Temperature Modeling to Support TMDL Development for the Klamath and Eel Rivers

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TETRA TECH

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Presentation Overview

- 2 separate temperature modeling projects
  - Klamath River Model
    - Linked model to evaluate impacts of point and nonpoint sources, impoundments, and operations
  - Eel River Model
    - Riparian and topographic shading analysis
- Discussion
  - Background
  - Model Capabilities and Results
  - Applicability and Limitations

Acknowledgments

- Klamath River TMDL Modeling
  - U.S. EPA Regions 9 and 10
  - North Coast RWQCB
  - Oregon DEQ
- Eel River TMDL Modeling
  - U.S. EPA Region 9
- Tetra Tech Modelers
  - Dr. Rui Zou, Mustafa Faizullabhoy, Amy King

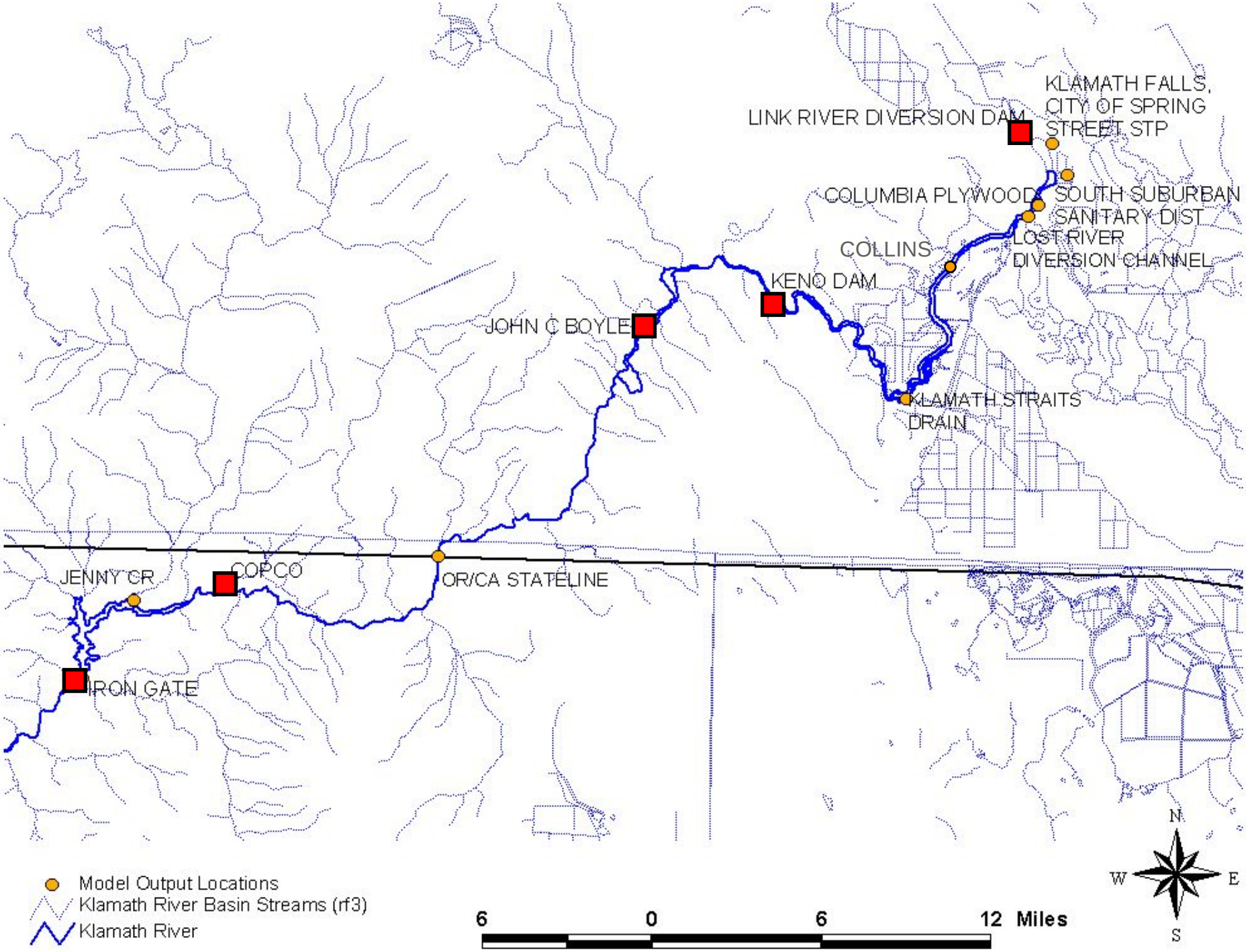
Total Maximum Daily Load (TMDL) Modeling

- Both projects have supported determination of TMDLs
- Driven by water quality impairments and Clean Water Act requirements
- What is a TMDL?
  - A pollution budget: $TMDL = \sum WLA + \sum LA + \sum MOS$
  - Included in a plan identifying needed pollutant reductions to meet water quality standards or goals
  - Determines how much of a pollutant a water can absorb (assimilative capacity) without violating criteria
- Models are frequently applied to TMDL determination

Klamath River Model

Background

- Series of riverine segments, reservoirs, and estuary
- Addressed region from Upper Klamath Lake to the Pacific Ocean
- Includes multiple hydroelectric developments and a nongenerating dam
- Historically supported one of the largest salmon runs in the U.S.
- Multiple fish kills have occurred
  - 33,000 Trinity River Chinook Salmon in September 2002
- Temperature and other impairments *(including DO, chlorophyll a, pH, ammonia toxicity, organic enrichment, and nutrients)*


KLAMATH FALLS, CITY OF SPRING STREET STP
LINK RIVER DIVERSION DAM
COLUMBIA PLYWOOD
SOUTH SUBURBAN SANITARY DIST
LOST RIVER DIVERSION CHANNEL
COLLINS
KENO DAM
JOHN C BOYLE
KLAMATH STRAITS DRAIN
JENNY CR
COPCO
OR/CA STATELINE
IRON GATE
Model Output Locations
Klamath River Basin Streams (rf3)
Klamath River
6 0 6 12 Miles
N
W
E
S

Modeling Objectives

- Assess cause-effect relationship between source contributions/impacts and the response of the Klamath River, its reservoirs, and the estuary
- Use existing models and available data to support and provide an acceptable level of reliability in the technical analysis
- Meet current and future TMDL development and management needs
- Strengthen the model with an external peer review

Modeling Approach

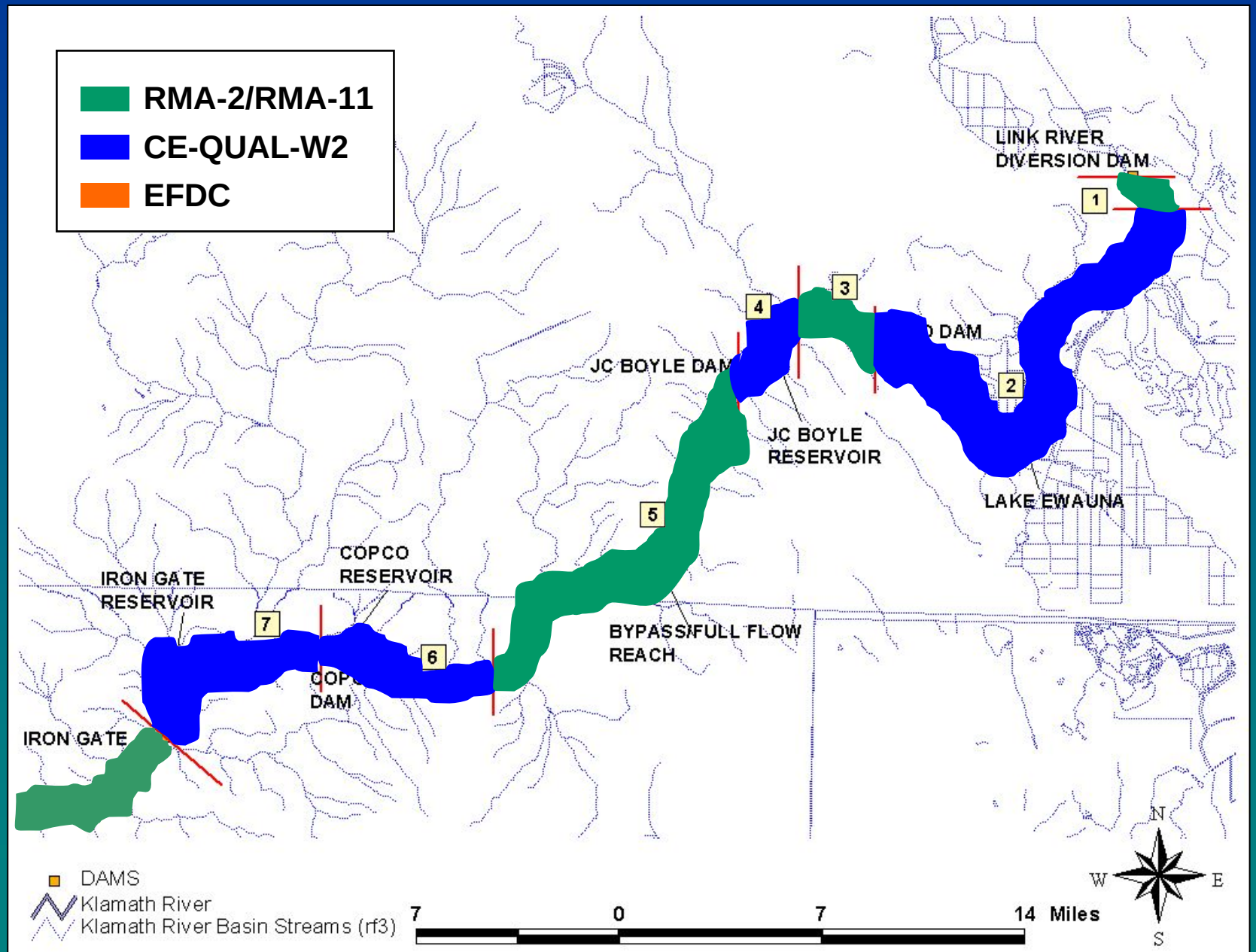
- Enhanced existing linked CE-QUAL-W2 and RMA modeling framework for TMDL needs
  - Developed by PacifiCorp (technical support provided by Watercourse Engineering) for FERC relicensing
  - Hydrodynamics (including temperature), nutrient cycles, and dissolved oxygen
  - Dynamic (time-variable)
- Added model component for estuary (EFDC)

Model Configuration

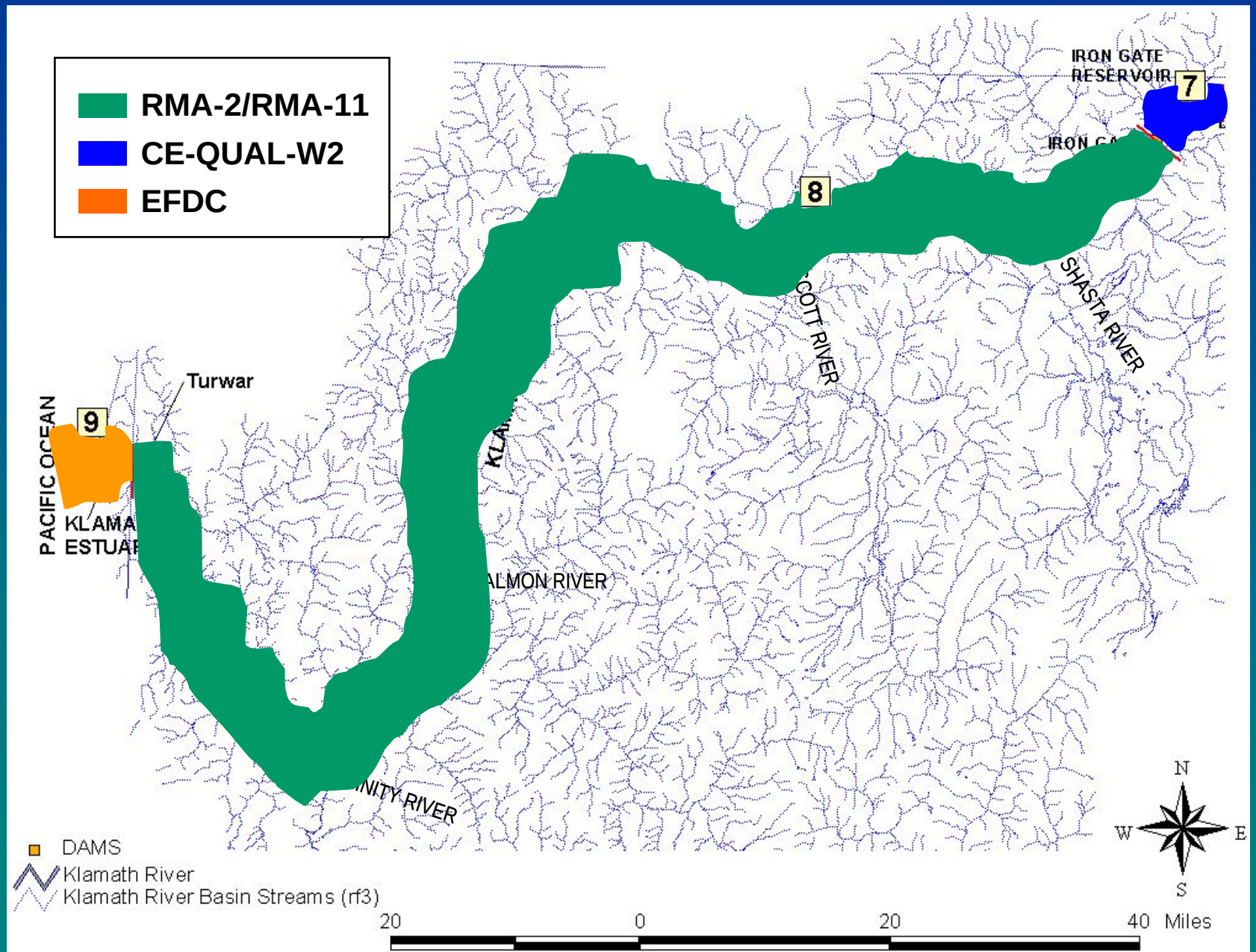
Modeling Segment	Segment Type	Model(s)	Dimensions
Link River	River	RMA-2/RMA-11	1-D
Lake Ewauna-Keno Dam	Reservoir	CE-QUAL-W2	2-D
Keno Dam to J.C. Boyle Reservoir	River	RMA-2/RMA-11	1-D
J.C. Boyle Reservoir	Reservoir	CE-QUAL-W2	2-D
Bypass/Full Flow Reach	River	RMA-2/RMA-11	1-D
Copco Reservoir	Reservoir	CE-QUAL-W2	2-D
Iron Gate Reservoir	Reservoir	CE-QUAL-W2	2-D
Iron Gate Dam to Turwar	River	RMA-2/RMA-11	1-D
Turwar to Pacific Ocean	Estuary	EFDC	3-D

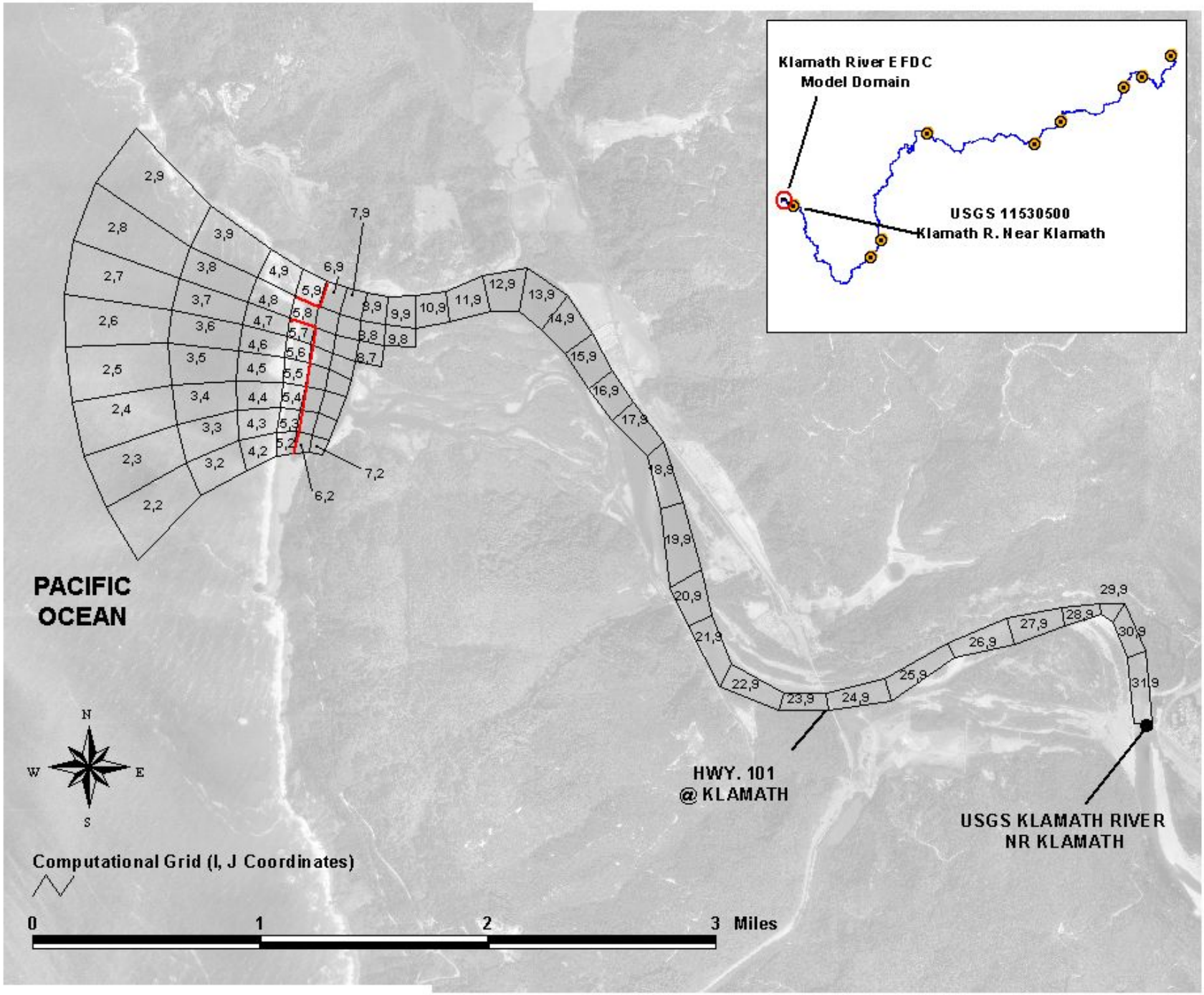
- 9 model segments
- Rivers: 75 - 300 m node distances
- Reservoirs: 0.61 - 1.0 m segment thicknesses and 37 - 714 m lengths
- Estuary: 75 grid cells

Upper Klamath Lake to Iron Gate Dam



Iron Gate Dam to the Pacific Ocean




Klamath River EFDC
Model Domain
USGS 11530500
Klamath R. Near Klamath
PACIFIC
OCEAN
HWY. 101
@ KLAMATH
USGS KLAMATH RIVER
NR KLAMATH
N
W
E
S
Computational Grid (I, J Coordinates)
0
1
2
3 Miles

Temperature Modeling Capabilities

- Heat balance
  - Short and long wave radiation
  - Back radiation
  - Evaporative heat loss
  - Heat conduction
- Major difference among models is dimensionality
  - CE-QUAL-W2 (2-dimensional)… Army Corps of Engineers
  - RMA (1-dimensional)… Resource Management Association
  - EFDC (3-dimensional)… EPA
- CE-QUAL-W2 also includes dynamic shading (topographic and vegetative) and ice formation

Considerations

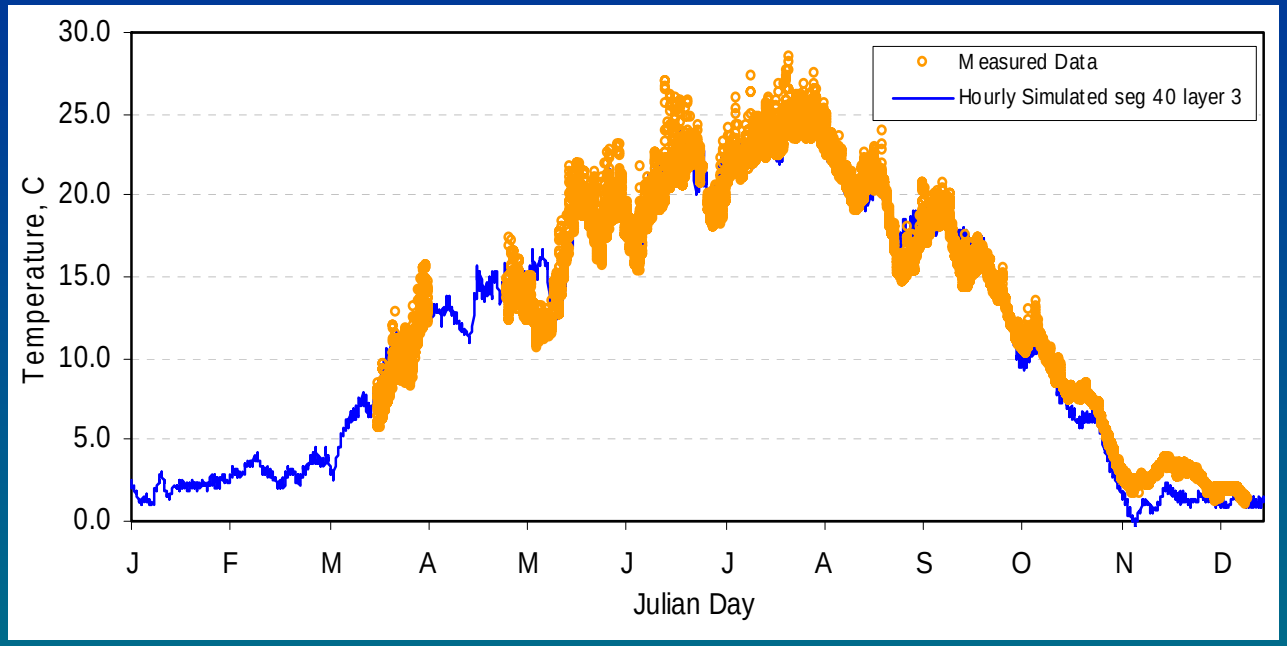
- Upstream external flows and temperature
- Tributary inflows and temperature
- Withdrawals
- Atmospheric conditions
- Point source inputs
- Dam operations

Results

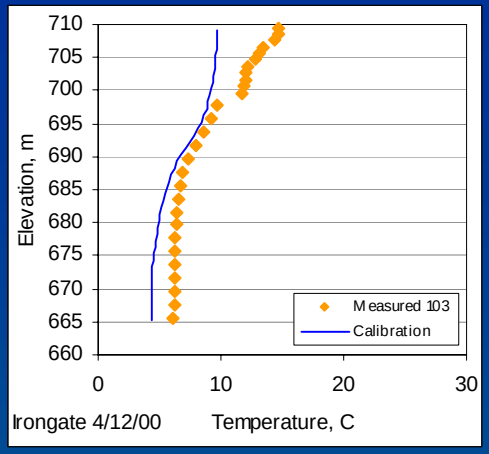
- Spatial
  - Rivers: every 75 - 300 meters
  - Reservoirs: every 35 - 700 meters and at every 0.6 - 1.0 meter depth
  - Estuary: every 200 - 700 meters, at every 0.1 to 0.8 meter depth, and at every 100 - 400 meters laterally
- Temporal
  - Sub-hourly
  - Modeling period focused on 2000, 2002, and 2004, however it can be expanded to include other years

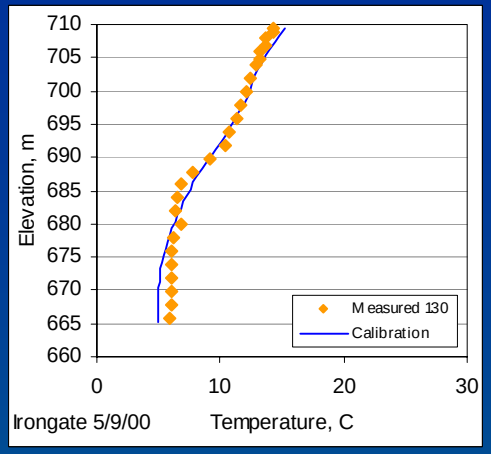
Temperature Model Testing (Calibration)

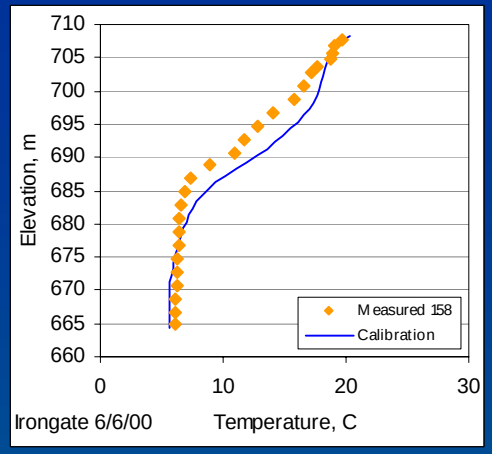
Lake Ewauna – Miller Island

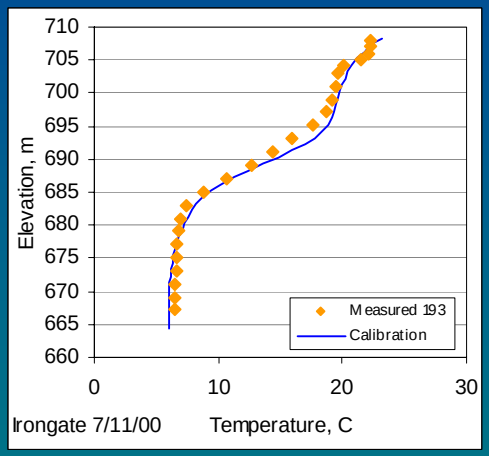


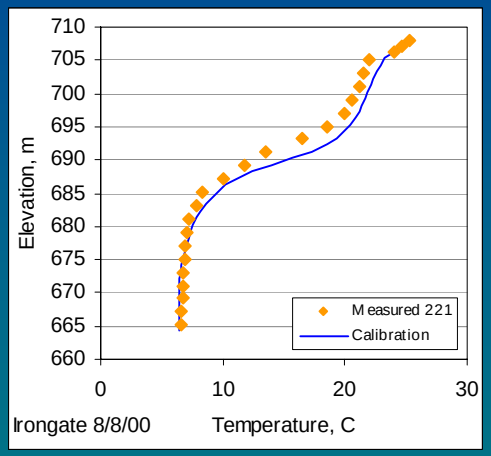
Klamath River at Seiad Valley

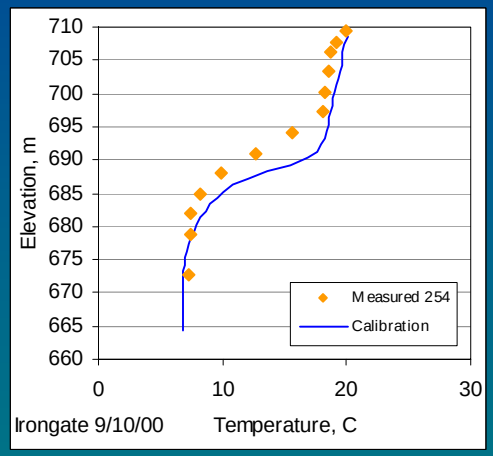


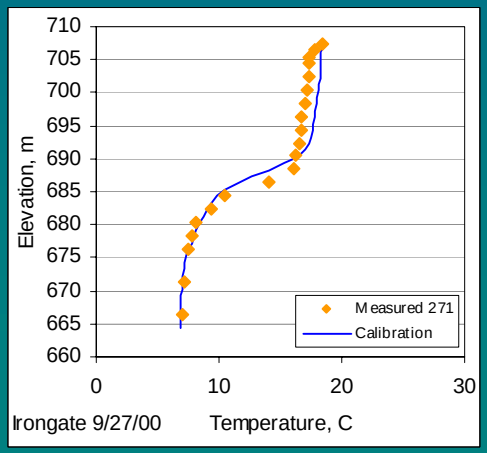


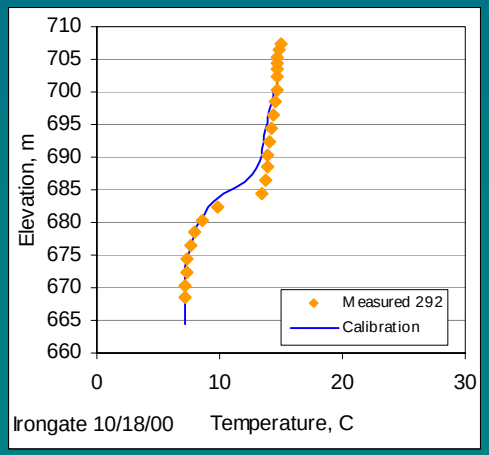












Calibration Example

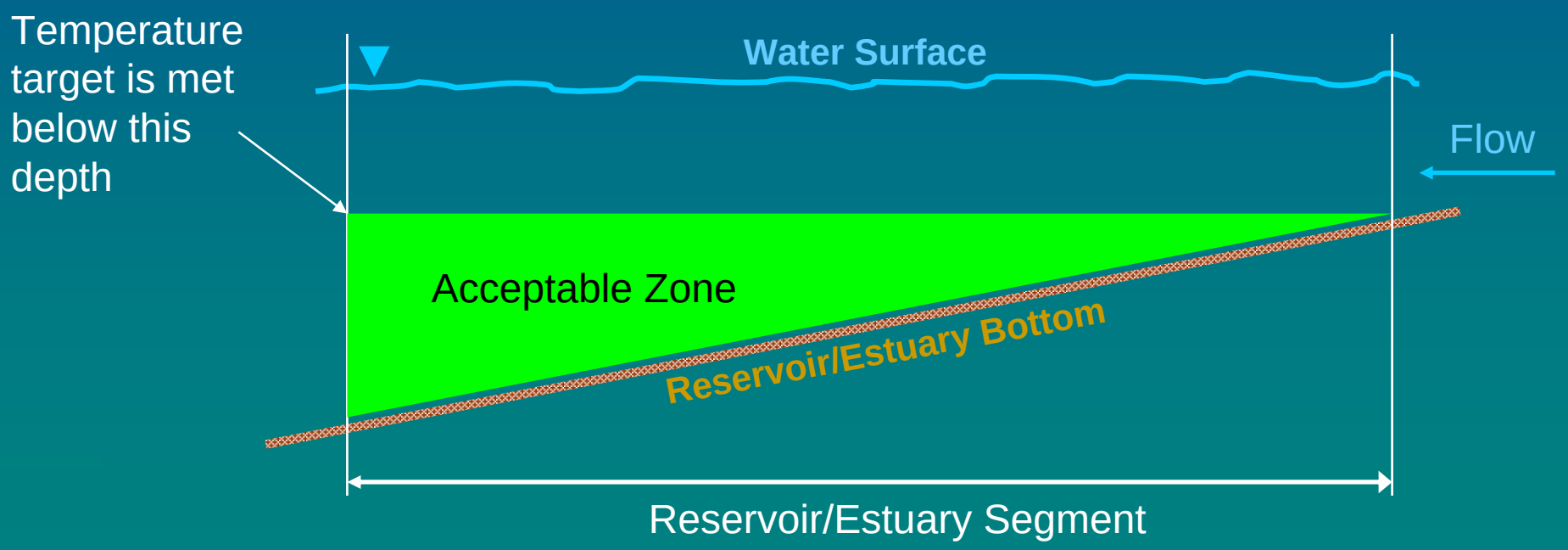
Iron Gate Reservoir

Model Applicability

- Temperature criteria
  - Compare to numeric targets
  - Evaluate allowable increase above natural conditions
- Thermal refugia
  - Determine extent of acceptable temperature zones
- Natural conditions
  - Simulate temperature in absence of dams, point sources, and anthropogenic nonpoint source influences
- Point source thermal impacts
  - Evaluate incremental change in temperature due to each source

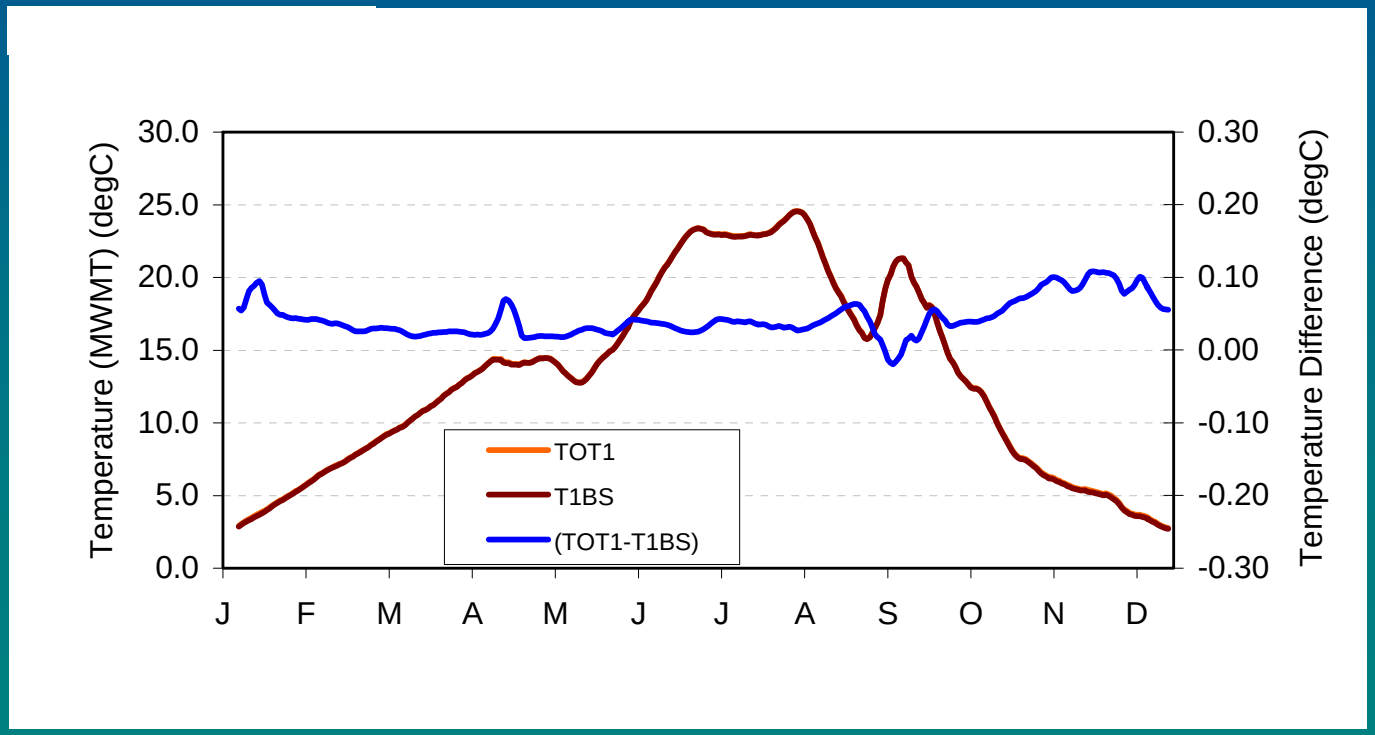
Thermal Refugia

- **Quantify volume and location of acceptable temperature zones**
- **Applicable to 2- and 3-dimensional model segments**
- **3-dimensional segments may also be used to evaluate refugia laterally**



Point Source Thermal Impacts

- Quantify temperature difference between presence and absence of discharge
- Example shown is for 7-day daily average

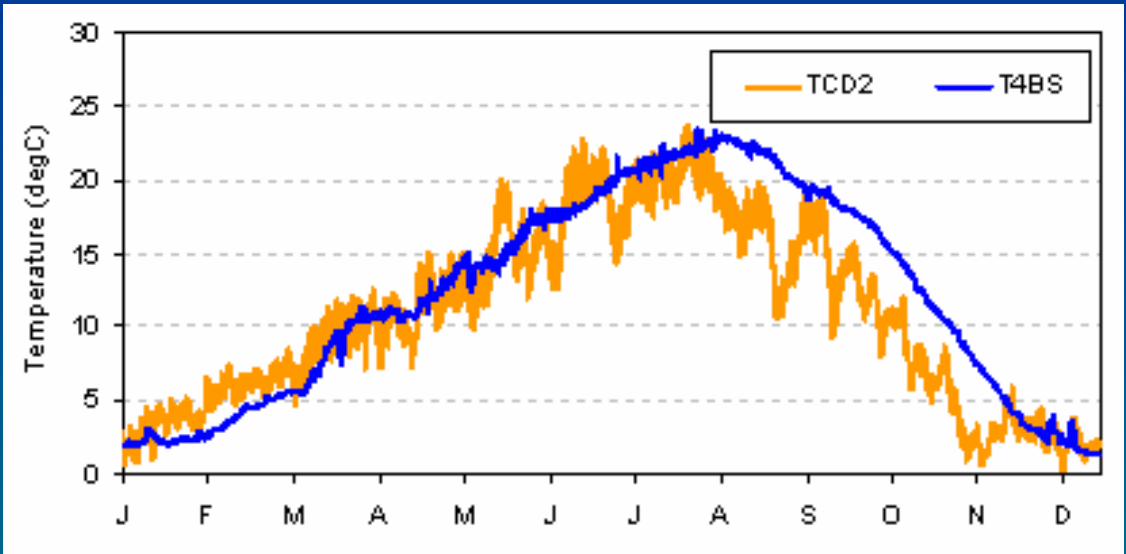


Model Applicability (continued)

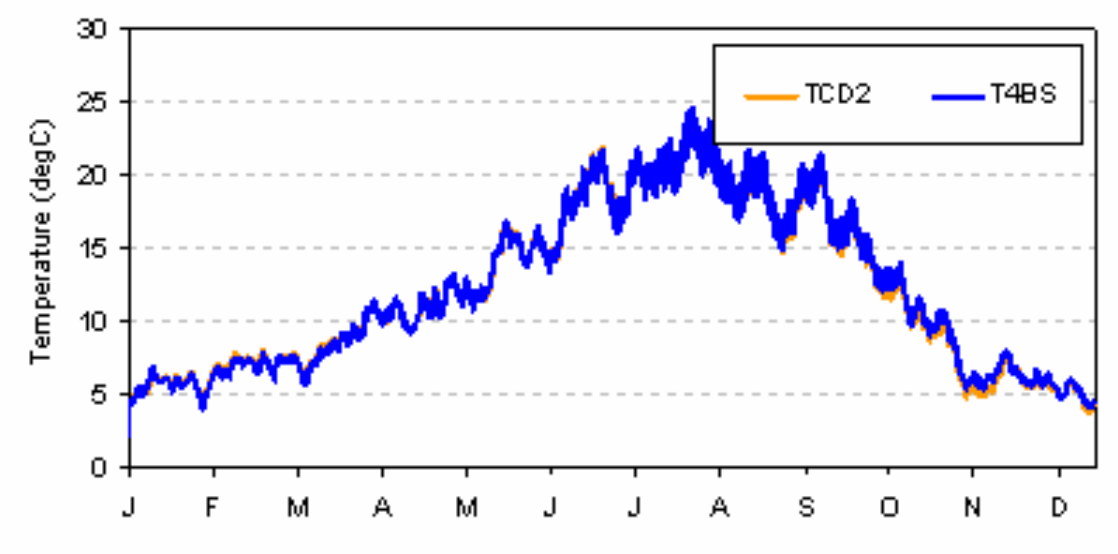
- Reservoir impacts
  - Simulate alternative release strategies (temporally, depth of withdrawal)
- Tributary management
  - Represent increased shading and changes in flow
- Changing climate conditions
  - Use synthetic (predicted) meteorological data
  - Would require accompanying hydrologic analysis

Reservoir Impacts

Downstream of a reservoir



Upstream of the estuary



TCD2 represents natural conditions
T4BS represents conditions with dams present

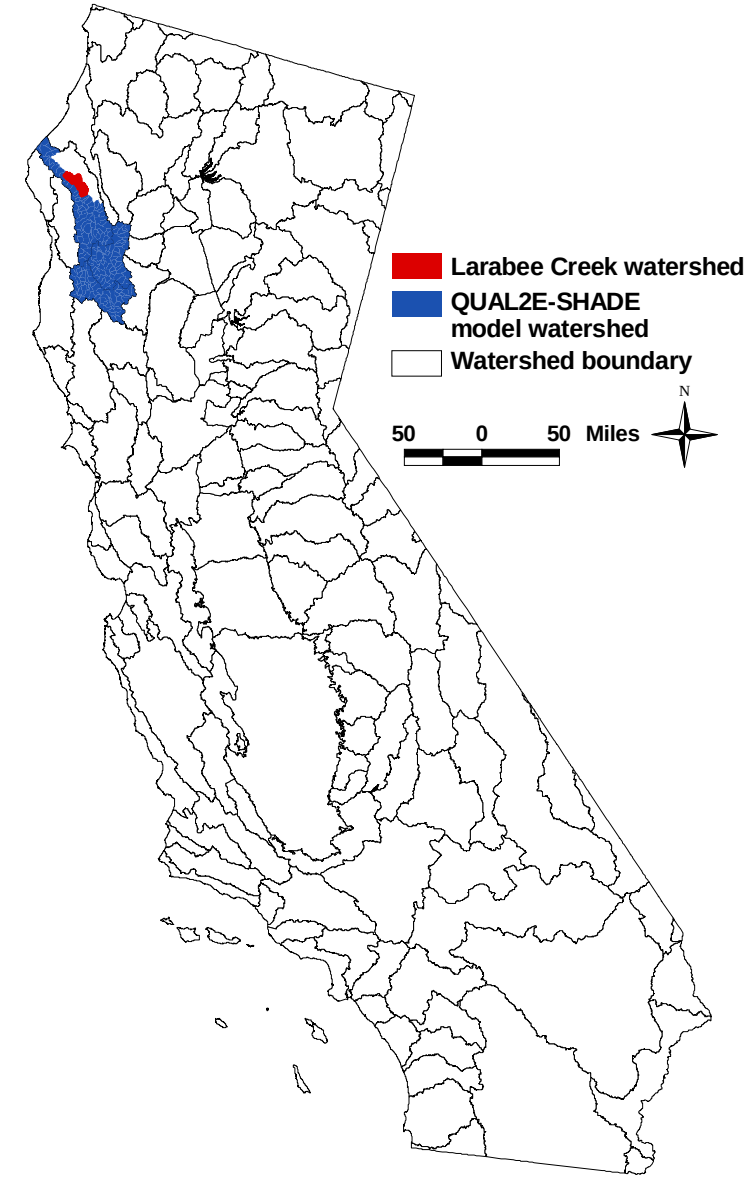
Model Limitations

- Boundary conditions
  - Limited temporally-variable data for all inputs
  - Relied on interpolation
  - 4 weather stations are used to represent entire basin
  - Groundwater impact is assumed to be insignificant
- Spatial representation
  - Limited by size of model segments
  - Laterally-averaged reservoirs and riverine segments
    - Assumes lateral variability of temperature is insignificant
  - Fixed opening for the estuary
- No linked watershed model
  - Limits representation of landuse changes and land-based implementation within the modeling framework

Eel River Model

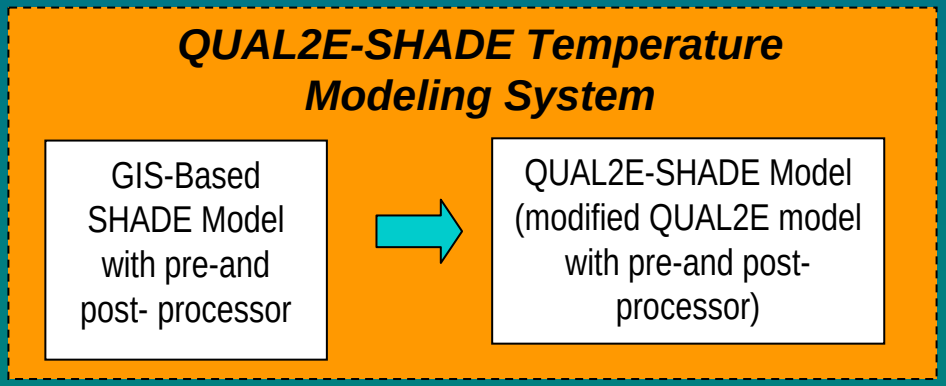
Background

- Wild and Scenic River designation
- Logging has led to lack of riparian buffer and shading
- Severely elevated water temperatures during summer
  - Temperature listings for multiple segments
- Decline in coastal salmon and steelhead populations
- Objective:
  - Evaluate the impact of riparian shading improvements on in-stream temperature



Modeling Approach

- **GIS-based shade and temperature modeling system**
  - **Calculates effective solar radiation from sunrise to sunset on an hourly time step**
  - **Relates solar path geometry to shade angles**
  - **Considers topographic and vegetative shading**
  - **Transfers key input parameters to a QUAL2E receiving water model**
  - **Simulates temperature variability throughout a stream network**



GIS SHADE Model

GIS Preprocessor

INPUT Layers
a) Vegetation
b) DEM
c) RF3 Streams
d) Watershed

↓

i) Select Watershed
ii) Specify Stream Sampling Interval
iii) Specify Buffer Width

↓ *Run Script to Setup model SHADE model configuration*

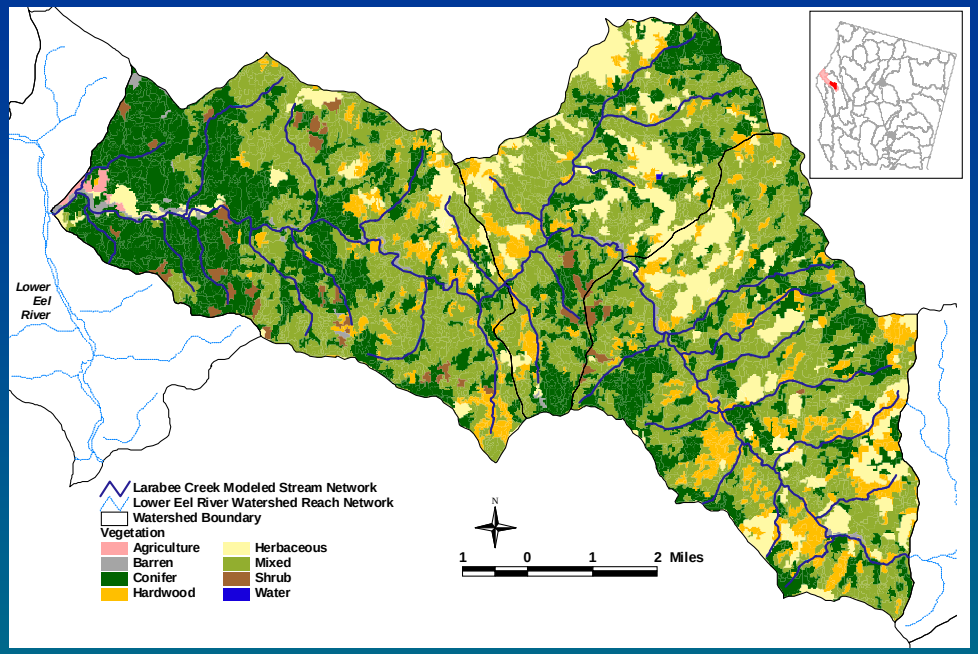
i) Create Stream Sampling Points (SSP)
ii) Create Buffer Widths along SSP
iii) Determine Latitude & Longitude
iv) Characterize Topography
v) Characterize Vegetation

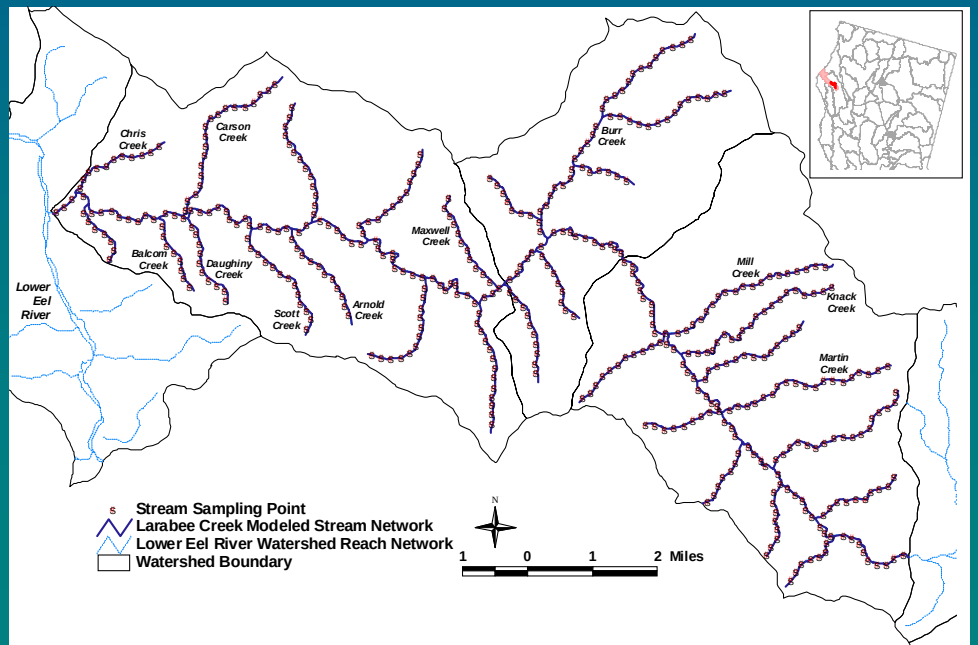
↓ *Run Scripts to Generate SHADE Inputs*

Input Files For Each Reach
a) Master Control File (*.ctl)
b) Topographic Input File (*.tp)
c) Vegetation Input File (*.csv)

↓ *Run SHADE model*

SHADE Output
(Hourly attenuated solar radiation output at each SSP in the watershed)



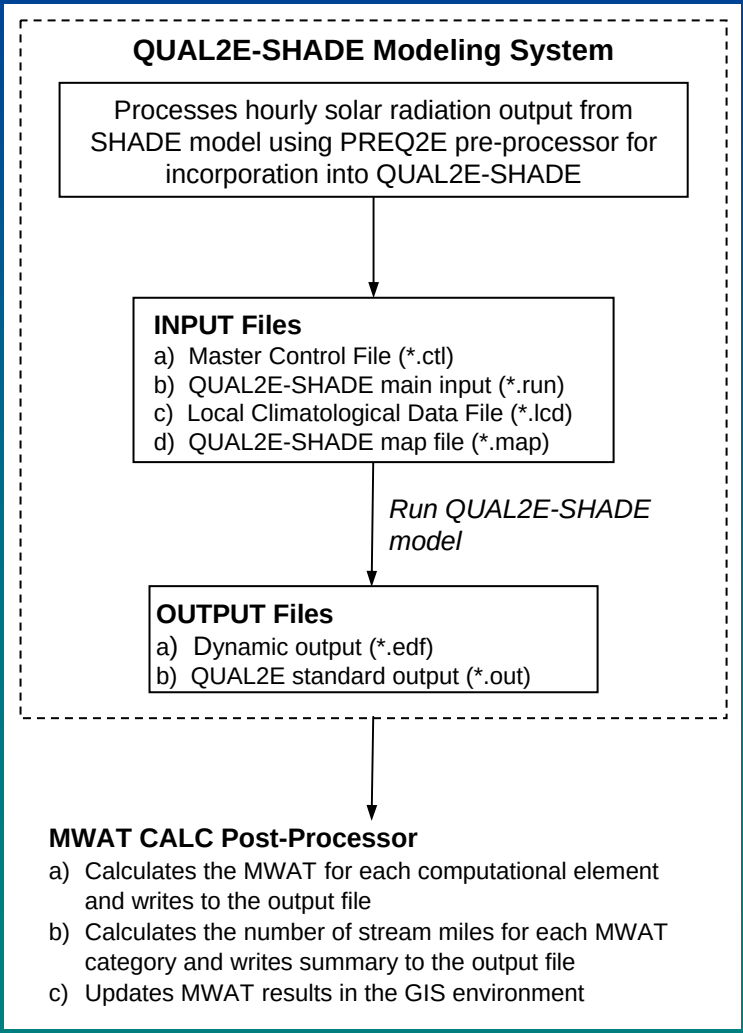


GIS SHADE Model Output

- Output from the GIS preprocessor
  - SSP coordinates
  - Topographic shading characteristics
  - Vegetation shading characteristics
- Output from SHADE Model
  - Hourly solar radiation data

QUAL2E-SHADE Model

- Basic QUAL2E model linked to SHADE
- Interprets:
  - Solar radiation time series
  - Heat balance
- Simulates temperatures
- Components:
  - Pre-processor
  - Model algorithms & input
  - Post-processor to summarize for TMDL analyses



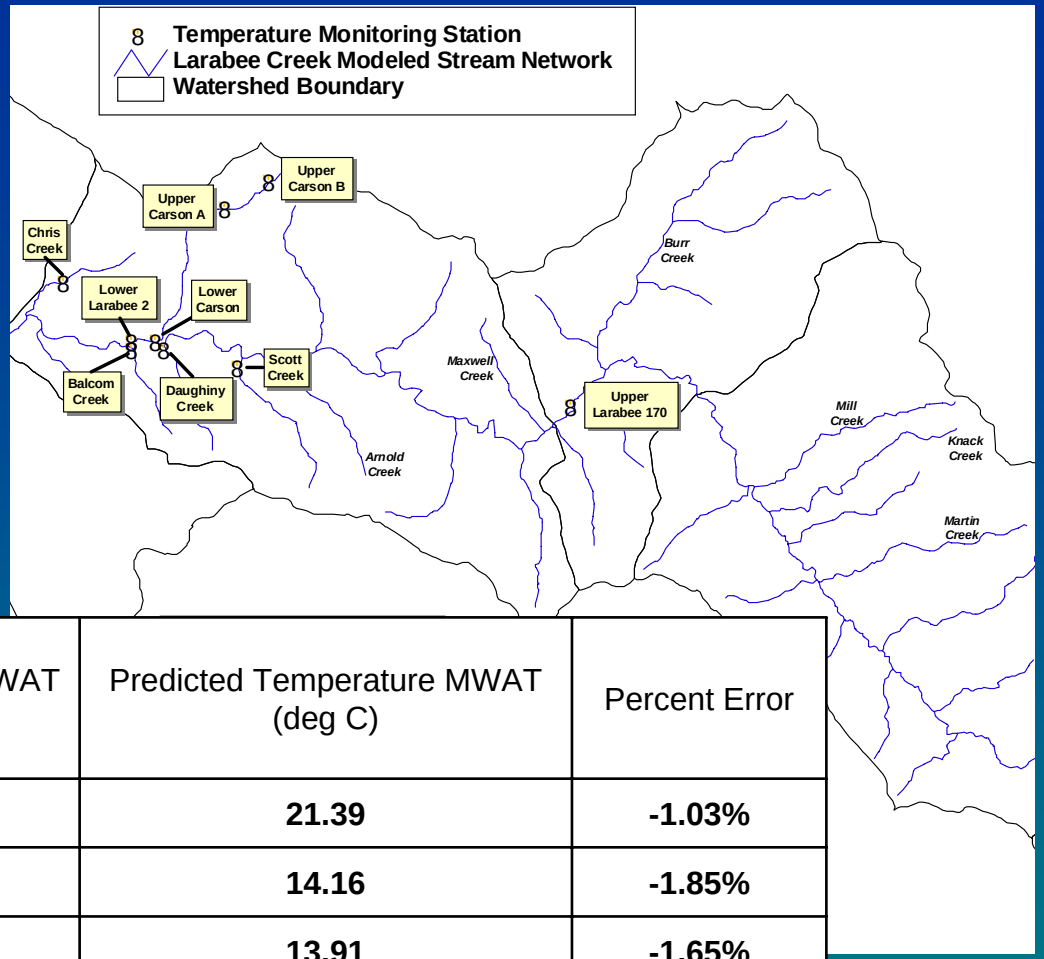
QUAL2E-SHADE Model Configuration

- SHADE output
- Headwater conditions
  - Constant flow and temperature
- Channel hydraulics
  - Power equations to calculate velocity ($v=aQ^b$) & depth ($d=cQ^d$)
  - Rating curves for coefficients and exponents
- Climatological data
  - Atmospheric pressure, dry bulb temperature, wet bulb temperature, wind speed, cloud cover

QUAL2E-SHADE Model Operation

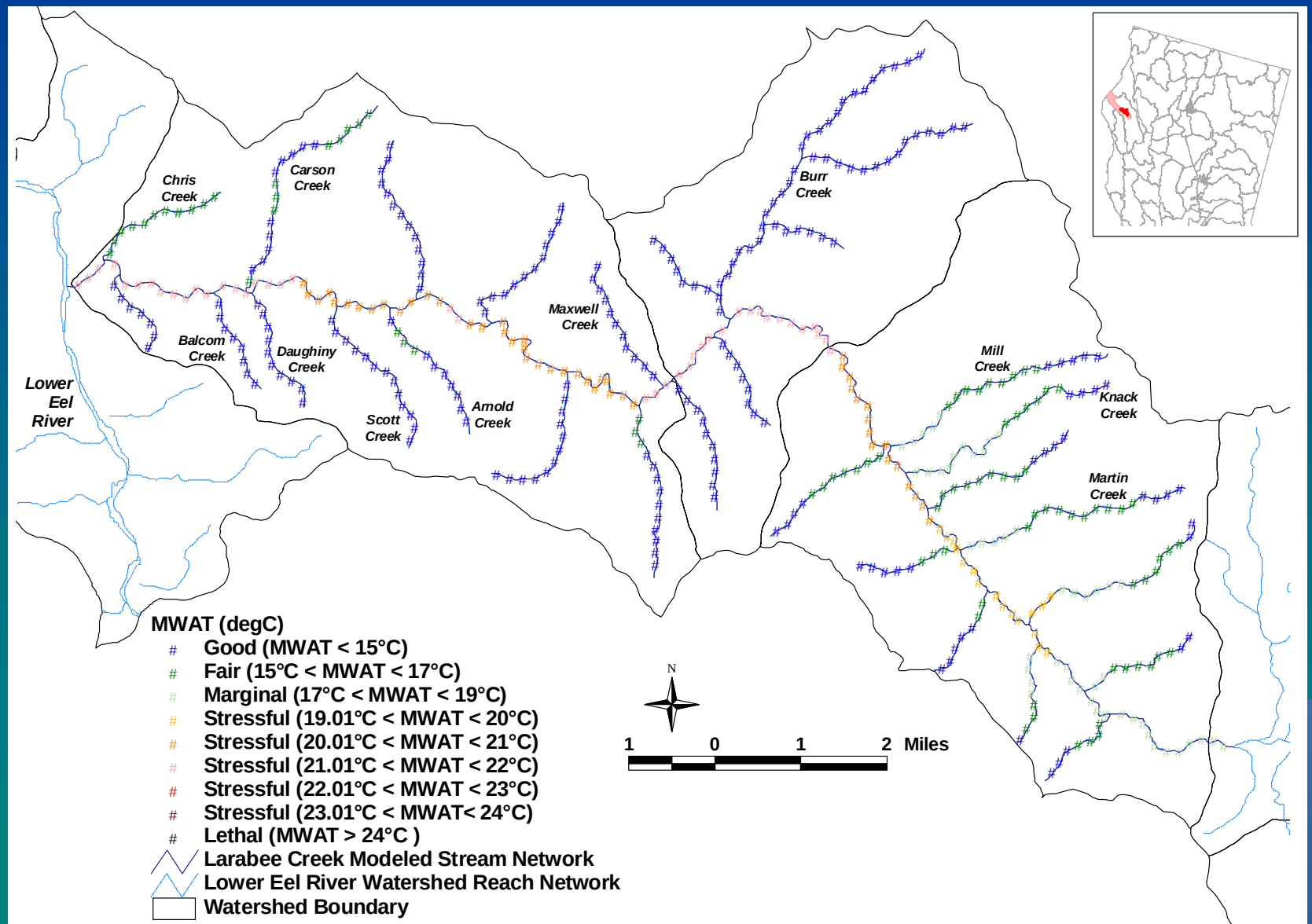
- Quasi-dynamic operation during critical conditions
  - Constant flow and temperature inputs
  - Hourly climatological data causes diurnal response
- Calibration: output vs. observed temperatures
- Output
  - Maximum Weekly Average Temperature (MWAT) at each Stream Sampling Point
  - Stream miles by temperature category

Model Calibration



Location	Observed Temperature MWAT (deg C)	Predicted Temperature MWAT (deg C)	Percent Error
Upper Larabee 170	**21.61**	**21.39**	**-1.03%**
Scott Creek	**14.43**	**14.16**	**-1.85%**
Daughiny Creek	**14.14**	**13.91**	**-1.65%**
Upper Carson B	**15.25**	**15.08**	**-1.14%**
Upper Carson A	**14.62**	**15.00**	**2.61%**
Lower Carson	**15.67**	**15.26**	**-2.60%**
Lower Larabee 2	**21.54**	**21.27**	**-1.26%**
Balcom Creek	**14.95**	**14.73**	**-1.47%**
Chris Creek	**15.63**	**15.20**	**-2.75%**

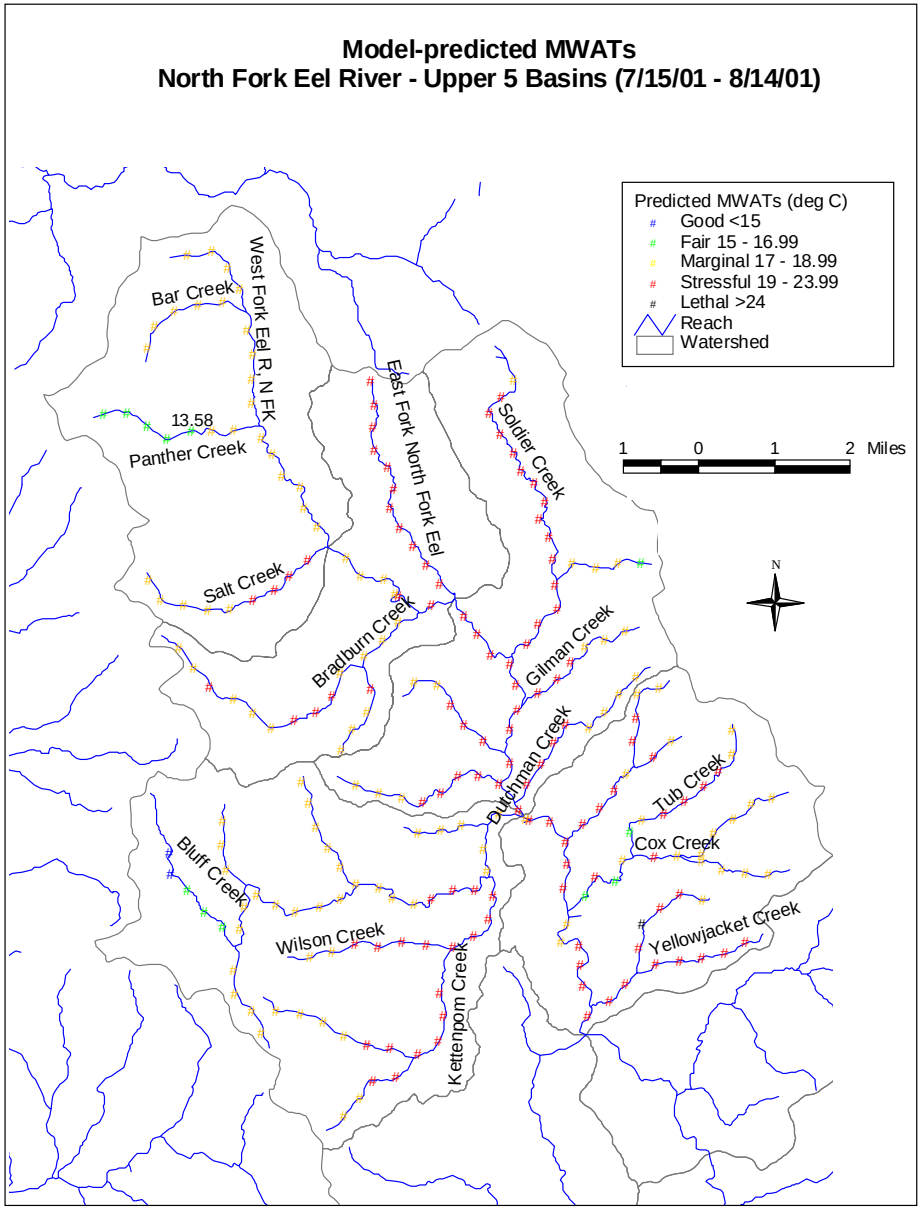
Model Results: MWAT

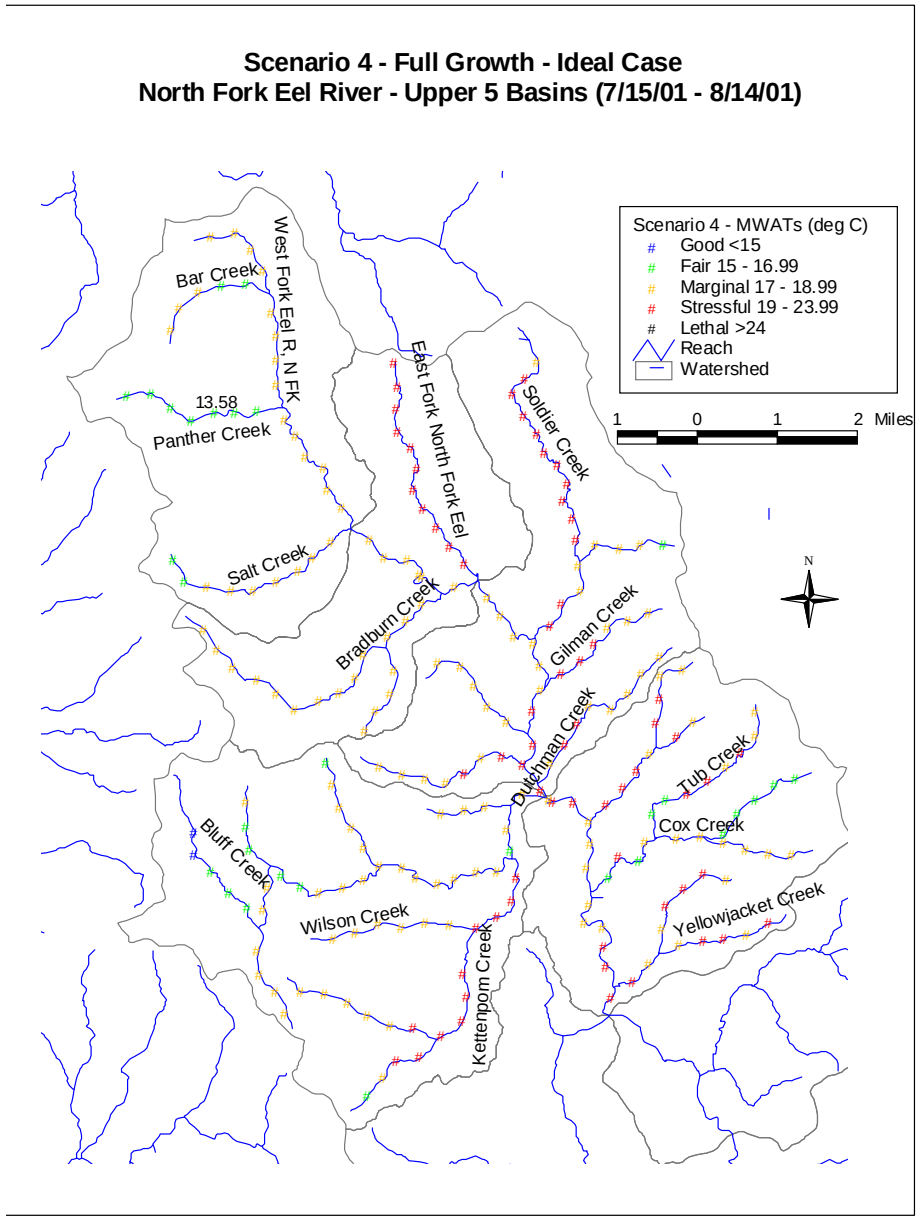


Model Applicability

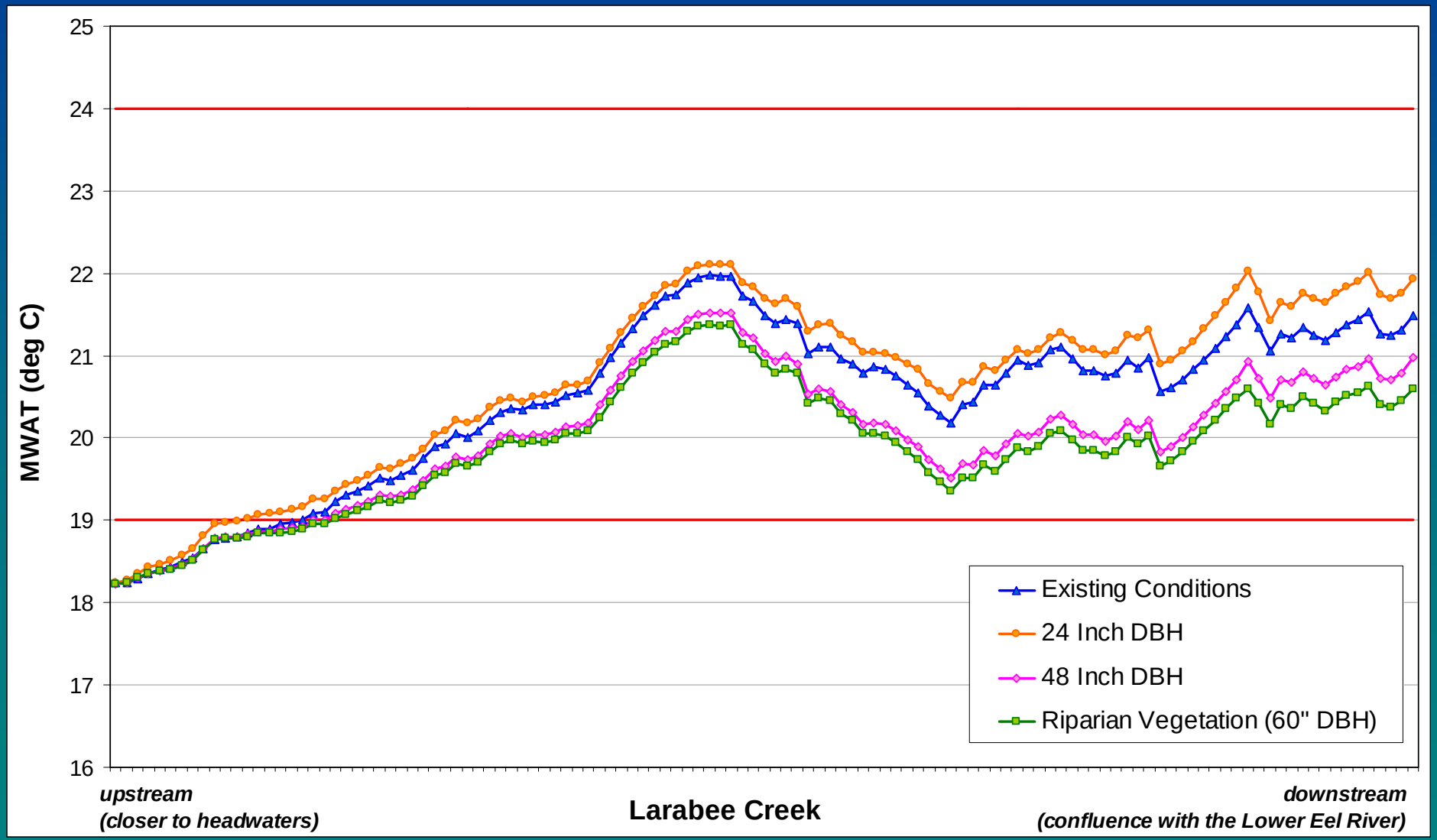
- Existing conditions
- Natural conditions
  - Simulate temperature under natural/full growth scenario
- Varied vegetative cover scenarios
  - No vegetation (topographic shading only)
  - Variable DBH (diameter at breast height) relationships
    - 24-inch
    - 48-inch
    - 60-inch
    - other

Full-growth vs. Existing Conditions

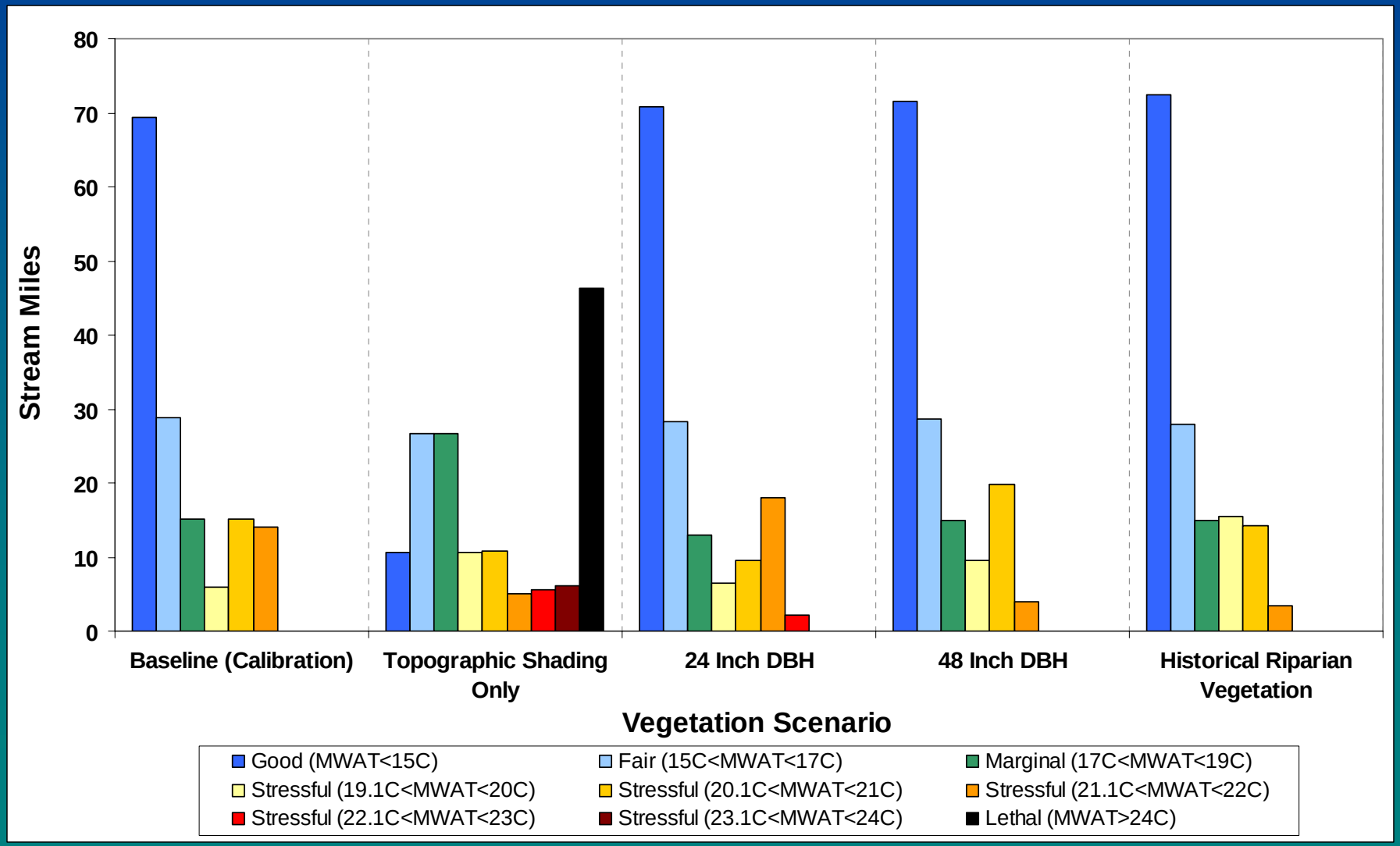




Vegetative Cover Scenarios



Vegetative Cover Scenarios:
Stream Mile Comparison



Model Limitations

- Represents one flow condition at a time (not fully dynamic)
- Laterally- and depth-averaged segments
  - Assumes lateral variability of temperature is insignificant
  - Assumes vertical variability of temperature is insignificant
- Limited by size of model segments
- Groundwater representation is not fully predictive
  - Temperatures must be assigned within the model
- Designed for MWAT calculation