DEVELOPMENT AND APPLICATION OF A HYDROCLIMATOLOGICAL STREAM TEMPERATURE MODEL WITHIN SWAT

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Introduction and background

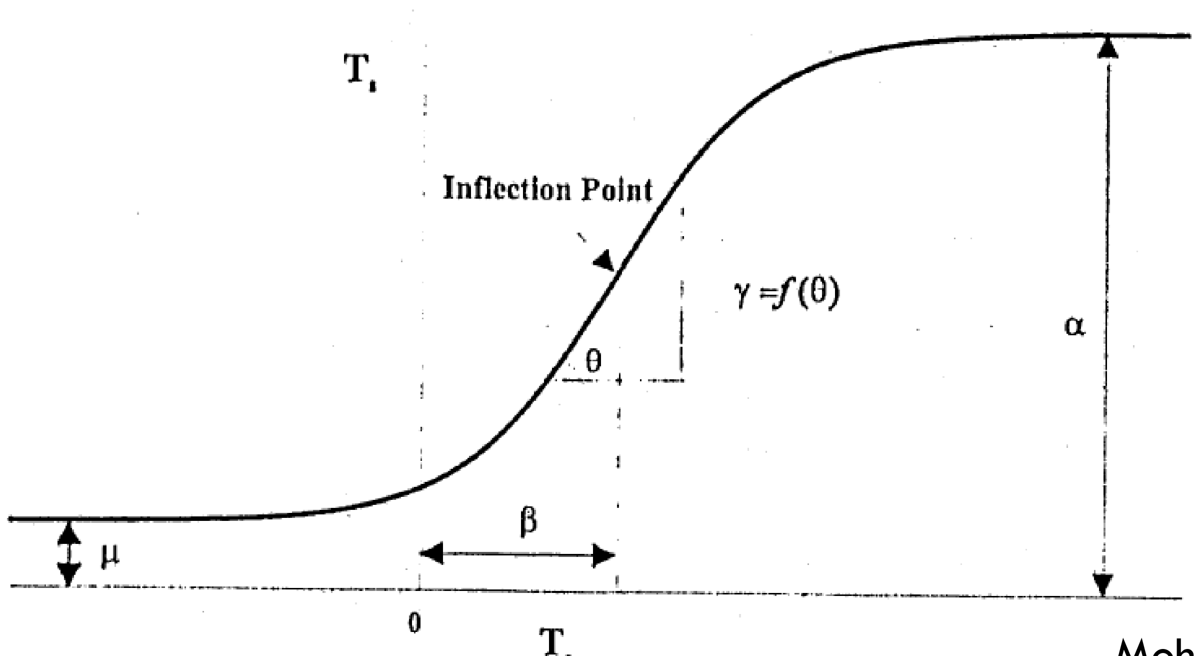
- Stream temperature has direct and indirect effects on aquatic species health
- Stream temperatures reflect the combined influence of meteorological and hydrologic factors
  - Stream temperature strongly correlated to air temp.
  - Low streamflow, lower the capacity for heat storage
  - Snowmelt, surface runoff, and groundwater entering the stream have different temperature signatures

Introduction and background

- Many studies successfully model stream temp. based solely on a relationship with air temp.
- Others use a S-shaped function

Upper bounds

Lower bounds



Mohseni et al., 1998

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Introduction and background

- SWAT estimates stream temperature from relationship developed by *Stefan and Prued'homme* [1993]

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

T_{water} = average daily water temperature (°C)
T_{air} = average daily air temperature (°C)
**does not account for influence of streamflow, groundwater inflow, snowmelt

- We develop a stream temp. model within SWAT that reflects the combined influence of meteorological (air temp.) and hydrological conditions (streamflow, snowmelt, groundwater, surface runoff, and lateral soil flow) on water temperature within a watershed.

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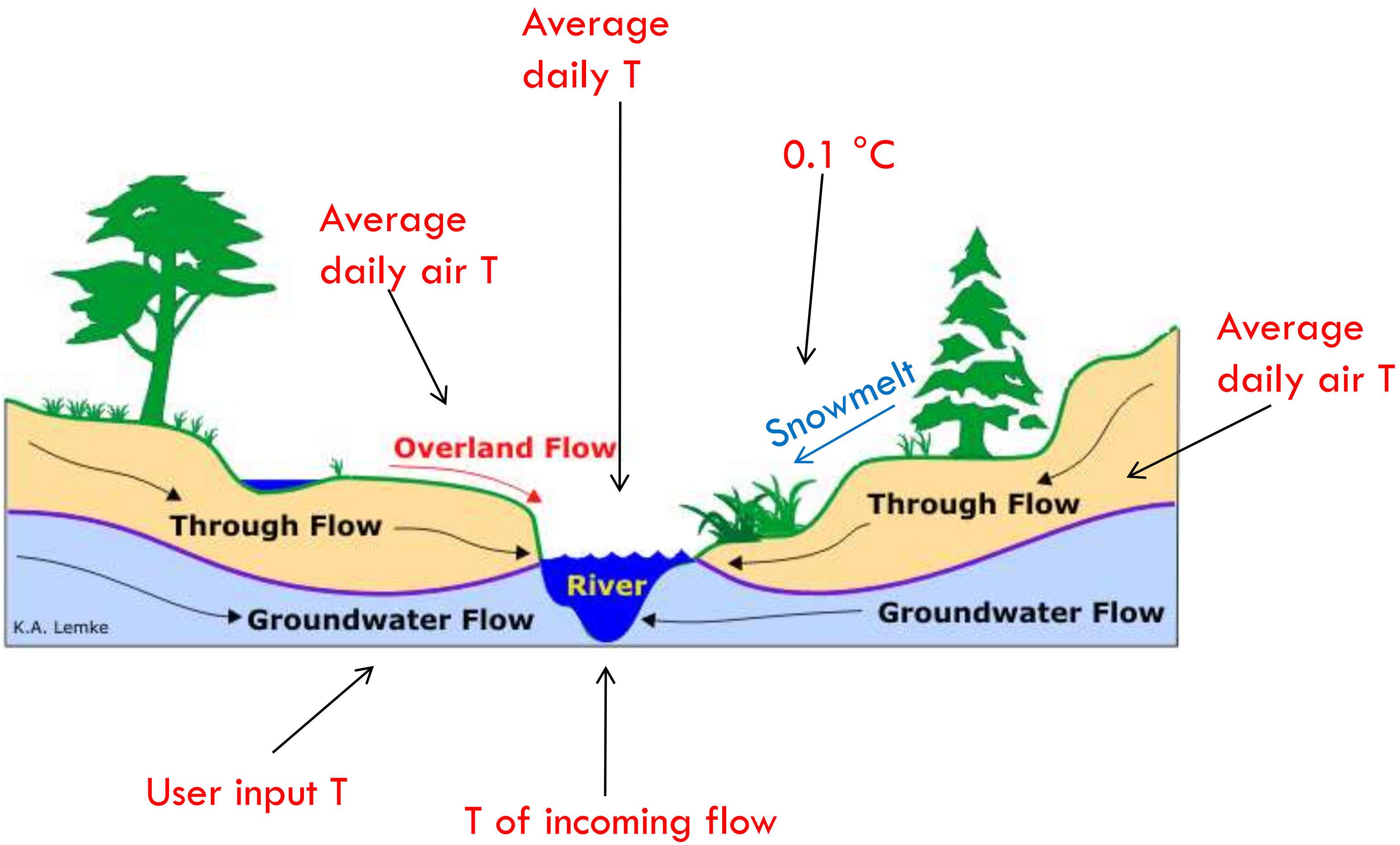
New stream temperature model



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New stream temperature model

- New model estimates in-stream temp. by three components:
- [1] temperature and amount of local water within the subbasin

$$T_{w,local} = \frac{\alpha(0.1 \cdot sub\_snow) + \beta(T_{gw} \cdot sub\_gw) + \lambda(T_{air,lag} \cdot (sub\_surq + sub\_latq))}{sub\_wyld}$$

- *α, β, λ*: calibration coefficients relating the relative contribution of the hydrologic components to local water temp (dimensionless)
- *sub_snow*: snowmelt contribution in subbasin (assume snowmelt temp. to be 0.1 °C)
- *sub_gw*: groundwater contribution in subbasin (mm) with a temperature T_{gw} (°C)
- *sub_surq*: surface runoff in subbasin (mm)
- *sub_latq*: lateral soil flow in subbasin (mm)
- *sub_wyld*: water yield in subbasin (mm)
- $T_{air,lag}$: average daily air temperature with a lag (°C)

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New stream temperature model

- [2] temperature and inflow volume from upstream subbasin(s)

$$Twater_{intial} = \frac{T_{w,upstream} * (Q_{outlet} - sub\_wyld) + (T_{w,local} * sub\_wyld)}{Q_{outlet}}$$

  - $T_{w,upstream}$: water temperature of stream entering subbasin (°C)
  - Q_{outlet}: streamflow discharge at the outlet of subbasin (m^3/s)
  - $Twater_{initial}$ = Tw,local for headwater streams (°C)
  - $T_{w,local}$ and sub_wyld previously defined

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New stream temperature model

- [3] air-water temperature transfer during the streamflow travel time in the subbasin

$$T_{water} = Twater_{intial} + (T_{air} - Twater_{intial}) * K * (TT) \quad if\ T_{air} > 0$$

$$T_{water} = Twater_{intial} + ((T_{air} + \varepsilon) - Twater_{intial}) * K * (TT) \quad if\ T_{air} < 0$$

  - T_{water}: temperature of water (°C)
  - T_{air}: average daily air temperature (°C)
  - K: calibration conductivity parameter (dimensionless)
  - TT: travel time of water through the subbasin (hour)
  - ε: air temperature addition coefficient (°C)
  - $Twater_{initial}$ is previously defined

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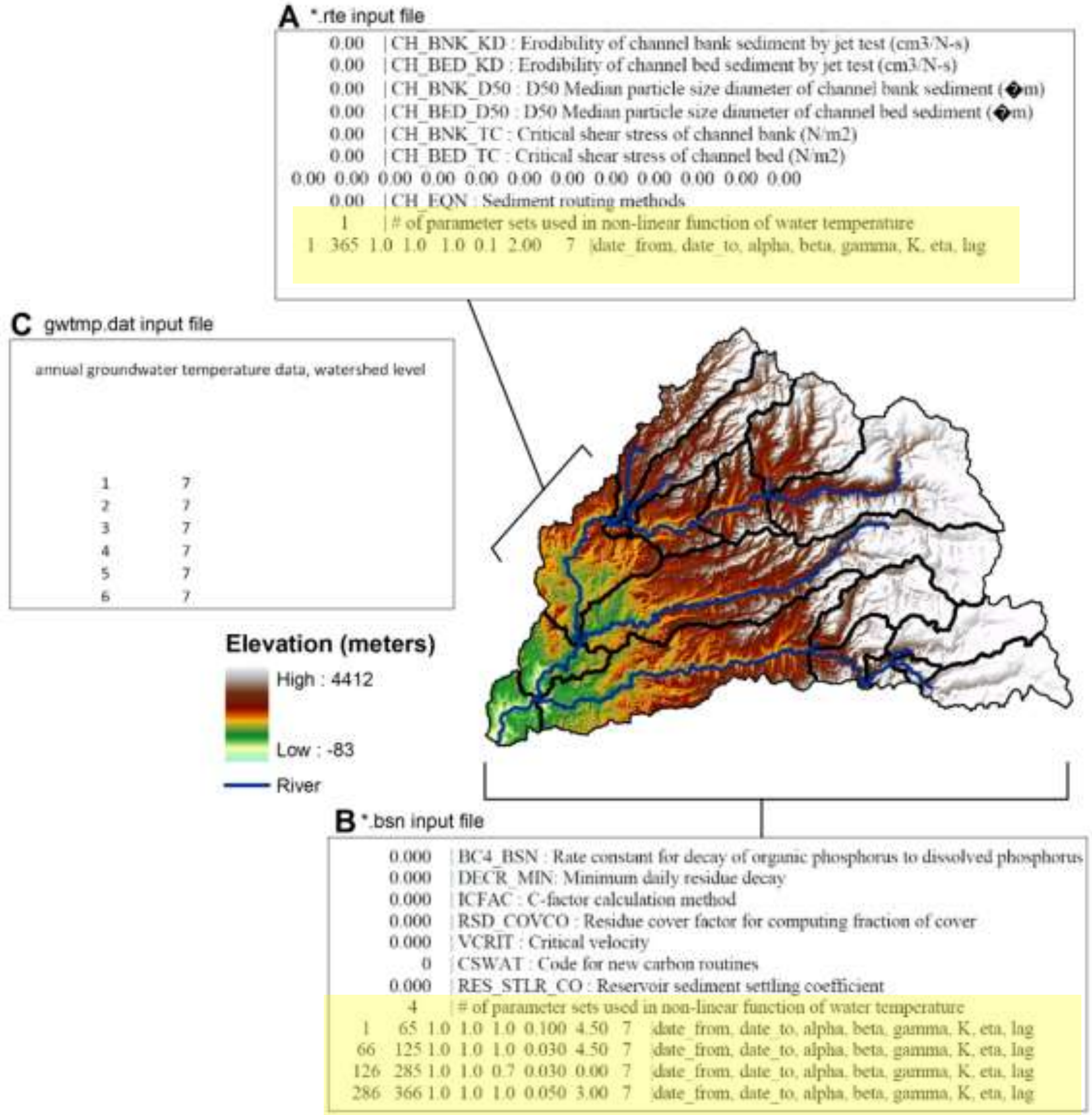
Implementation of model

- Two spatial options:
  - subbasin level (A)
  - basin level (B)

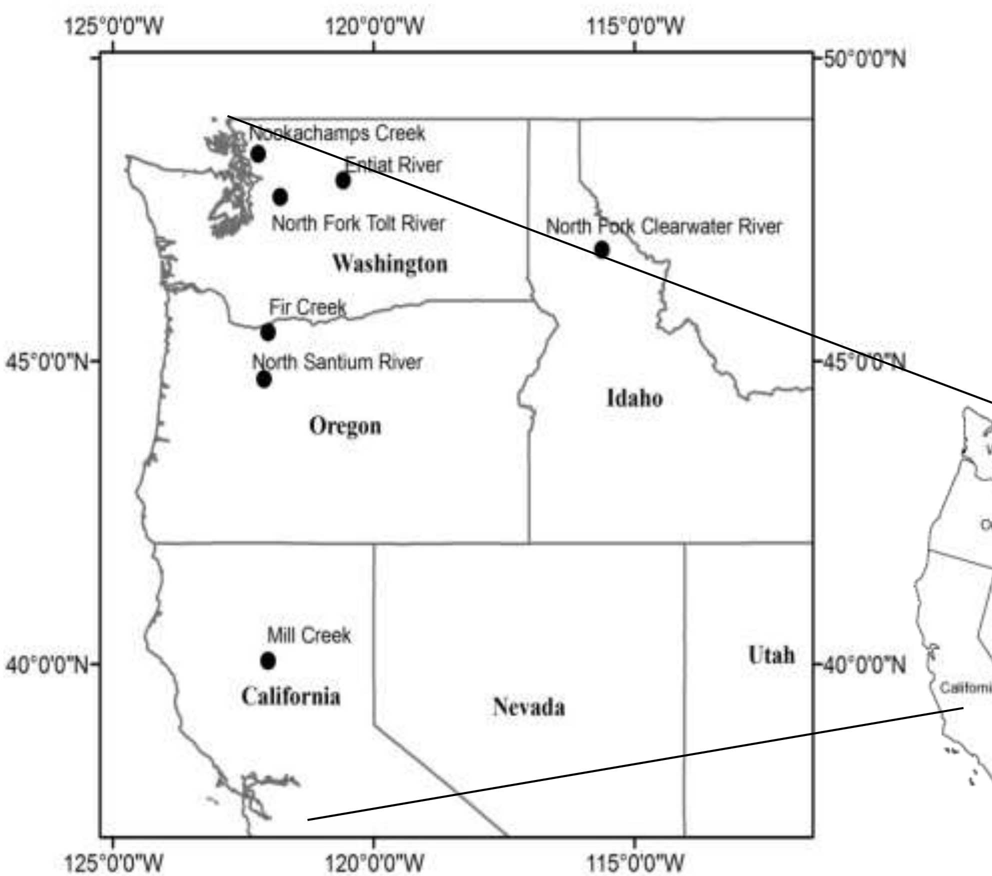
- Two temporal options:
  - annual (A)
  - seasonal (B)
    - Julian date boundaries

*GW temp at the annual scale



Model testing

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



Model testing

- Sites first calibrated for daily streamflow

	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

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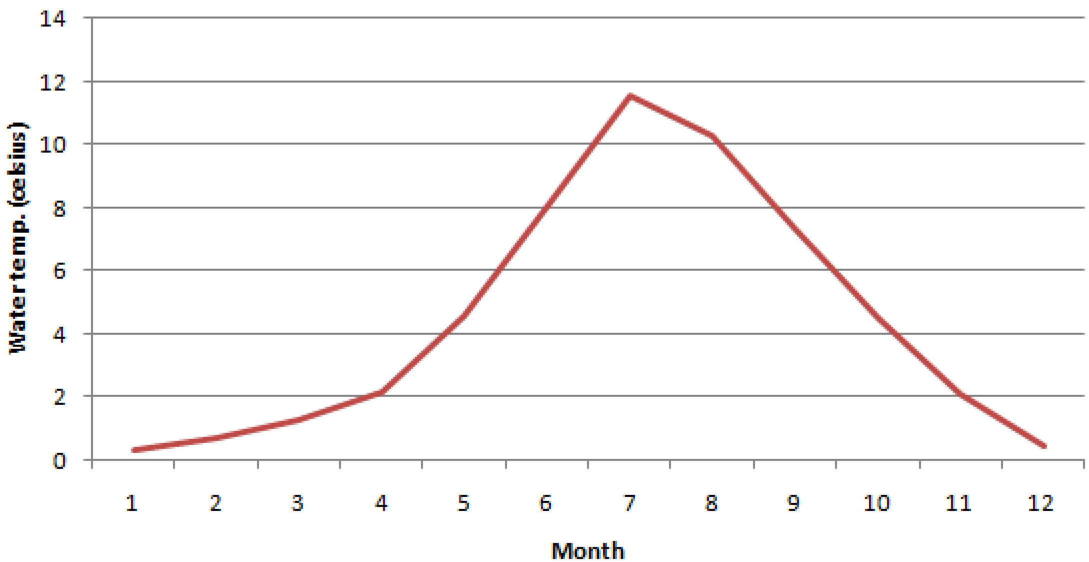
Model testing

- Manually calibrated for each watershed at basin scale (*.bsn input file)
- K (conductivity parameter) most sensitive parameter
- Hydrologic coefficients generally left at 1
- Seasonal modeling: split up winter and summer



Model testing

Calibration/Validation results

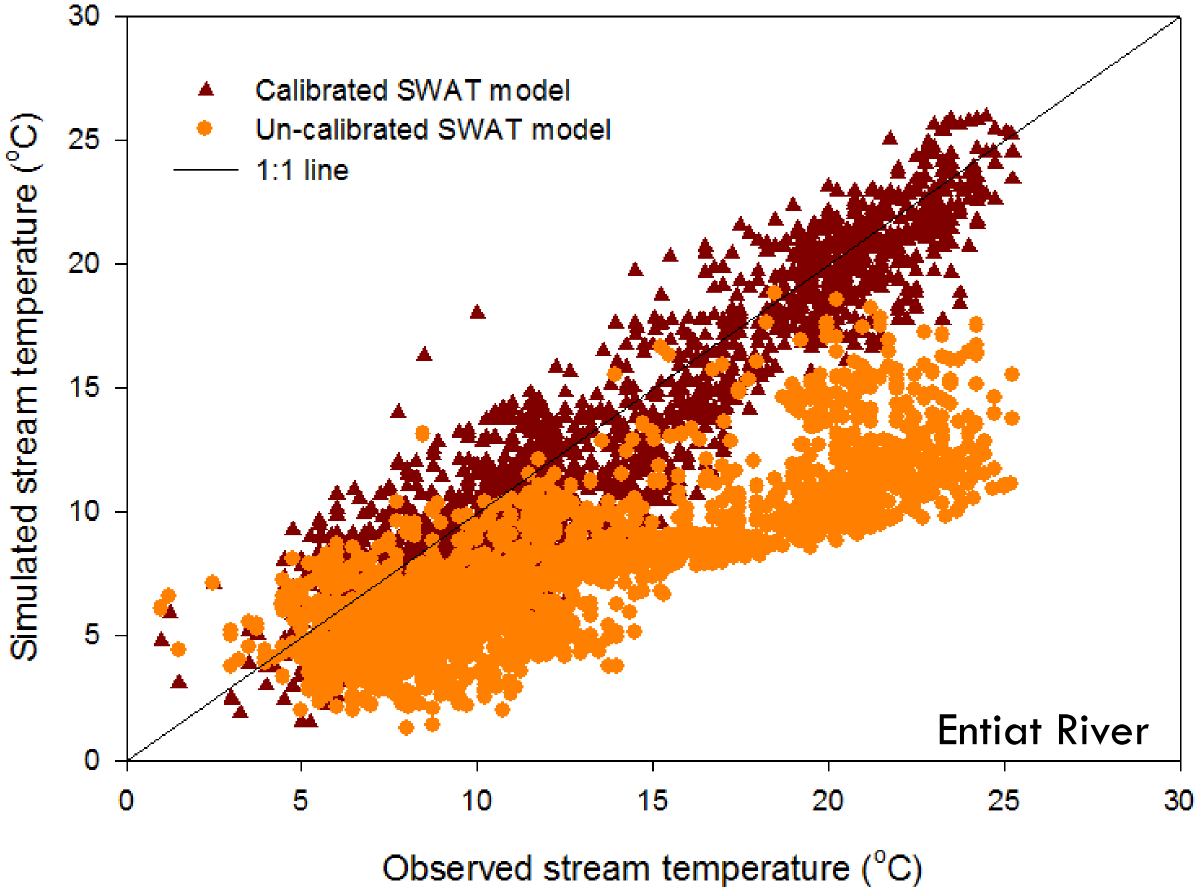
		Original SWAT stream temperature model					New SWAT stream temperature model				
		Calibration			Validation			Calibration			Validation	
River	**Years**	**NS**	**RMSE (ºC)**	**Years**	**NS**	**RMSE (ºC)**	**Years**	**NS**	**RMSE (ºC)**	**Years**	**NS**	**RMSE (ºC)**
Entiat River	2003-2004	-0.08	3.97	2005	-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

Model sensitivity

- Sensitivity to SWAT hydrology calibration

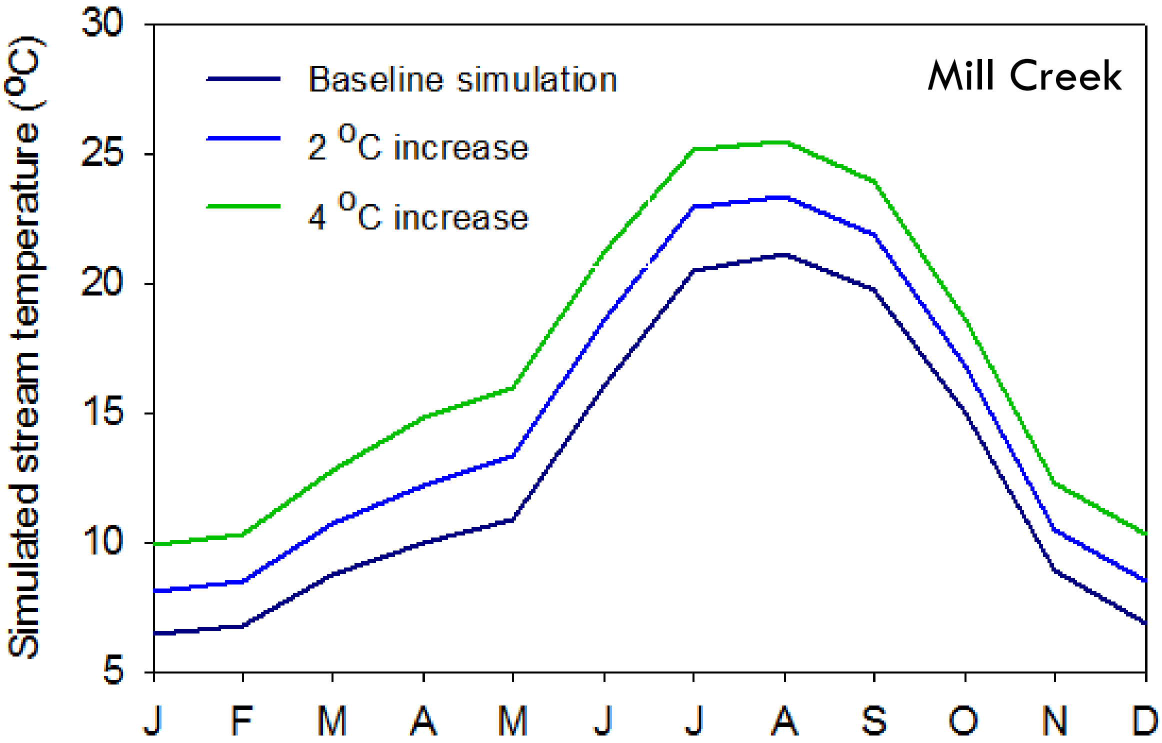


Model sensitivity

- Air temperature sensitivity

Larger increases during summer than winter

Shows the effects of earlier snowmelt with an earlier snowmelt pulse



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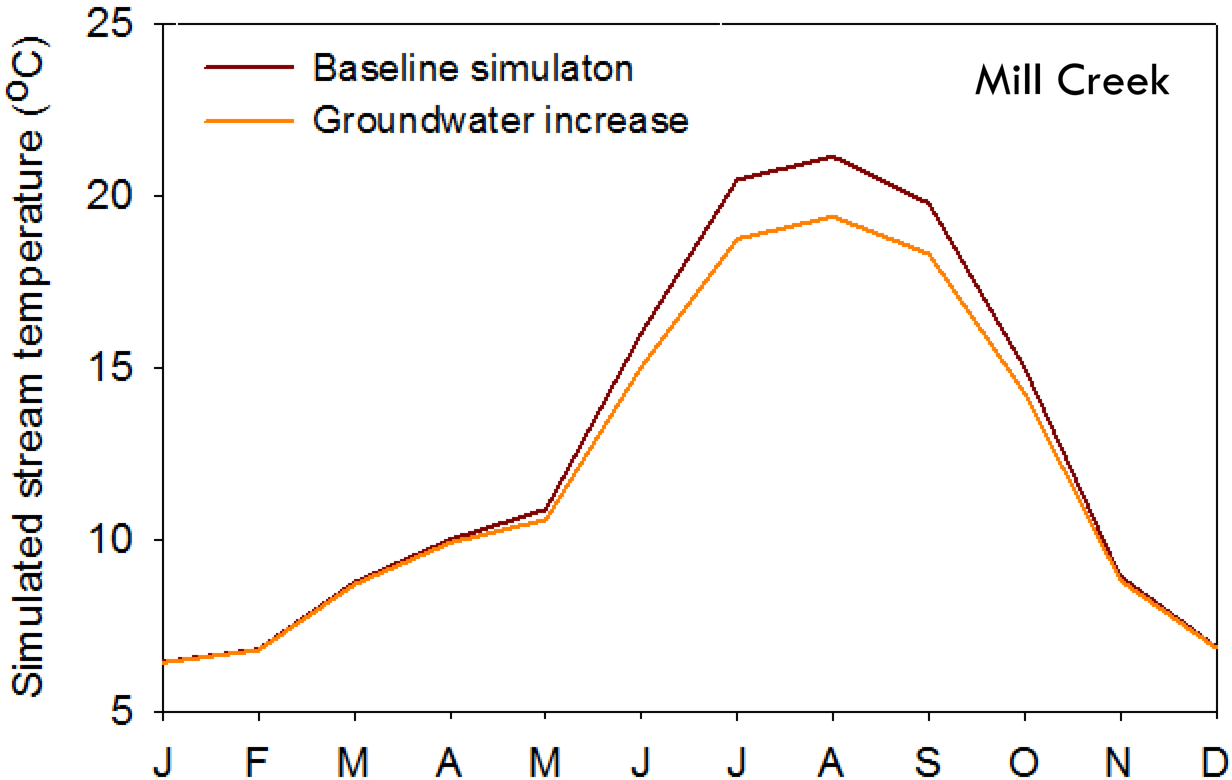
Model sensitivity

- Groundwater inflow sensitivity

Decreased groundwater threshold depth (GWQMN) from 1500 to 750 mm

Decrease in stream temp during summer months due to increased groundwater inflow



Model sensitivity

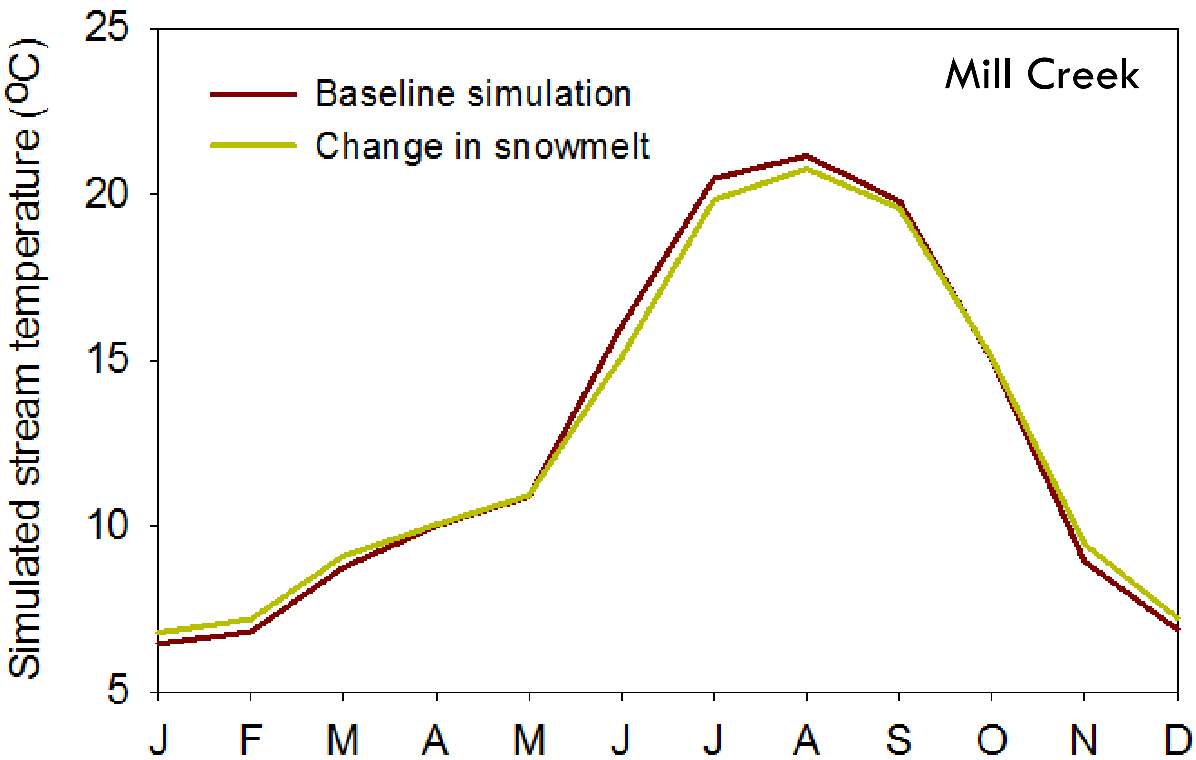
- Snowmelt sensitivity

Increased SFTEMP (snow temp. threshold) and SMTMP (snowmelt temp. threshold) by 2 °C

-less snow and delay of snowmelt

Increase in winter stream temp. by 0.5 °C when there is less snowmelt occurring

Decrease in spring/summer stream temp. by 0.75 °C when more snowmelt is occurring



Conclusions

- New model stream temp. is determined as a function of
  - inflow from the upper basins
  - snowmelt, surface runoff, lateral soil flow, and groundwater flow
  - air temperature
- New model does not require more information beyond what is already provided by the user or SWAT
- Calibration is achieved using few parameters

Conclusions

- Tested on 7 mountainous watersheds throughout the Western United States
- New stream temp. model performed better than original SWAT stream temp. model
  - Thus better able to simulate other water quality processes dependent on stream temp.
- Sensitivity analyses suggest that new model is sensitive to local hydrology

Future work

- Test the stream temp. model in various locations throughout the world
  - Currently successfully able to model stream temp. in Sierra Nevada mountains in the United States

- Include irrigation parameters that includes the effects of irrigation runoff on stream temp.
- Include effects or reservoir releases on stream temp.

Thanks!