Water Temperature Transaction Tool (W3T)

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Outline

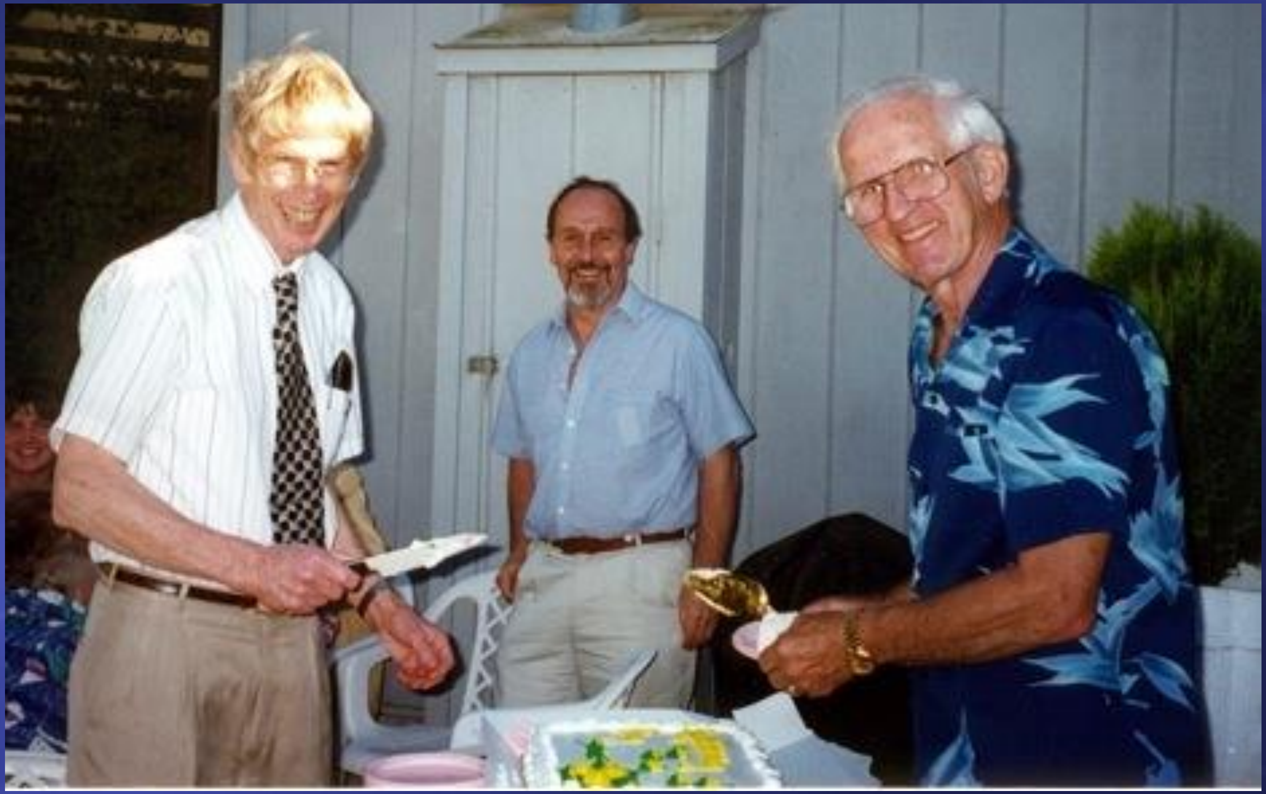
- Recognitions
- Some thoughts on “simple” models
- Development of an equilibrium temperature approach

Recognitions

- CWEMF
  - Mission: To increase the usefulness of models for analyzing California’s water- and environmental related problems
- A few special people

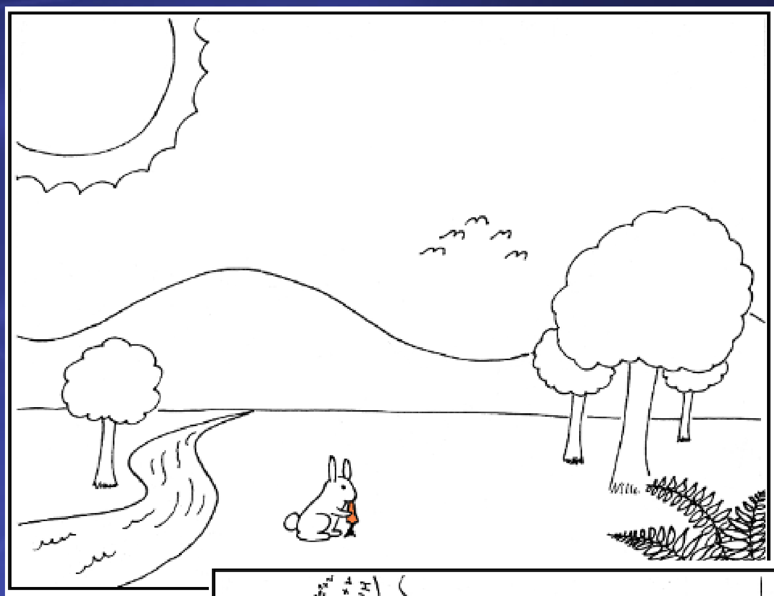
Recognitions

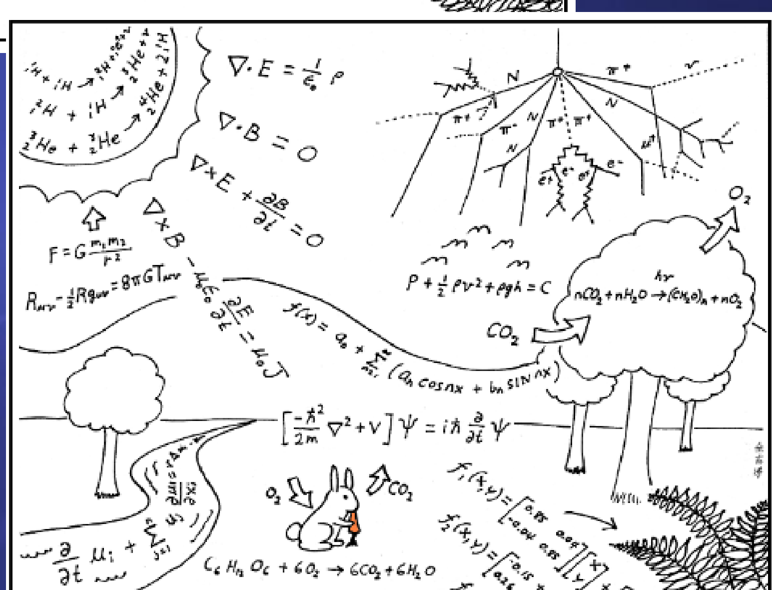
- A few special people

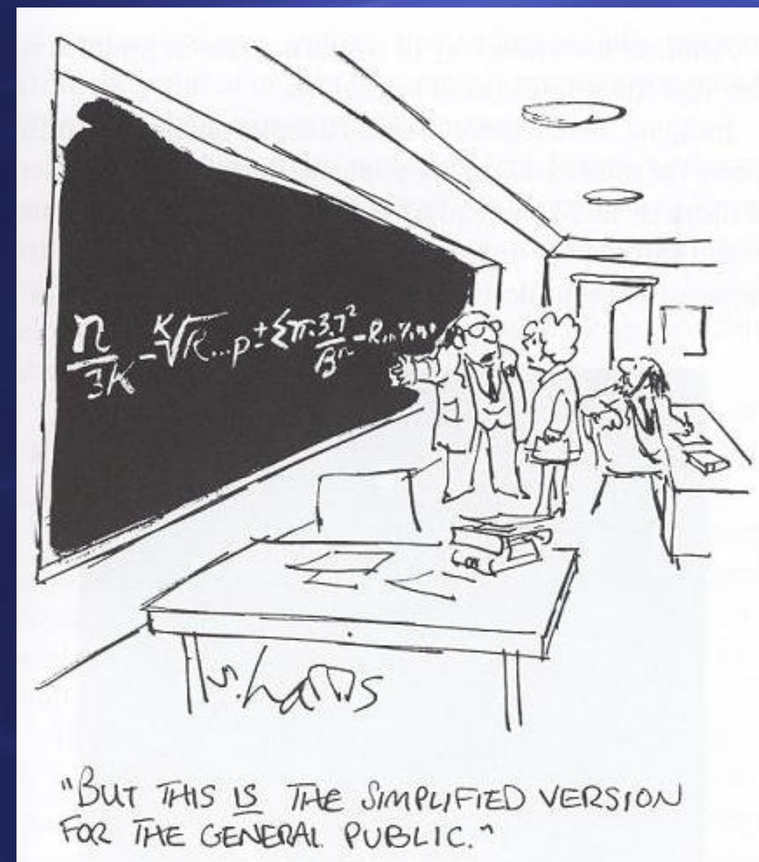


Ray Krone   Ian King   Jerry Orlob

Communicating Results







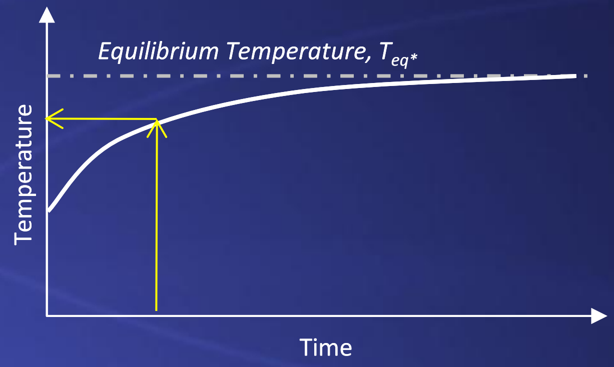
The Modeling Process (simplified)

Evolution of Equilibrium Temperature Modeling

- What is Equilibrium Temperature?
- Sierra Nevada Application: RTEMP
- Water Temperature Transaction Tool: W3T

Equilibrium Water Temperature Modeling

- Theoretical Equilibrium Water Temperature ($T_{eq(theory)}$)



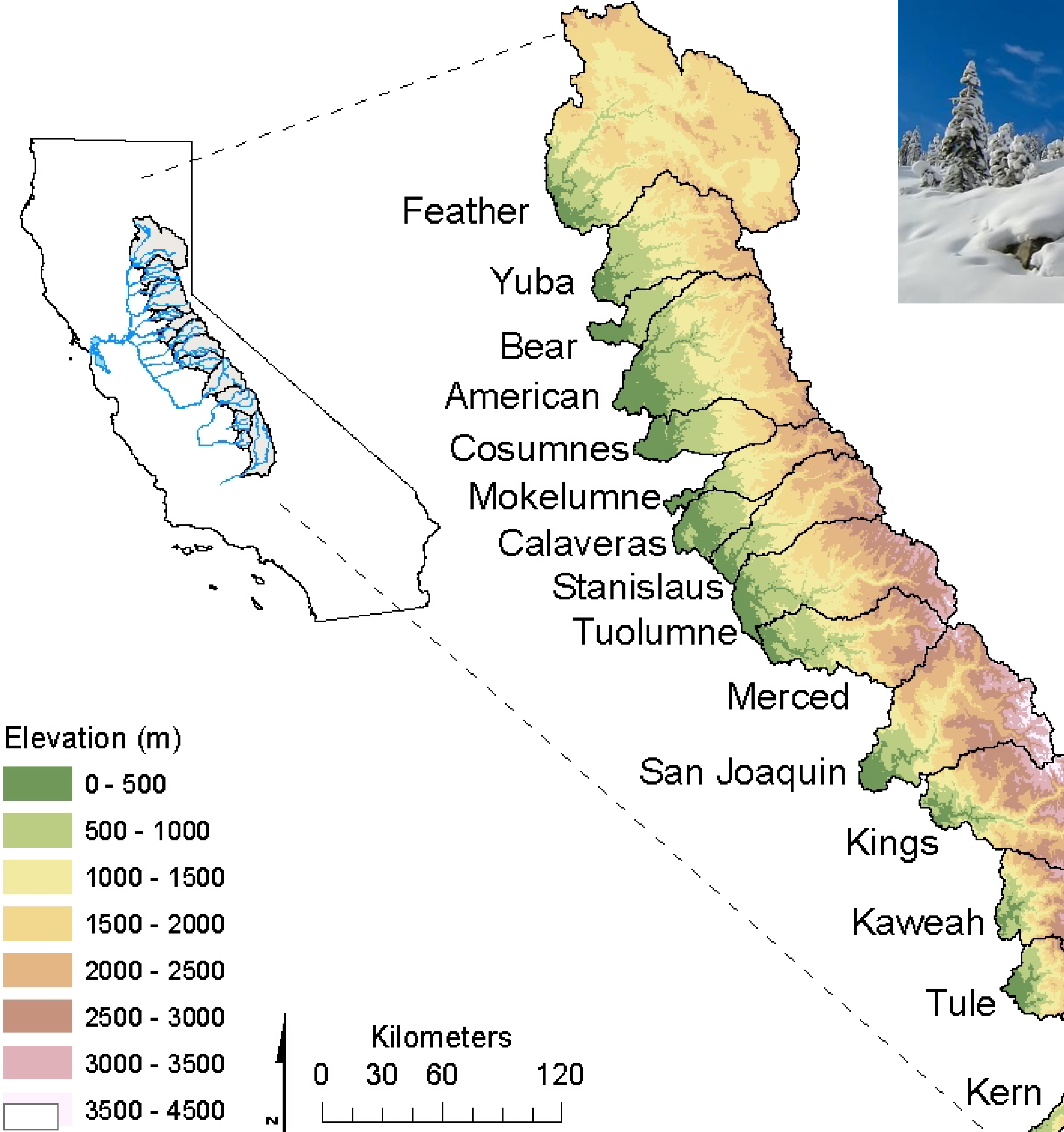
$$Q_n = (Q_{sw} + Q_{atm} - Q_b - Q_l + Q_s) + Q_b = 0$$

- Dynamic Equilibrium Water Temperature (T_{eq})

$$\frac{dT}{dt} = \frac{Q_n A}{\rho C_p V}$$

Sierra Nevada: RTEMP

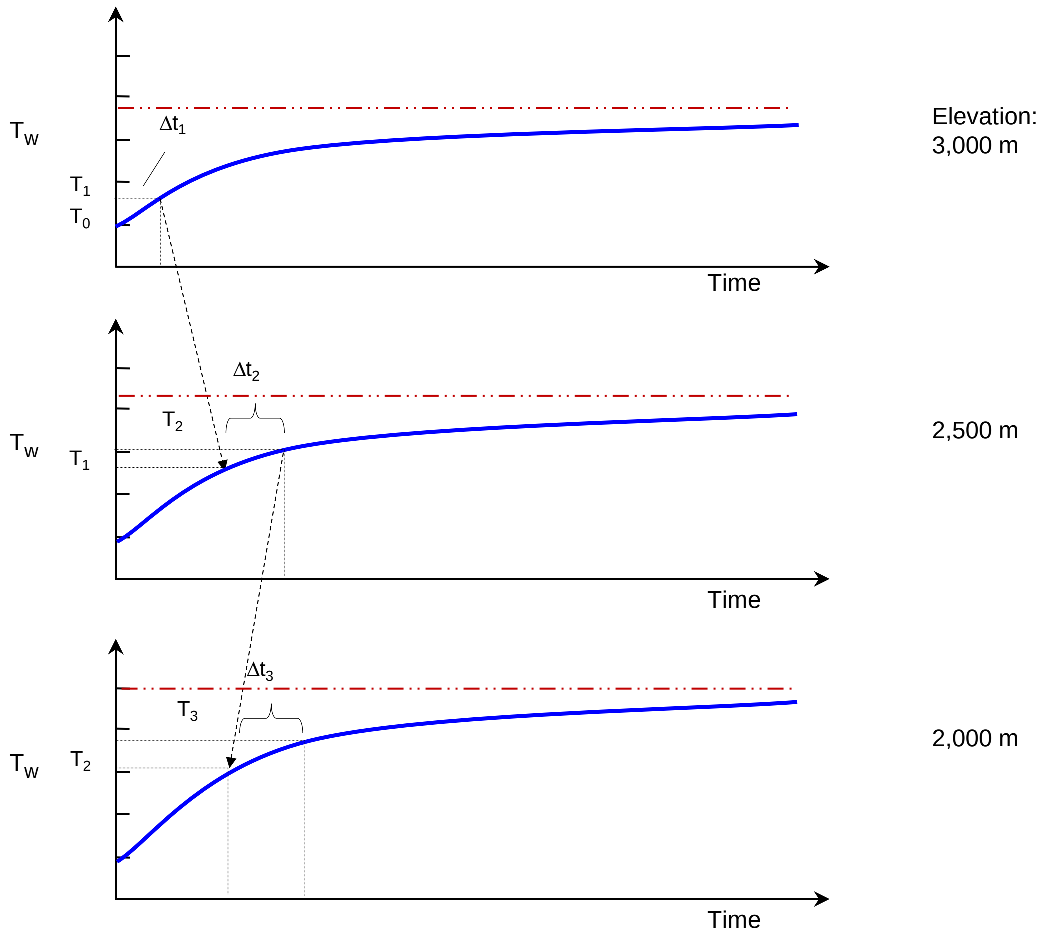
- Objective: Develop a Sierra Nevada-scale water temperature model capable of:
  - Assessing implications of climate change under unimpaired and an impaired hydrologic settings
  - Encompassing a large spatial area (western slope of the Sierra Nevada)
  - Providing sufficient temporal resolution to describe sub-monthly water temperature response

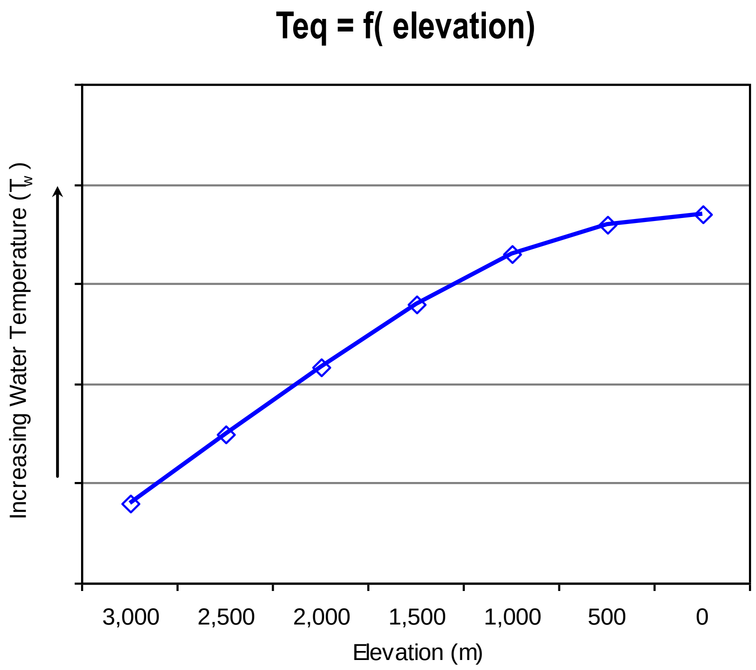

Feather
Yuba
Bear
American
Cosumnes
Mokelumne
Calaveras
Stanislaus
Tuolumne
Merced
San Joaquin
Kings
Kaweah
Tule
Kern
Elevation (m)
0 - 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
2500 - 3000
3000 - 3500
3500 - 4500
N
Kilometers
0 30 60 120

Conceptual Model

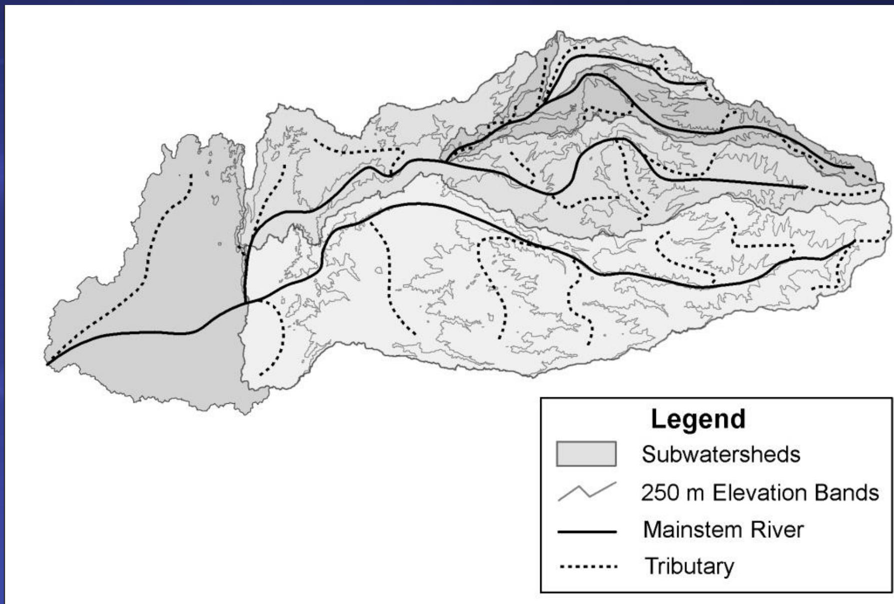
- Track water in individual reaches from the Sierra Nevada crest to the Central Valley
- "Map" the history of this as:
  - Waters seek T_{eq} in respond to local meteorological conditions (elevation bands or cells)
  - Adjust water temperature in response to deviations from T_{eq} curve (e.g., snowmelt, colder or warmer tributaries, groundwater contributions)

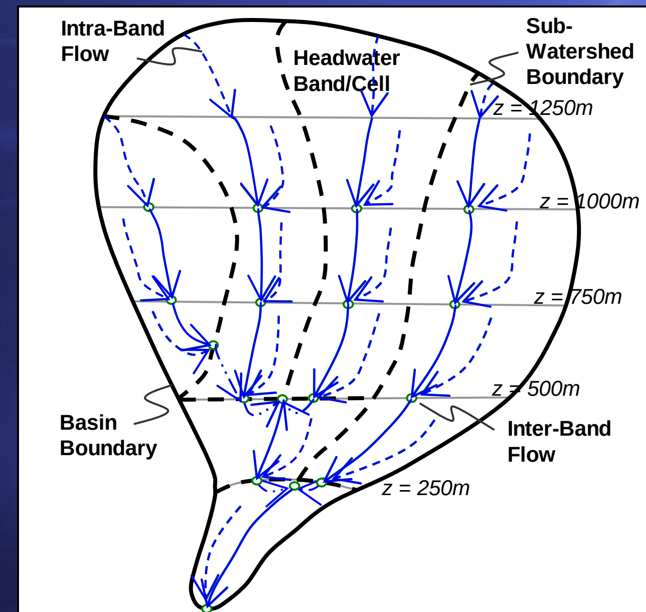
Representing Water Temperature in Space and Time

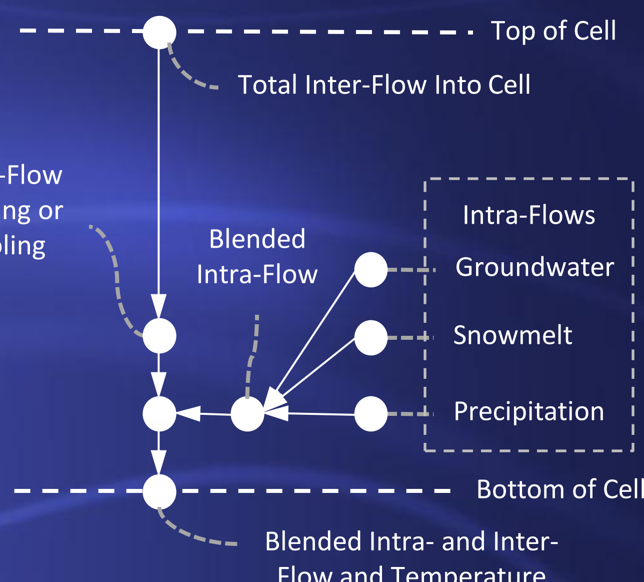




Representative Watershed





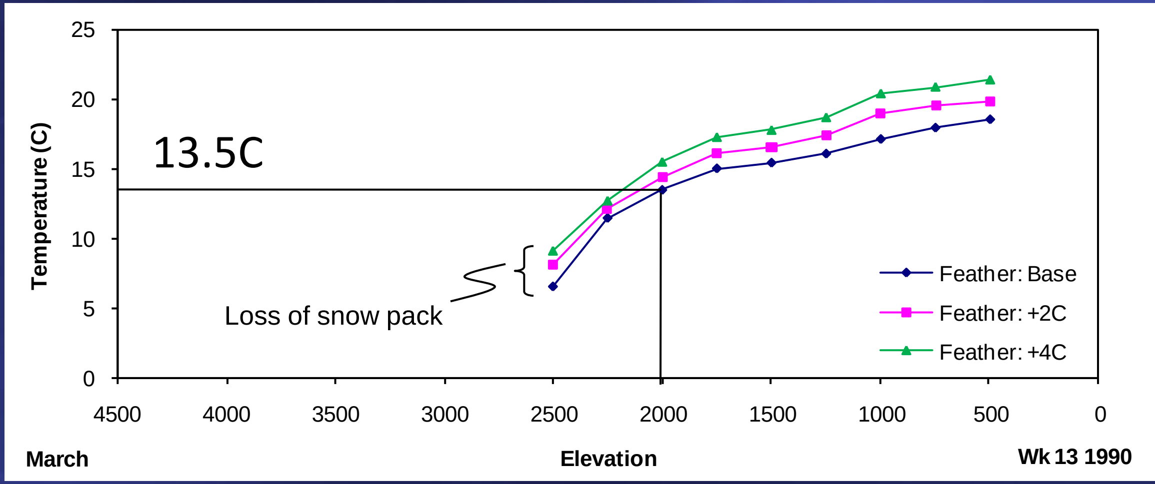


Initial Application

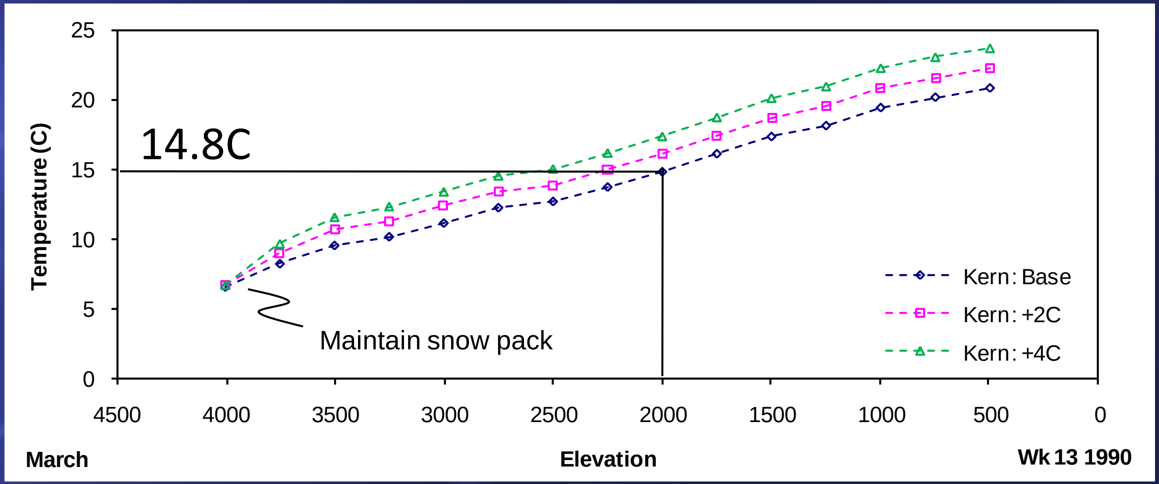
- Based on output from a WEAP model of the Sierra Nevada
  - Unimpaired hydrology (no infrastructure)
  - 20 water years (WY1981 - WY2001), Δt = weekly
  - 15 river basins (Feather, Yuba, Bear, American, Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule, and Kern)
- Climate change: 2°C, 4°C, and 6°C increase in air temperature uniformly applied throughout domain

Feather & Kern Comparison

- Feather



- Kern

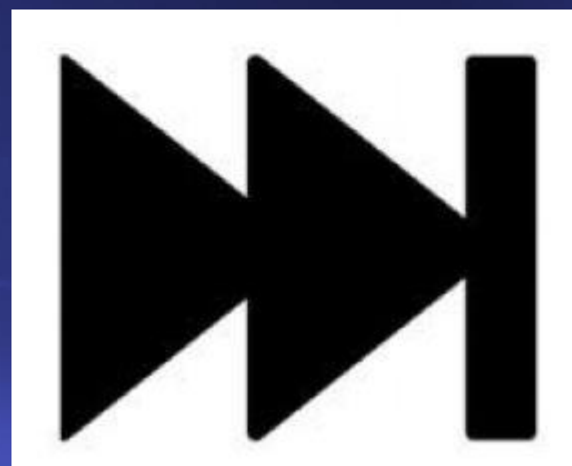


Conclusions

- Despite several assumptions (simplified geometry, snow coverage, groundwater temperatures, etc.) the model provided valuable insight into climate change dynamics under an unimpaired condition.
- The equilibrium approach was an effective simplification that allowed range-scale simulation of sub-monthly water temperature over an extended time series:
  - 20 yrs
  - 15 basins
  - Weekly time step

  } Simulation Time: 15 minutes

- Fast forward a few years



Water Temperature Transactions Tool (W3T)

- NFWF Conservation Innovation Grant to target flow transactions that included a water quality element
- Objective:

Develop a transparent and easy to use tool to explore flow transactions and their potential temperature impacts.

Technical Elements of Model Development and Use

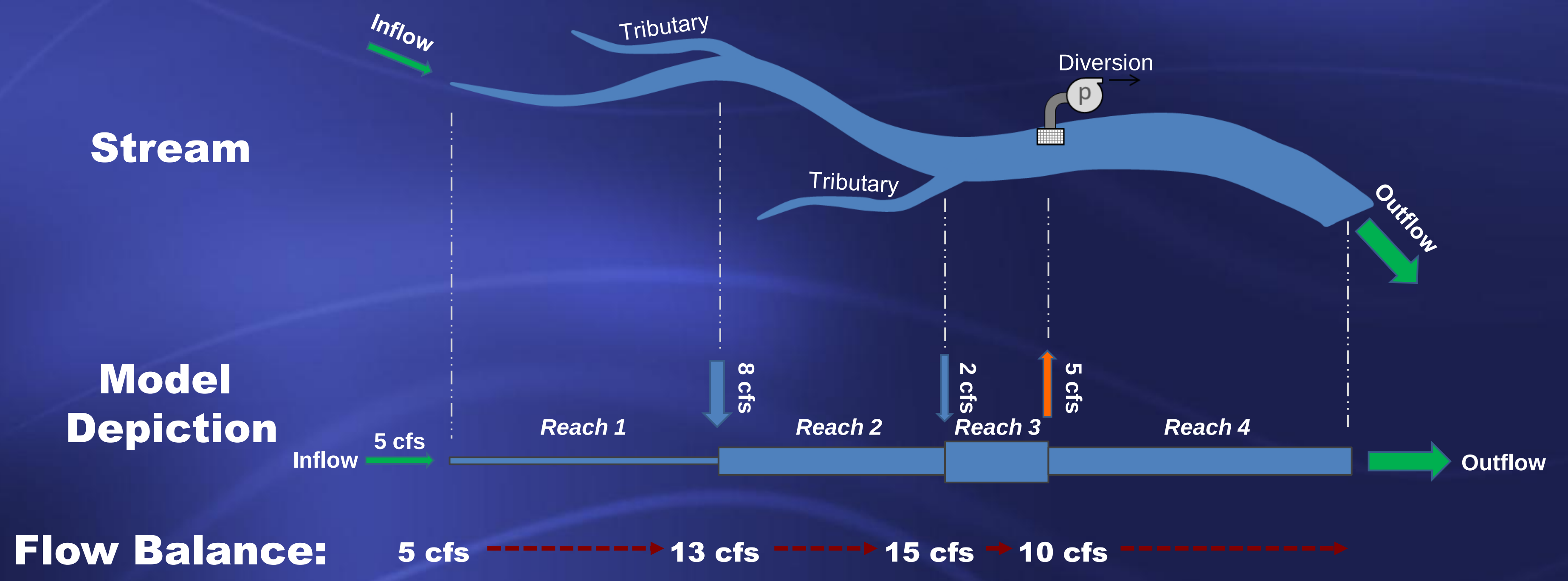
- Heat Budget
- Advection of thermal energy
  - Lagrangian assumption
- Data Needs
- Model Outputs
  - Graphical
  - Tabular
- Model Calibration and Testing
- Excel based (VBA)

Flow Representation

- Basic Assumptions
  - Steady flow based on Manning's equation

$$Q = uA = \frac{1.49}{n} A R^{0.66} S^{0.5}$$

  - River reach representation and flow balance



Flow Representation

- Basic Flow Approach: steady, uniform flow on a reach basis – Manning Equation

$$Q = uA = \frac{1.49}{n} A R^{0.66} S^{0.5}$$

Q – flow (cfs)
n – channel roughness
A – cross section area (ft^2)
R – hydraulic radius (ft), where R = A/P
P – wetted perimeter (ft)
S – channel slope (ft/ft)

– Mass balances at the confluences

- Tributary or inflow: $Q_{ds} = Q_{us} + Q_{trib}$
- Diversion or outflow: $Q_{ds} = Q_{us} - Q_{div}$

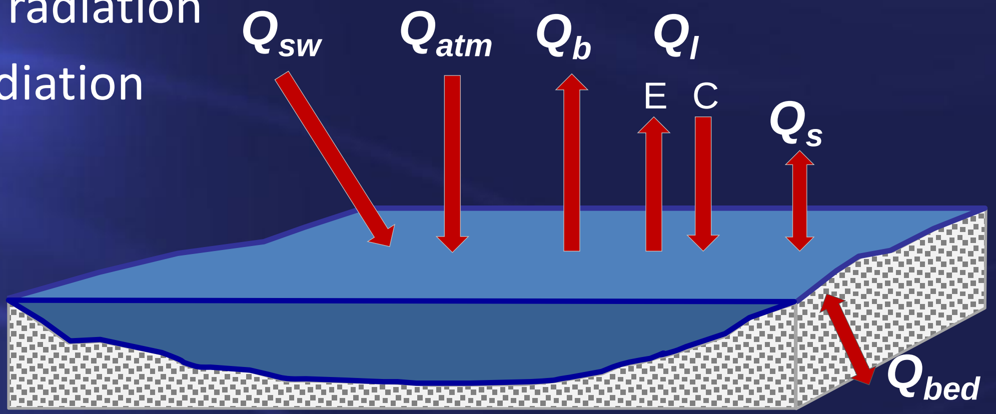
Reach-by-reach specification of Stream attributes

Flow and Temperature in Streams

- Basic heat budget (e.g., Heat Source, QUAL2K, others)

$$Q_n = (Q_{sw} + Q_{atm} - Q_b - Q_l + Q_s) + Q_b$$

  - Q_n – Net heat flux
  - Q_{sw} – Shortwave radiation (solar)
  - Q_{atm} – Longwave atmospheric radiation
  - Q_b – Longwave water body radiation
  - Q_l – Latent heat flux
  - Q_s – Sensible heat flux
  - Q_{bed} – Bed conduction



Flow and Temperature in Streams

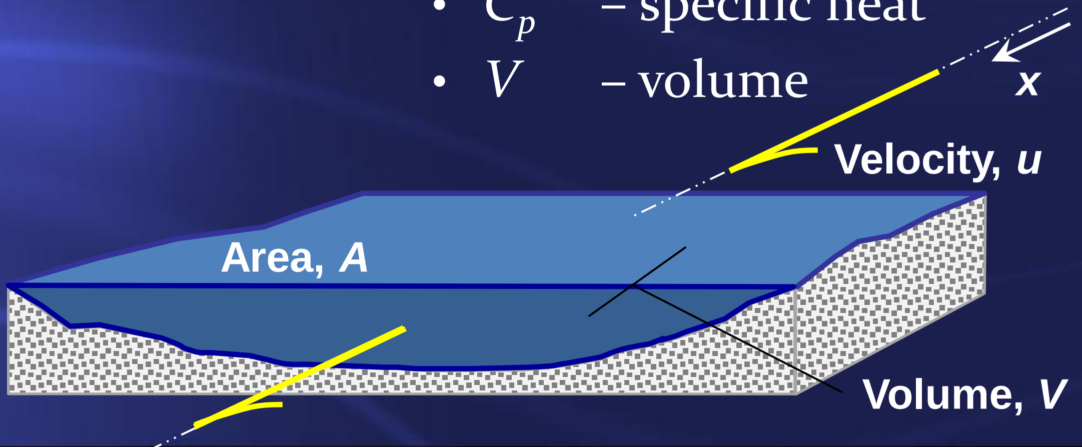
- Fate and Transport: advection-diffusion equation (one-dimensional, laterally and depth averaged formulation)

$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} + D\frac{\partial^2 T}{\partial x^2} \pm S$$

$$S = \frac{Q_n A}{\rho C_p V}$$

- T – water temperature
- t – time
- u – velocity
- D – diffusion
- S – sources/sinks
- Q_n – net heat flux

- A – surface area
- ρ – density
- C_p – specific heat
- V – volume



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Lagrangian Assumption

Neglect at reach scale

$$S = \frac{Q_n A}{\rho C_p V}$$

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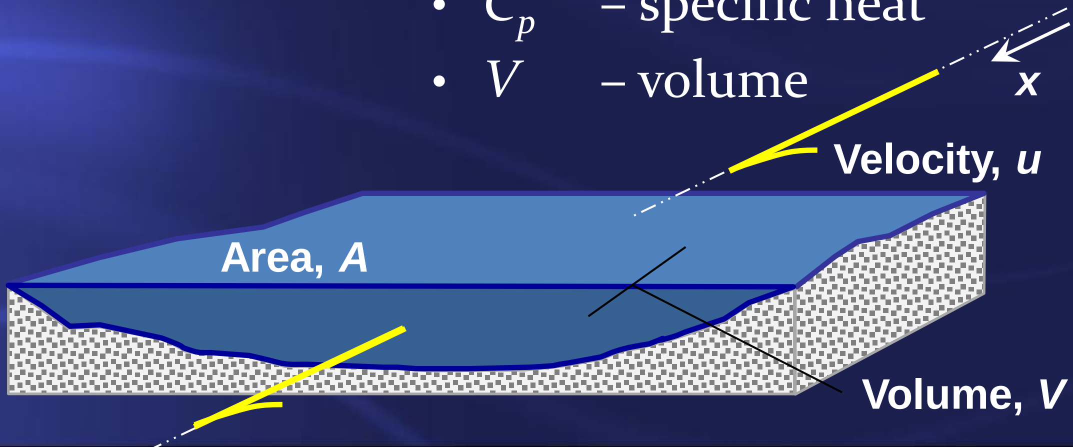
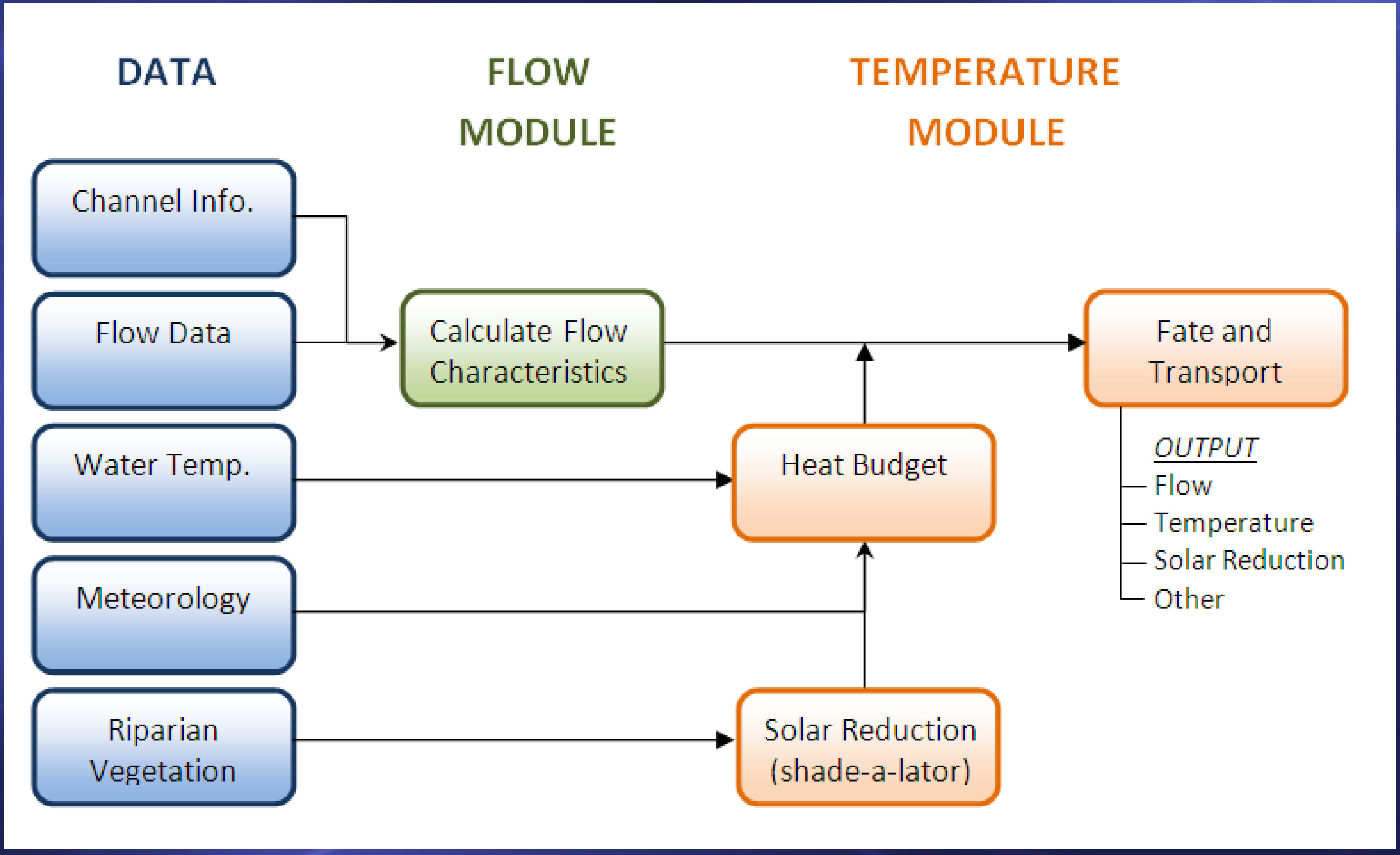
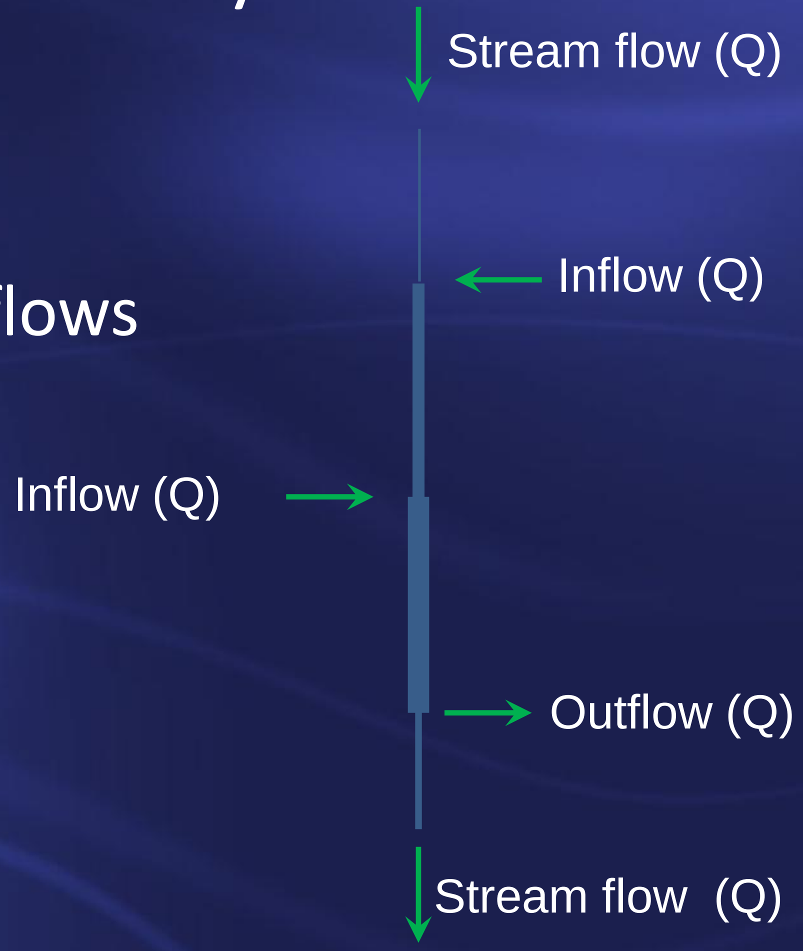


W3T Model Structure



Key Model Inputs

- Model can account for key processes affecting water temperature in aquatic systems.
- Can assess:
  - Flow (diversions/inflows)
  - Water temperature of inflows
  - Stream Morphology
  - Meteorology (sub-daily)
  - Stream shade



Key Model Elements

- Model can account for actual processes affecting water temperature in aquatic systems.
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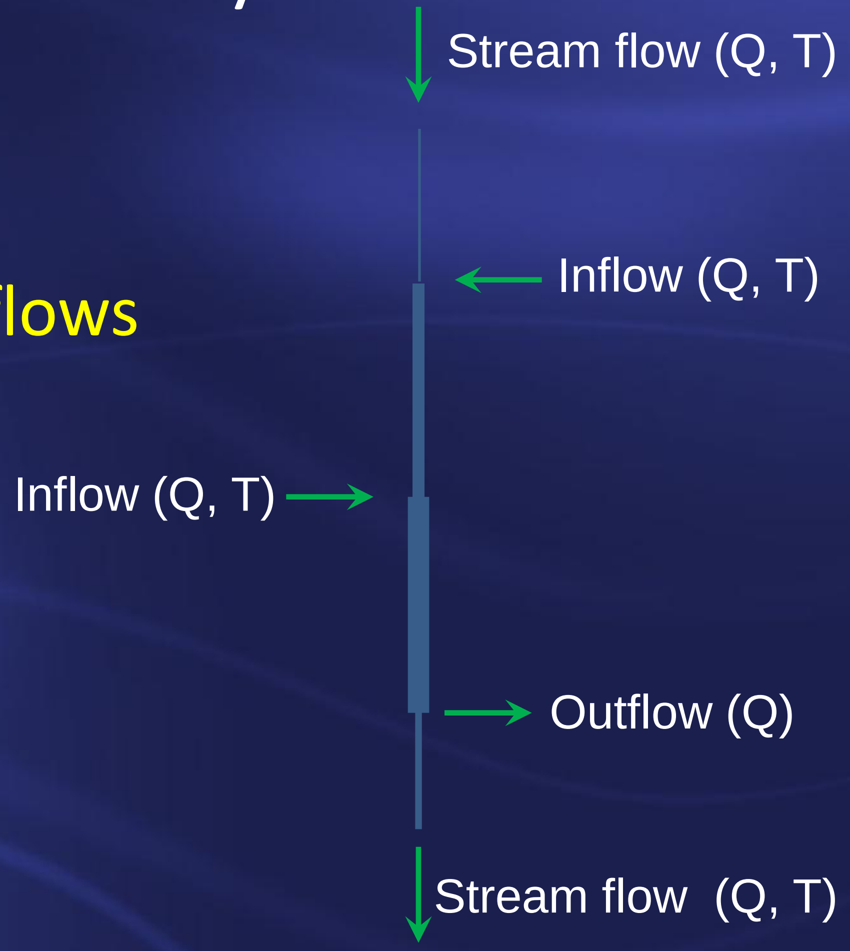

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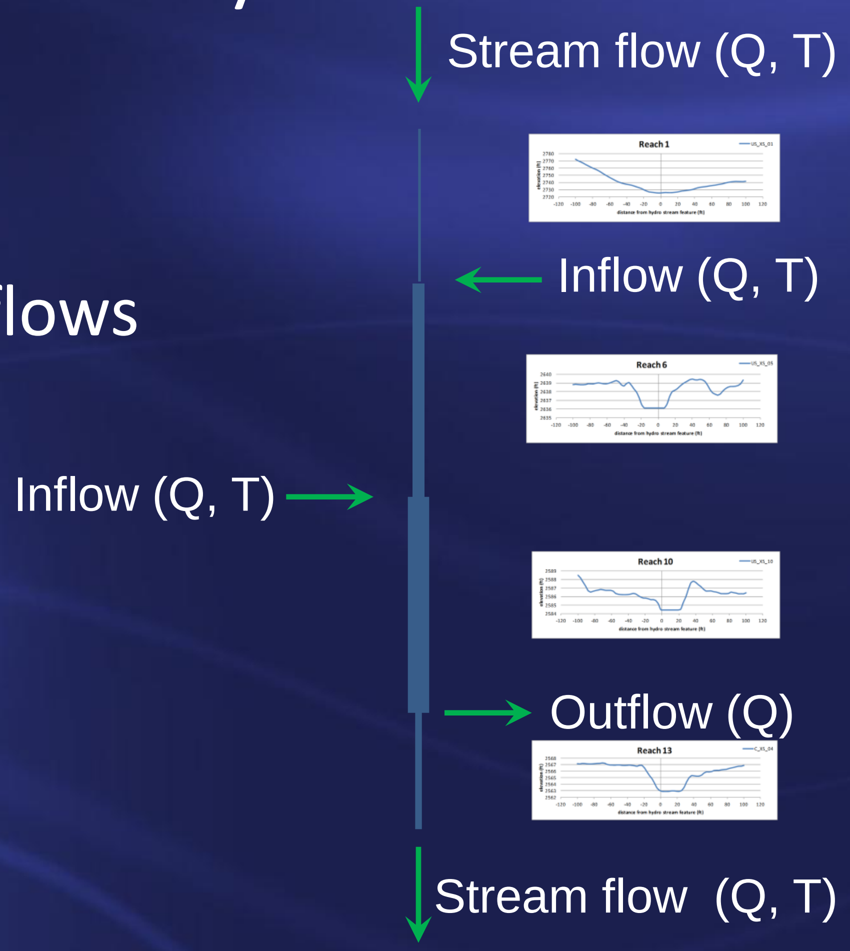

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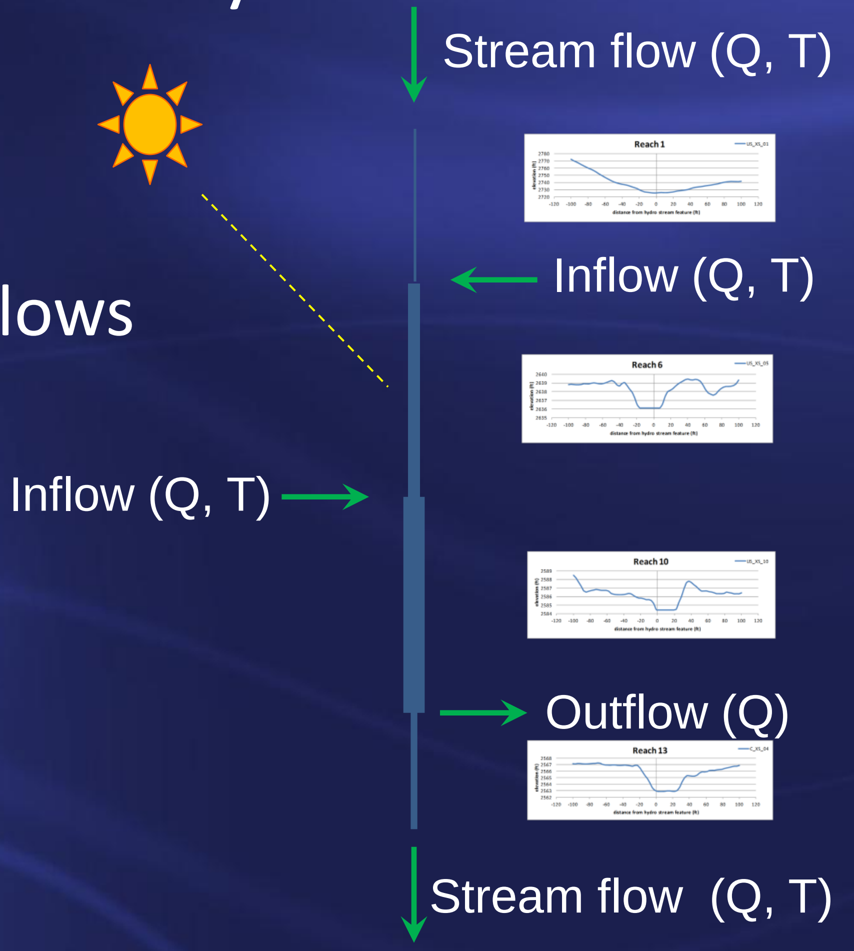

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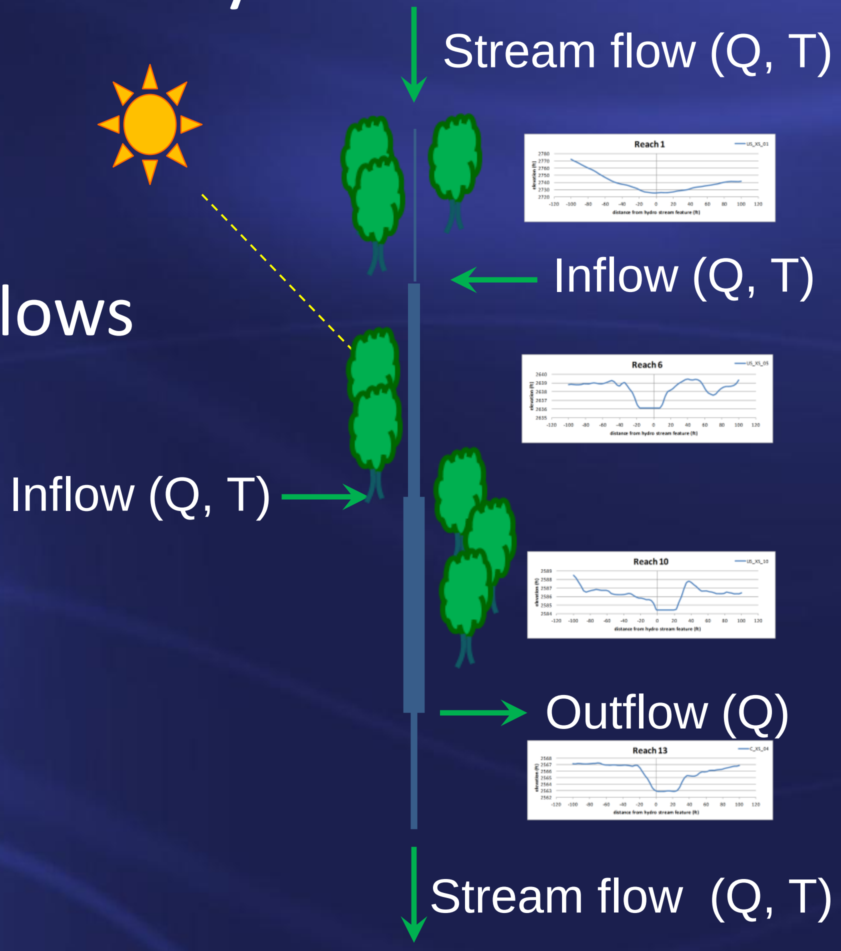
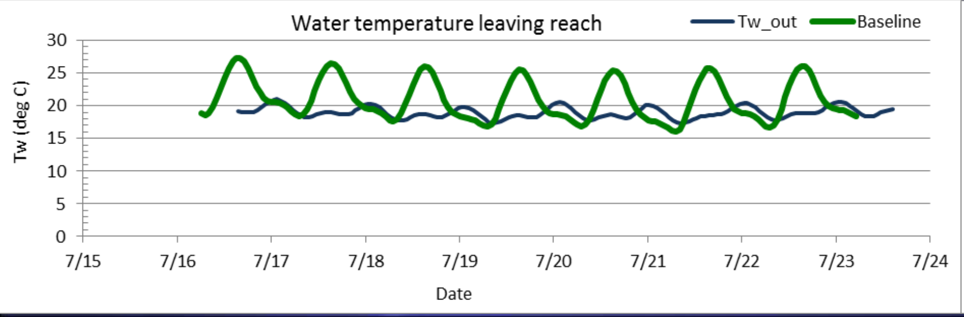
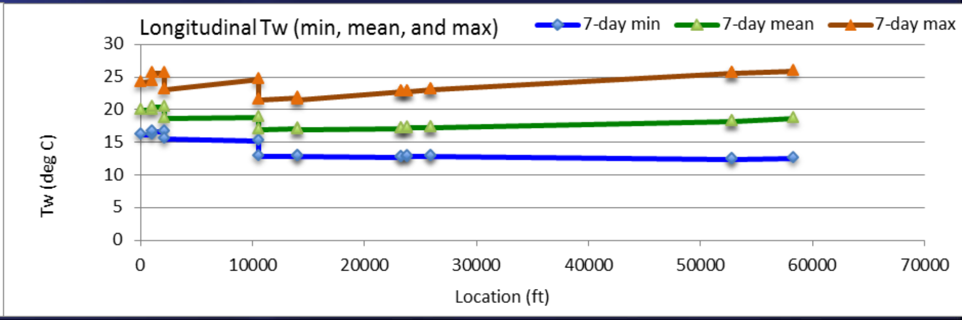


W3T Output

- Hourly time series data – upstream and downstream
  - Biological Tw metrics (7DADA, 7DADM, etc.)
- Baseline versus “scenario” comparison
- Longitudinal profile (reach specific conditions)
- Solar radiation reduction (shade)
- Tabulated data summary
- Multiple sheets summarizing results to provide transparency and verification





W3T Model Elements: Summary

- Model incorporates key processes affecting water temperature in aquatic systems
  - Heat transfer (Heat budget)
  - Stream shade elements (Vegetation/topo)
  - Morphology/geometry ($A_{surface}$, V)
  - Flow and Temperature
    - Impacts of flow changes (thermal mass)
    - Transport of heat energy
    - Assessment of cold/warm water additions
    - Modified operations/land use
    - Sub-daily temperature (hourly)
- Temperature effects of flow transactions can be effectively quantified for a range of conditions

Conclusion

- Detailed spatial and temporal models have high value, but can be computationally intensive and difficult for parties to understand.
- Faced with different/specific objectives, simplified models can be developed to provide:
  - Longer time series versus detailed simulations for a selected few years (e.g., wet, dry, normal)
  - Short simulation times, allowing for many simulations to be completed
  - Gain wider use and acceptability because they are transparent, simple, and accessible