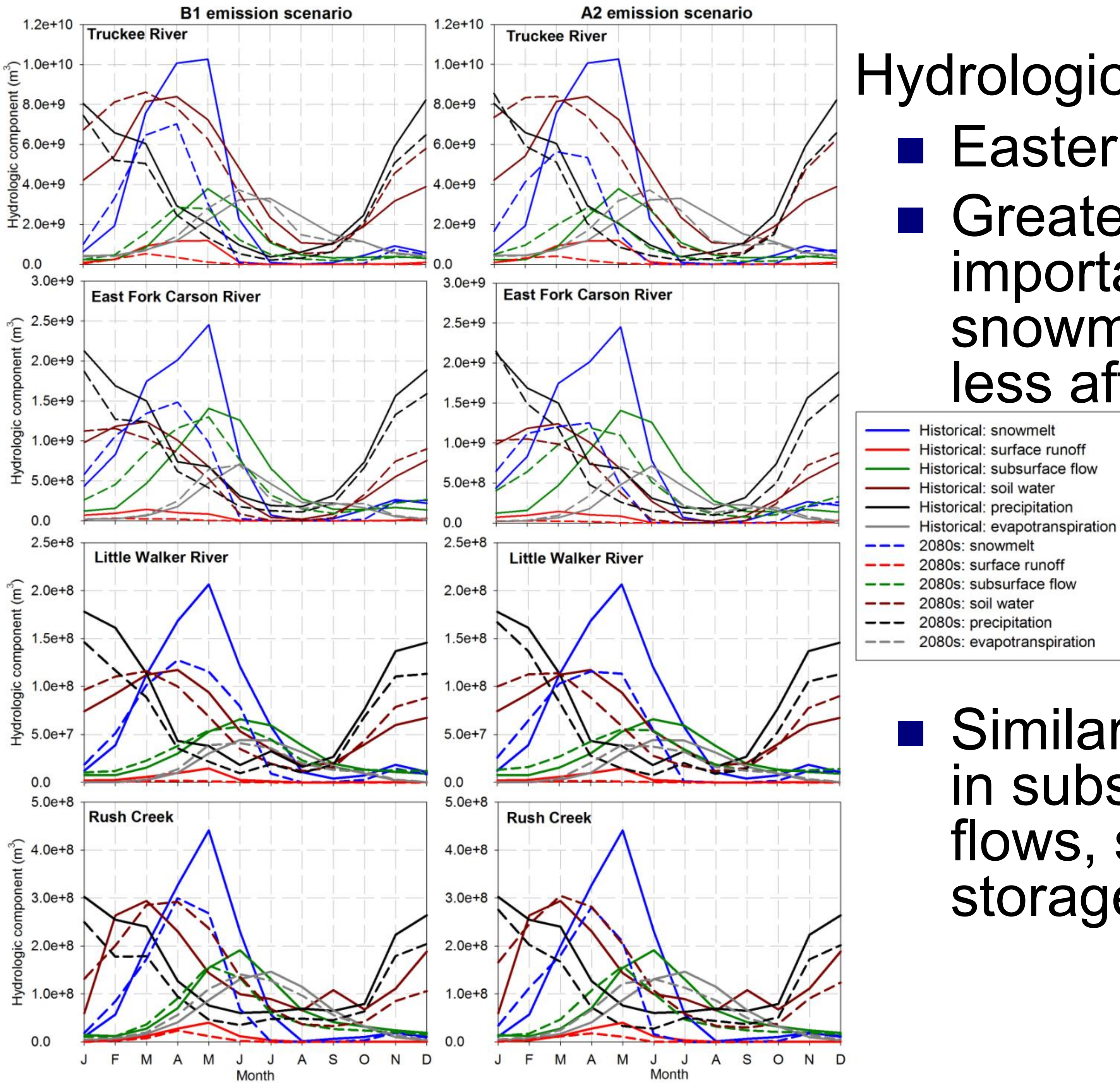
Ficklin DL, Stewart IT, Maurer EP. *Effects of projected climate change on the hydrology in Mono Lake Basin, California*. Submitted to Climatic Change, 2011.

Hydrologic Components

- Western Sierras
  - Regional differences in soil storage and importance of snowmelt runoff pulse
  - Snowpulse advanced and diminished



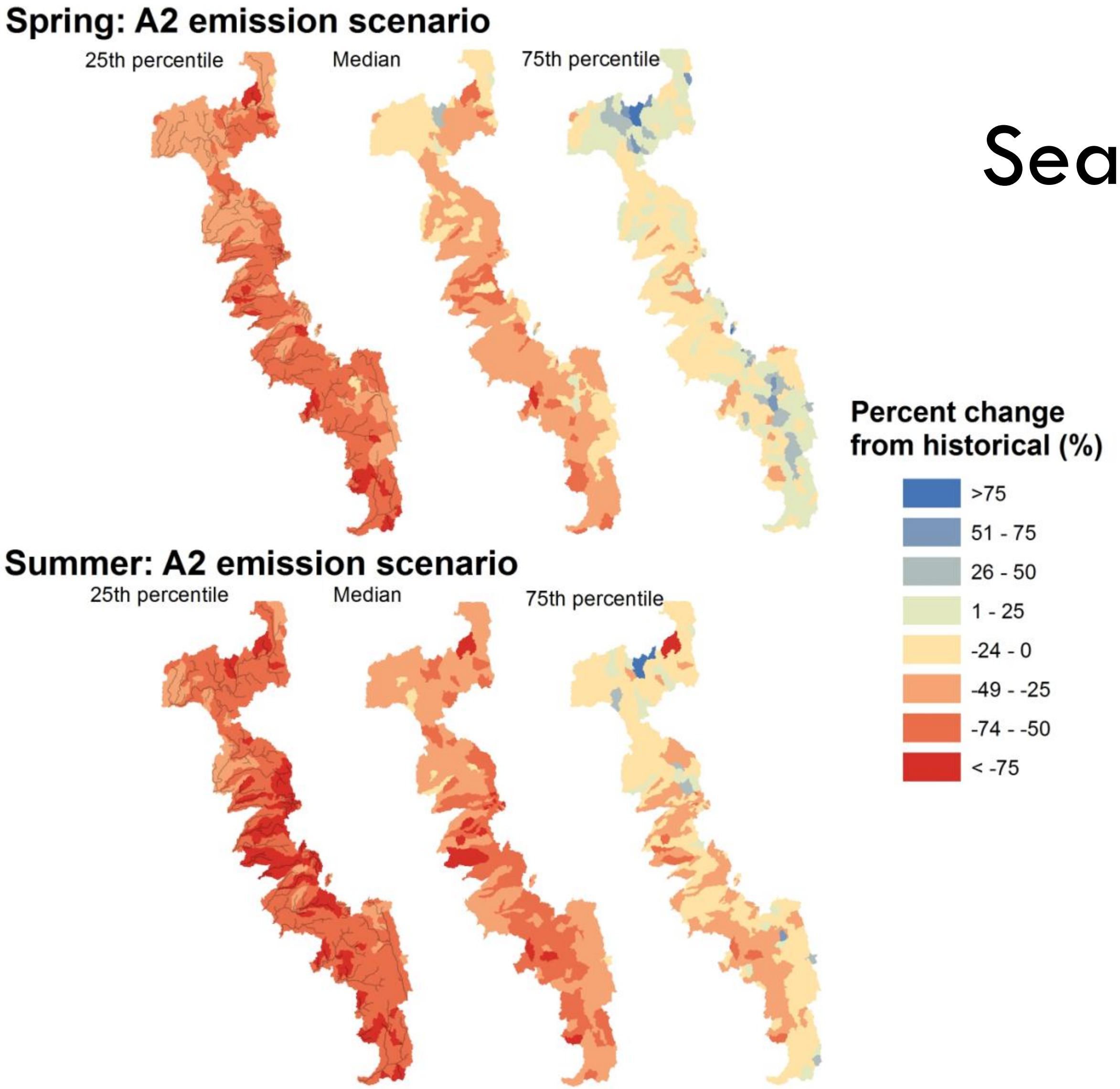
  - Subsurface flows and soil water storage shift to earlier in the season, declines for spring and summer
  - Earlier ET
  - Winter and spring declines of surface runoff



Hydrologic Components

- Eastern Sierras
- Greater importance of snowmelt pulse, less affected
- Similar advances in subsurface flows, soil storage, and ET

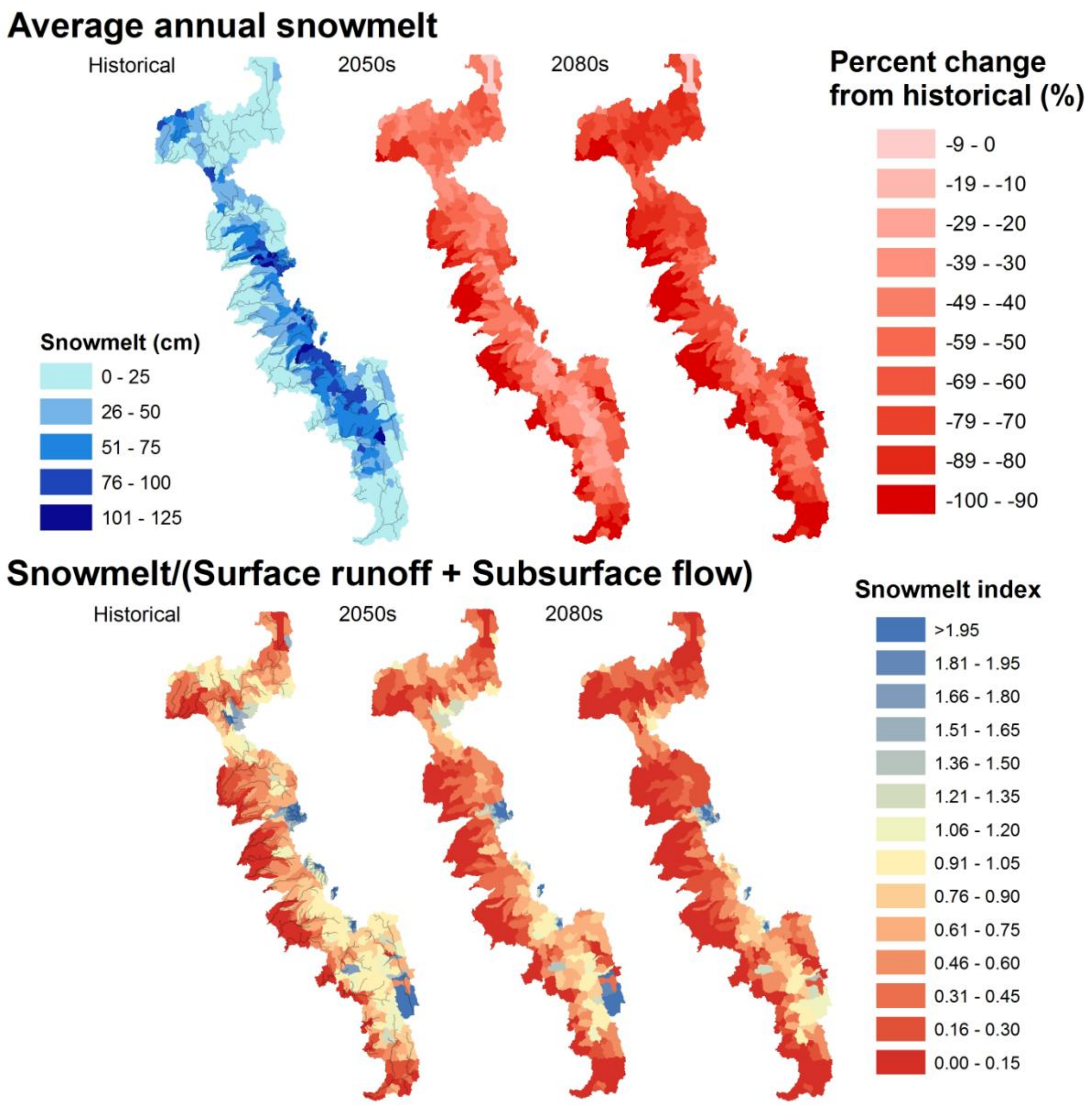
% Change in Seasonal Flow by 2100

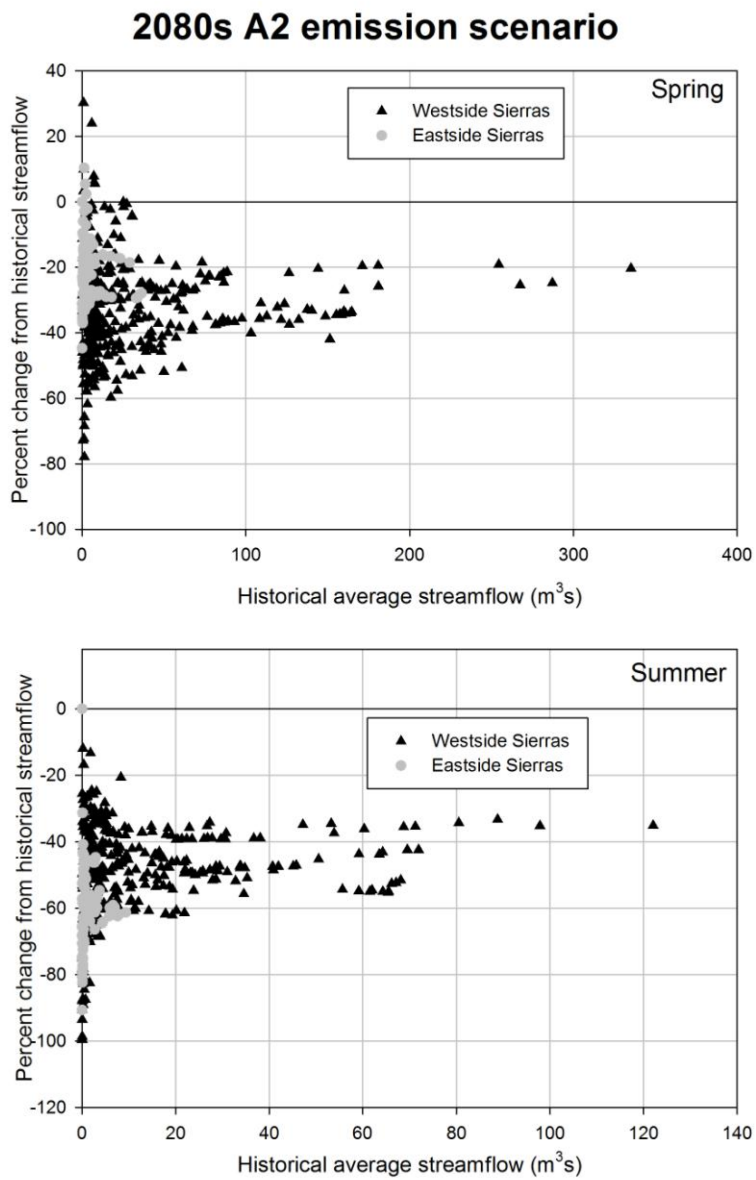


- Substantial flow decreases in headwaters and downstream basins
- Decreases in spring and summer

Changes in snowmelt and surface runoff components:

- Less snowmelt
- greatest changes in lower reaches with higher flows

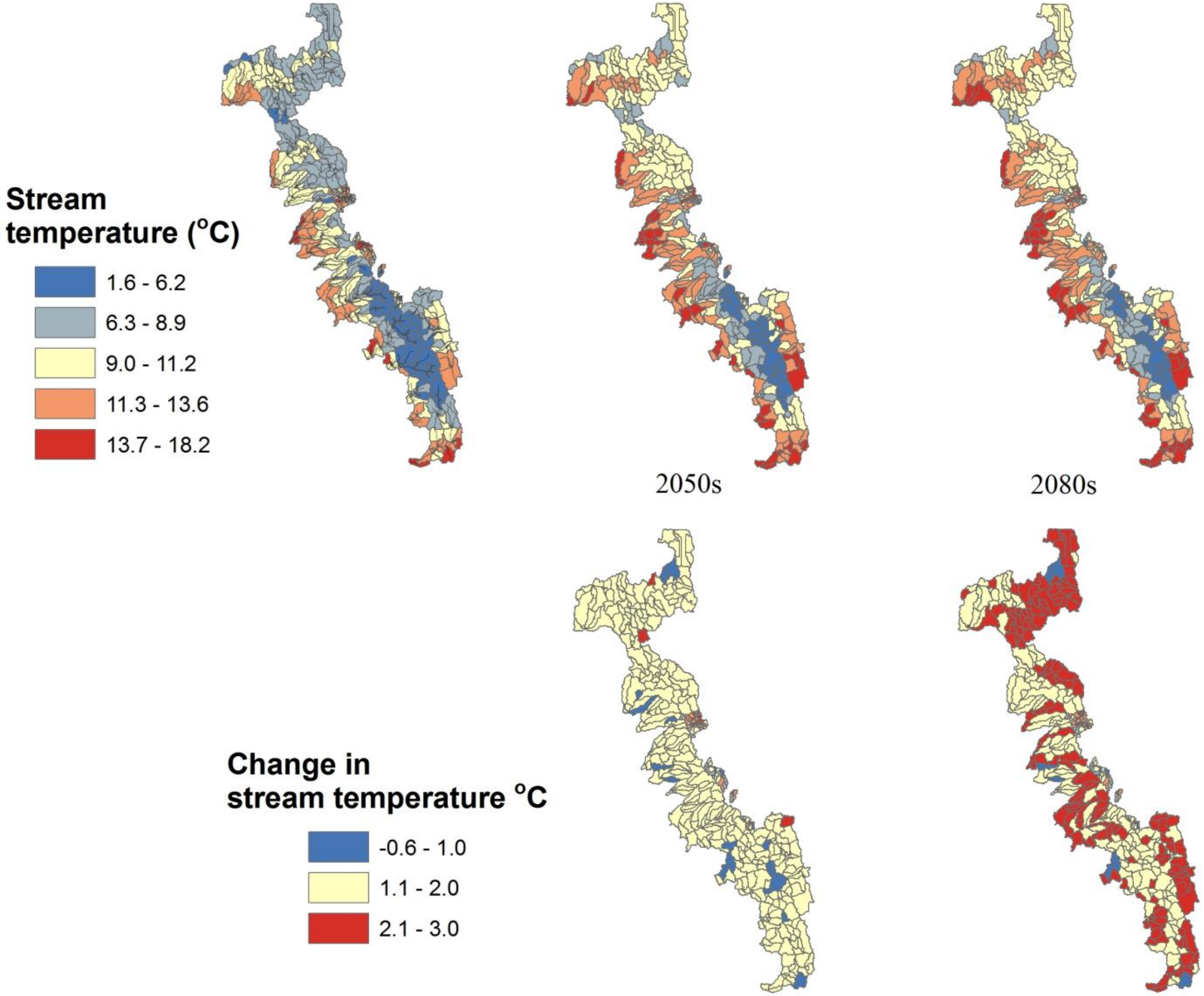




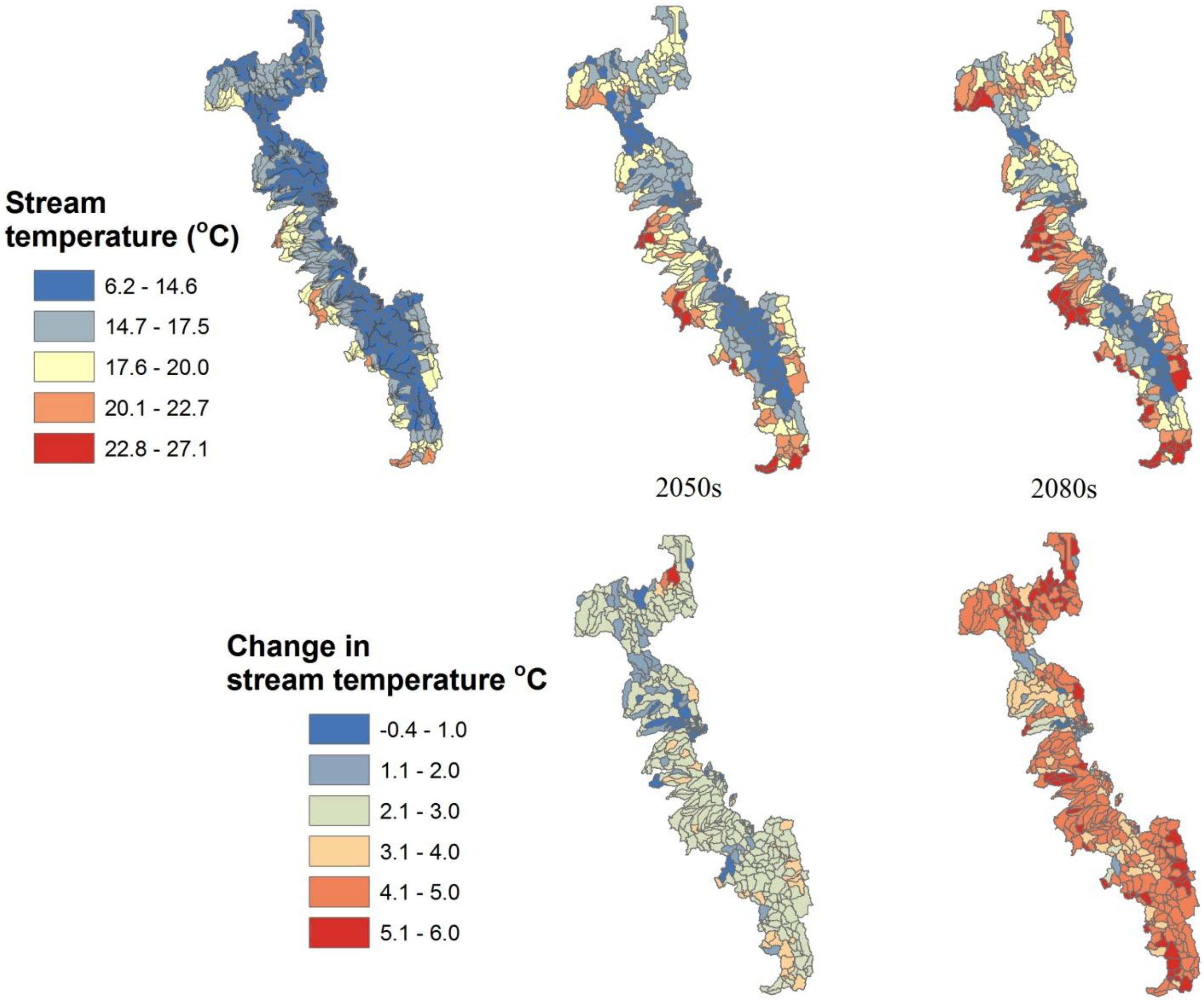
% Change vs. Historic Flow Volumes

Large basins likely to experiece ~20-40% less flow in Spring, and ~30-60% in Summer

Spring stream temperature increases of 1-3 C by the end of the century (A2)



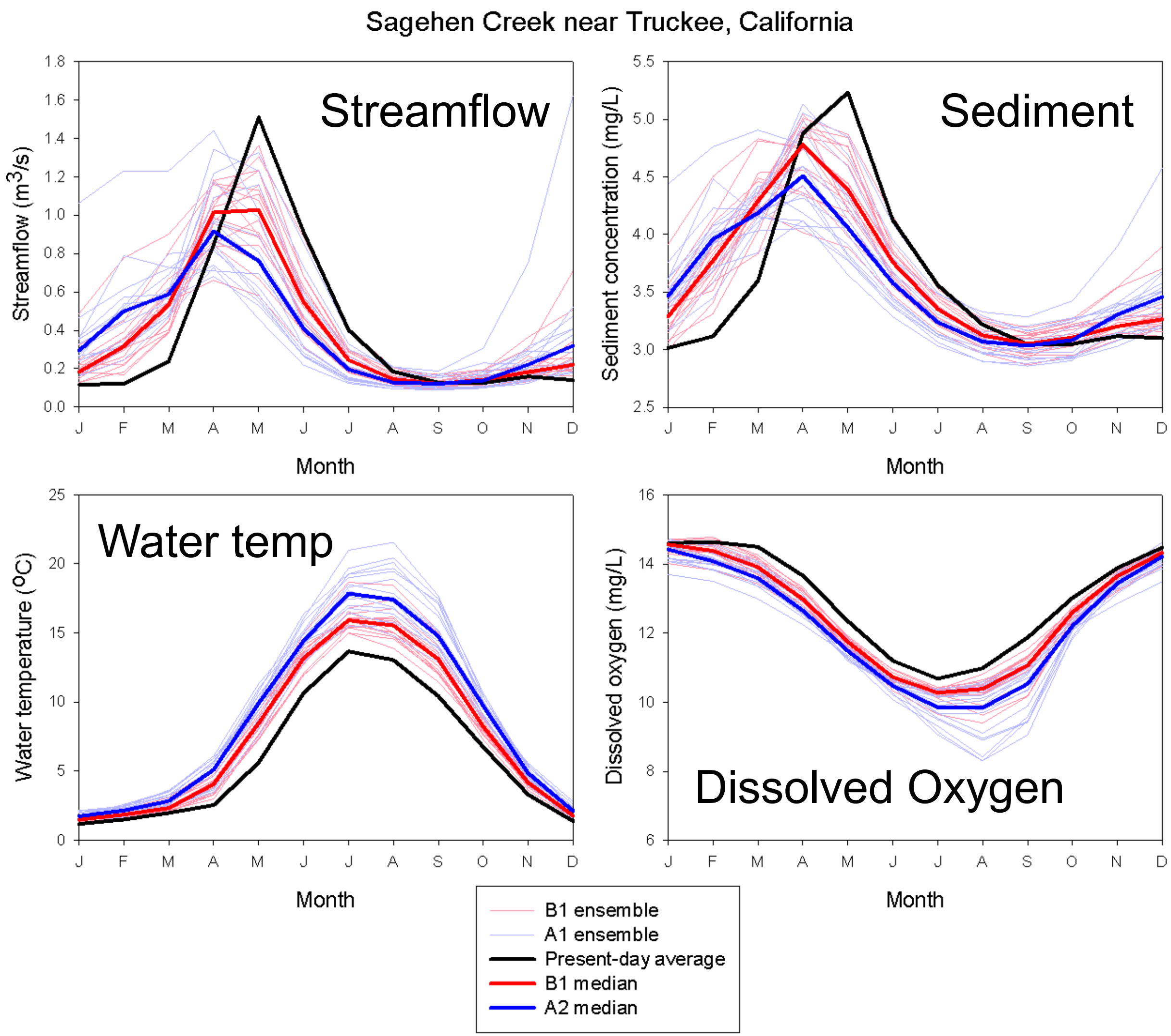
Summer stream temperatures increases of 2-6 C by end of century (A2)



Sagehen Creek

Contains Rainbow Trout !

- Earlier streamflow and significantly lower summer flows
- Summer water temperatures warming by 5 degC and more
- Significant decrease in Spring sediment transport
- Decreases in summer dissolved oxygen



Aquatic ecosystem degradation for more than cold-water species

Conclusions

- Cannot expect stationarity in the regimes, need to examine if existing tools can capture changes, development of new tools
- Warmer temperatures not only affect the timing of snowmelt runoff but shift the timing and relative magnitude of other hydrologic components (soil storage, surface and subsurface flow) with potential ecological consequences
- Substantial expected decreases in Sierra Nevada flow volumes for spring and especially for summer, contribute to stream temperature increases by several degrees.
- Subbasin scale allows identification of the most vulnerable basins and aid in policy and management decisions

Future work

- Calibration and water flow and quality simulation of basins throughout the West
- Evaluation of simulation results and uncertainties for ensemble GCMs, 2 scenarios, different temporal and spatial scales, within basin and region-to-region differences
- Identification of most sensitive basins and their characteristics
- Assessment of impact on aquatic ecosystems, i.e. what is the probability that a threshold is exceeded?