Use of the thermal potential approach to assess temperature impairment

Workshop on water temperature in the North Coastal landscape

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Stillwater Sciences

Outline

- Stream temperature theory
- Thermal potential and thermal regimes
- Models available to assess thermal potential
- An example model: *BasinTemp*
- Applications to South Fork Eel and South Fork Ten Mile
- Quantifying spatially-varying controls on stream temperature
- Incorporating climate change effects
- Summary and conclusions

Stream temperature theory

$$\Delta T_w = \frac{\Delta H}{\rho V C_p}$$

T_w is water temperature (ºC)

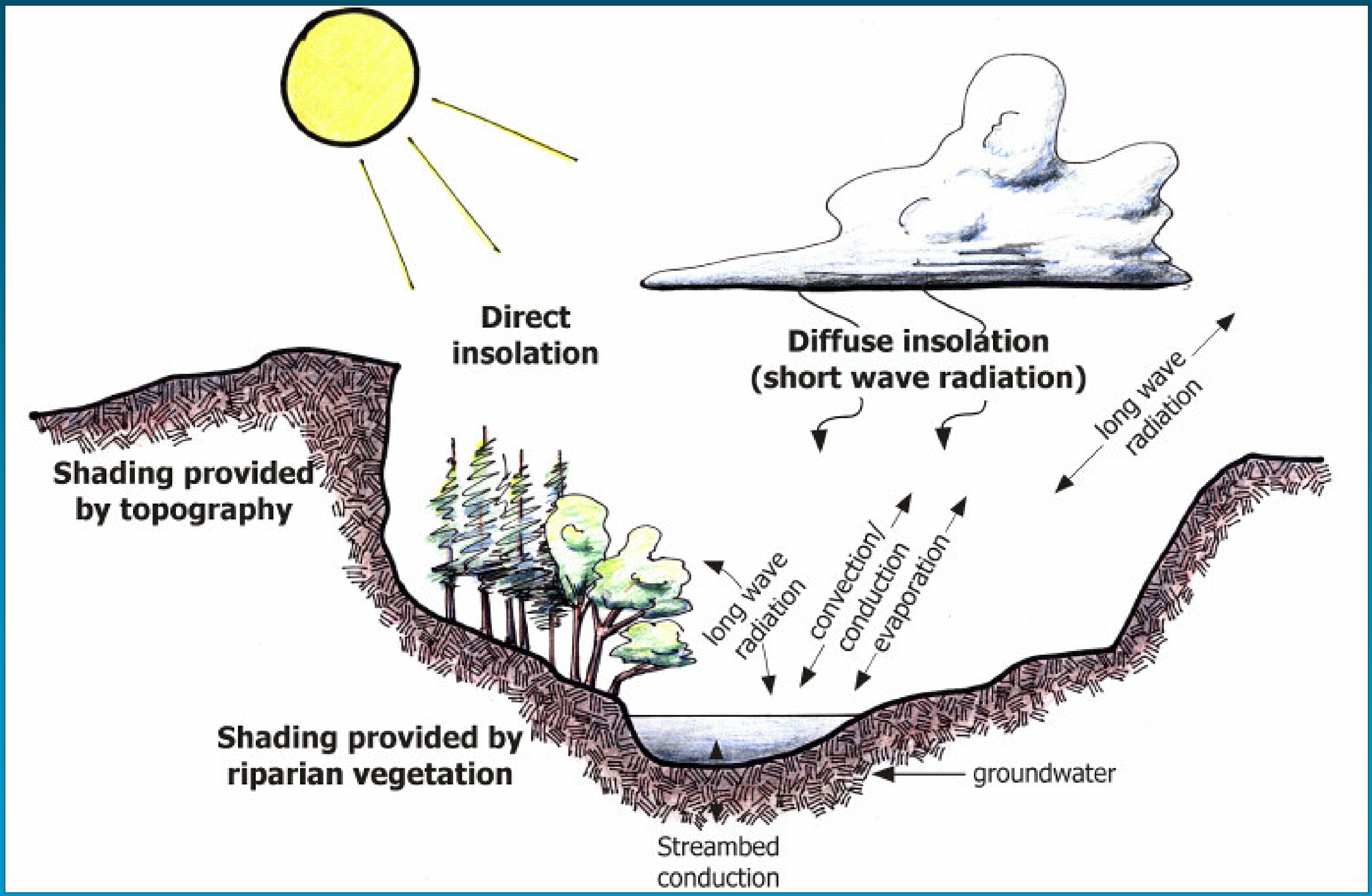
H (J) is the amount of heat contained in volume V (m^3)

ρ is density (kg m^{-3})

C_p is the specific heat of water (J kg^{-1} $ºC^{-1}$)

H represents all weather terms, and the ρVC_p term represents hydrology

Theory continued



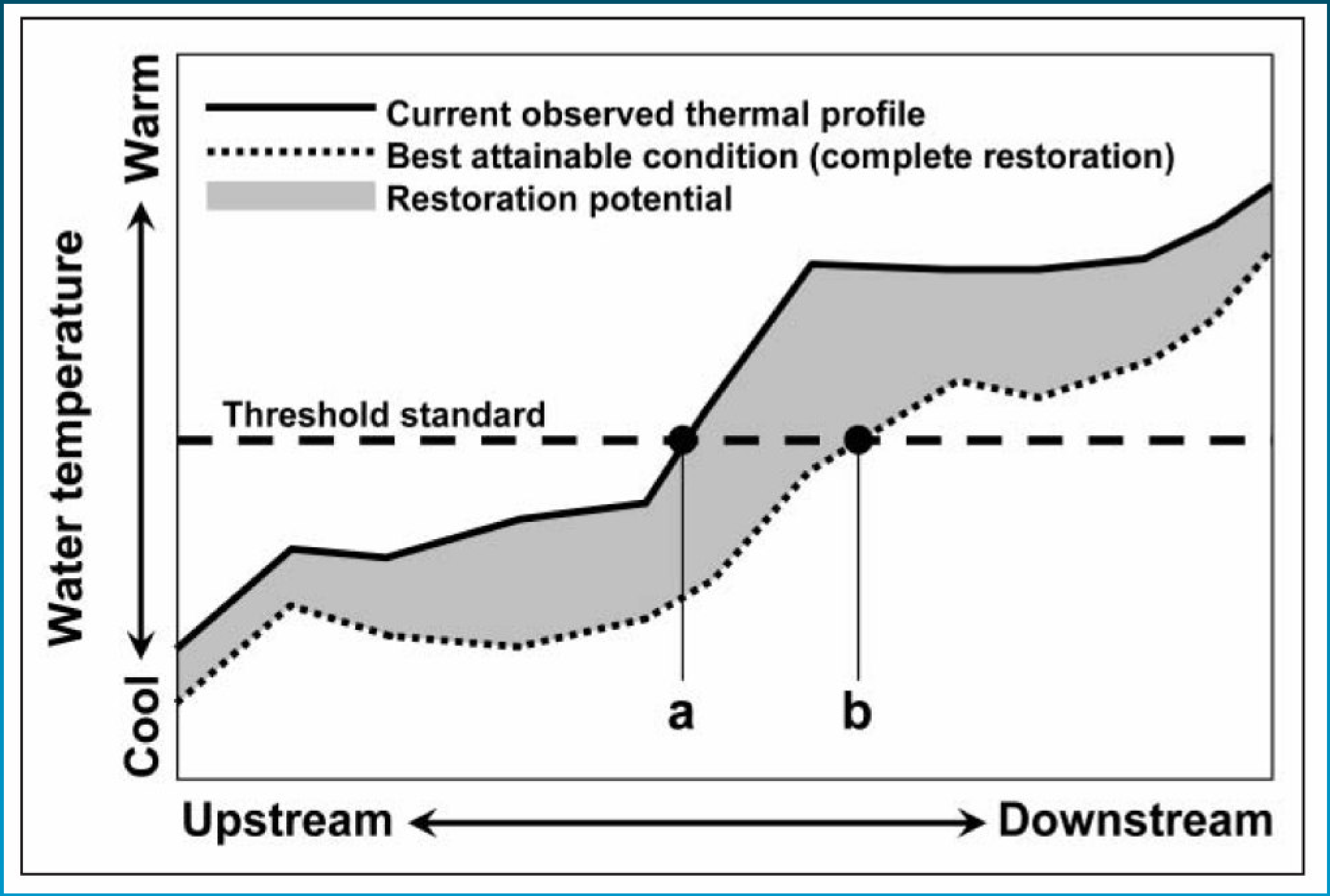
Thermal potential in 303(d) narrative standard

- Thermal potential is defined as "natural receiving water temperature"
- 303 (d) process addresses thermal potential as follows:
  - "The natural receiving water temperature of inland surface waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Board that such alteration in temperature does not adversely affect beneficial uses.
  - The temperature of any cold or warm freshwater habitat shall not be increased by more than 5°F (2.8°C) above natural receiving water temperature."

Thermal potential assessment

- Included in temperature objective to address site-specific and geographic considerations
- Stream temperature can and does vary significantly over space and time, therefore:
- When and where does it make sense to focus on the natural range of temperature variation (thermal regime) and the narrative standard, instead of a single numeric standard, or a suite of numeric standards (e.g., ODEQ)?

Thermal regime analysis



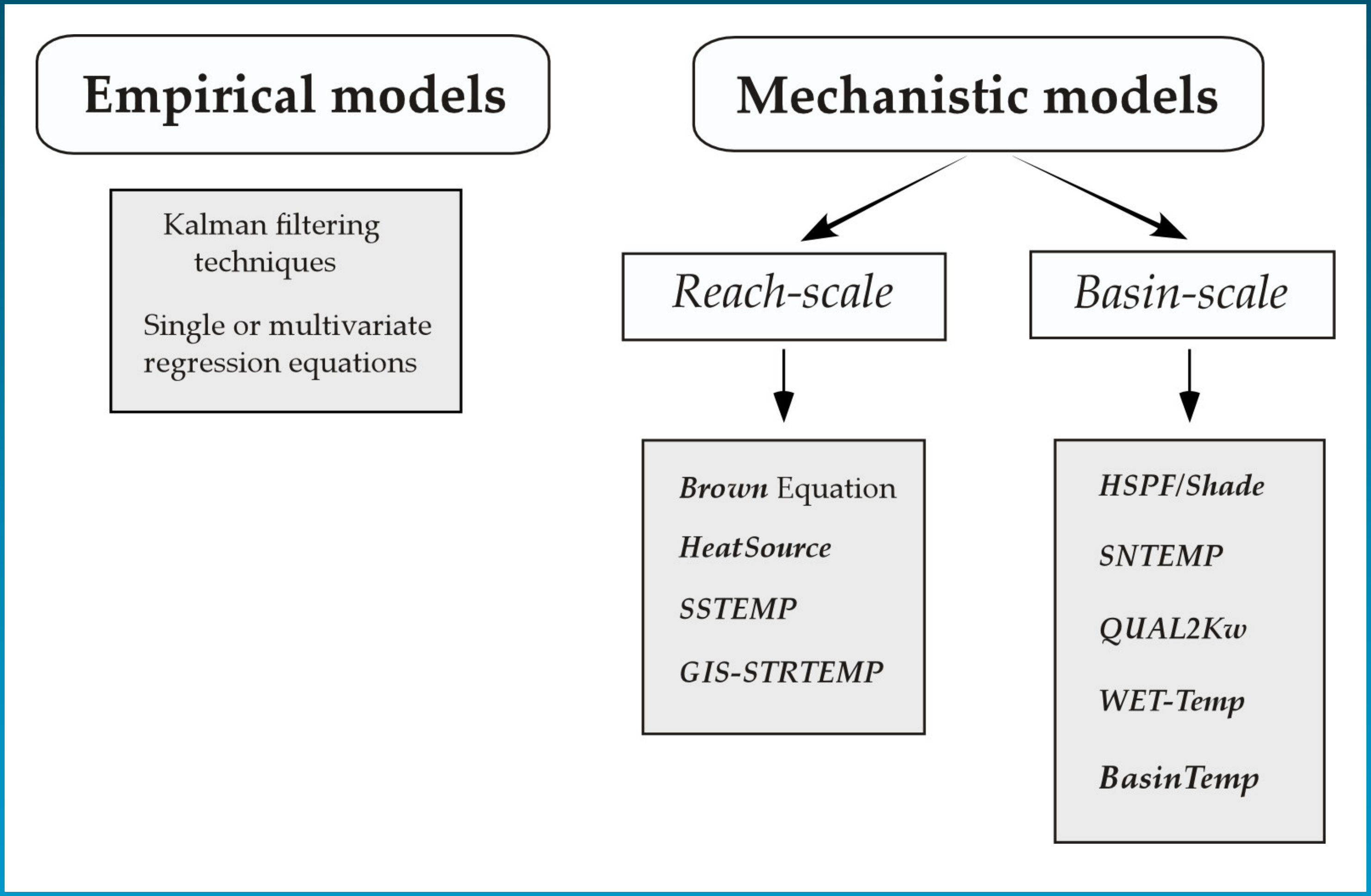
Poole et al. 2004. *BioScience*, Vol. 54 (2), pp. 155-161

Thermal potential assessment

- What are the tools available to determine thermal potential (i.e., the “natural background” thermal regime)?
  - Demonstrate that current temperatures reflect natural background conditions (e.g., non-degraded wildland watersheds)
  - Comparisons to a reference stream
  - Historical data
  - Inference based on historical fish distributions
  - Stream temperature models

EPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards.

Existing stream temperature models



Temperature modeling

BasinTemp is discussed here as an example of a process-based model designed for application at the basin-scale

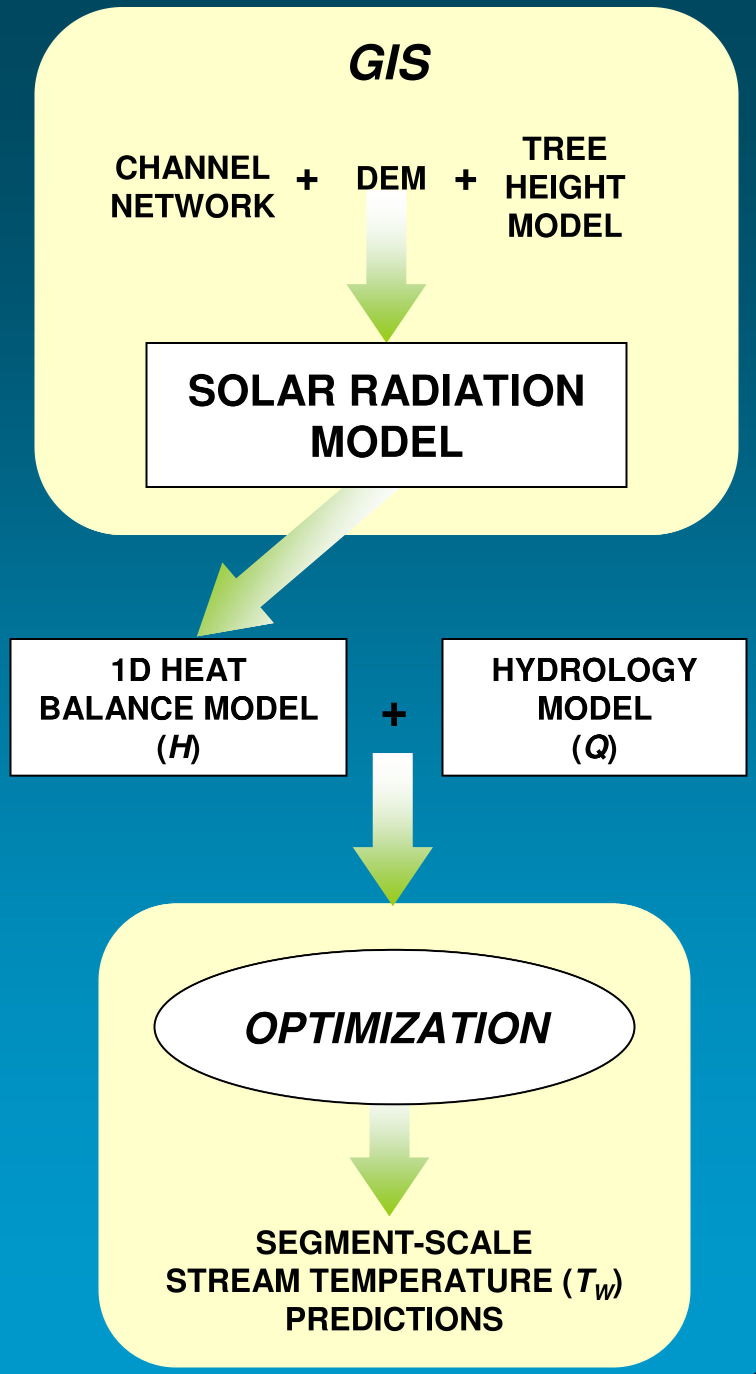
- Advantages to this type of modeling approach
  - Allows site-specific analysis of temperature potential
  - Compatible with species and life-stage specific considerations in a basin
  - Can explicitly quantify anticipated climate change effects
  - Forward-looking analysis that can be built into TMDL process
    - Facilitates load allocation and riparian shade target development
    - Framework for implementation and monitoring plans
  - Can be used to direct management
    - Effects of particular tributaries on a basin's thermal regime
    - Help set priorities for reach- and site-specific management actions
    - Cumulative effects analysis

Stillwater Science's *BasinTemp* model:

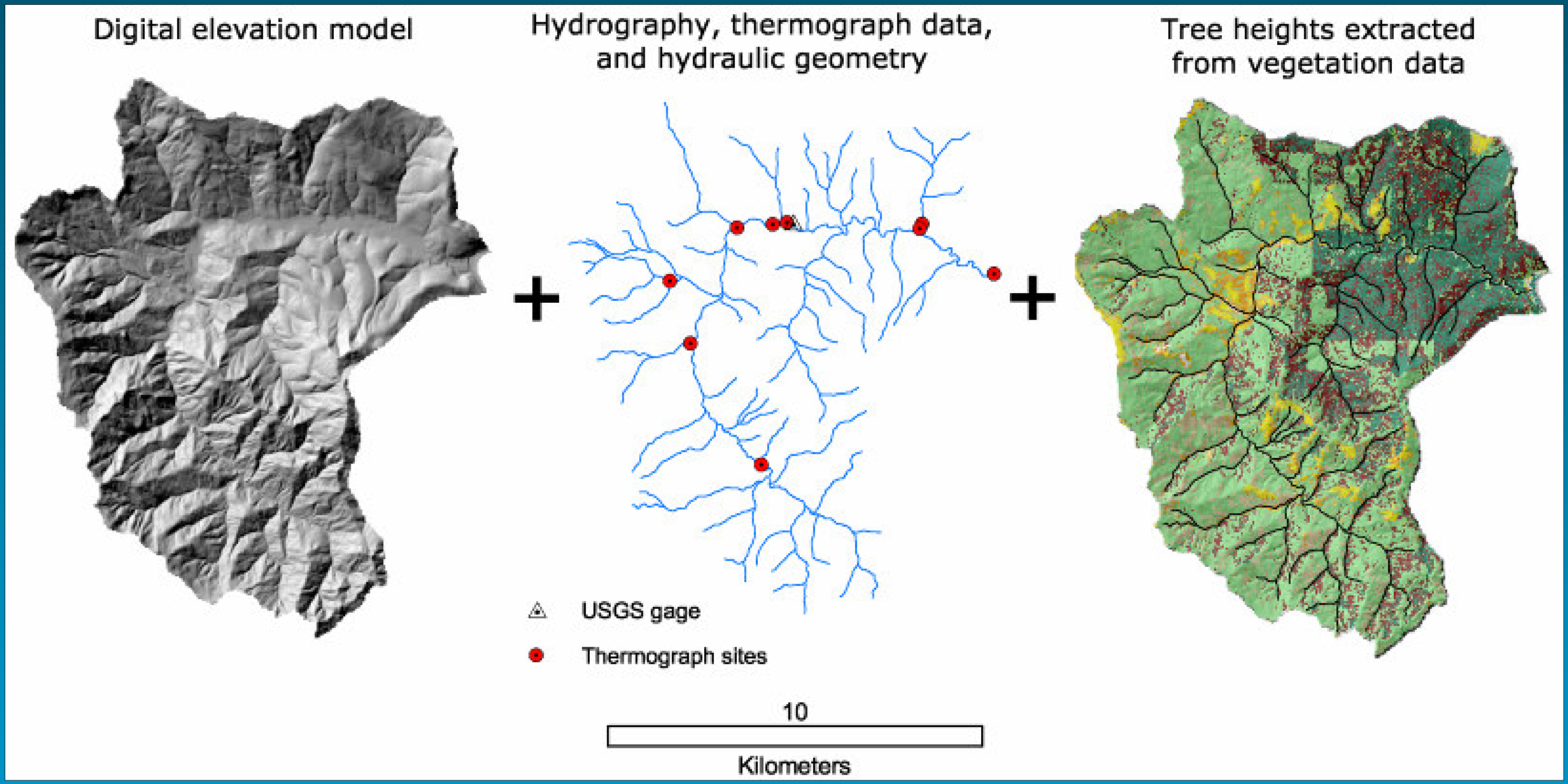
- ***Process-based*** model structure
- ***Basin-scale*** application
- Quantifies near-stream ***riparian and topographic shading*** regime for very short reaches
- Physically-based ***hydrological model***
- ***Minimal field-measured data*** requirements
- Include ***riparian tree height adjustment*** functionality, permits assessing local and cumulative downstream temperature effects

BasinTemp. . .

- A GIS preprocessor where **insolation modeling** is performed
- A simple 1D **heat-balance model**
- A simple **hydrology model** which assumes linear groundwater accretion as a function of drainage area
- An **optimization routine** which improves model predictions using measured temperature data



GIS preprocessor

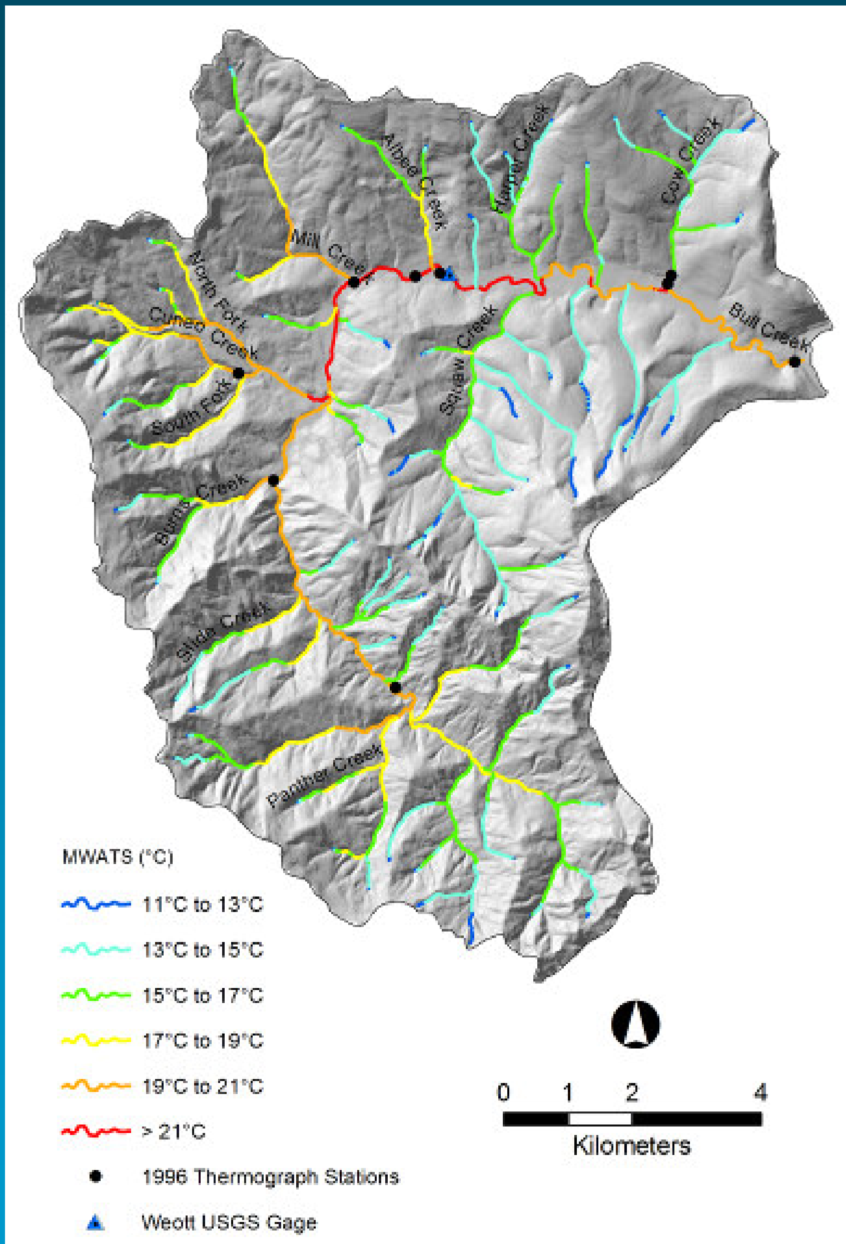


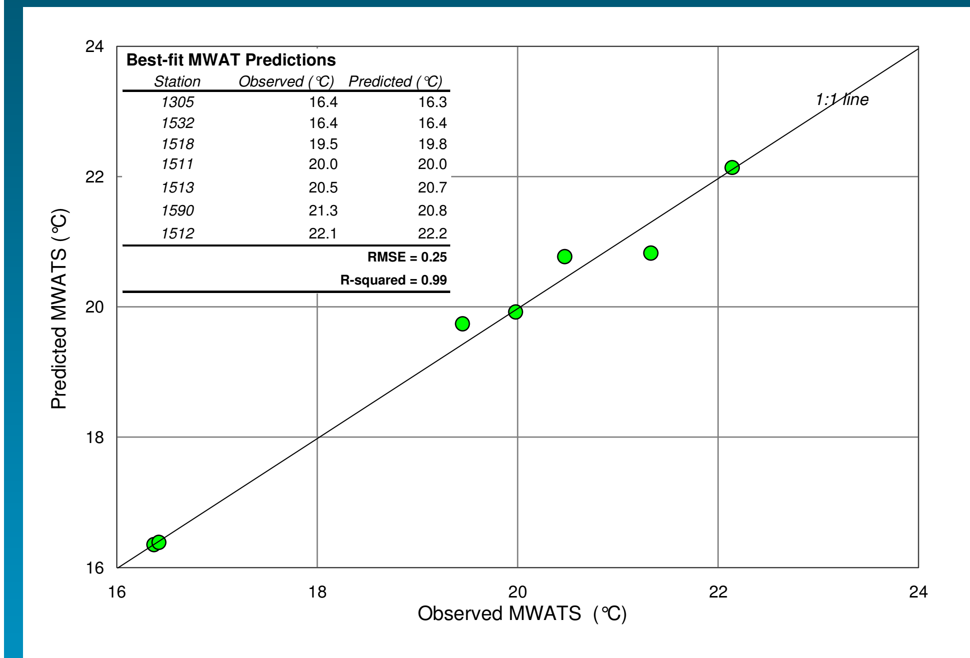
Digital elevation data is combined with digital hydrography and vegetation data (diameter-at-breast-height information converted to tree heights)

Examples of *BasinTemp* applications

- South Fork Eel River TMDL (U.S. EPA, 1999)
- South Fork Ten Mile River Stream temperature assessment, 2006-2009,
  - the first 3-years of this temperature assessment have coincided with more extreme climate conditions
    - 2006 July heat wave
    - 2007-2008 drought (low summer flows)

MWAT temperature predictions *Bull Creek, South Fork Eel*





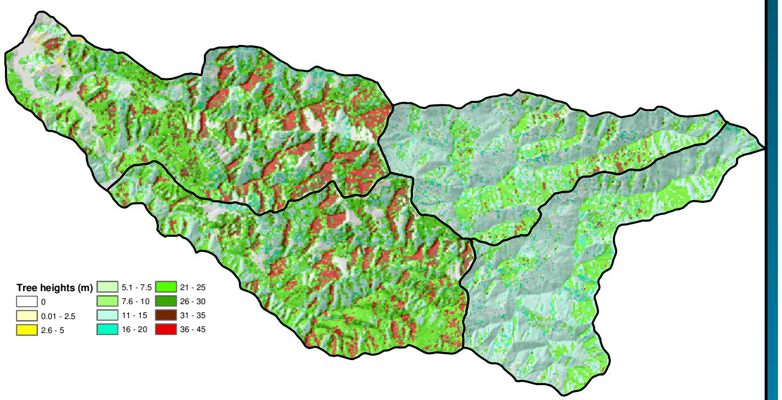
South Fork Ten Mile River application

- How does the thermal potential analysis differ from applications of traditional numeric standard?
- What type of data are required to run this model?
  - Flow
  - A handful of Hobo-temps (water temperature recorders)
  - Vegetation information (tree heights)
  - GIS-based channel information and a DEM
- How could this application be used in the listing process?

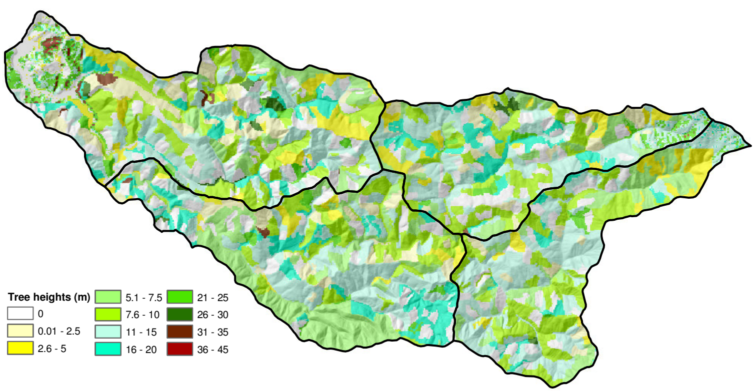
Tree height model

South Fork Ten Mile River

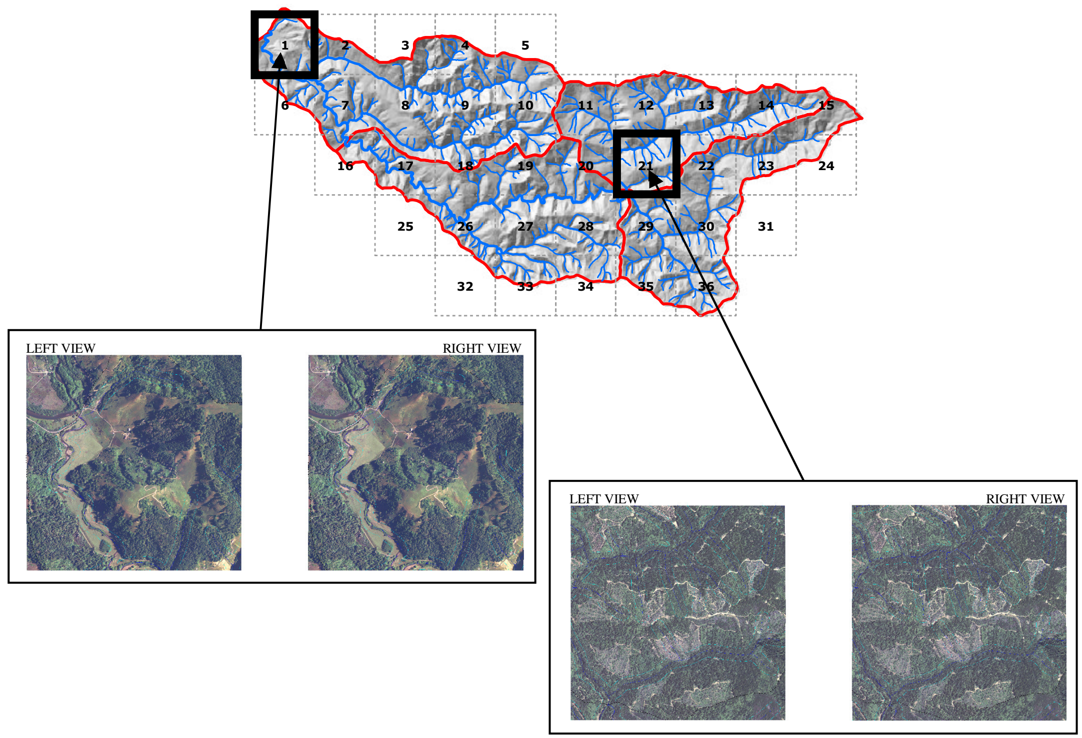
1994 CWHR Landsat data



2005 Campbell Timber Co. data

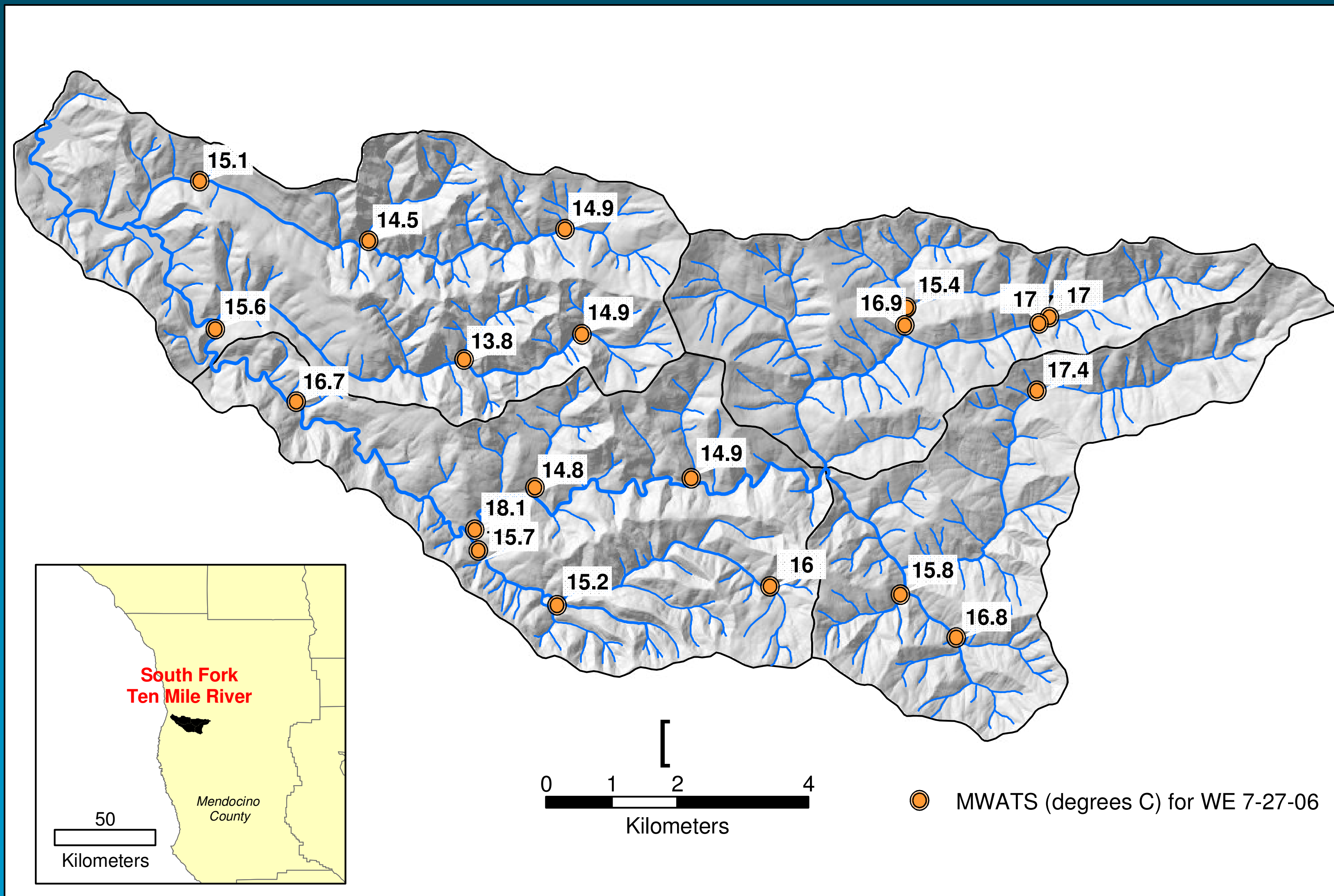


2005 National Agricultural Imagery Program data



Observed 2006 MWATS

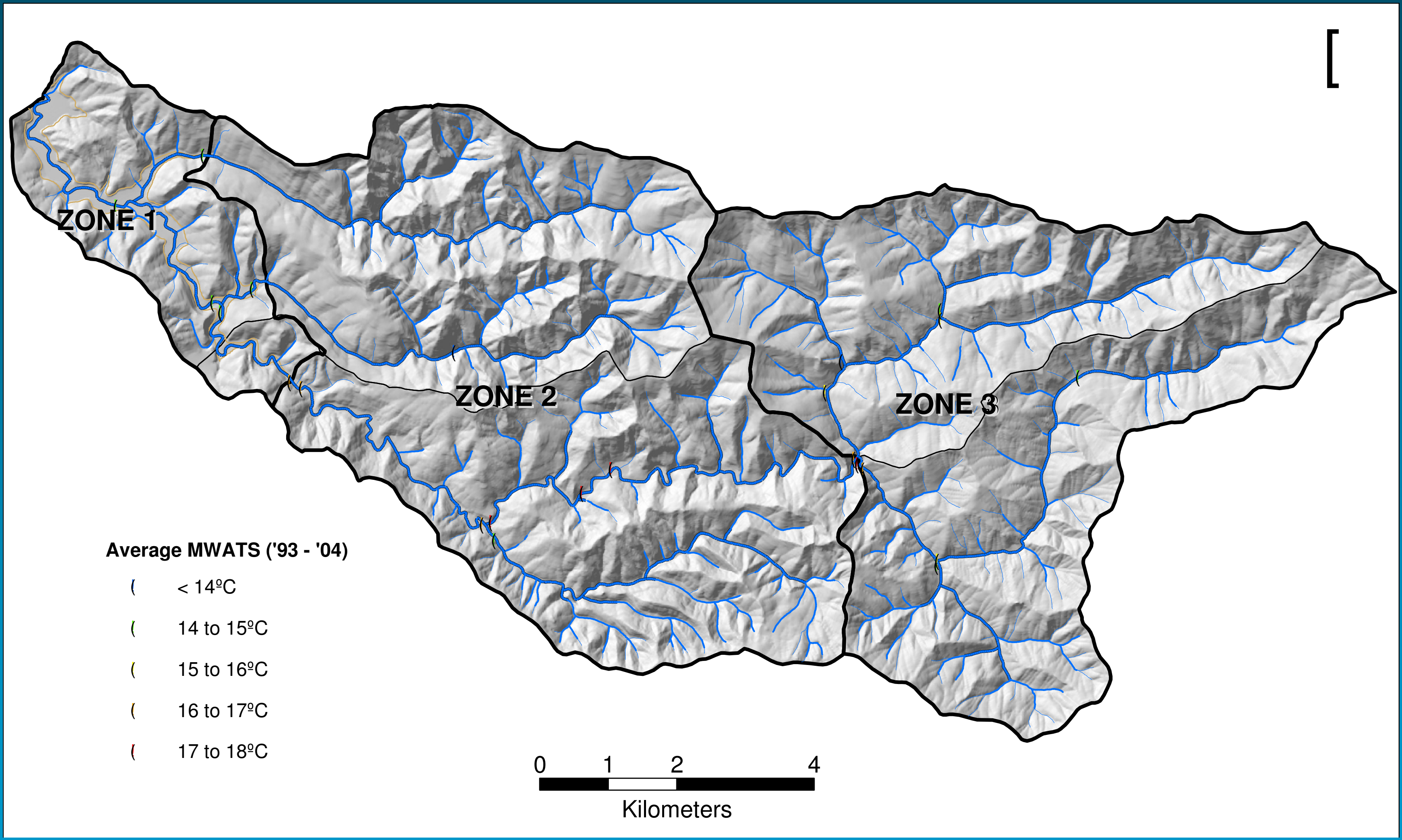
South Fork Ten Mile River



Incorporating spatially-varying temperature controls in temperature predictions

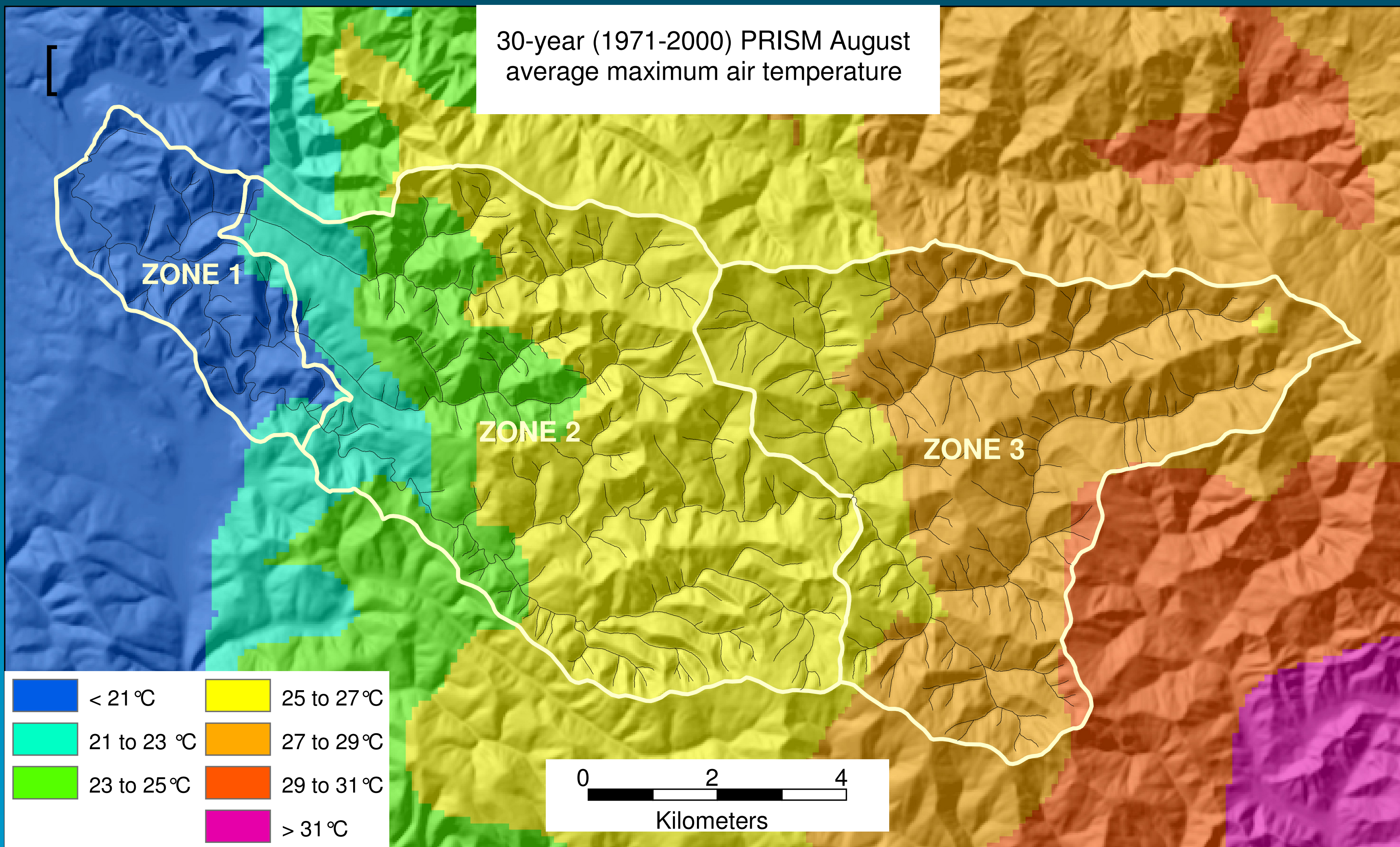
- Identifying the upstream extent of maritime fog influence (e.g. South Fork Ten Mile River)
- Identifying interactions between geology, topography, and vegetation (e.g. Rattlesnake Creek, South Fork Eel)

Fog zone defined by mainstem temperatures



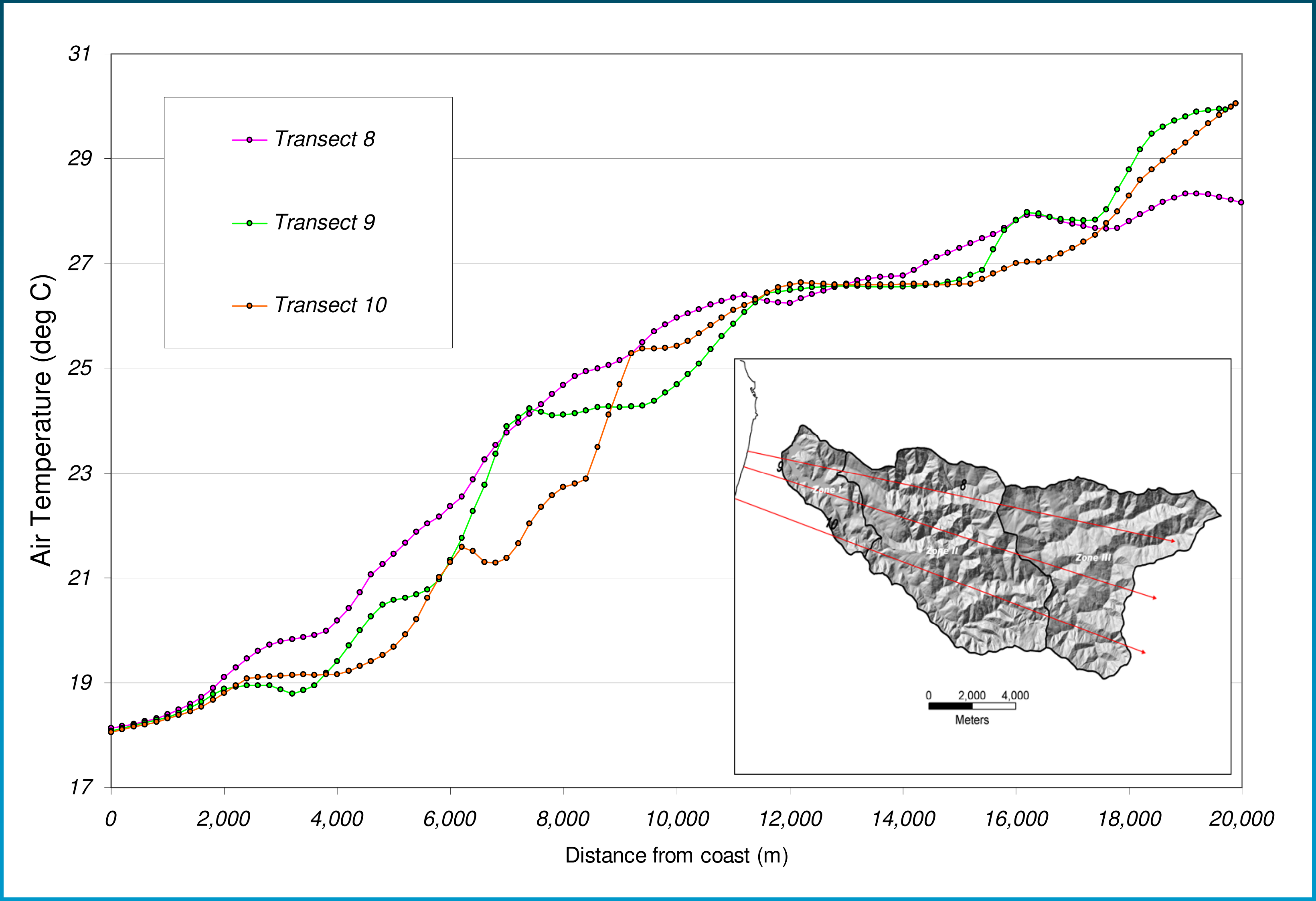
South Fork Ten Mile River

Validated using data stratifying air temperature trends



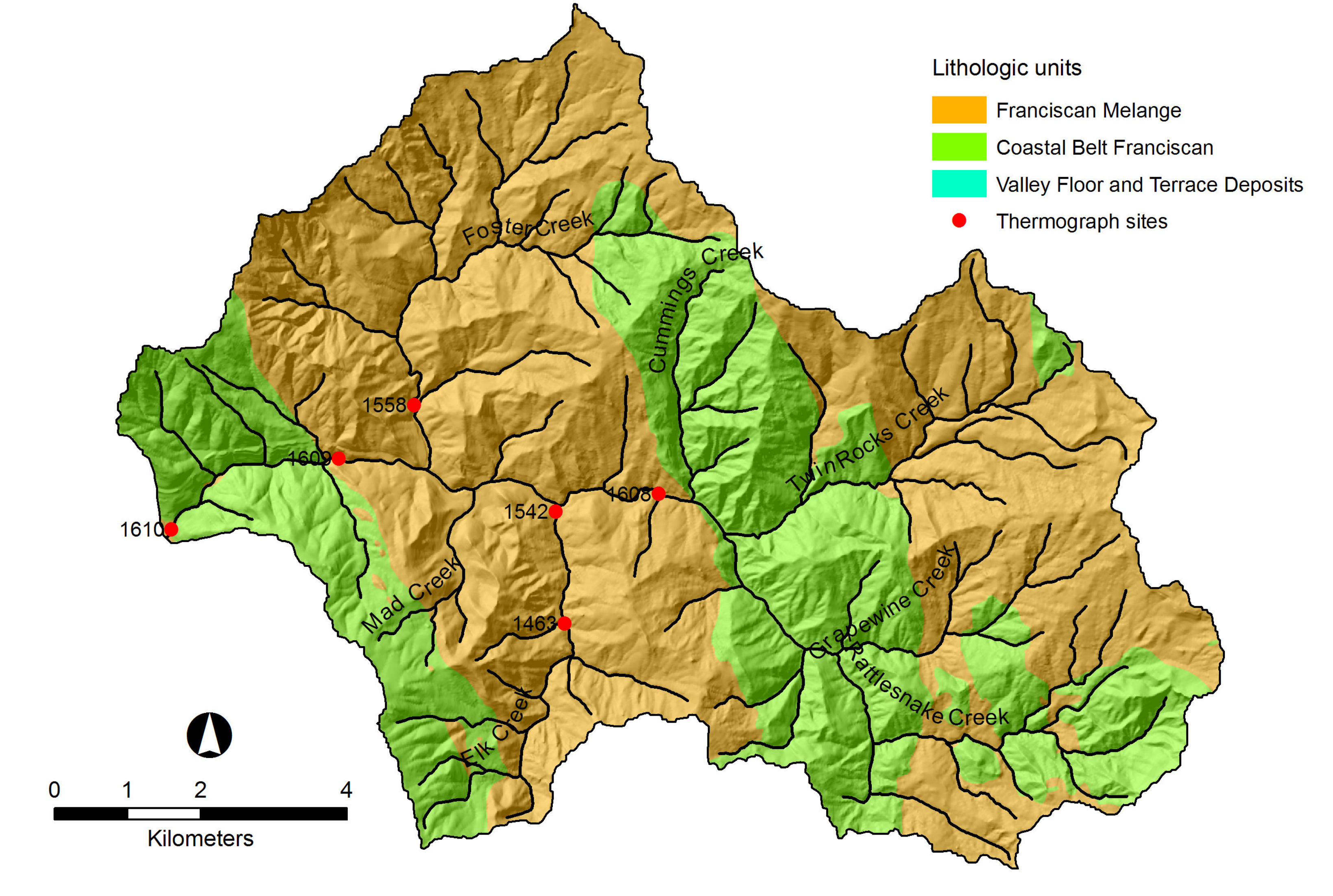
South Fork Ten Mile River

Identify west-to-east air temperature trends



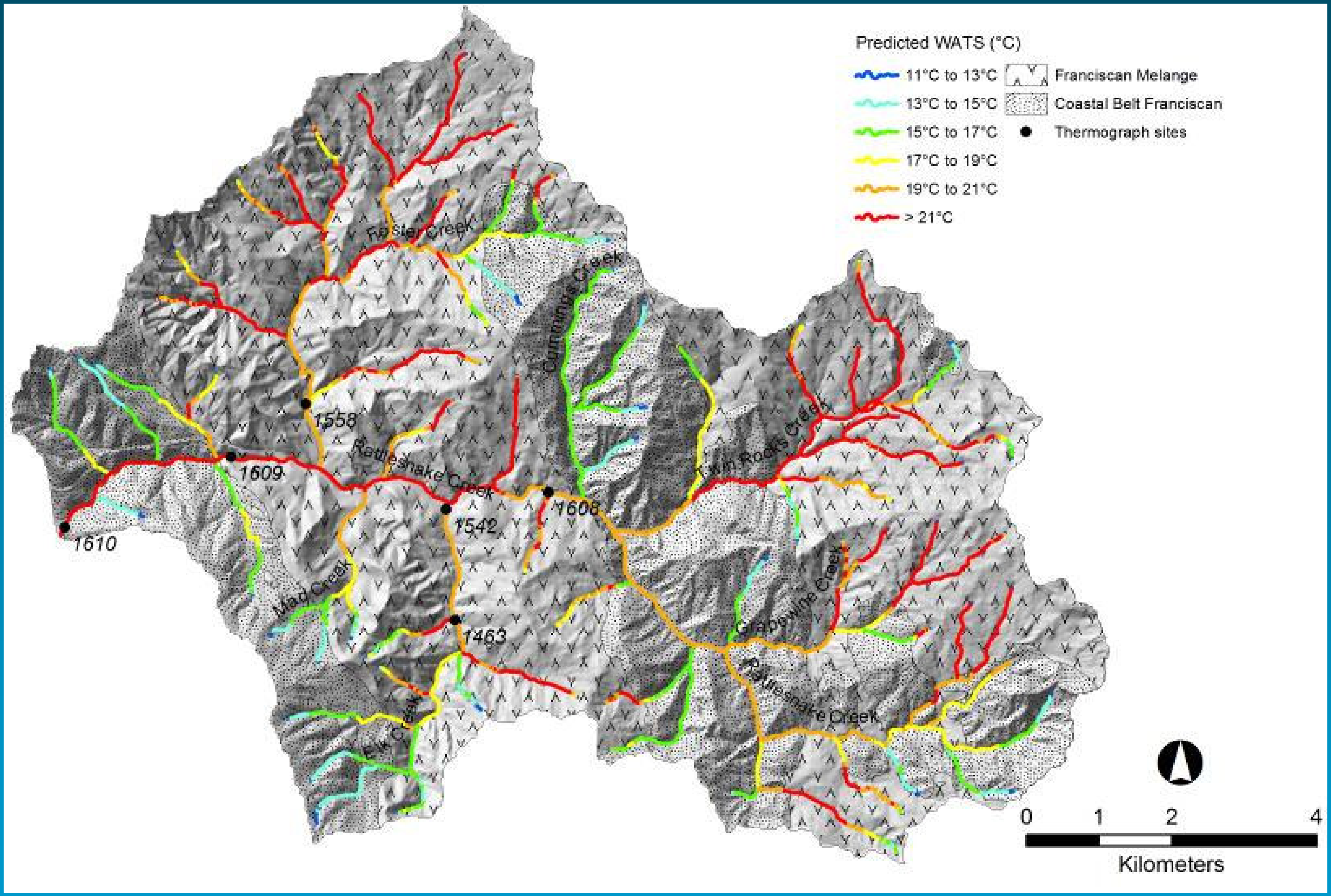
South Fork Ten Mile River

Lithologic controls on groundwater seepage rates



Rattlesnake Creek, South Fork Eel River

. . . and hence on predicted stream temperatures



Rattlesnake Creek, South Fork Eel River

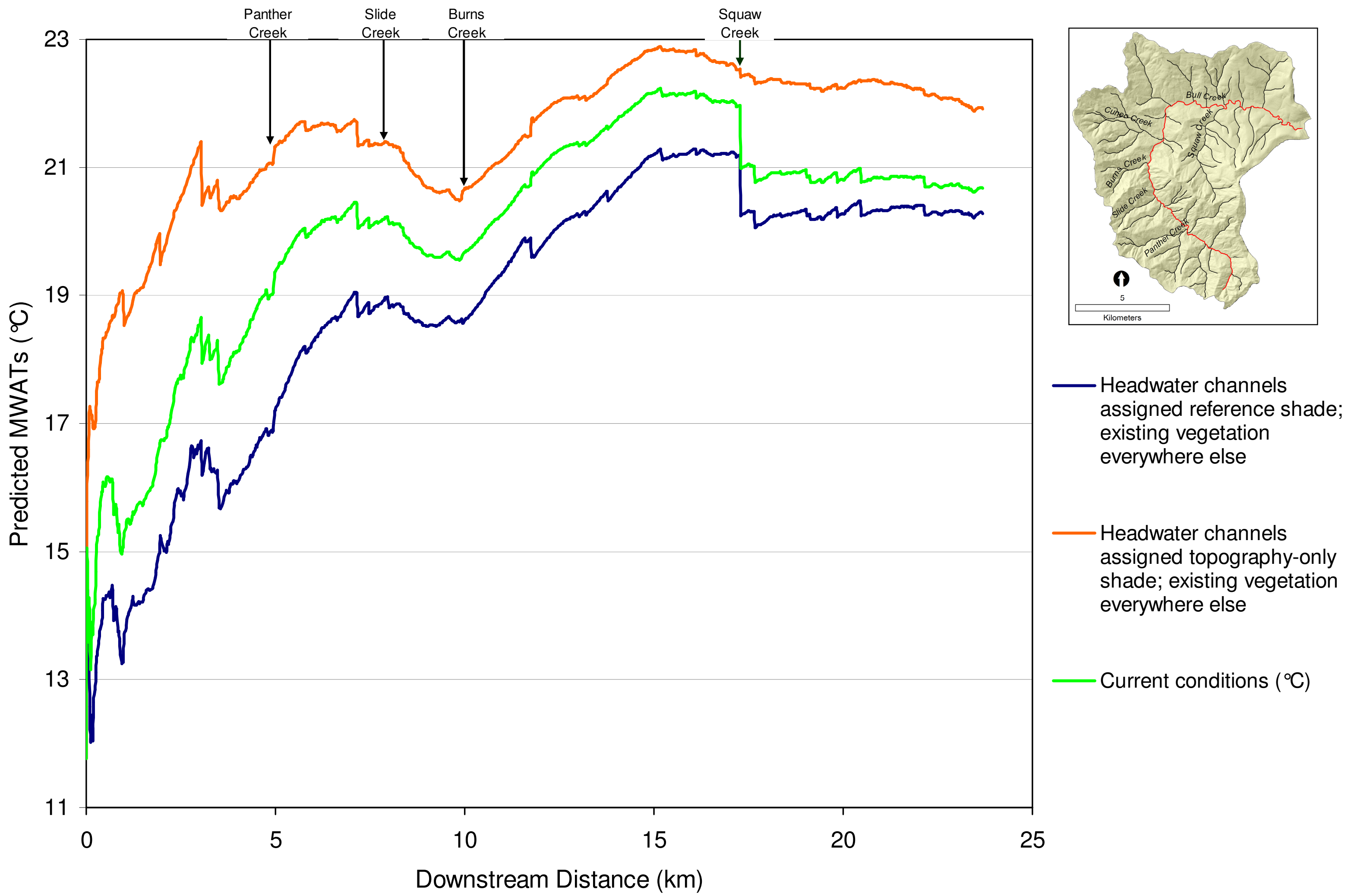
Climate change impacts on stream temperatures in California

- The two most important climate change impacts on stream temperature are expected to be:

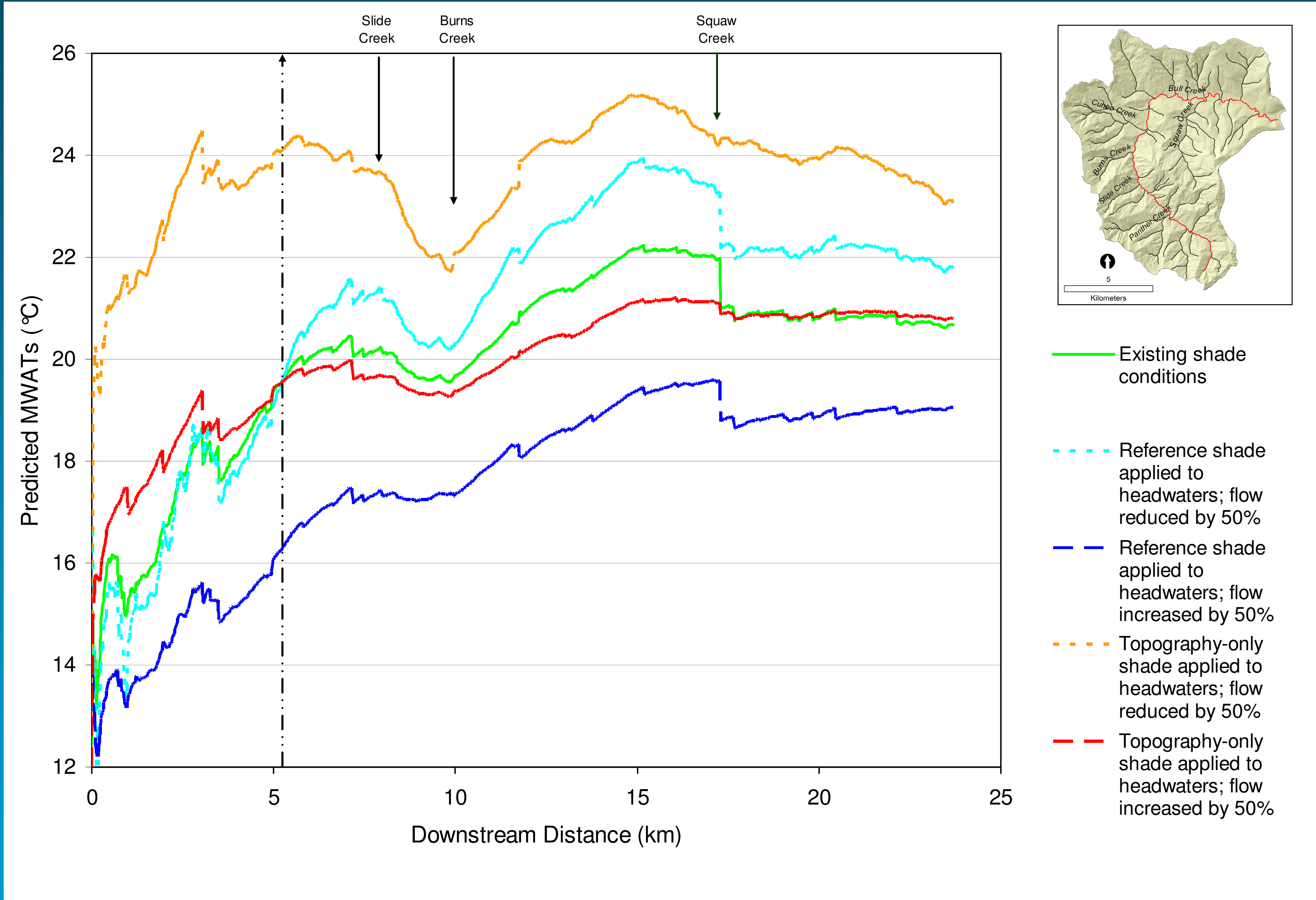
  1. Increased ambient air temperatures (e.g., 2006 July heat wave)

  2. Shift in the hydrologic cycle and including increased drought frequency (e.g., 2007-2008 low flow conditions)

Downstream cumulative effects: *role of shade*

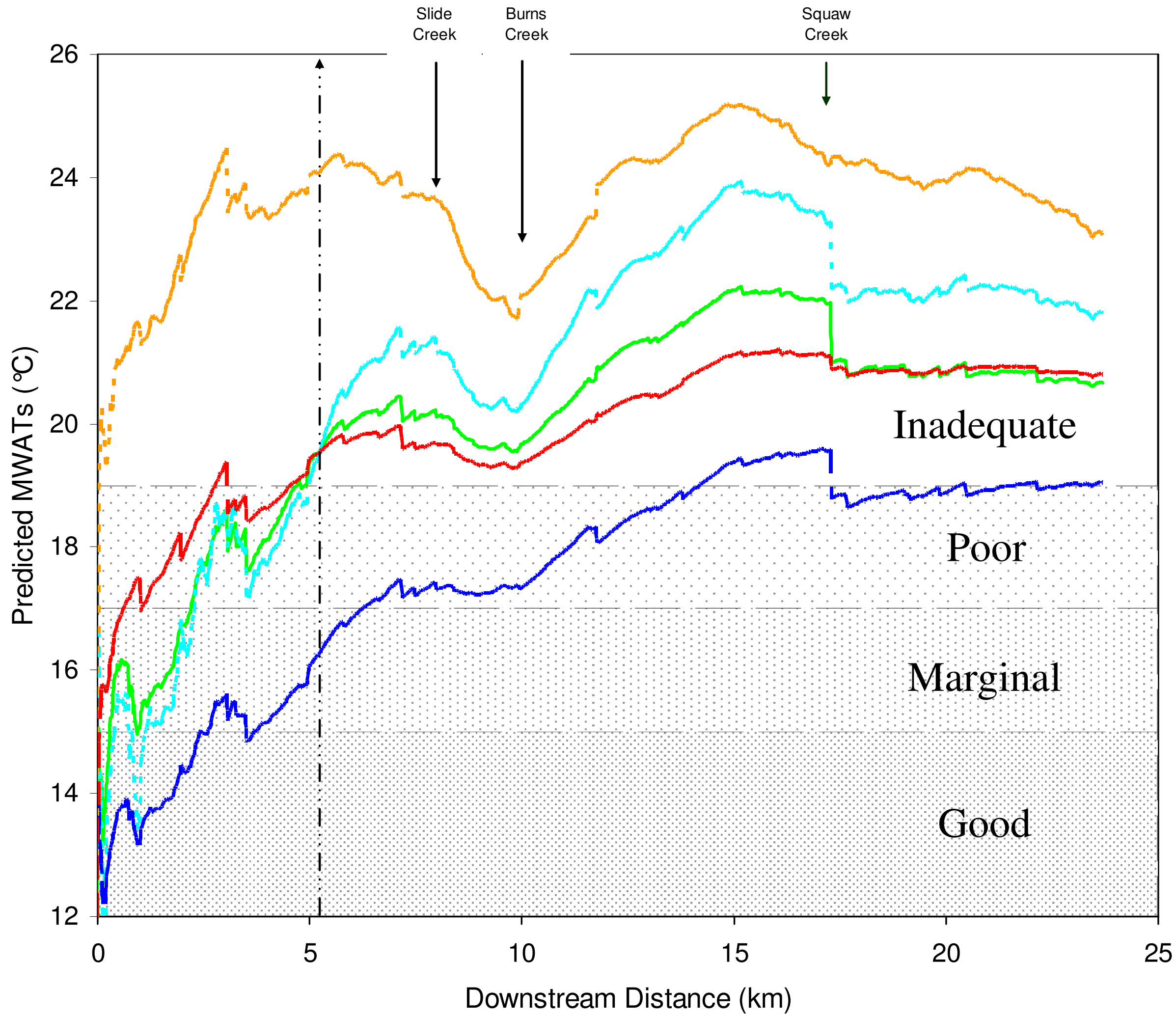


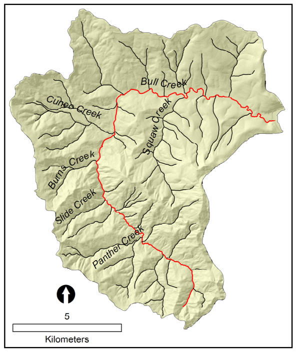
Downstream cumulative effects:
the role of shade and +/- discharge



Bull Creek, South Fork Eel River

Shade and discharge effects on available habitat





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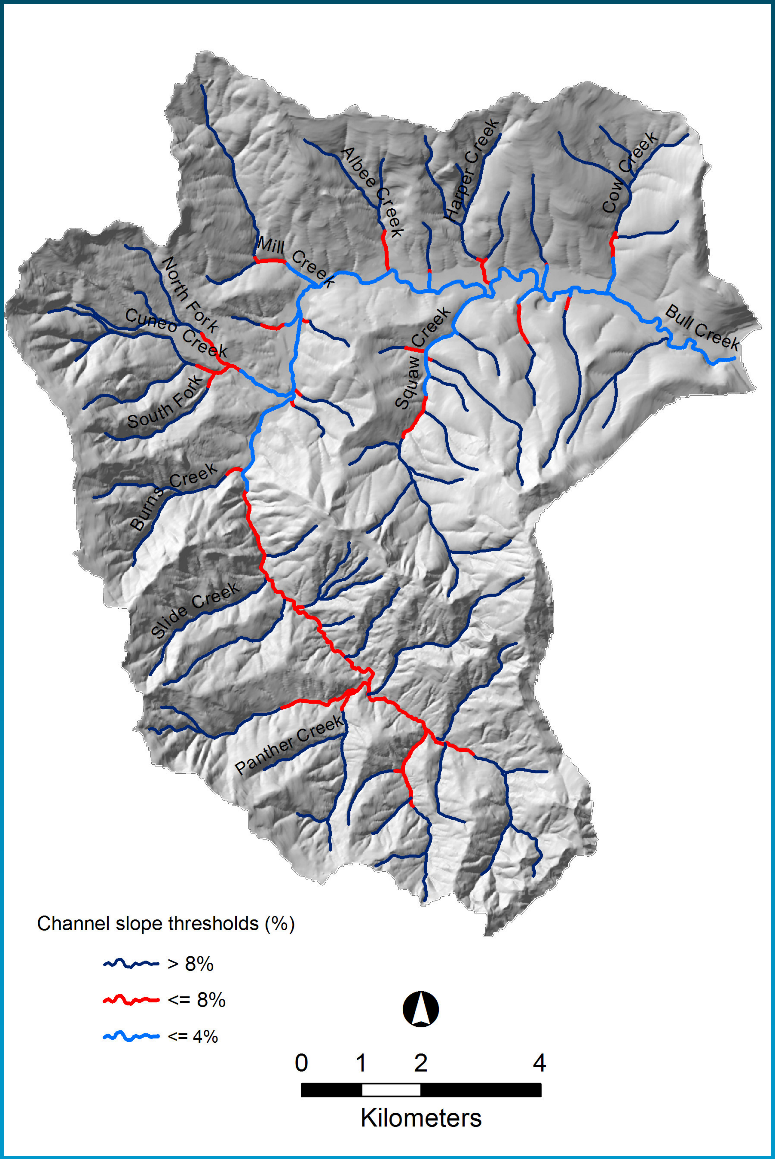
Salmon summer rearing habitat temperature criteria from S Fork Eel TMDL (EPA 1999)

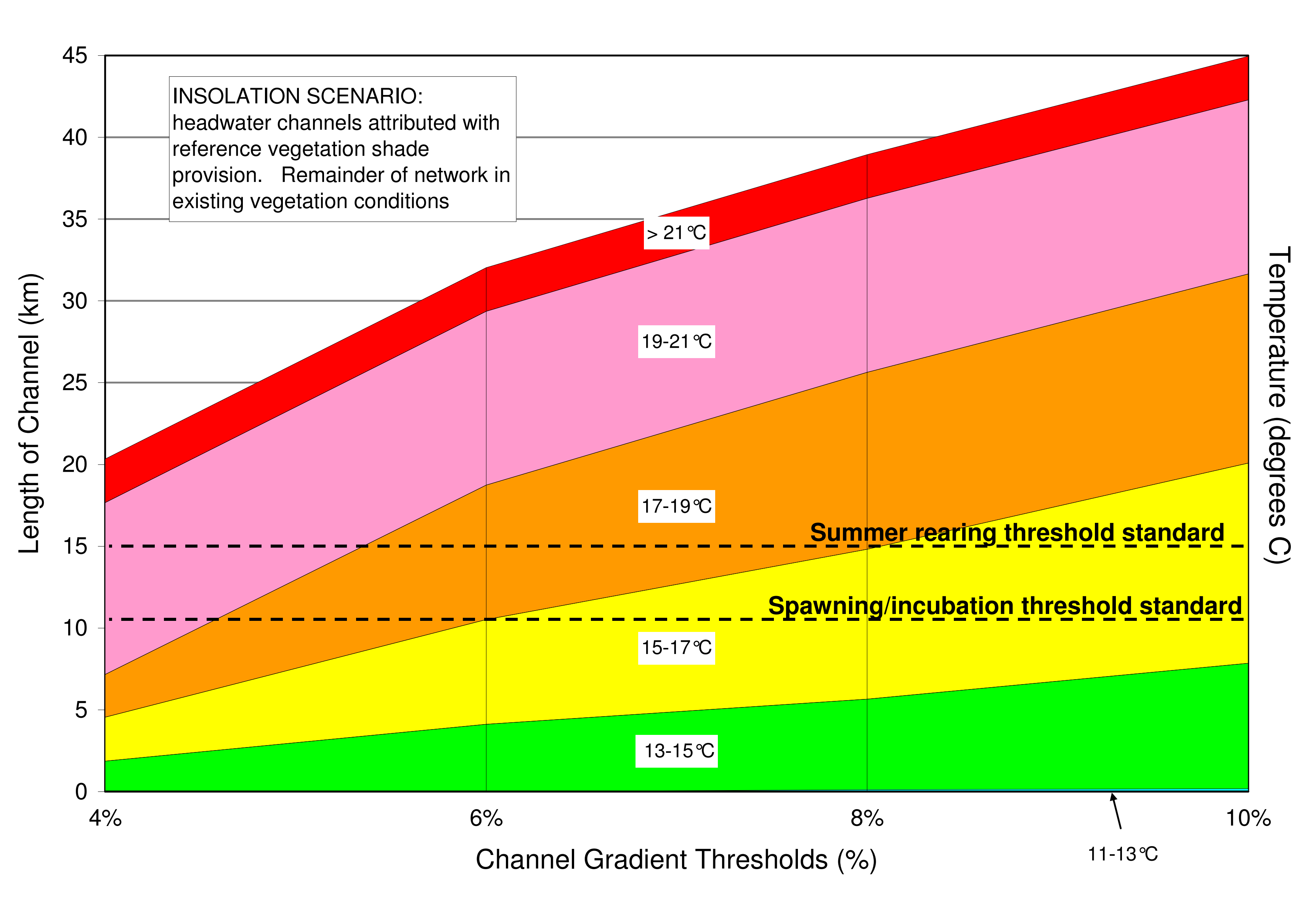
California Forest Practice Rules: stream classification system

Class I	Class II	Class III
(Fish always or seasonally present. Includes habitat to sustain fish migration and spawning)	[(1) Fish always or seasonally present offsite within 1000 feet downstream, and/or, 2) Aquatic habitat for non-fish species]	(No aquatic life present. Capable of sediment transport to Class I and II streams under normal high water flow conditions.)

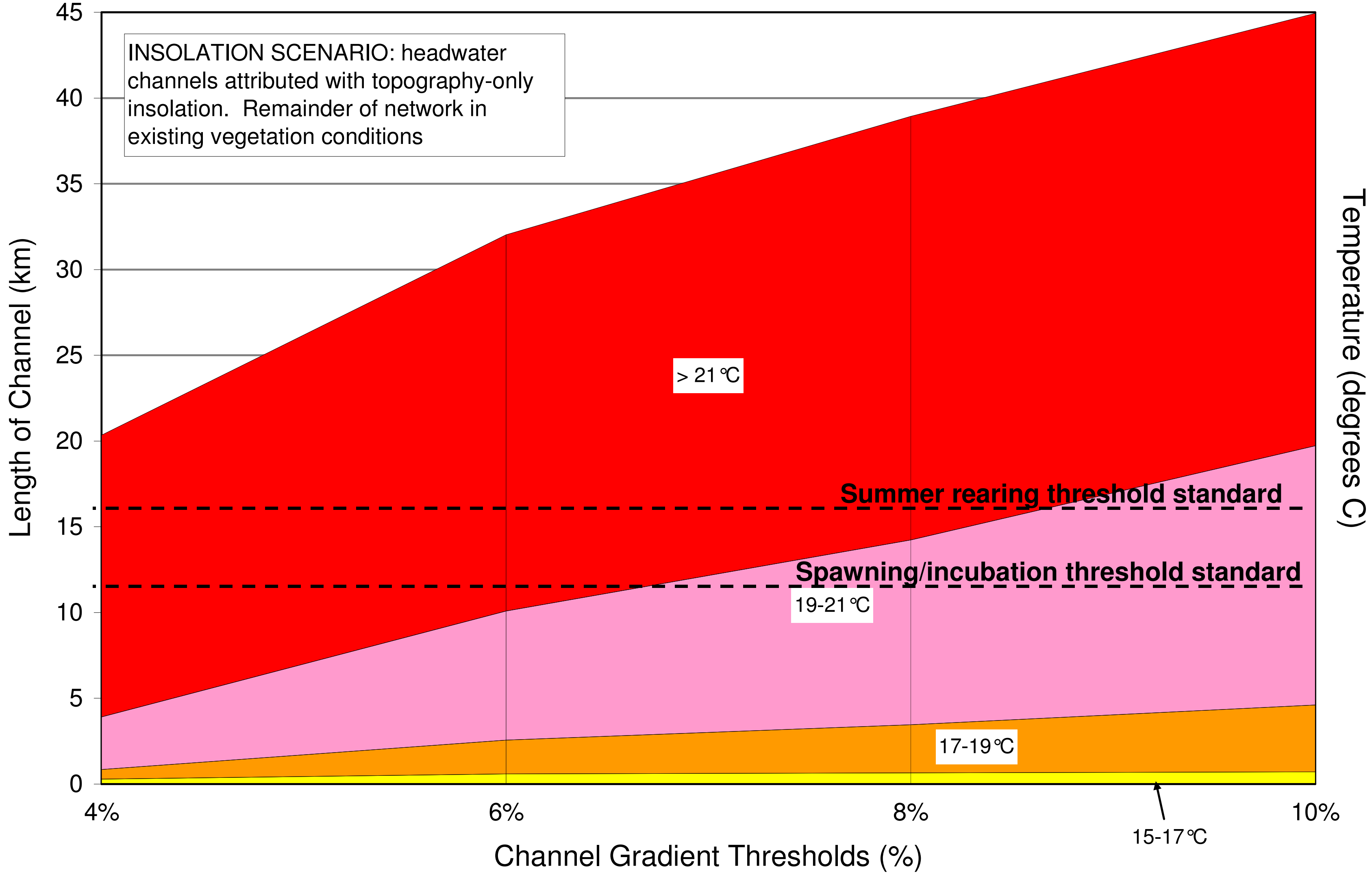
Slope-based stream classification system: Bull Creek, N. Cal.



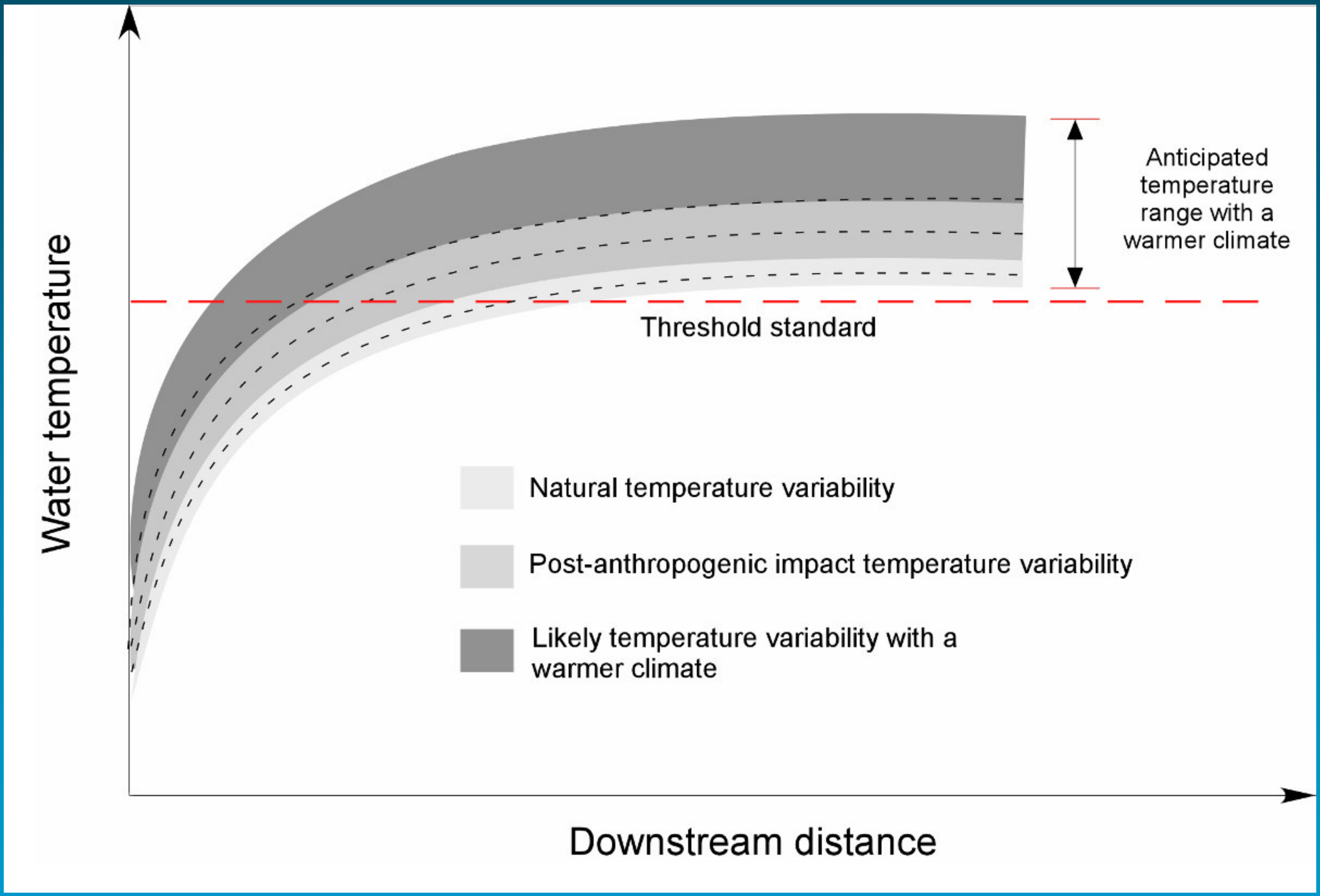
Cumulative temperature effects: fully shaded headwaters



Cumulative temperature effects: unshaded headwaters



Summary and conclusions



Summary and conclusions

- Advantages to thermal potential approach
  - Addresses natural variability in stream temperature regimes
  - Avoids pitfalls of the one-size-fits-all numeric standard approach
  - Facilitates more site-specific and ecoregion-specific targets and management
  - Links to different life history needs of salmonids
- Disadvantages to thermal potential approach
  - Can be costly to model every basin and stream
- Take home considerations that can inform listing process
  - Could be useful in the listing process, but cost factors come into play
  - Potential value for delisting basins that are in good condition but with high natural temperature potential
  - Landowners can use results in their management plans (e.g., TMDL implementation plans, HCPs, SYPs/PTEIRs, range management plans)

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Additional slides