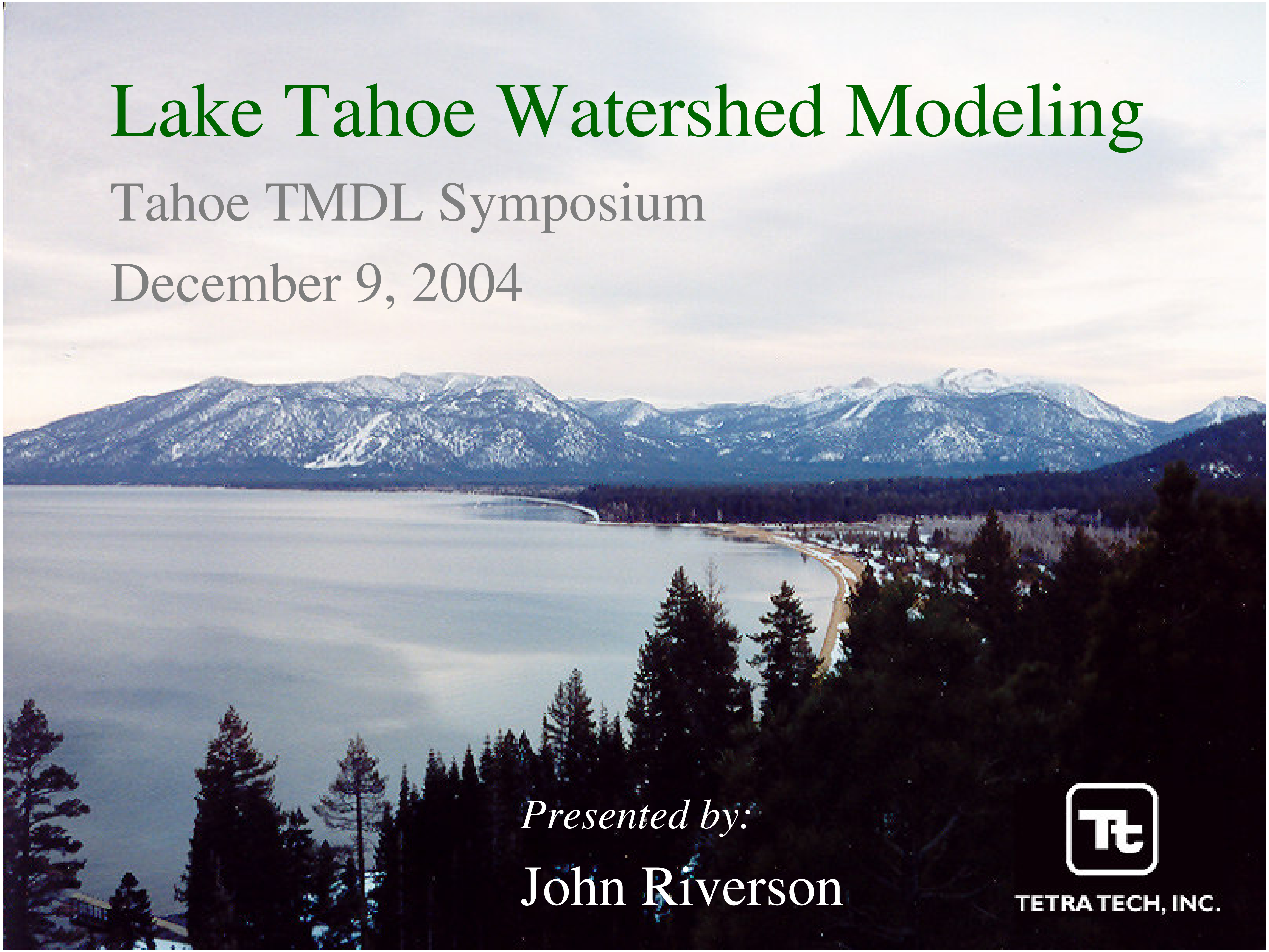
Lake Tahoe Watershed Modeling

Tahoe TMDL Symposium

December 9, 2004



Presented by:

John Riverson

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Presentation Outline

- Project background & objectives
- Model setup and parameter selection
- Hydrology: Ward Creek example
  - Meteorological data
  - Model testing, calibration & validation
- Sediment and water quality
  - Methodology
  - TRG stormwater monitoring dataset
  - LTIMP monitoring dataset
- Next Steps

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Why do we need a watershed model?

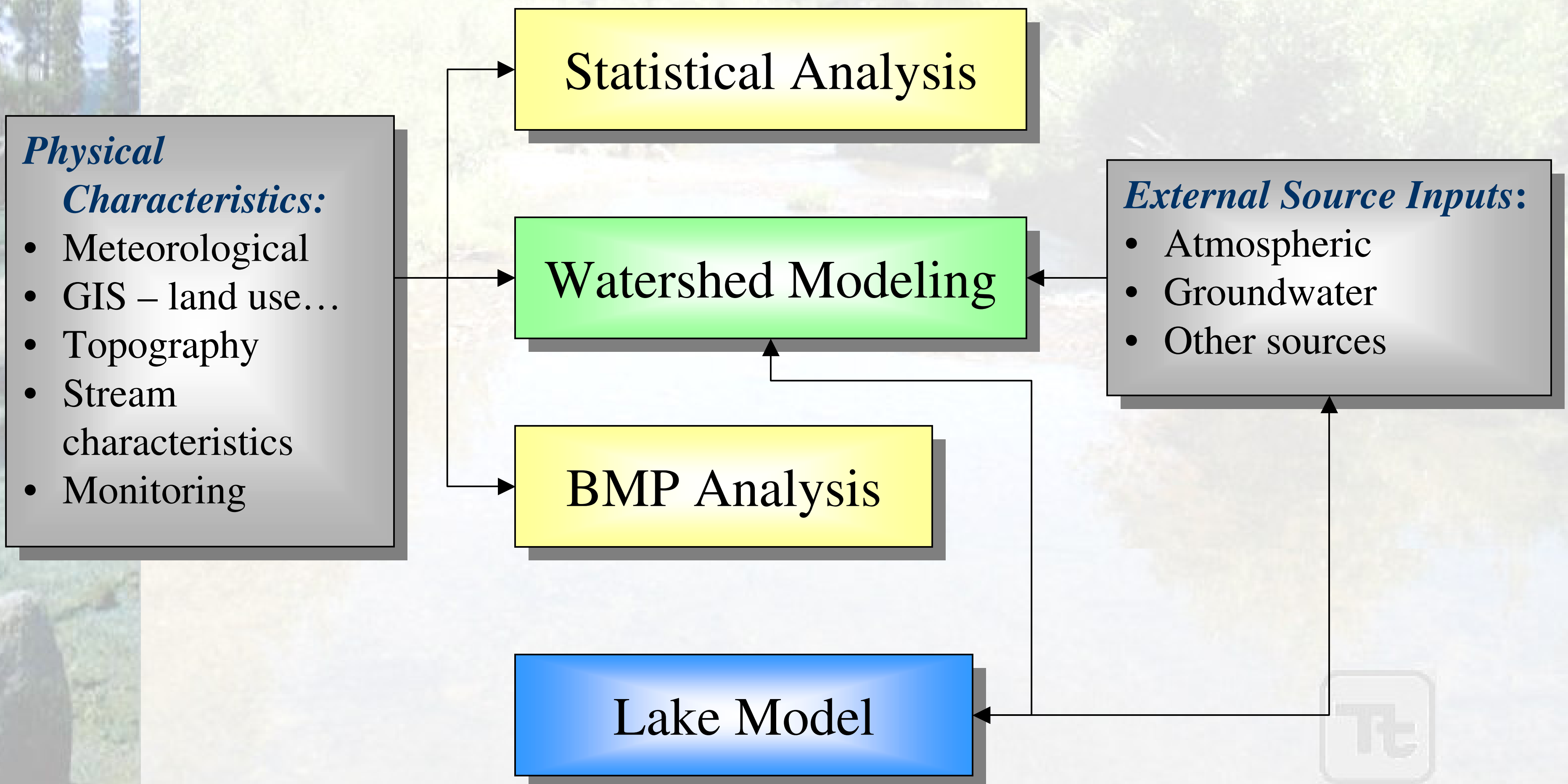
- Organize and integrate very detailed spatial and temporal data to identify/confirm trends
- No such model has ever been developed for Tahoe
- The need was identified by the TMDL Program
- Data compilation effort for modeling not only represents a beneficial contribution for the TMDL program, but also, for many other future efforts. Examples include:
  - Land use layer development
  - Identifying potential disturbance factors
  - Meteorological data compilation and dissemination
  - Monitoring data compilation and dissemination

Watershed Modeling Goals

- Provide estimates for watershed loading of sediment and nutrients to Lake Tahoe
- Provide input to the Lake Clarity Model
- Evaluate management scenarios to meet loading targets
- Estimate TMDL allocation components

Integration of research results

Relationship to Other Tasks



Evolution of the Watershed Model

Phase I

- Model Scoping with D-Team Input
- Data Compilation (historic, ongoing)
- Preliminary Model Configuration and Calibration
    - Hydrology
    - Sediment
    - Nutrients
- Preliminary TMDL Analysis

Phase II

- Model Reconfiguration Using Research Results
- Model Recalibration and Validation/Verification
- Loading Alternative Evaluation
- TMDL Analysis

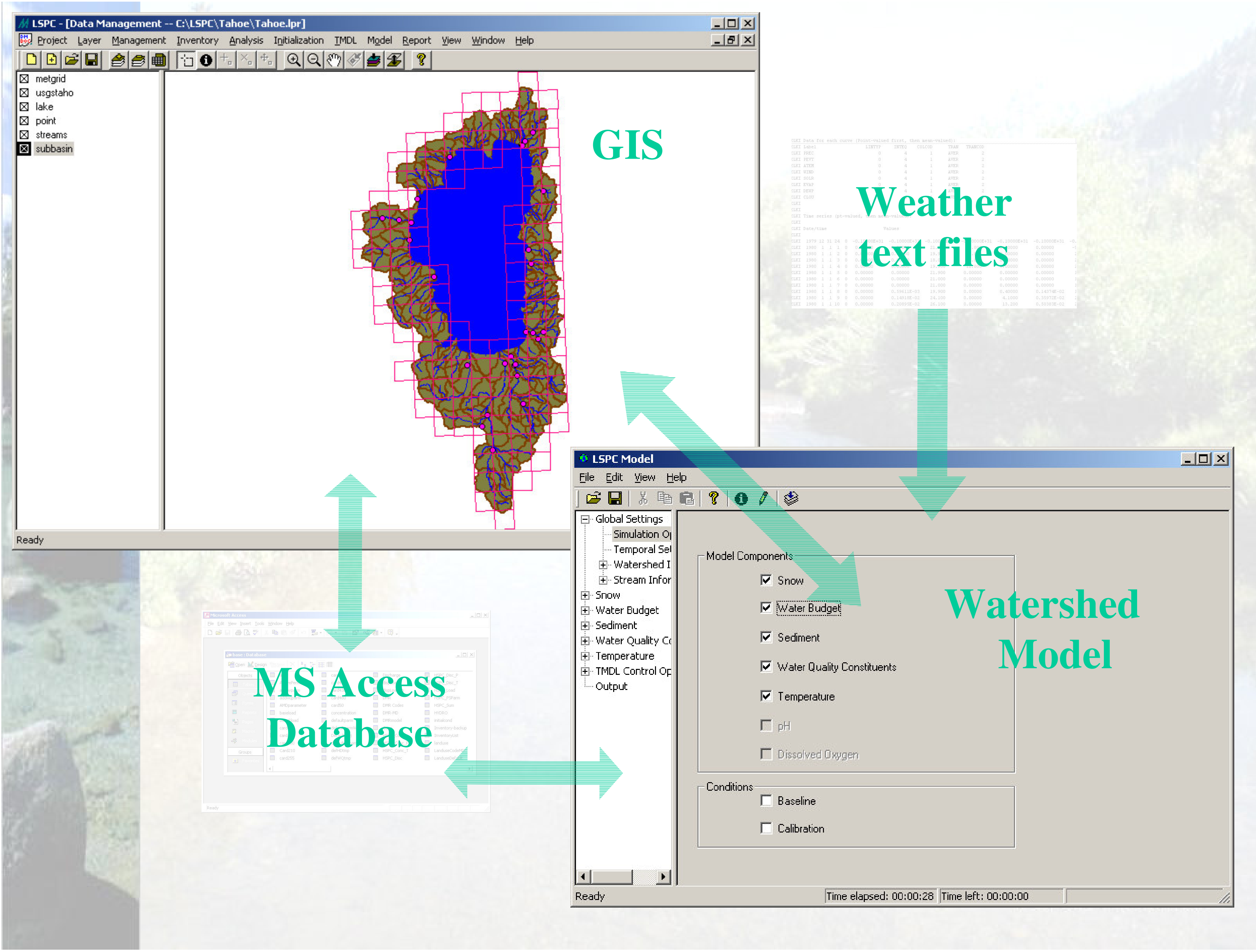
Model Selection

- Apply EPA's Loading Simulation Program in C++ (LSPC), a dynamic watershed model, to simulate snow and hydrologic processes, erosion and sediment transport, and nutrient production/transport for the Tahoe Watershed

<u>TMDL Modeling Toolbox</u>:

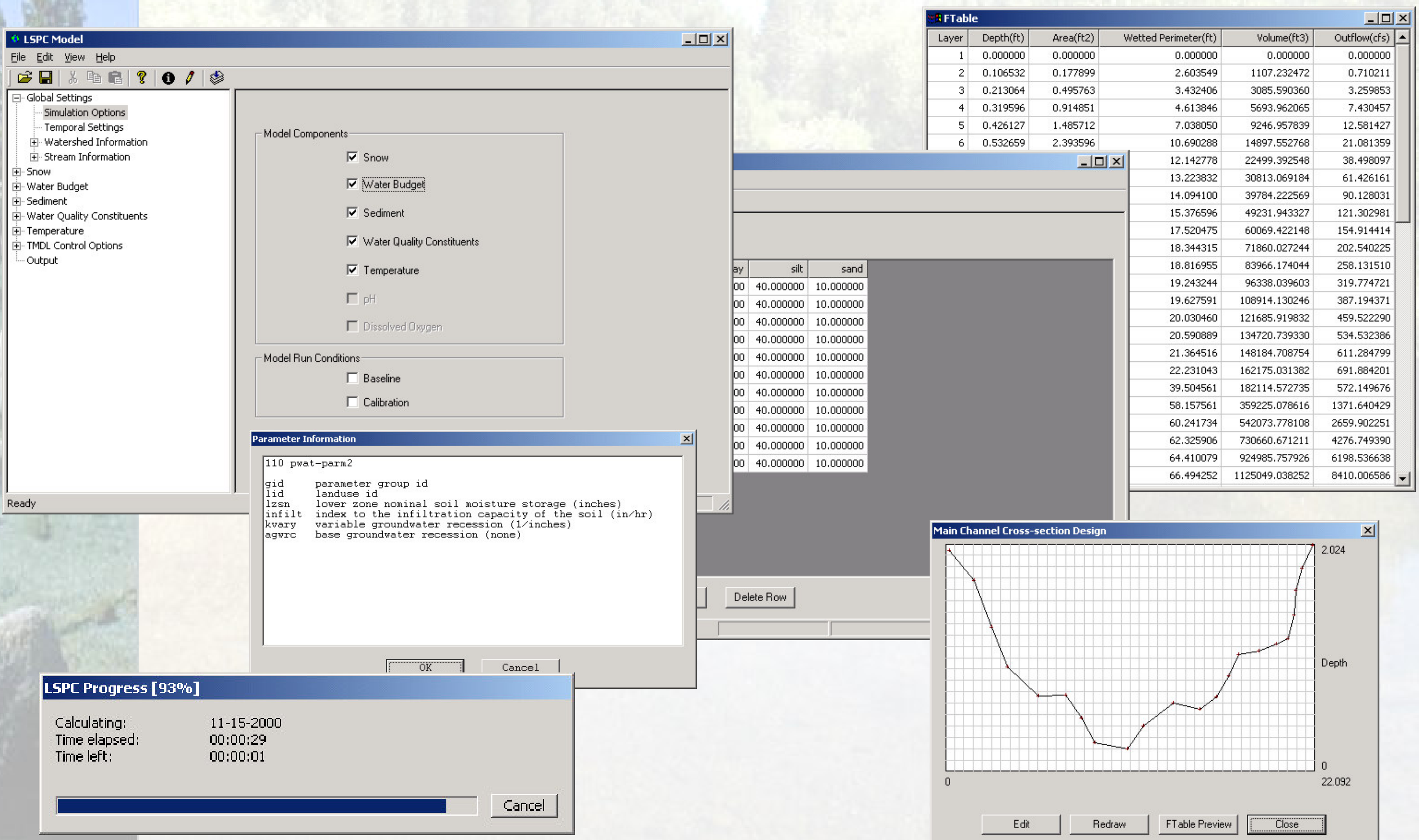
http://www.epa.gov/athens/wwqtsc/html/lspc.html

Google: "LSPC Model" or "LSPC EPA"



LSPC - [Data Management -- C:\LSPC\Tahoe\Tahoe.lpr]
Project Layer Management Inventory Analysis Initialization TMDL Model Report View Window Help
metgrid
usgstaho
lake
point
streams
subbasin
Ready
GIS
Weather text files
MS Access Database
LSPC Model
File Edit View Help
Global Settings
Simulation O
Temporal Se
Watershed I
Stream Infor
Snow
Water Budget
Sediment
Water Quality C
Temperature
TMDL Control Op
Output
Model Components
Snow
Water Budget
Sediment
Water Quality Constituents
Temperature
pH
Dissolved Oxygen
Conditions
Baseline
Calibration
Ready
Time elapsed: 00:00:28
Time left: 00:00:00
Watershed Model

LSPC Watershed Model

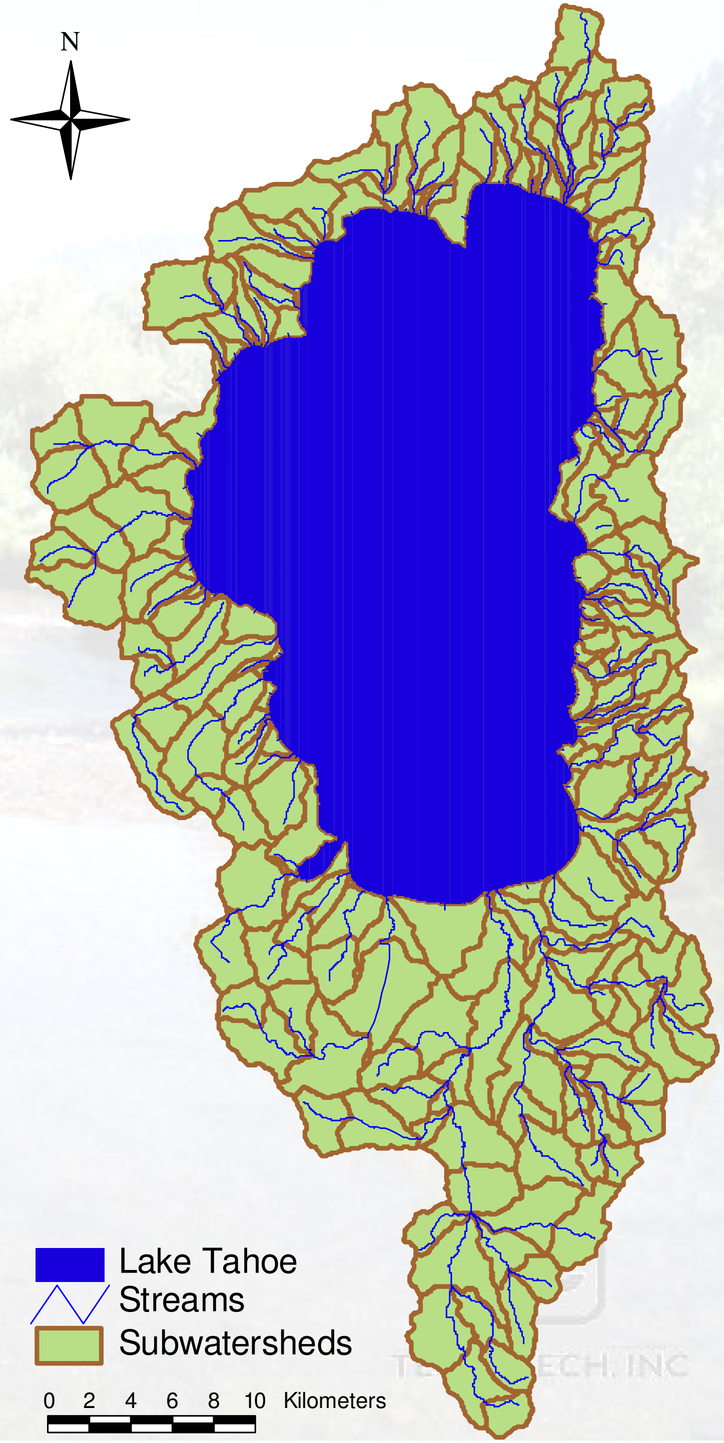


Watershed Modeling Outline

- Model Configuration
  - Locate monitoring locations
  - Determine watershed features, disturbance factors
  - Subwatershed delineation
  - Weather data
  - Model parameter selection based on physical data (landuse, slopes, soils)
- Model Testing, Calibration, Validation
- Model Production Runs & TMDL Scenarios

Subwatershed Delineation

- Lake Tahoe Basin was sub-divided into 184 discrete subwatersheds
- Delineation based on:
  - elevation (topographic data)
  - stream connectivity
  - location of flow and water quality monitoring stations
- Each subwatershed is modeled with one representative stream
- Stream segments distinguished from intervening zones



Data Representation in LSPC

Each landuse (Physical):
- Average slope
- Average length of overland flow

Each subwatershed:
- Landuse distribution
- Weather data
- Elevation (DEM)
- Representative soil behavior (NRCS Soils)

Each landuse (Process):
- Hydrology
- Sediment yield (particle sizes)
- Pollutant load generation

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Weather Data Application

	Land					Reaches		
	Temp	Snow	Water	Sediment		Water	Heat	Gen. Qual.
Precipitation	●	●	●	●		▲	▲	
Pot. ET			●	●		▲		
Air Temperature	●	●					●	
Wind Speed		●					●	●
Solar Radiation		●					●	
Dewpoint Temp.		●					●	
Cloud Cover		▲					●	▲

● Required

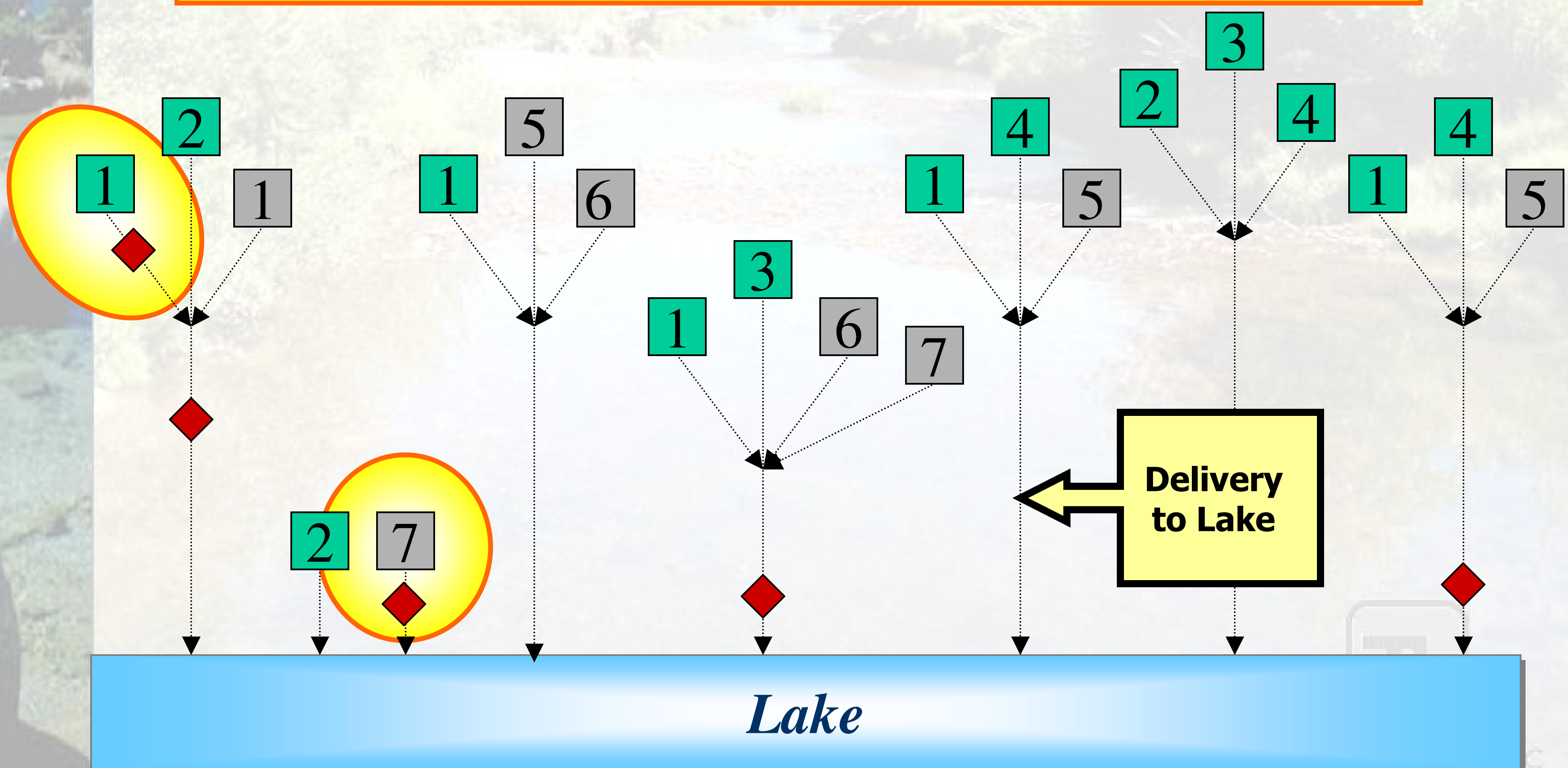
▲ Optional

Model Testing, Calibration, Validation

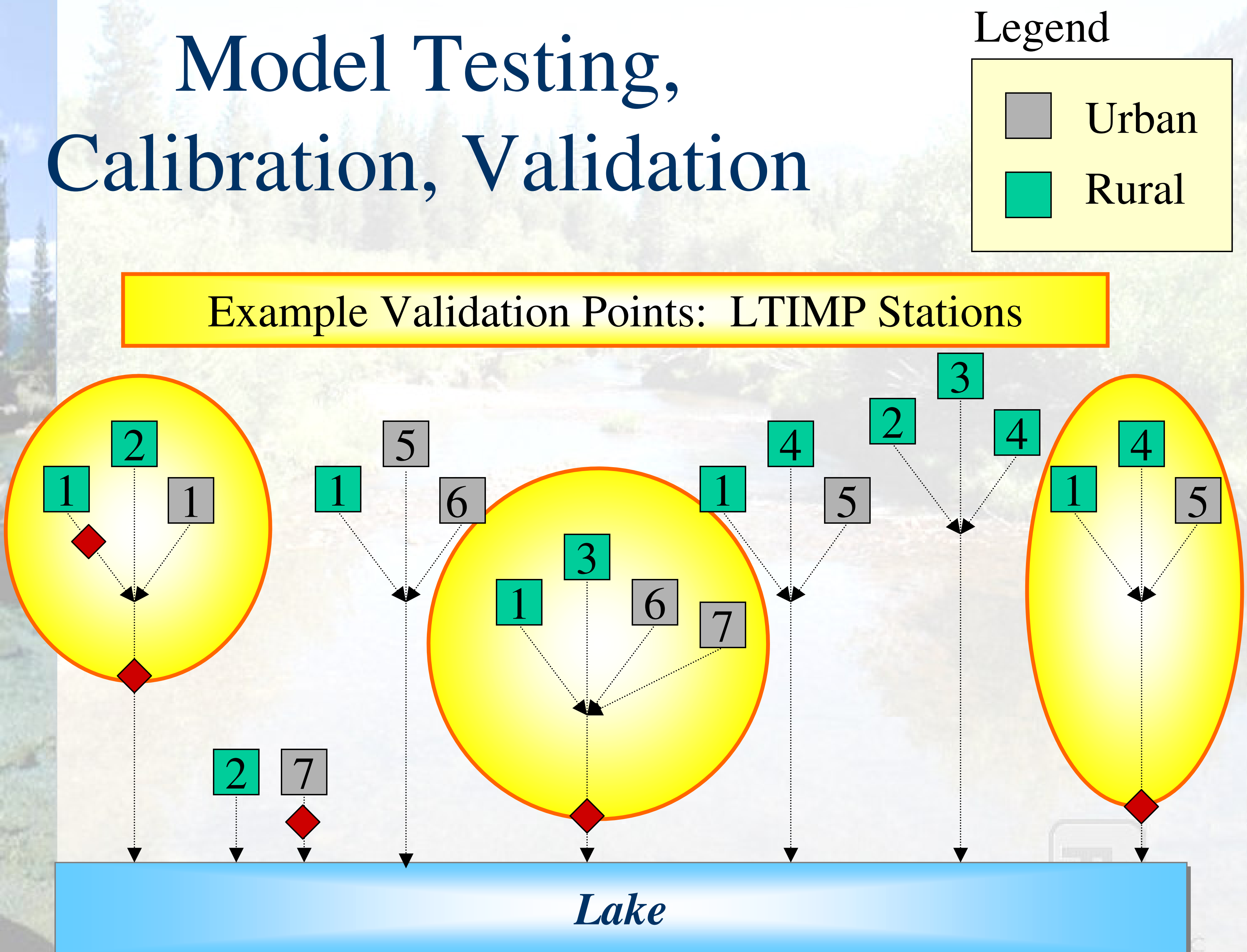
Legend

- Urban
- Rural

Example Calibration Points: TRG SWM Locations



Model Testing, Calibration, Validation



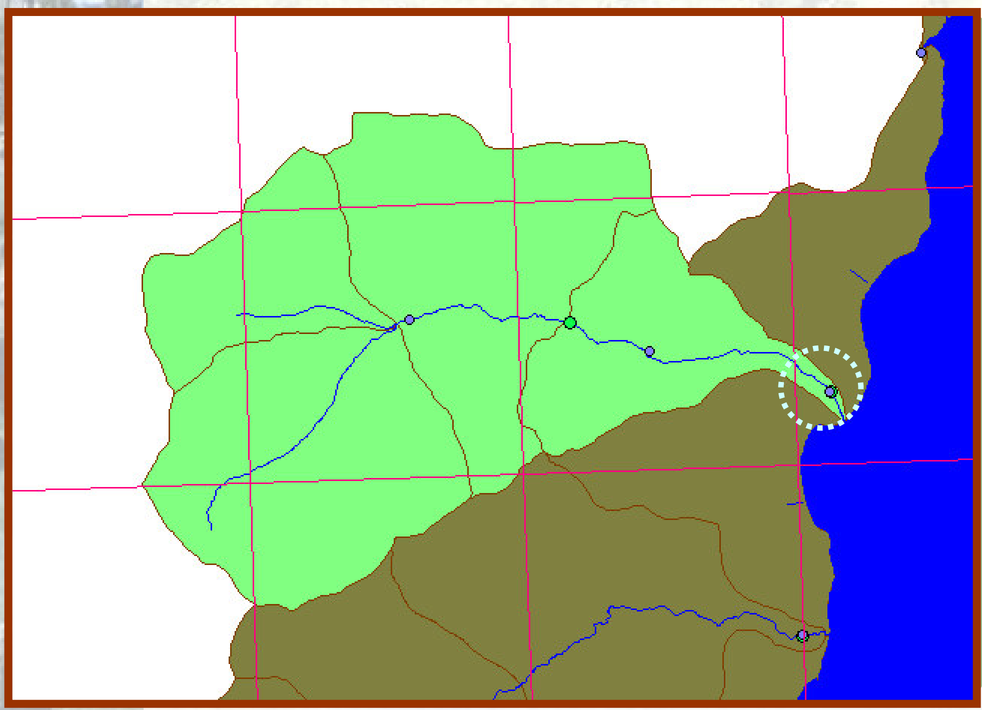
Model Testing, Calibration, Validation

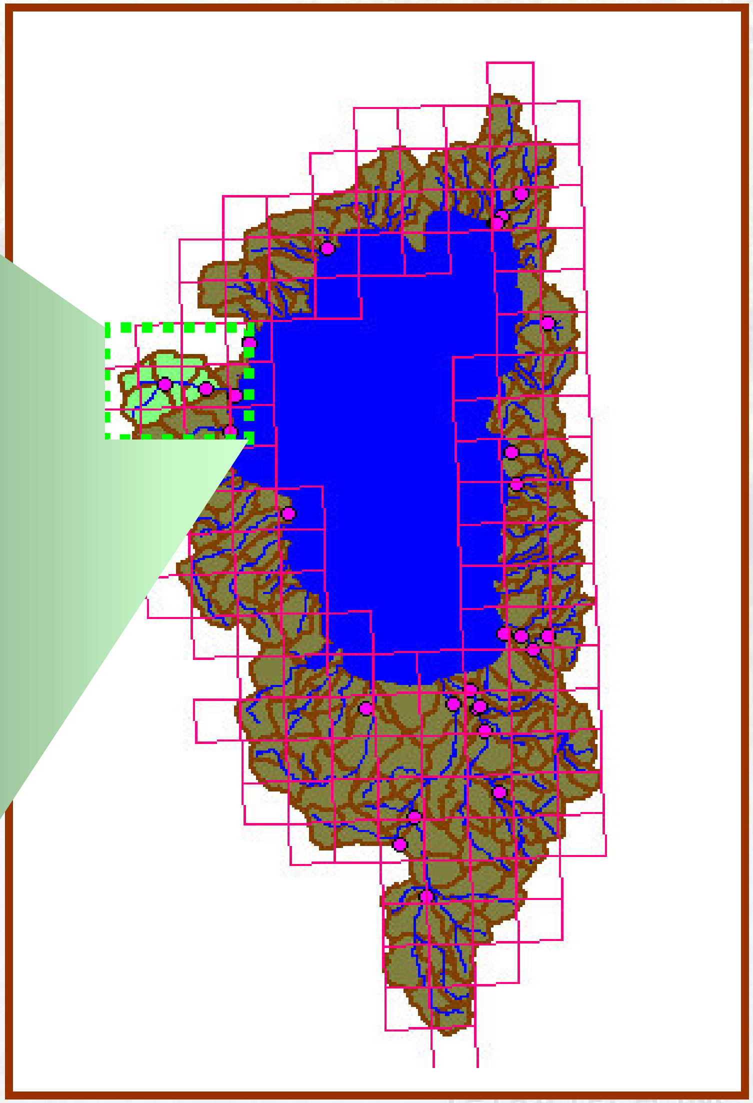
Modeling Sequence

- Hydrology
  - Process and parameters
  - Snow simulation
  - Stream hydraulics
- Sediment
  - Erosion & sediment yield
  - Instream settling and resuspension
- Water Quality
  - Dissolved nutrients
  - Sediment associated nutrients

Ward Creek Subwatershed

Focus Area





Snow at Elev. 6750 ft (SWS 8060)

Flow Calibration at USGS10336676

Ward Creek Model Configuration

- Site-specific meteorological data
- Snow simulation and model calibration
- Snowmelt, runoff, hydrologic response simulation and model calibration
- Hydrograph separation and baseflow/runoff analysis

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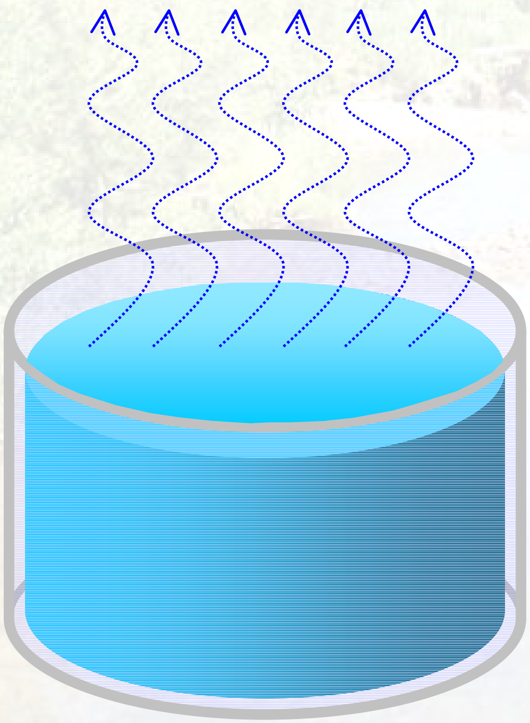
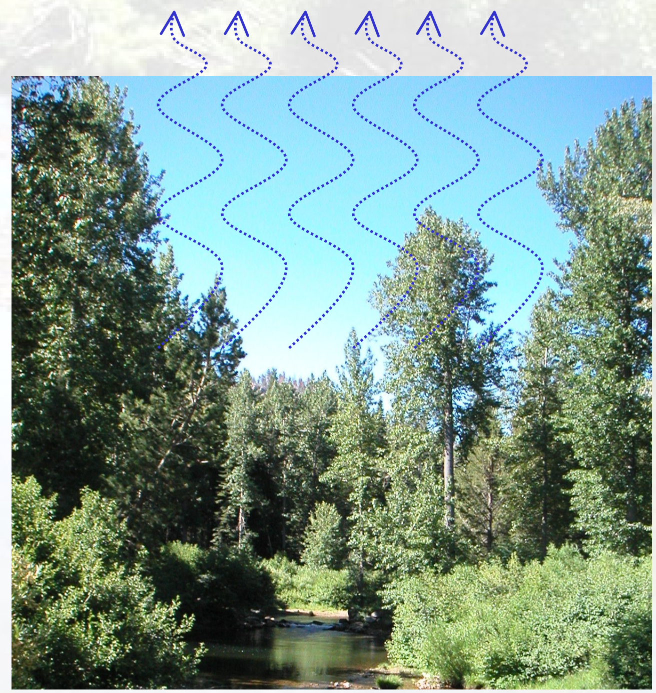
Site-Specific Meteorology

- <u>Hourly</u> SNOTEL data (WRDC1):
  - Temperature and precipitation (10/1/1996 – Present)
- NCDC Composites:
  - Dewpoint & windspeed (SLT Airport & Reno Airport)
  - Cloud cover for solar radiation (SLT Airport, Blue Canyon, Reno, Sacramento)
- Computed Parameters:
  - Solar Radiation (Hamon Method)
  - Potential Evapotranspiration (Penman Method)
  - The method we select has a significant impact on model predictive behavior

What is potential evapotranspiration? Why is it important here?

Evaporation + Transpiration





by plants in their natural environment.

What is potential evapotranspiration? Why is it important here?

- Typically computed empirically from other measurable parameters (i.e. temperature)
- Potential ET represents the MAXIMUM achievable ET that the model will predict
- Not all the Potential ET is necessarily actualized during the model run

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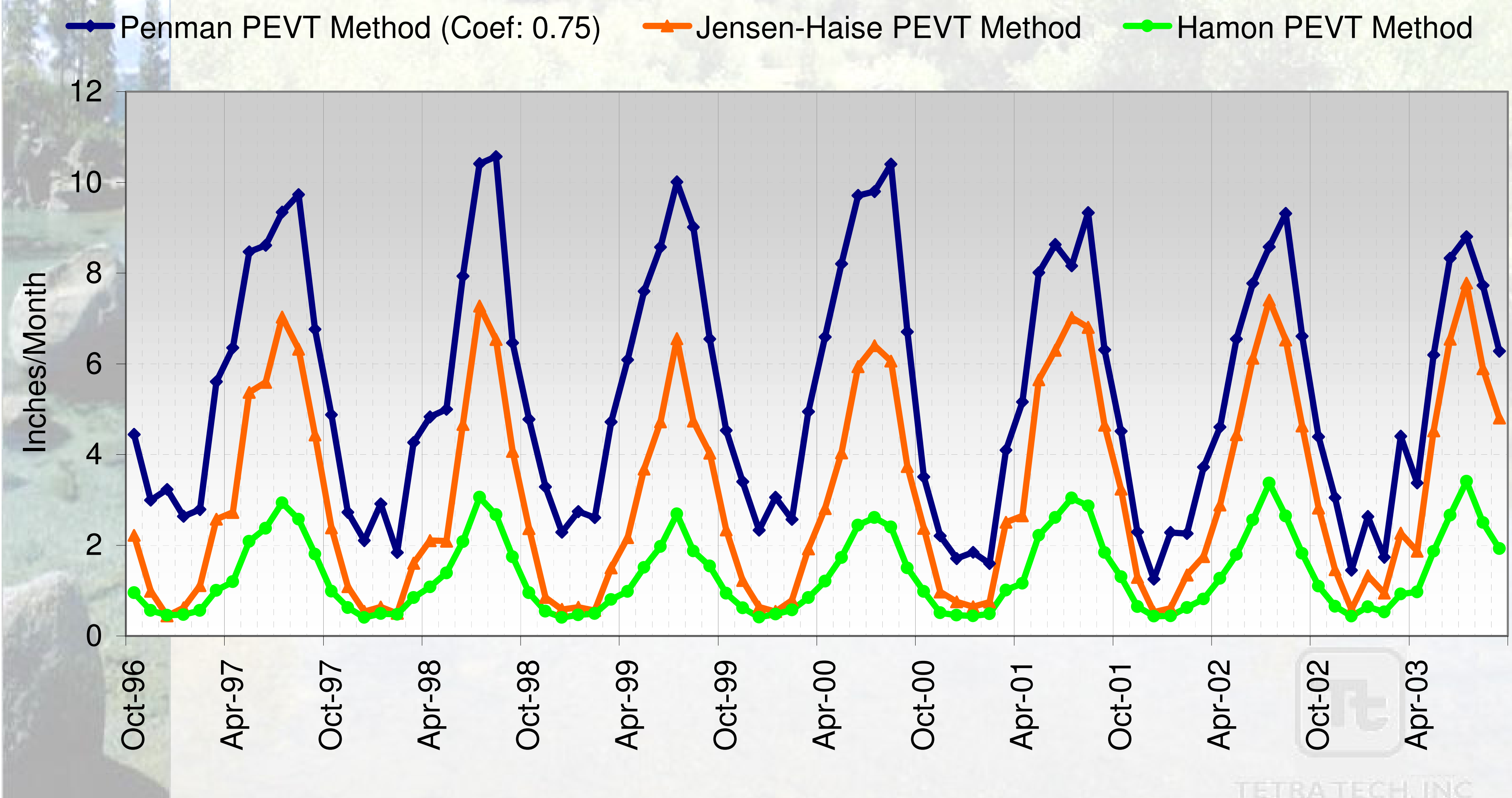
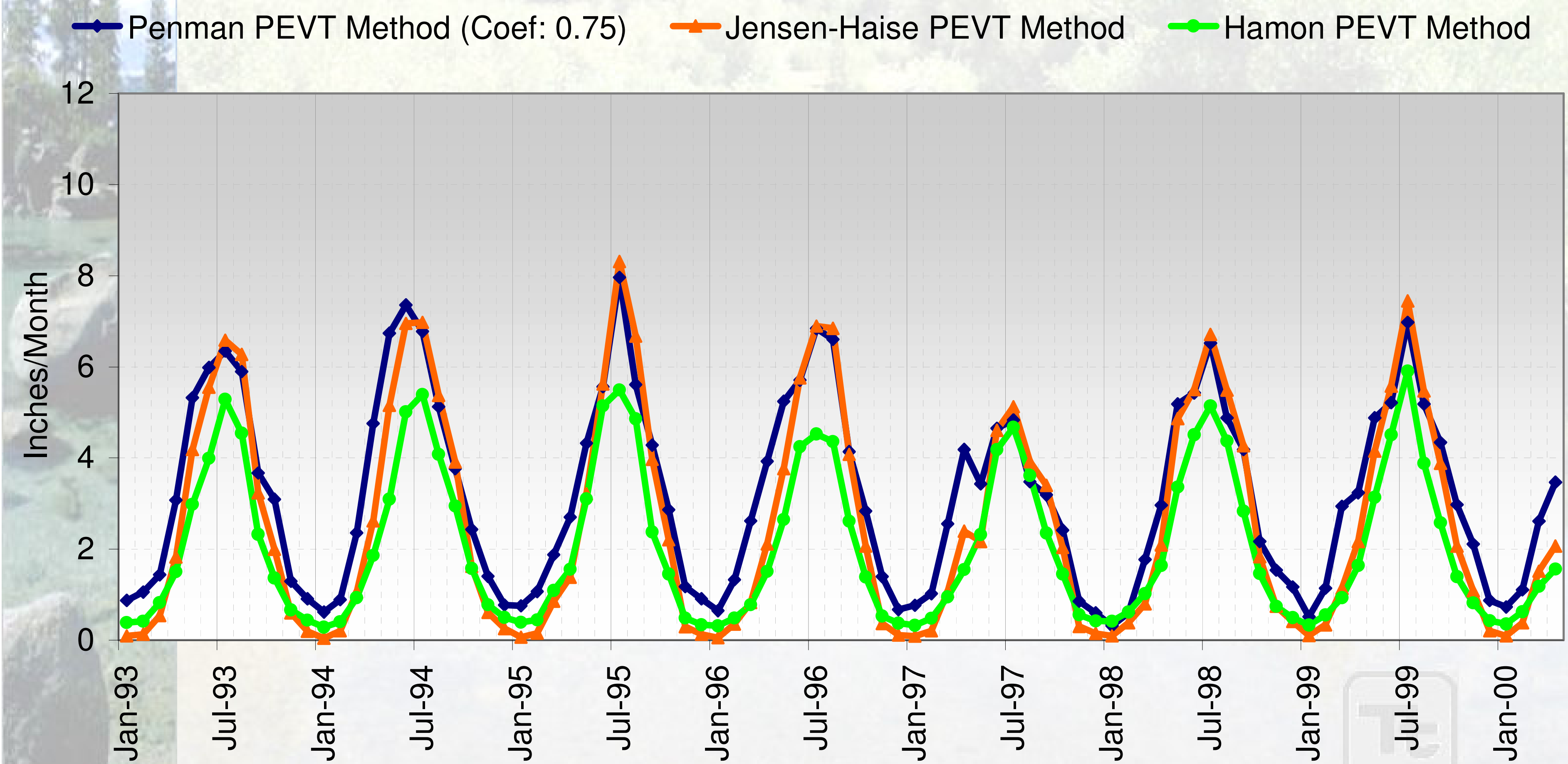
Potential Evapotranspiration Methods

Ward Creek SNOTEL (WRDC1)



Potential Evapotranspiration Methods

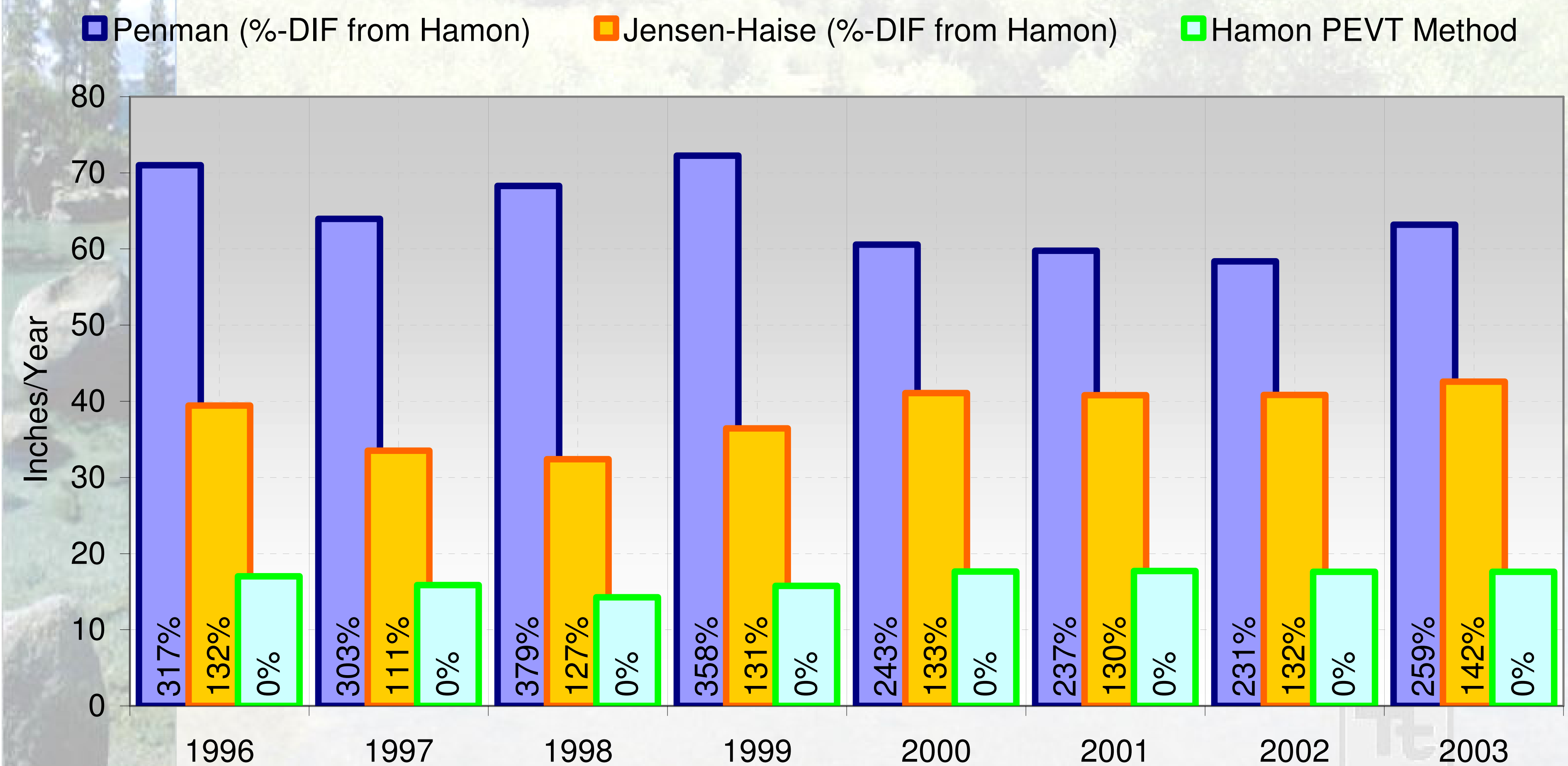
Milwaukee Mitchell Field Airport



Potential Evapotranspiration Methods

- Hamon (1961)
  - Function of only temperature and latitude
  - Default method under-estimates PEVT in Tahoe Basin
- Jensen-Haise (1963)
  - Function of temperature, solar radiation, and mean watershed elevation
  - Default better than Hamon, but also under-estimate PEVT
- Penman (1948)
  - Function of temperature, solar radiation, dewpoint or relative humidity, and wind movement
  - Default vegetation factor of 0.75 converts Pan-ET to PEVT
  - Most representative estimate of PEVT in Tahoe

Potential Evapotranspiration Methods



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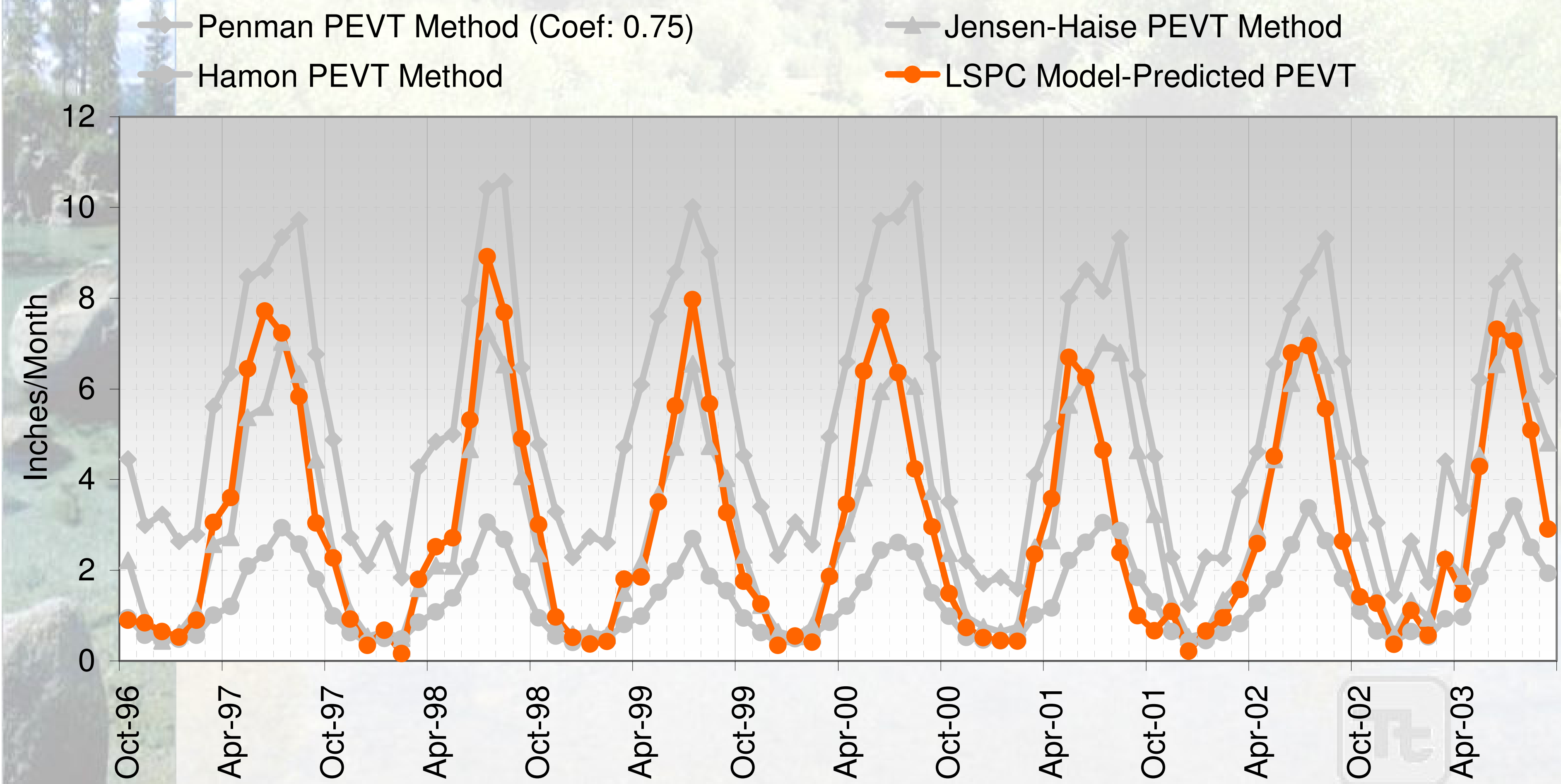
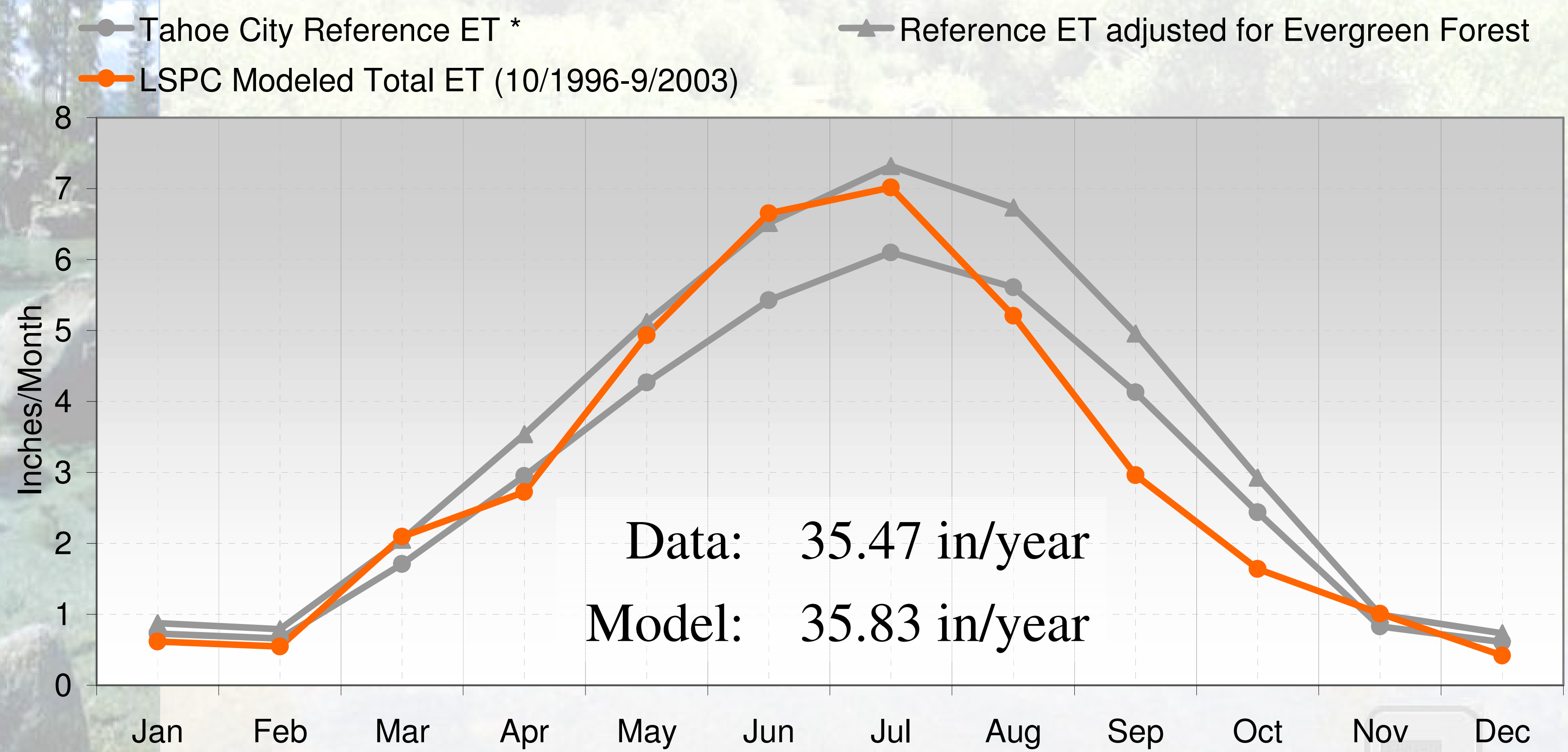
Evapotranspiration in Tahoe Basin

- Relatively low dewpoints & low humidity leads to a higher temperature/dewpoint gradient and therefore higher evaporation potential
- Wind and Solar Radiation are also influential – Penman considers their added influence on PEVT
- In other regions of the country, the three methods may yield more similar PEVT predictions
- The Tahoe basin's weather patterns are distinct characteristics of the watershed that when factored together, tend to predict higher potential evapotranspiration

Modeled ET vs. PEVT Methods



Modeled vs. Historical Reference ET



* Historical average monthly reference crop evapotranspiration for Tahoe City, California
UC Davis Division of Agriculture and Natural Resources, Publication 21454

Snow Simulation Considerations

Two commonly used SNOW simulation algorithms:

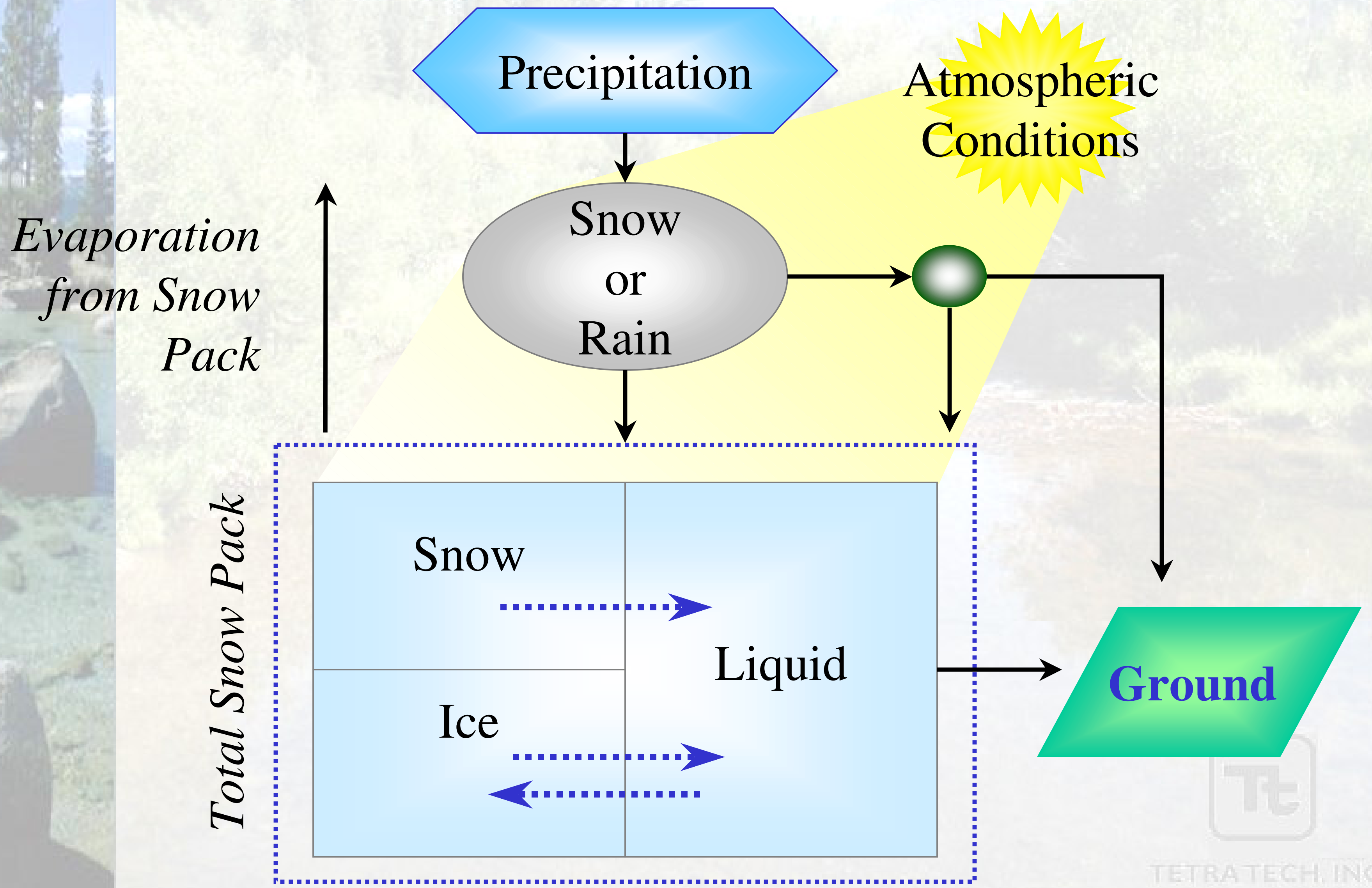
- **Energy Balance**
  - COE, 1956; Anderson Crawford, 1964; Anderson, 1968
- Temperature Index or "Degree-day"
  - Rango and Martinec, 1995

LSPC uses Energy Balance (most comprehensive)

Snow Simulation Considerations

Weather Data	Energy Balance	Degree Day
Precipitation	**Required**	**Required**
Air Temperature	**Required**	**Required**
Solar Radiation	**Required**	Not Used
Dewpoint	**Required**	*optional*
Wind Speed	**Required**	Not Used
Cloud Cover	*optional*	Not Used

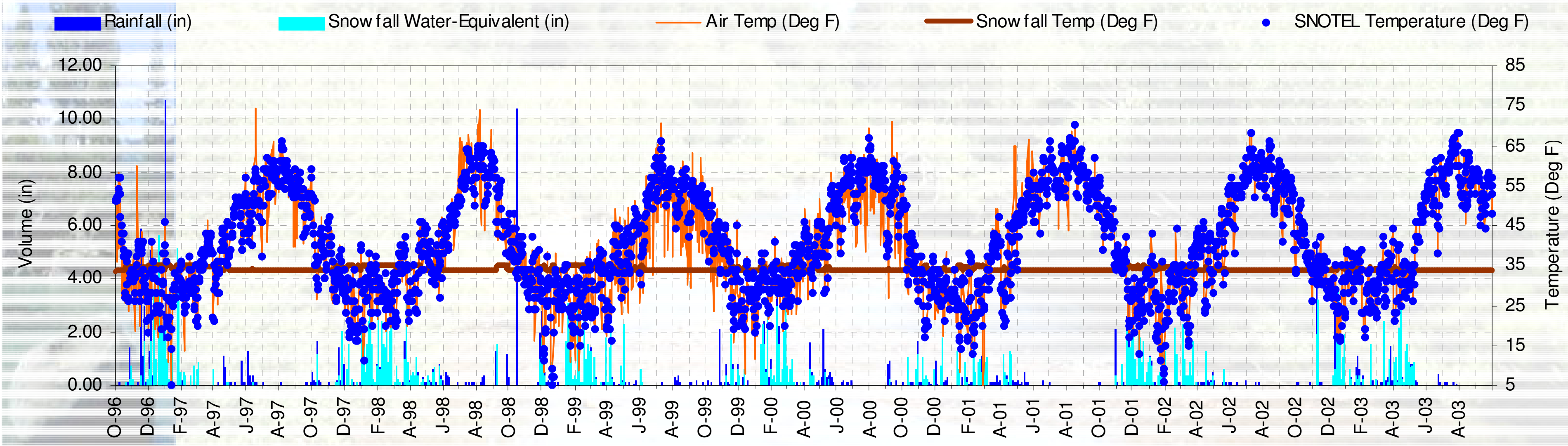
Snow Simulation Schematic

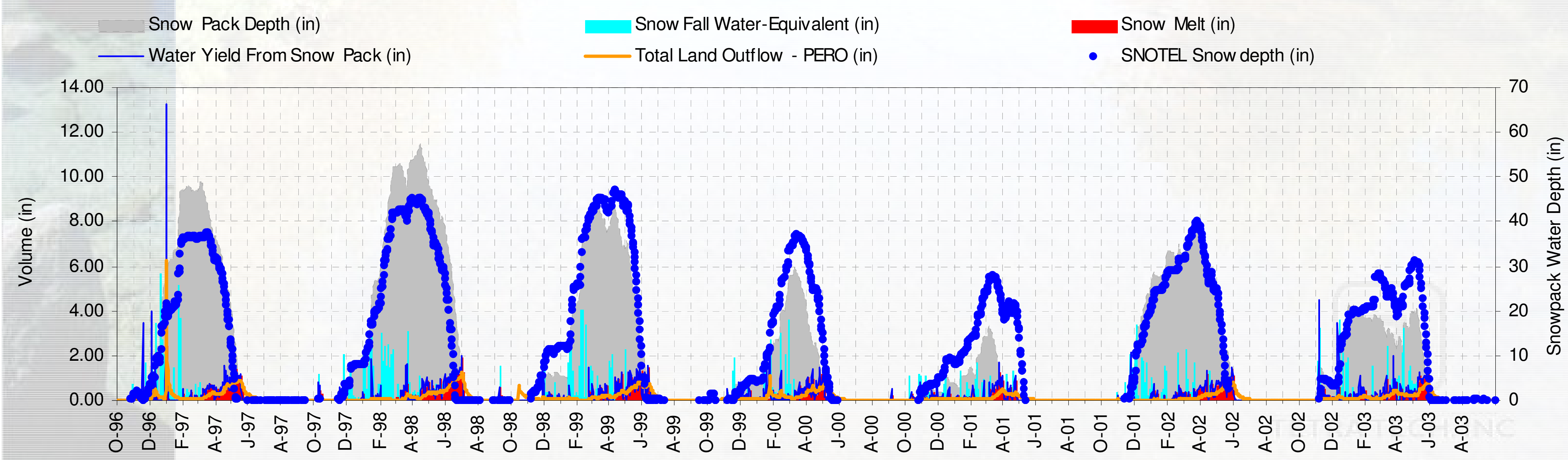


Evaluating LSPC Snow Simulation

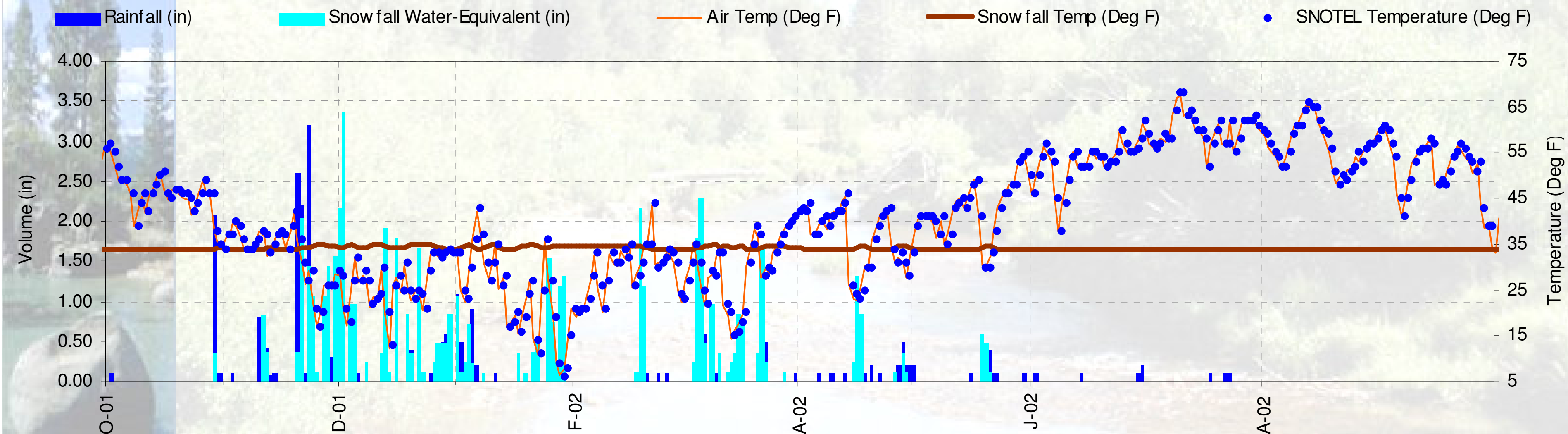
- Locally monitored SNOTEL surface air temperature, precipitation, and snow-pack (expressed as melted water equivalent depth) was compared against model simulated counterparts.
- Selected a subwatershed with average elevation most similar to SNOTEL gage elevation to use for comparison (SWS 8060).
- All water volumes from model output were normalized by drainage area to unit-area depth basis for comparison with observed depths.

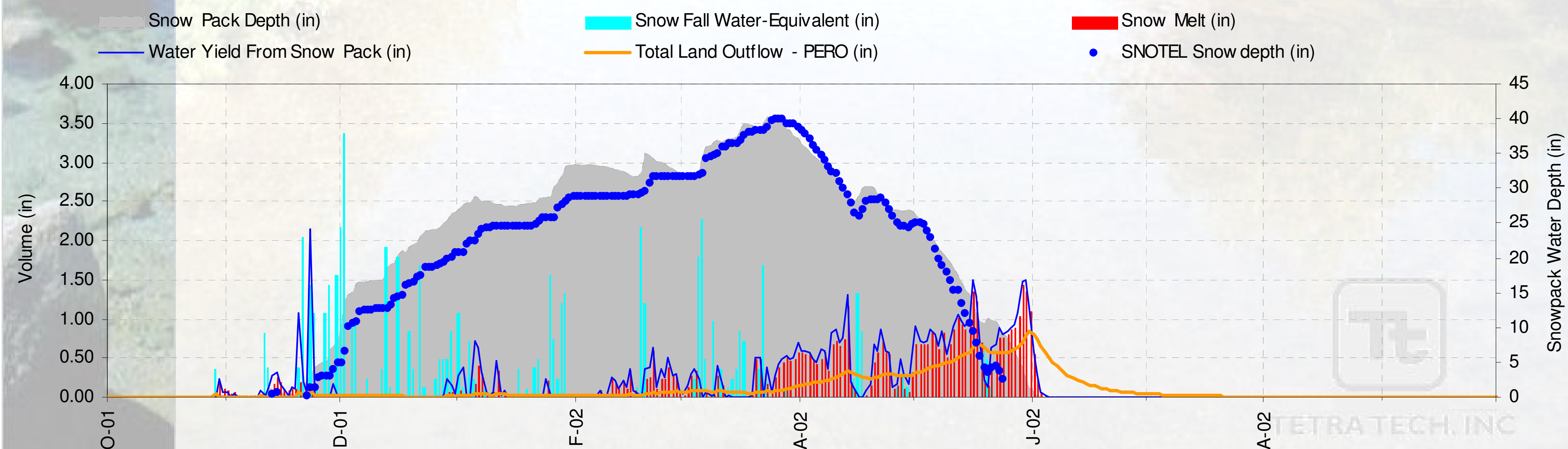
Snow Simulation (1996-2003)





Snow Simulation (Water Year 2002)





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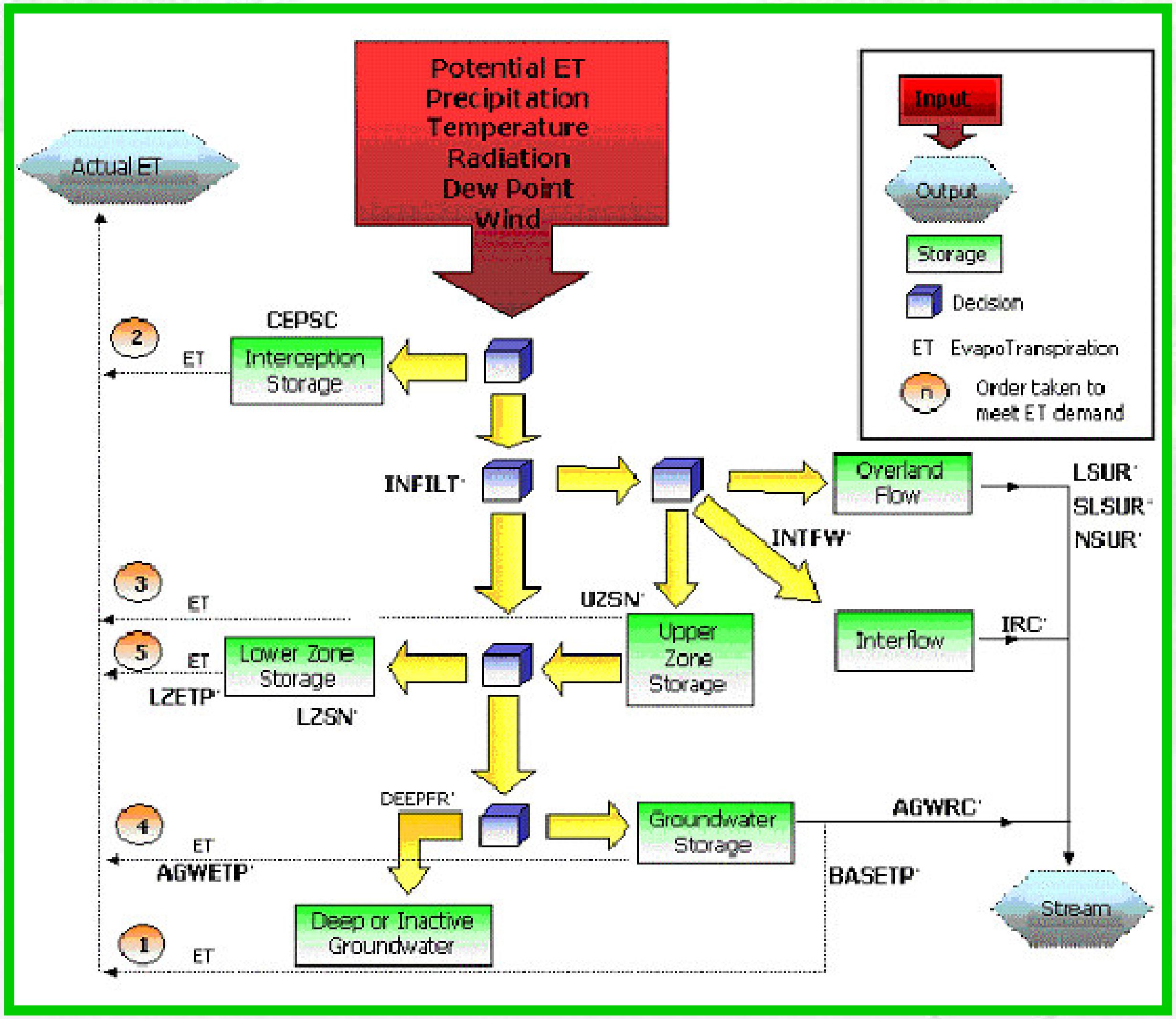
Temperature Lapse Rate in Tahoe

- Default model lapse rates (change in temperature per change in elevation) do not match observed trends in temperature and elevation data in Tahoe watershed.
- Four NCDC daily min/max temperature gages and six SNOTEL gages were used to estimate lapse rates using long-term average temperature and gage elevation for common time periods.
- Here is a comparison of lapse rates (Deg-F/ft):
  - Default lapse rates: 0.0035 to 0.0050
  - Tahoe lapse rates: 0.0015 to 0.0018
- This translates into a 35-40% reduction in the ELDAT parameter used in snow simulation.

Hydrologic Process & Parameters

- Hydrologic Components:
  - Precipitation
  - Interception
  - Evapotranspiration
  - Overland flow
  - Infiltration
  - Interflow
  - Subsurface storage
  - Groundwater flow
  - Groundwater loss



Source: Stanford Watershed Model

Hydrology Calibration

Level of Effort

- Calibrate to Local Observed Data
- Analytical Considerations
  - Annual water balance
  - Seasonal / monthly distribution
  - Distribution of hydrograph components
    - Storm flow
    - Base flow
  - Snowfall / snowmelt influence

Hydrology Calibration Indicators

- Hourly/Daily/Monthly Time series
- Monthly Scatter/Balance Plots
- Seasonal Plots (Multi-Year Composites)
- Flow Duration Curves
- Flow Accumulation Curves
- Cumulative Error Statistics
- Hydrograph Components

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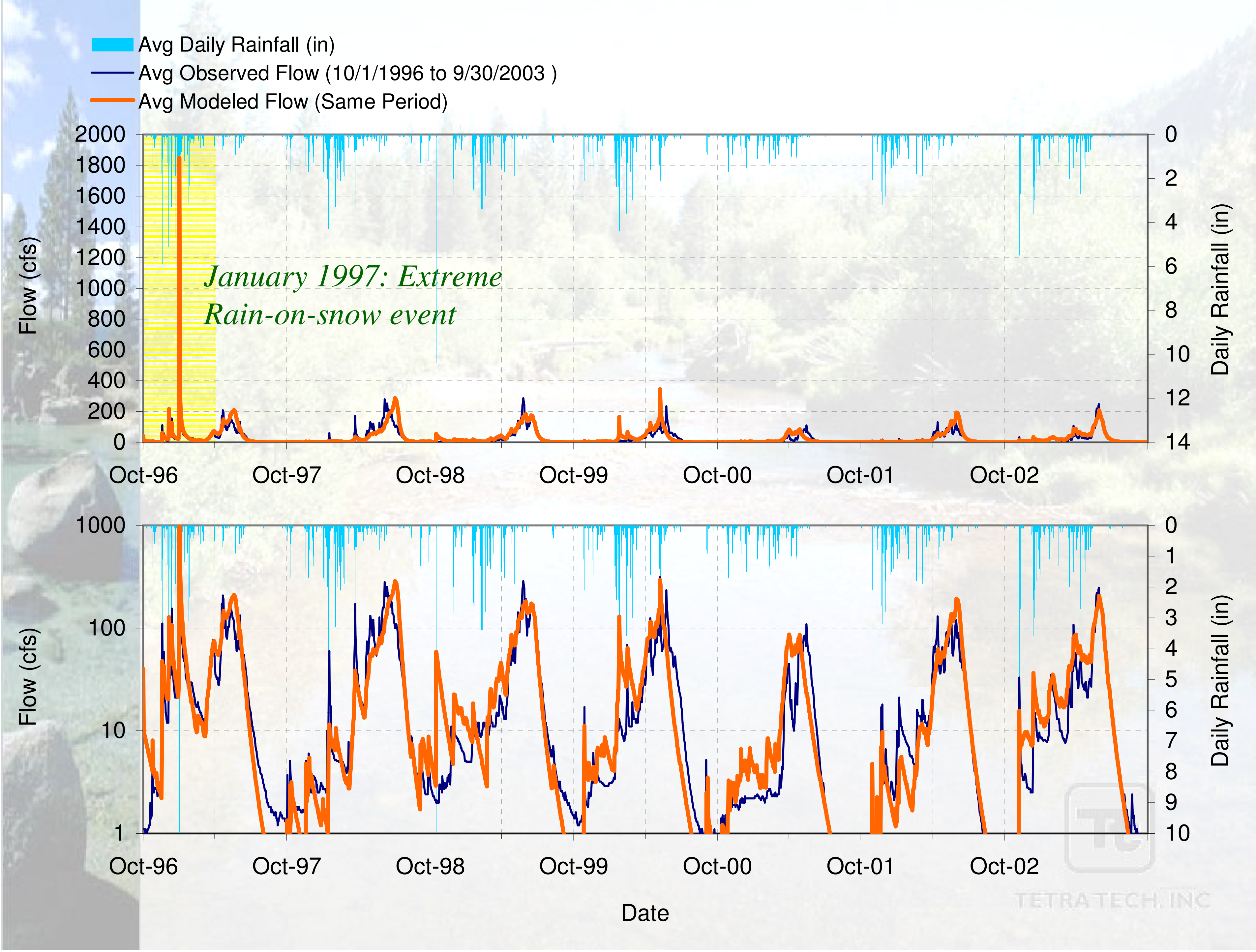
Avg Daily Rainfall (in)
Avg Observed Flow (10/1/1996 to 9/30/2003)
Avg Modeled Flow (Same Period)
January 1997: Extreme
Rain-on-snow event
Flow (cfs)
Daily Rainfall (in)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
Oct-96
Oct-97
Oct-98
Oct-99
Oct-00
Oct-01
Oct-02
1000
100
10
1
0
1
2
3
4
5
6
7
8
9
10
Date
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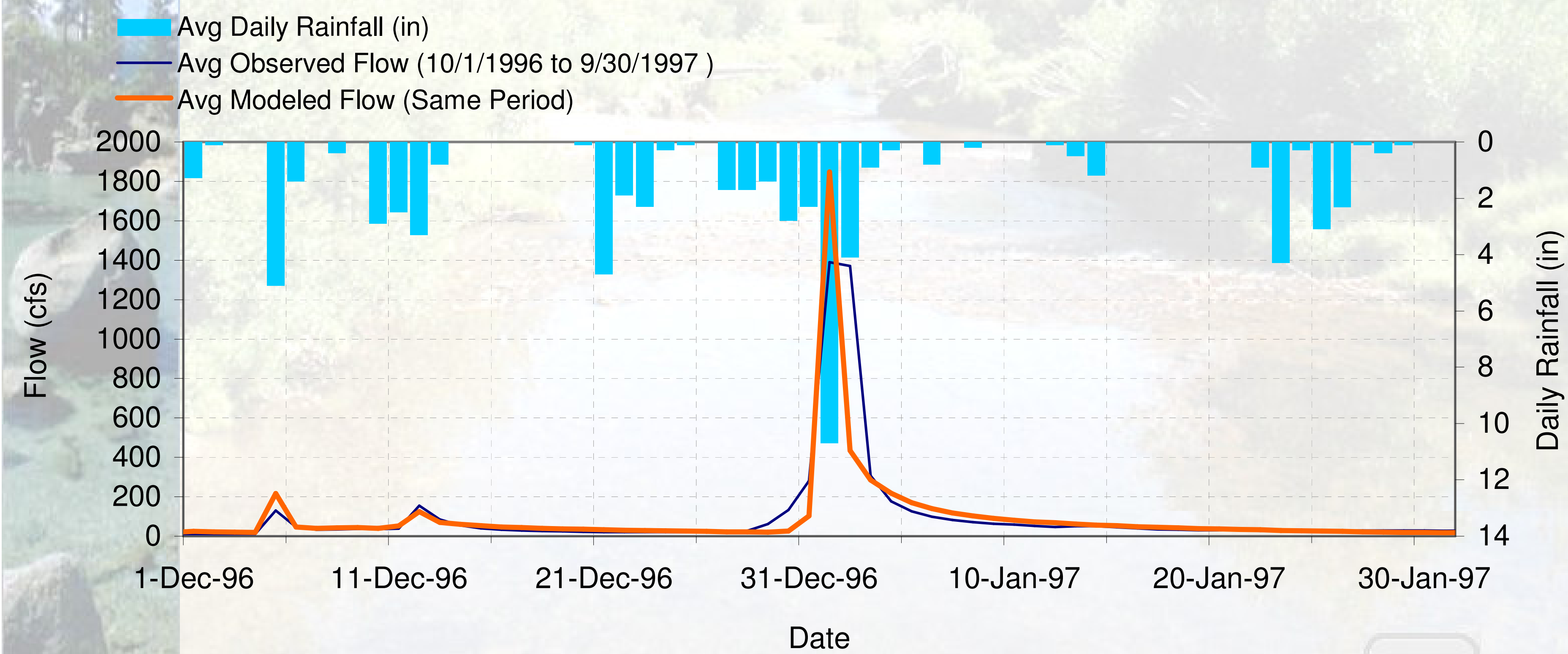
January 1, 1997 Rain-on-snow event

Do you remember where you were when…



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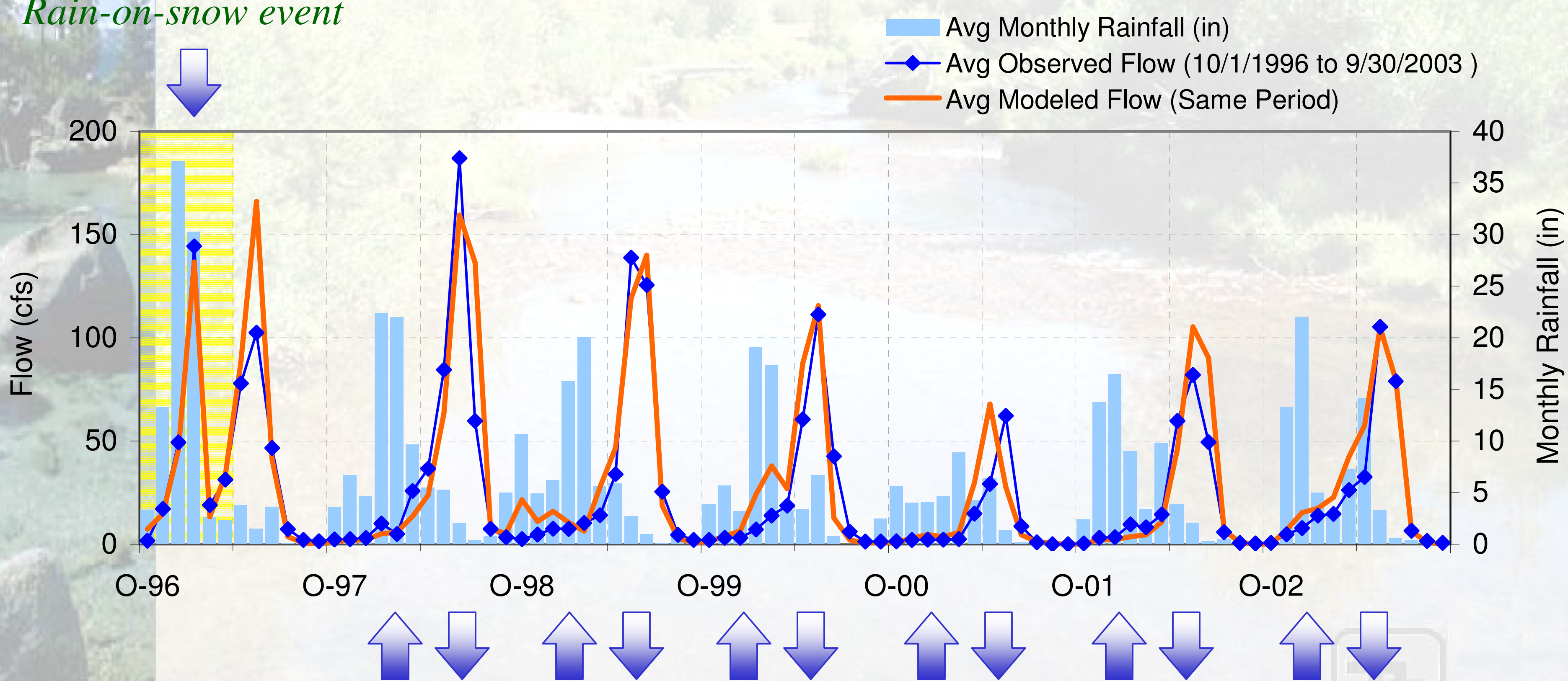
Ward Creek (Monthly Average)

January 1997: Extreme Rain-on-snow event



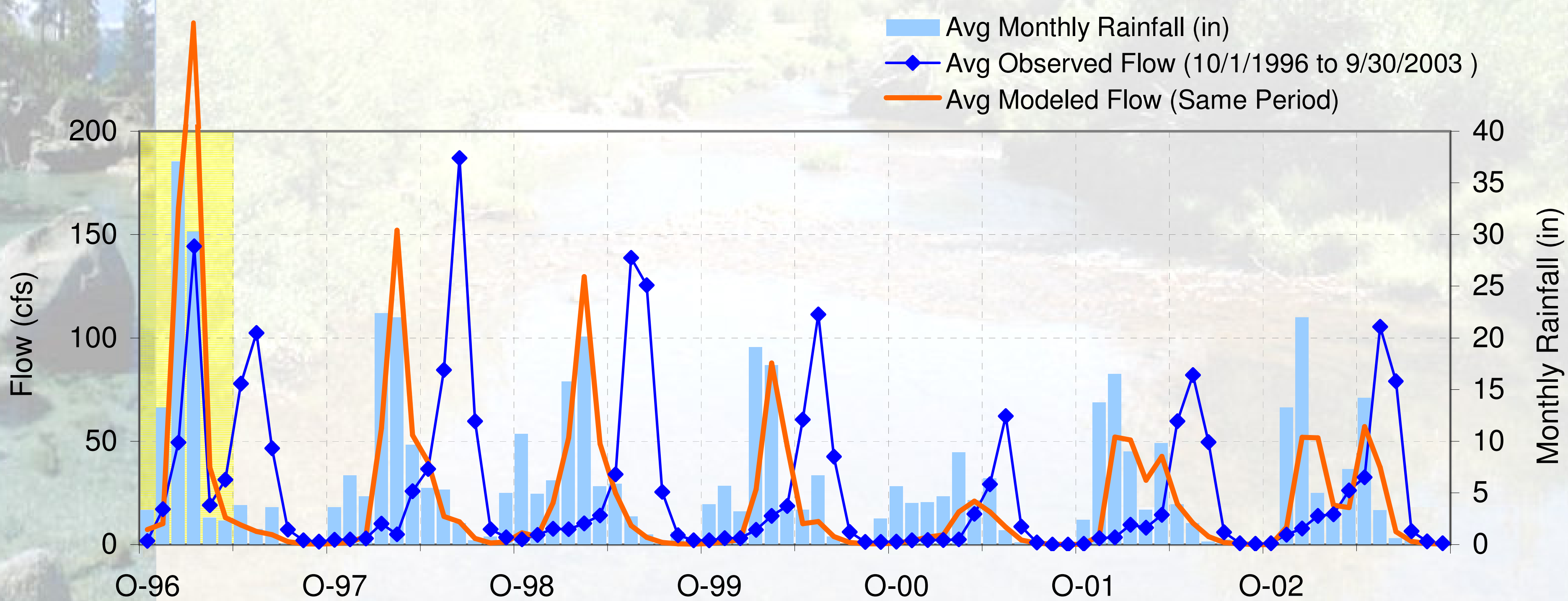
Typical Snowfall / Snowmelt Sequence

Typical Snowfall / Snowmelt Sequence

Typical Snowfall / Snowmelt Sequence

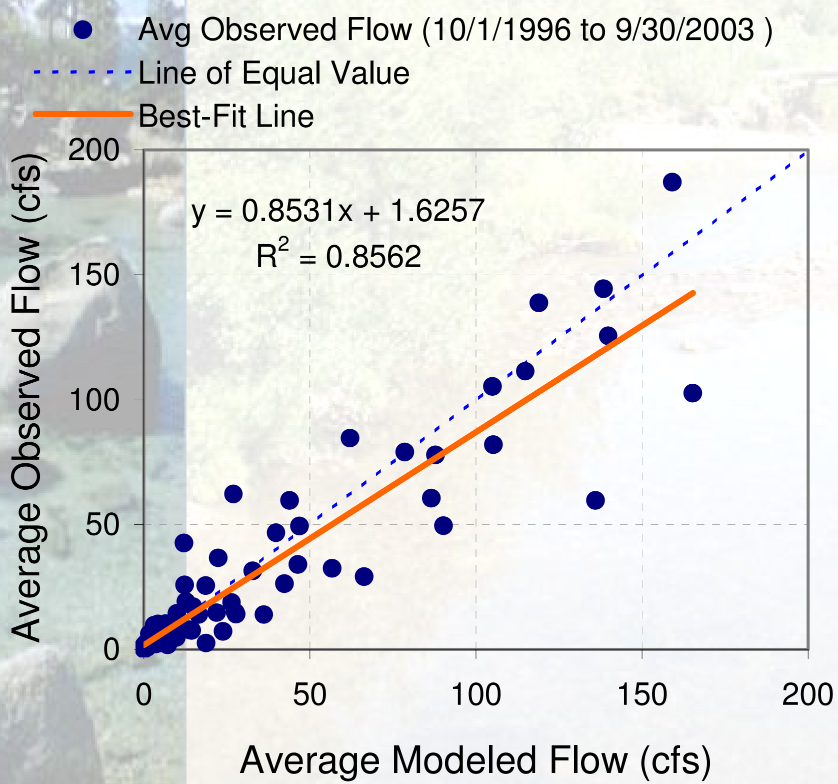
Ward Creek (NO Snow Simulation)

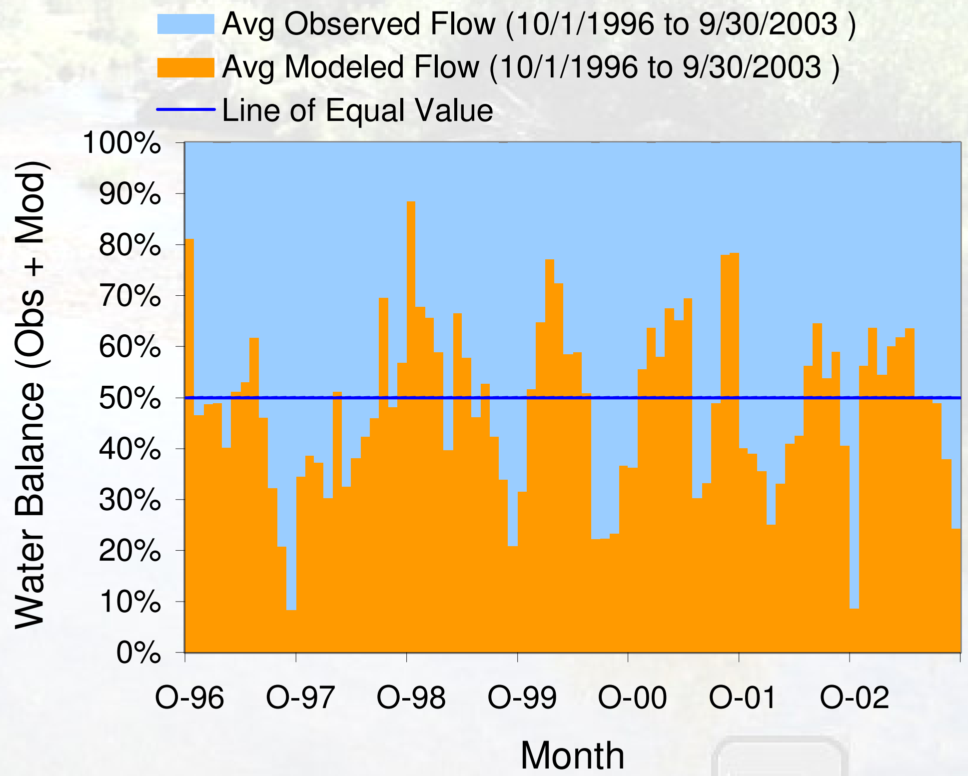
Snowfall/snowmelt results in a 3-month phase shift of peak flow



*With exception of the 1997 event, spring snowmelt peak is typically **higher** than if all precipitation had fallen as rain*

Ward Creek (Monthly Average)





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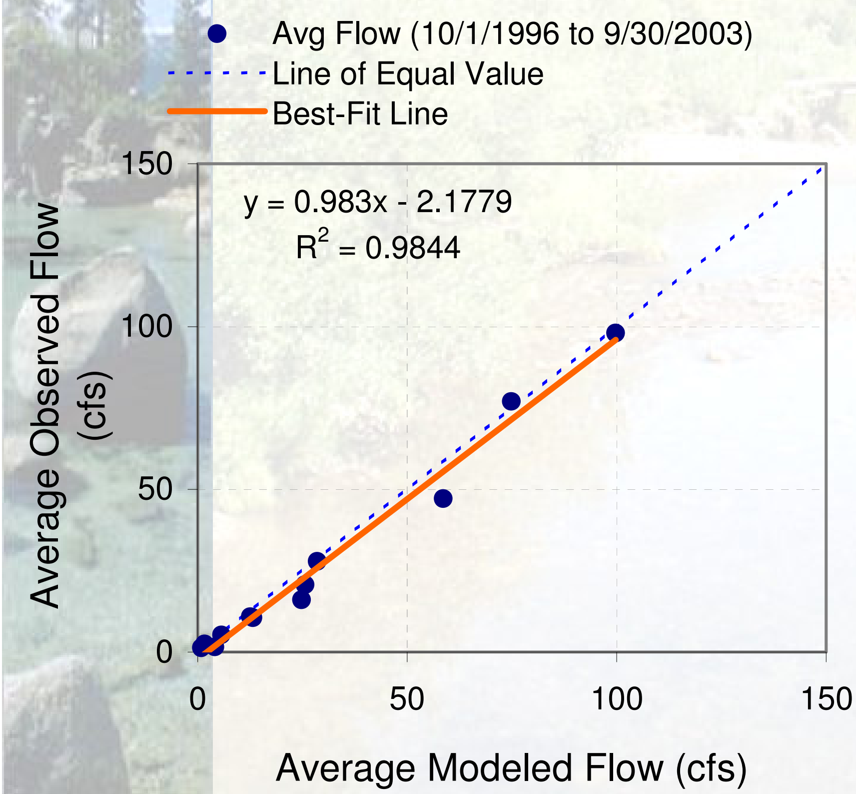
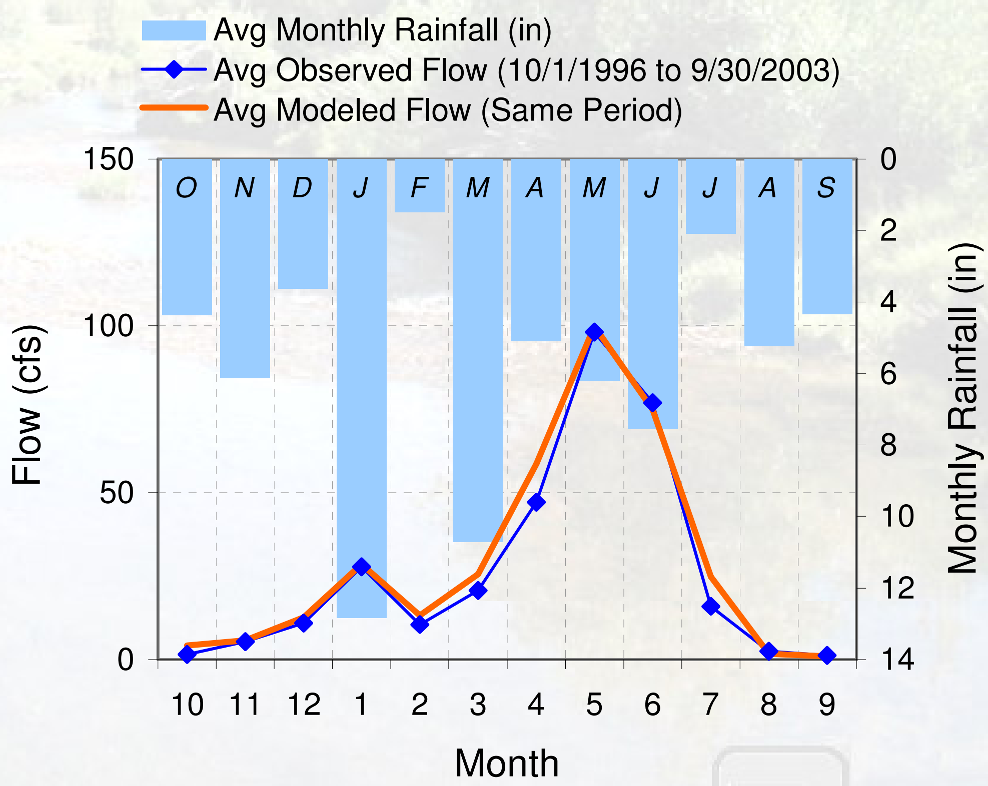
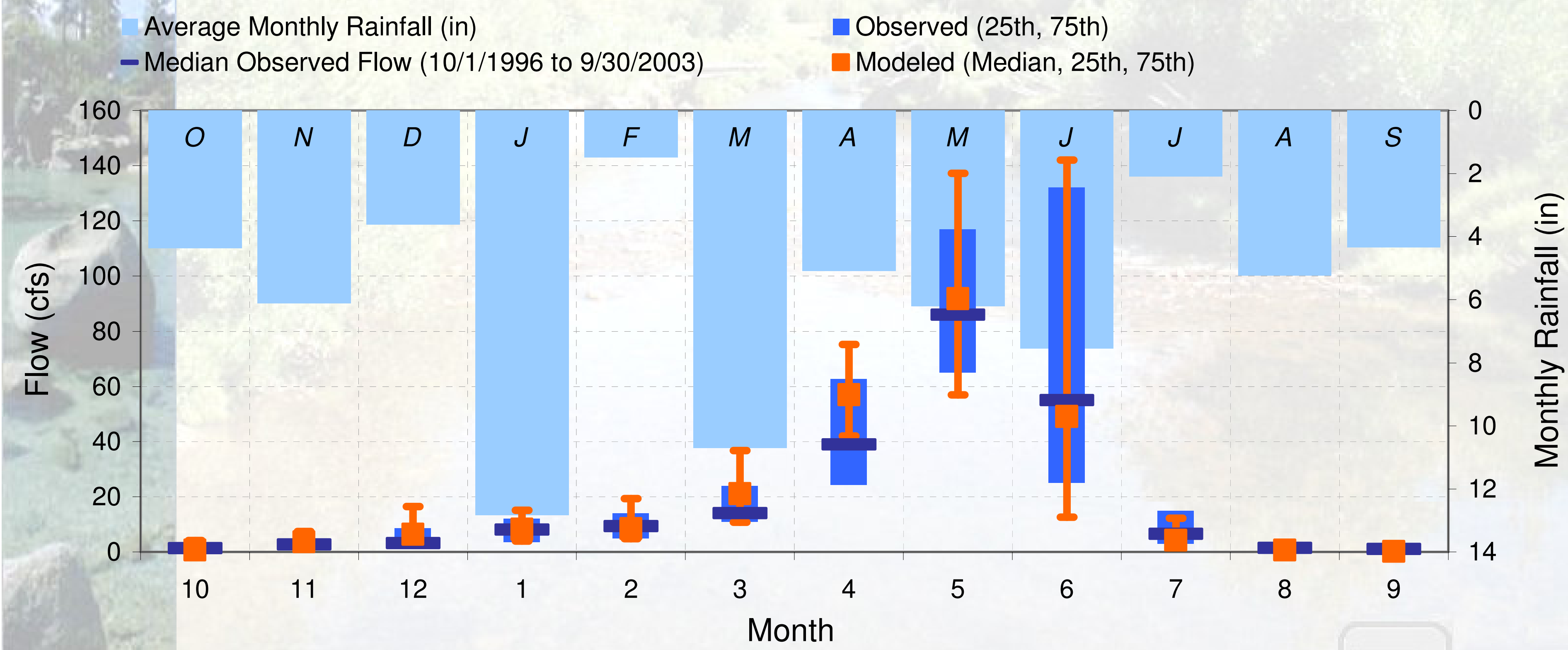
Ward Creek (7-Year Composite)



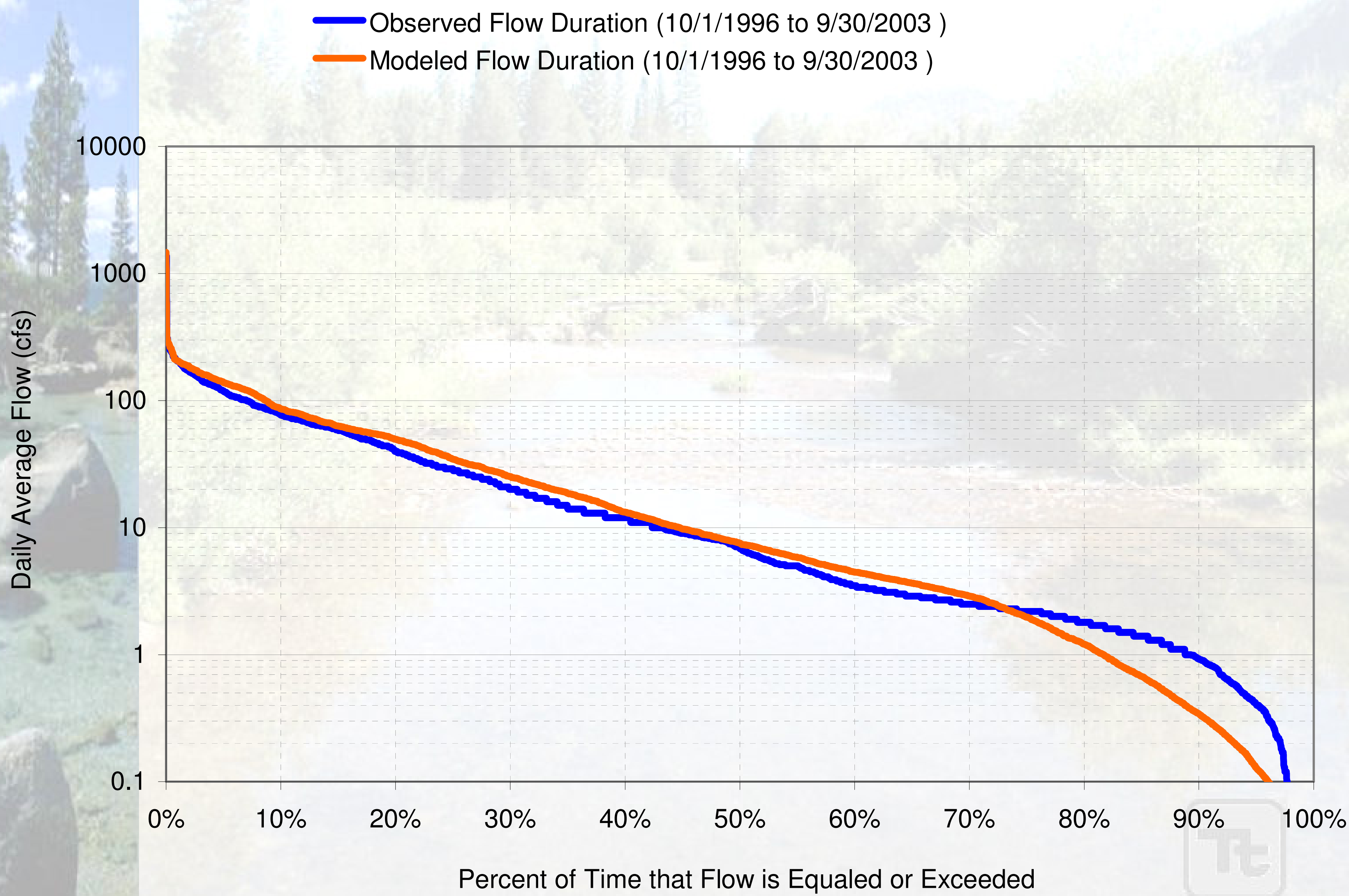


Model Test for Seasonality

Ward Creek (7-Year Composite)



Model Test for Seasonality


Observed Flow Duration (10/1/1996 to 9/30/2003)
Modeled Flow Duration (10/1/1996 to 9/30/2003)
Daily Average Flow (cfs)
10000
1000
100
10
1
0.1
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time that Flow is Equaled or Exceeded

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 8060		**USGS 10336676 WARD C AT HWY 89 NR TAHOE PINES CA**	
7-Year Analysis Period: 10/1/1996 - 9/30/2003 Flow volumes are normalized, with total observed as 100		Placer County, California Hydrologic Unit Code 16050101 Latitude 39°07'56", Longitude 120°09'24" NAD27 Drainage area 9.70 square miles	
Total Simulated In-stream Flow:	**110.06**	Total Observed In-stream Flow:	**100.00**
Total of simulated highest 10% flows:	**58.68**	Total of Observed highest 10% flows:	**53.74**
Total of Simulated lowest 50% flows:	**4.19**	Total of Observed Lowest 50% flows:	**4.45**
Simulated Summer Flow Volume (months 7-9):	**8.76**	Observed Summer Flow Volume (7-9):	**6.28**
Simulated Fall Flow Volume (months 10-12):	**7.11**	Observed Fall Flow Volume (10-12):	**5.60**
Simulated Winter Flow Volume (months 1-3):	**21.13**	Observed Winter Flow Volume (1-3):	**18.51**
Simulated Spring Flow Volume (months 4-6):	**73.06**	Observed Spring Flow Volume (4-6):	**69.61**
Total Simulated Storm Volume:	**6.88**	Total Observed Storm Volume:	**8.59**
Simulated Summer Storm Volume (7-9):	**0.59**	Observed Summer Storm Volume (7-9):	**0.41**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	9.14	10
Error in 50% lowest flows:	-6.04	10
Error in 10% highest flows:	8.42	15
Seasonal volume error - Summer:	28.30	30
Seasonal volume error - Fall:	21.20	30
Seasonal volume error - Winter:	12.41	30
Seasonal volume error - Spring:	4.72	30
Error in storm volumes:	**-24.97**	**20**
Error in summer storm volumes:	30.49	50

Hydrograph Separation Methods

USGS: *HYSEP*, Sloto & Cruise (1996)

- Separation interval (2N*) is an odd-integer number of days (between 3 and 11) – *function of* drainage area
- Fixed Interval: assigns lowest discharge in an interval to all values in that interval (Step by 2N*)
- Sliding Interval: assigns lowest discharge in a sliding interval to a given point (Step by one day)
- Local Minimum: selects local minimums within a sliding interval and connects them with a straight line (Step by one day until next local minimum)

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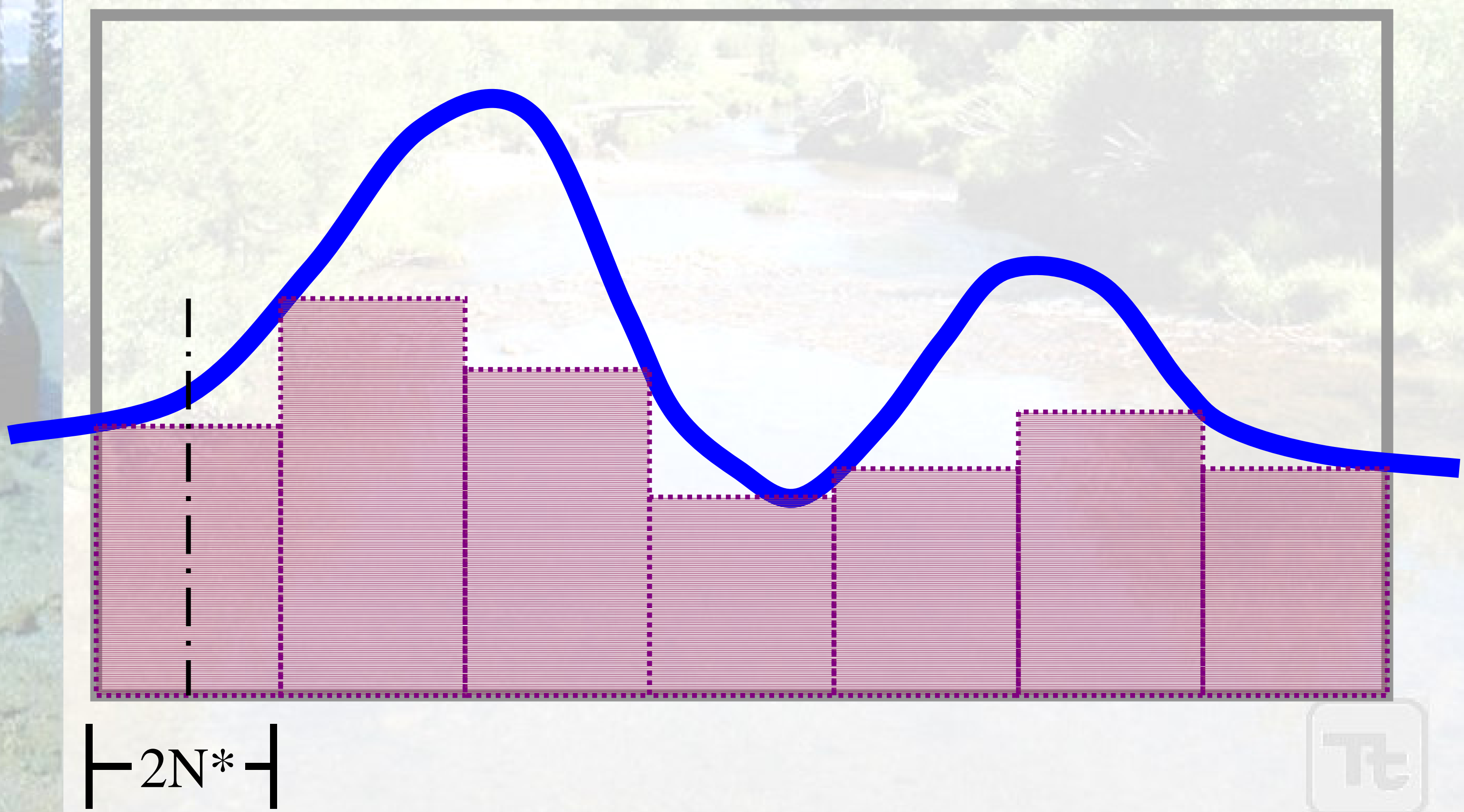
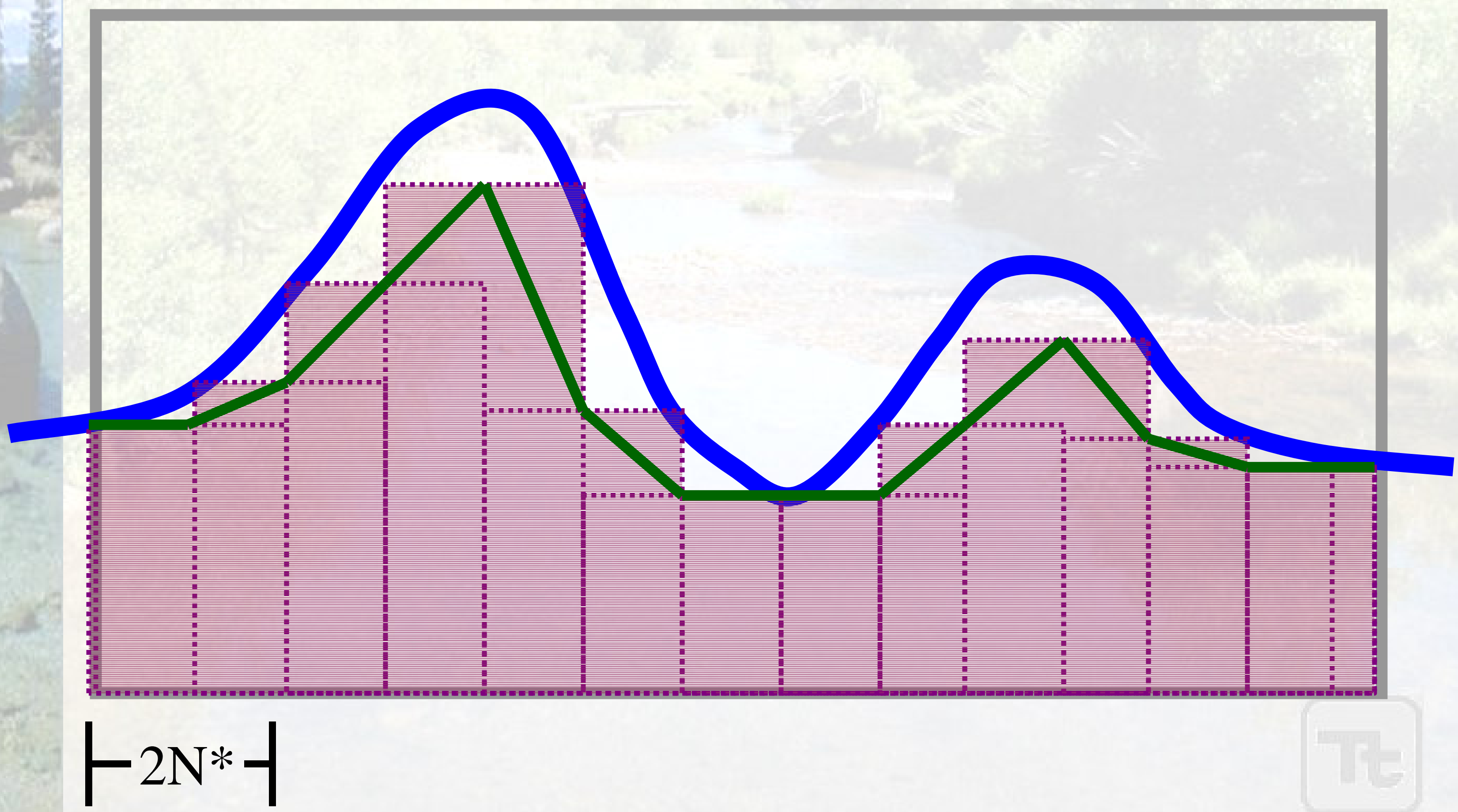
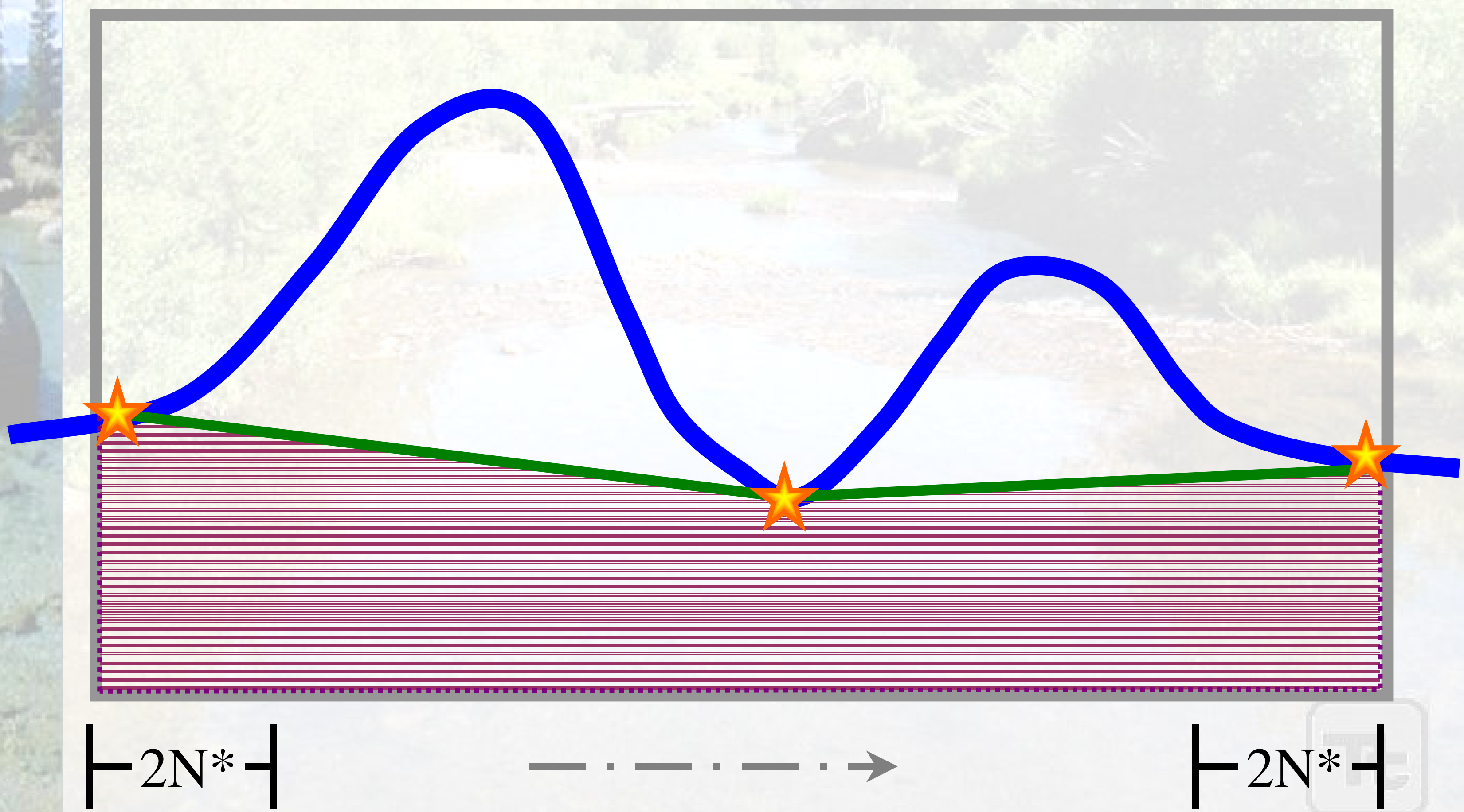
Fixed Interval Separation



Sliding Interval Separation



Local Minimum Separation



Model Hydrograph Components

Runoff

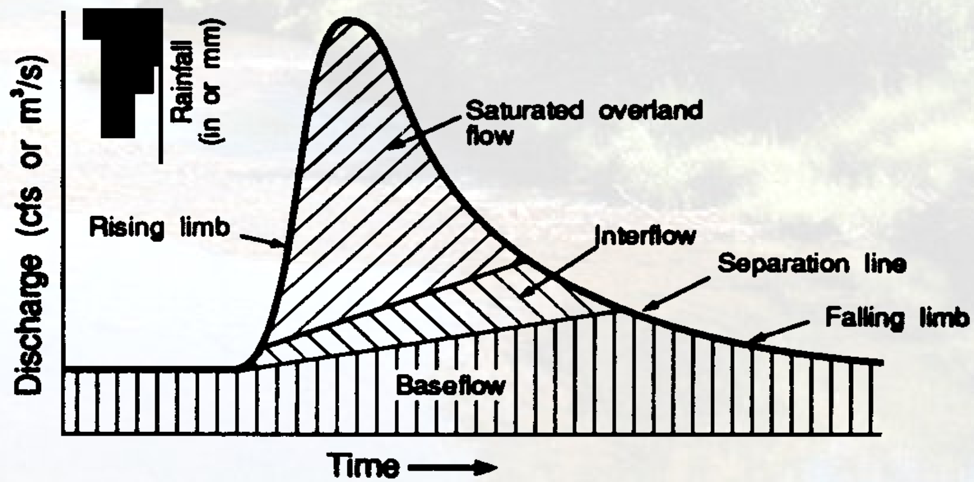
Interflow

Baseflow

Surface runoff - overland flow

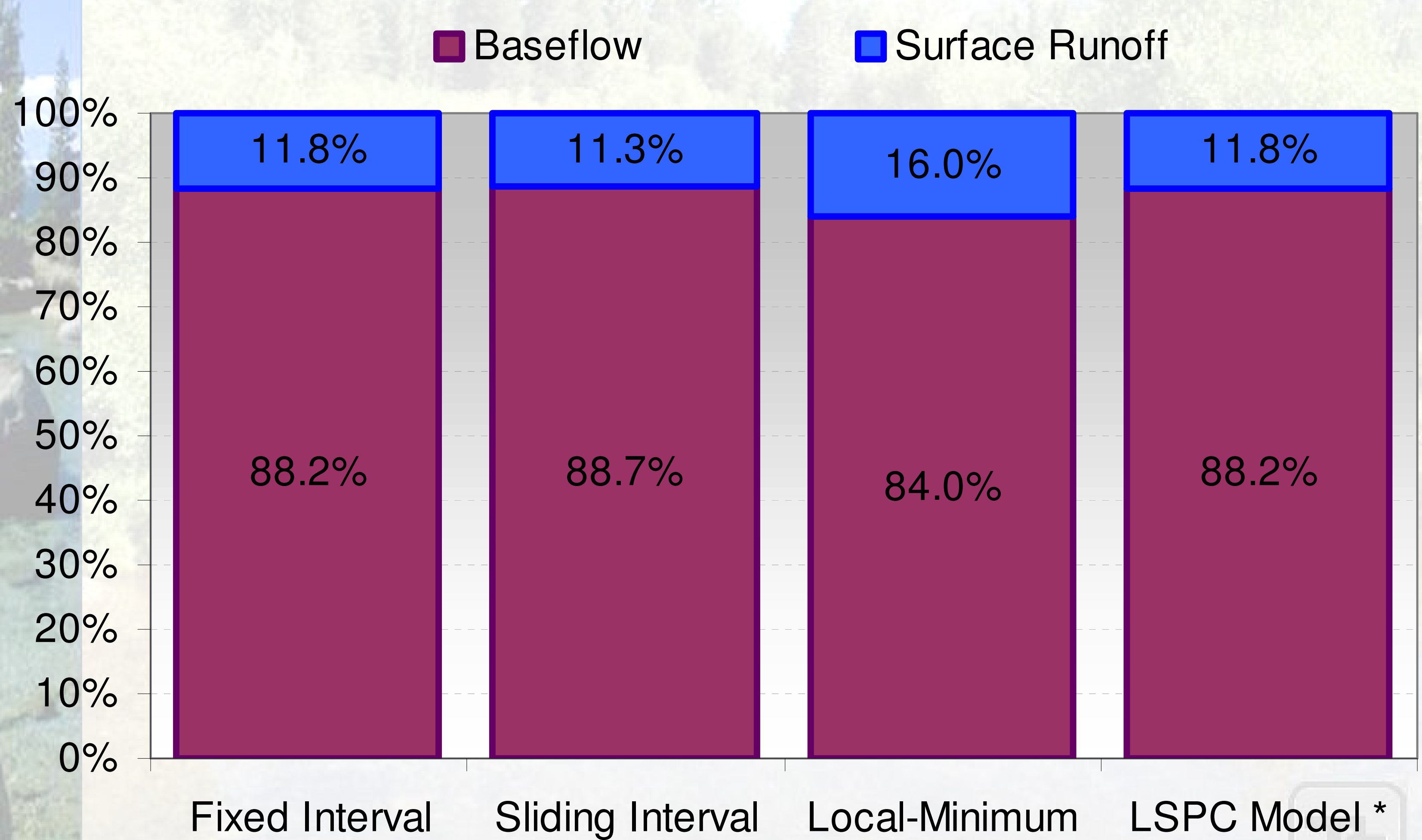
Interflow - flow through surficial layers of soil

Baseflow - groundwater seepage from springs and aquifers directly to the stream channel



Surface flow may actually include all or some of Interflow

Ward Creek (Oct 1996 – Sep 2003)

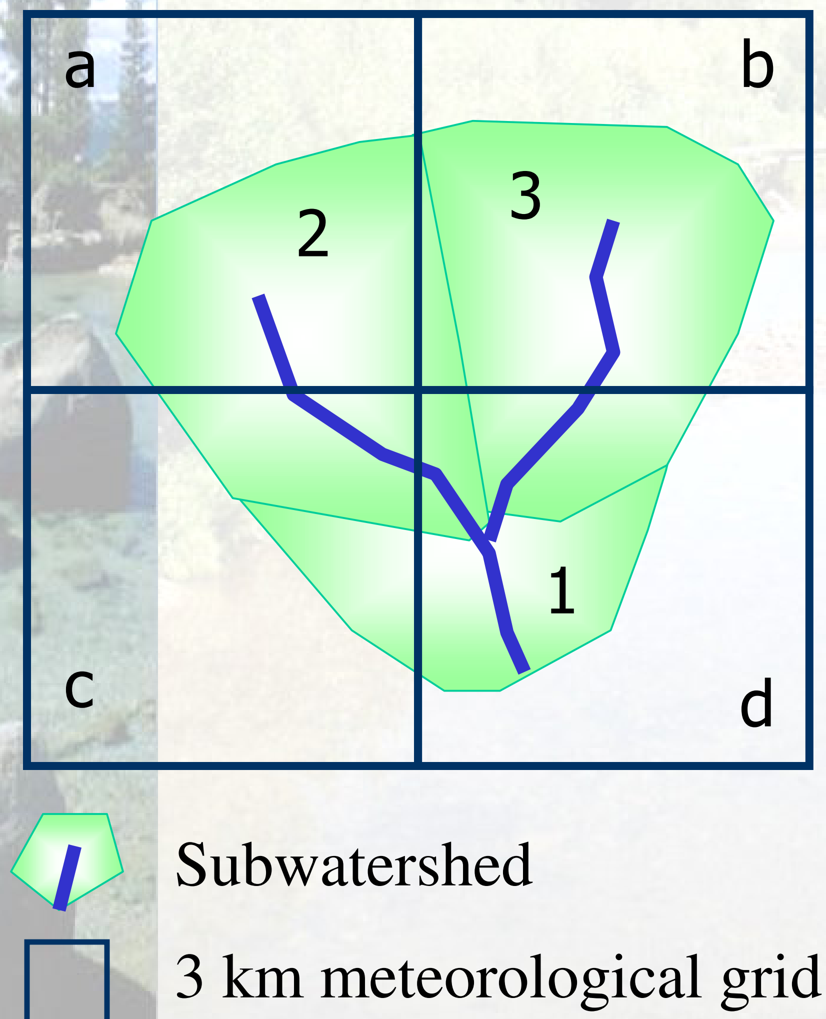


* Surface runoff interpreted as the sum of SURO and IFWO, Baseflow is AGWO

Lake Tahoe Reconstructed Weather

- 3-km by 3-km spatial resolution
- 142 grid cells cover Tahoe drainage area
- 42 years of hourly information at each grid
- Available information used include:
  - Precipitation
  - Temperature
  - Dew point
  - Wind speed
  - Solar radiation
- Potential evapotranspiration computed using Penman Method with 0.75 PEVT Coefficient
- LTRD information was spatially aggregated by subwatershed, resulting in 184 unique, spatially varied weather patterns throughout Tahoe Basin

Spatial Aggregation Method (Thiessen Polygon)



Subbasin Area-Weighting

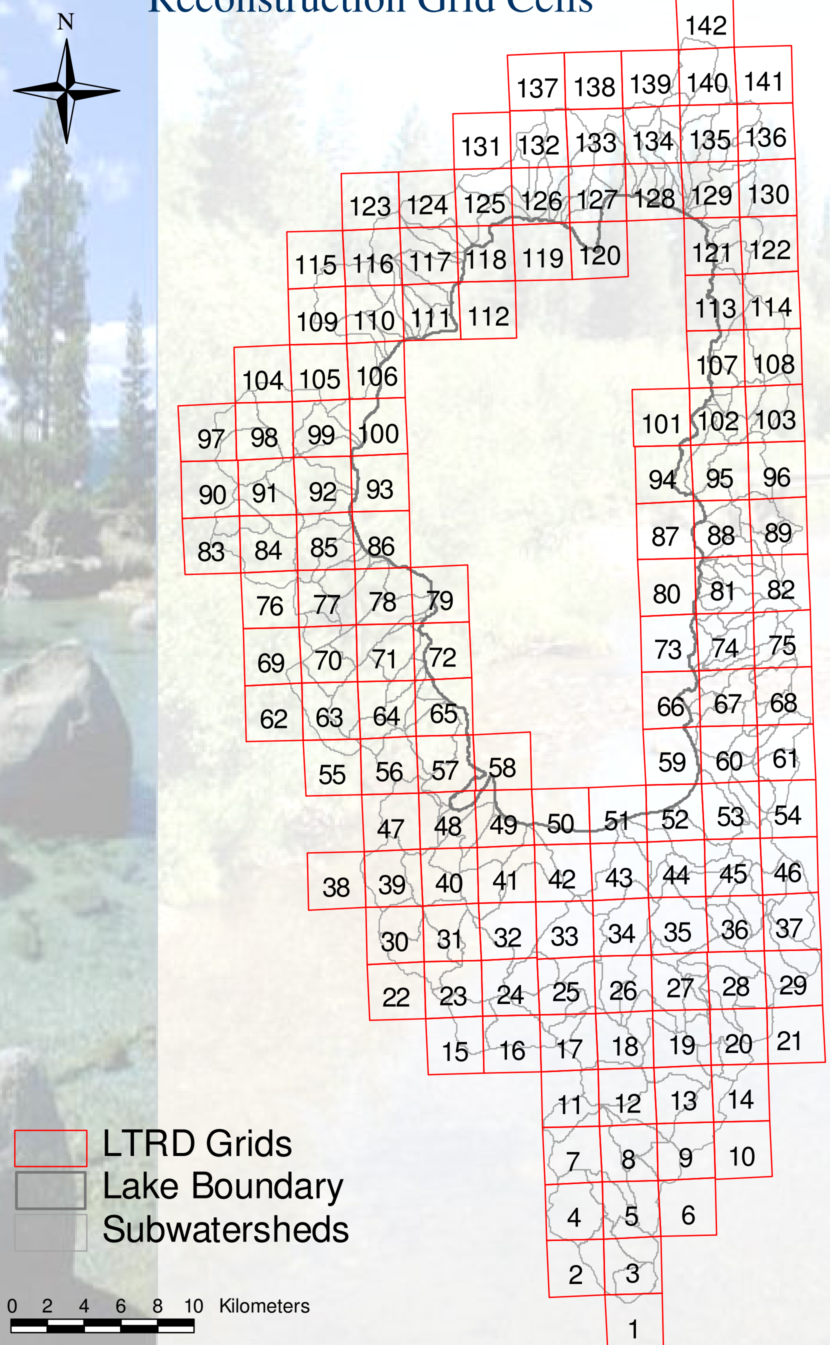
- Subbasin 1 =

  0.4 c + 0.6 d
- Subbasin 2 =

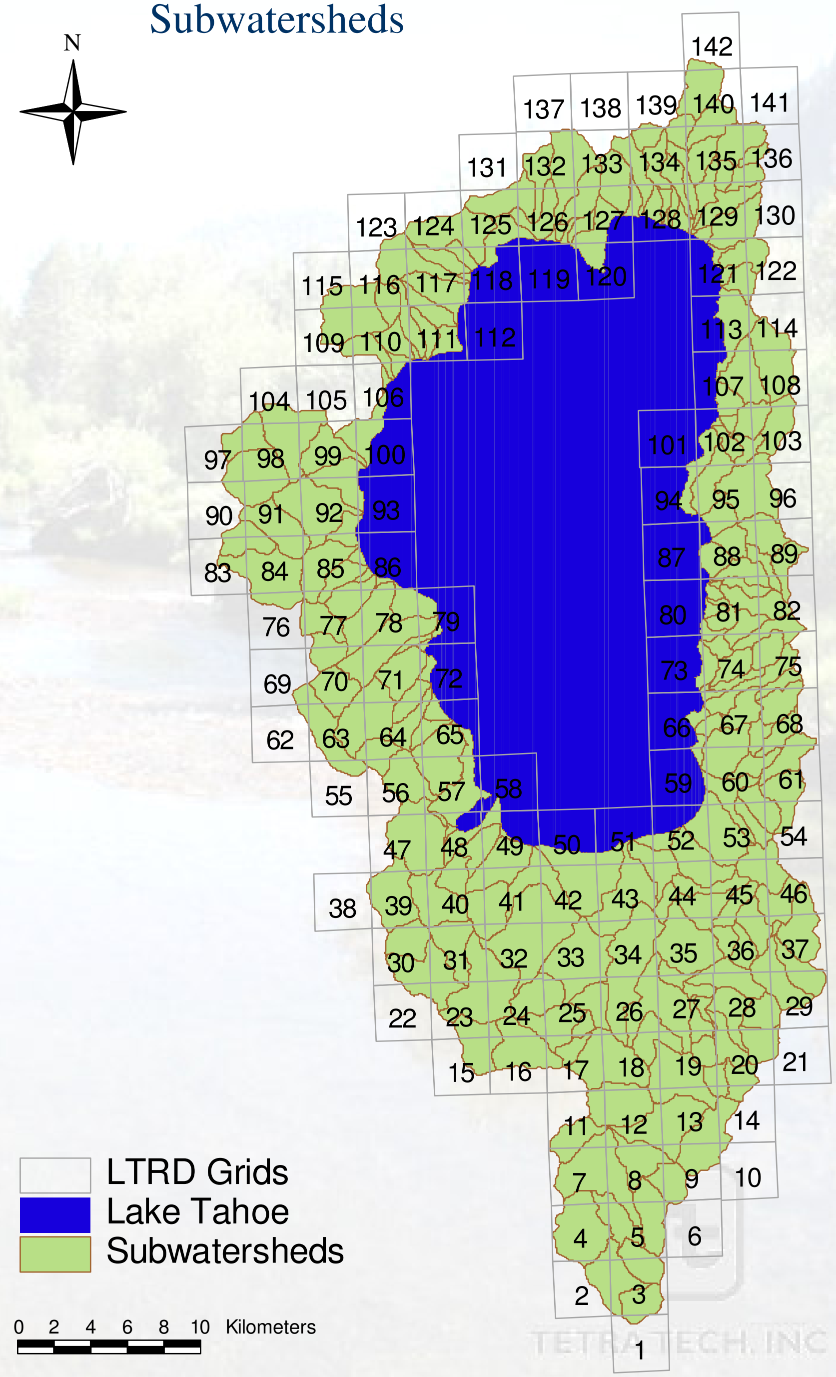
  0.5a + 0.1b + 0.3c + 0.1d
- Subbasin 3 =

  0.7 b + 0.3 d

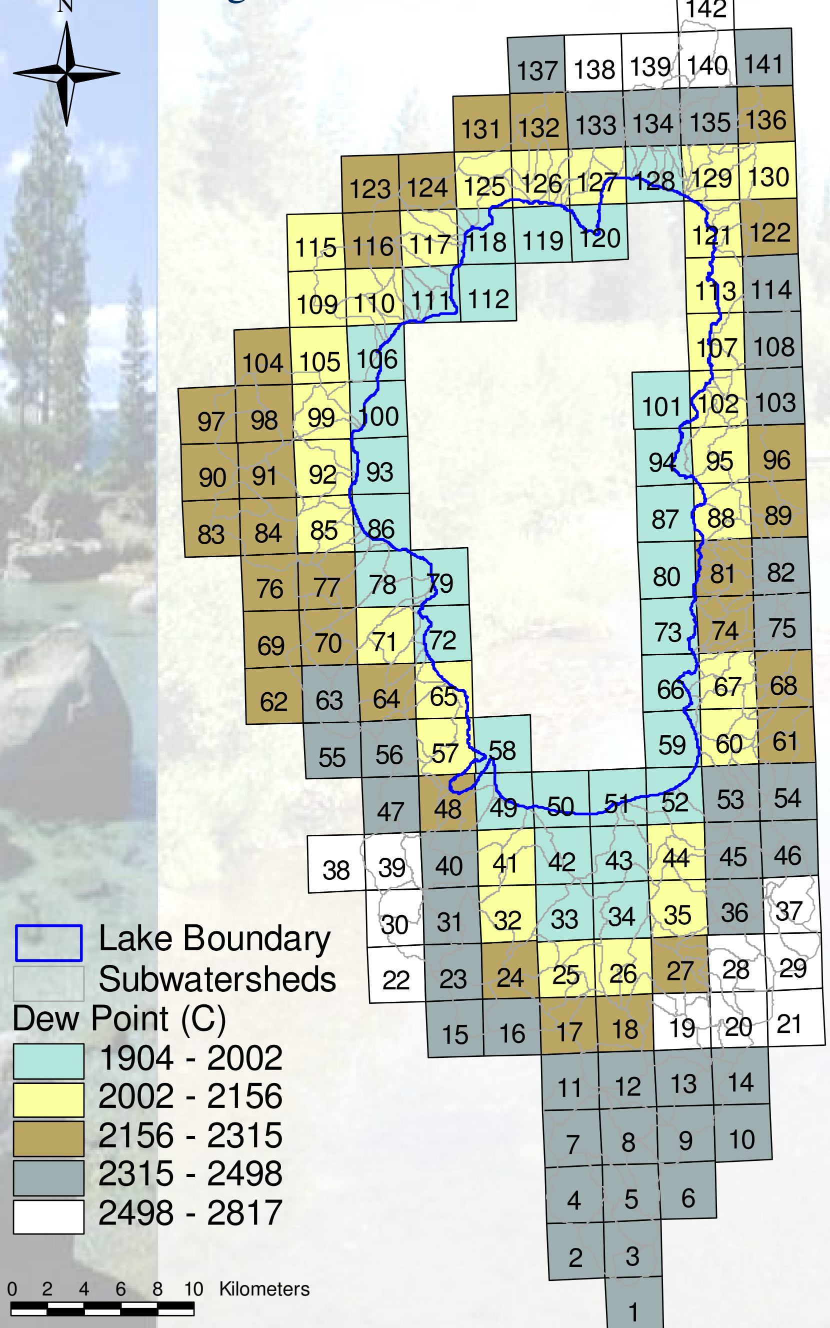
Reconstruction Grid Cells



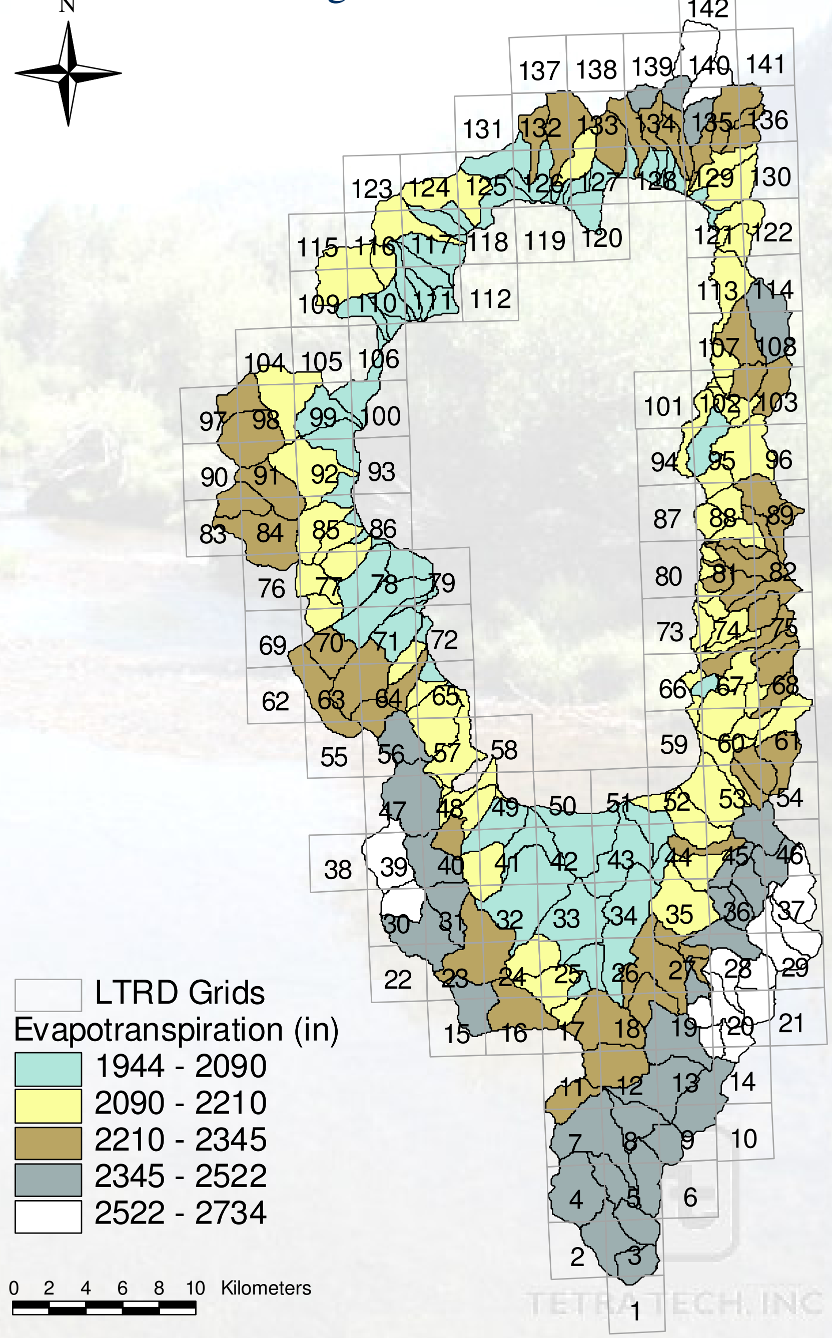
Subwatersheds

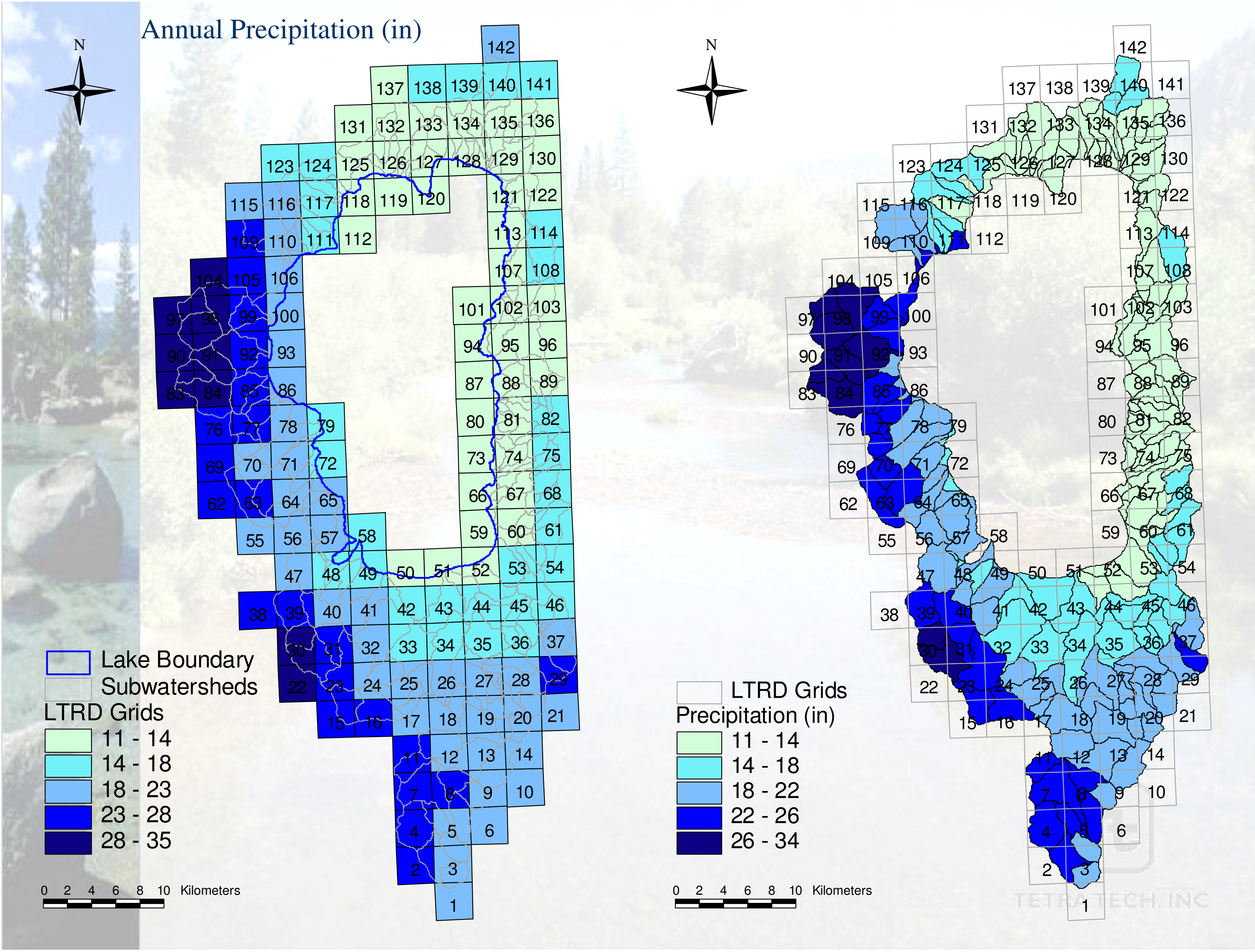


“Gage” Elevation



SWS “Gage” Elevation




Annual Precipitation (in)
N
Lake Boundary
Subwatersheds
LTRD Grids
11 - 14
14 - 18
18 - 23
23 - 28
28 - 35
0 2 4 6 8 10 Kilometers
N
LTRD Grids
Precipitation (in)
11 - 14
14 - 18
18 - 22
22 - 26
26 - 34
0 2 4 6 8 10 Kilometers
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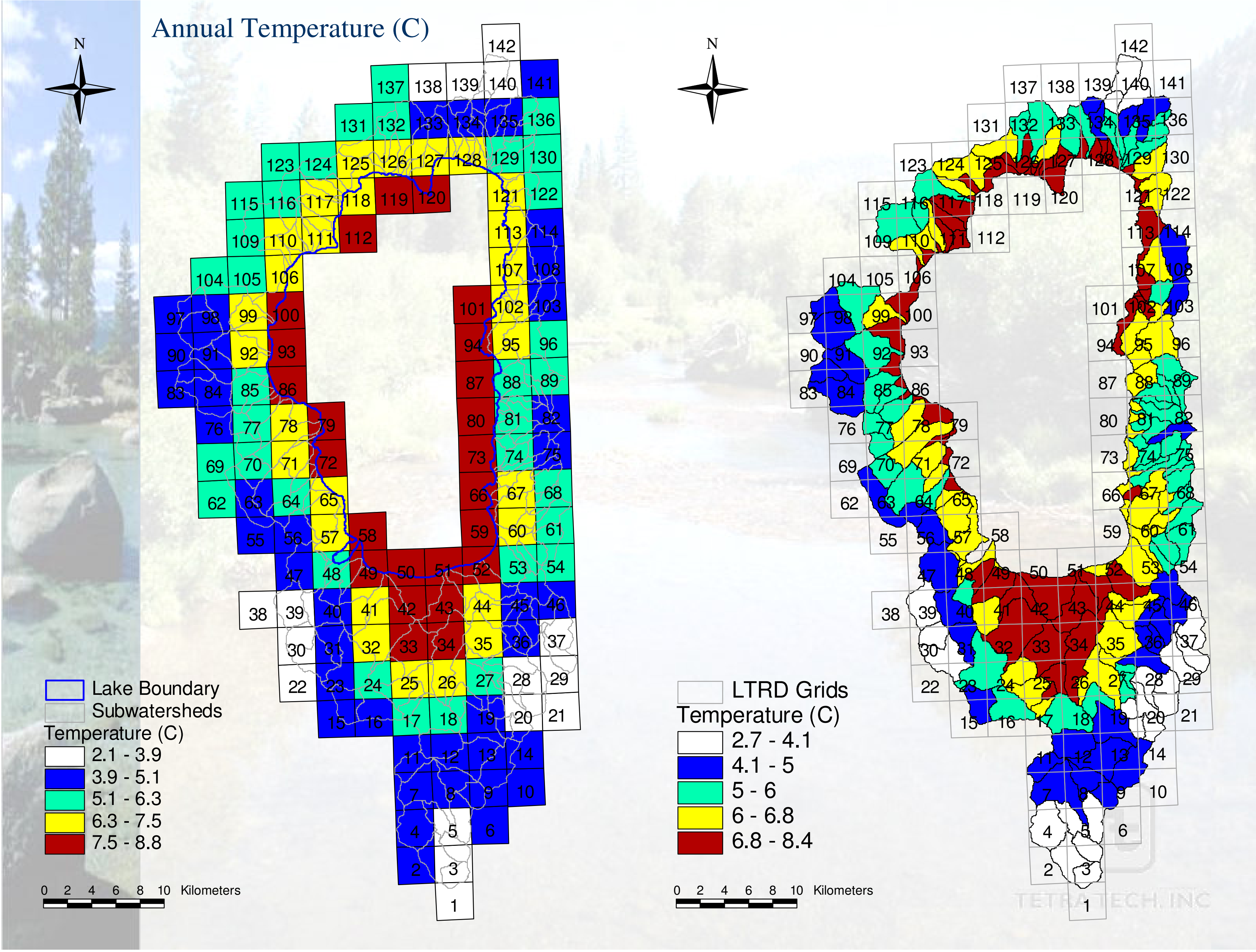
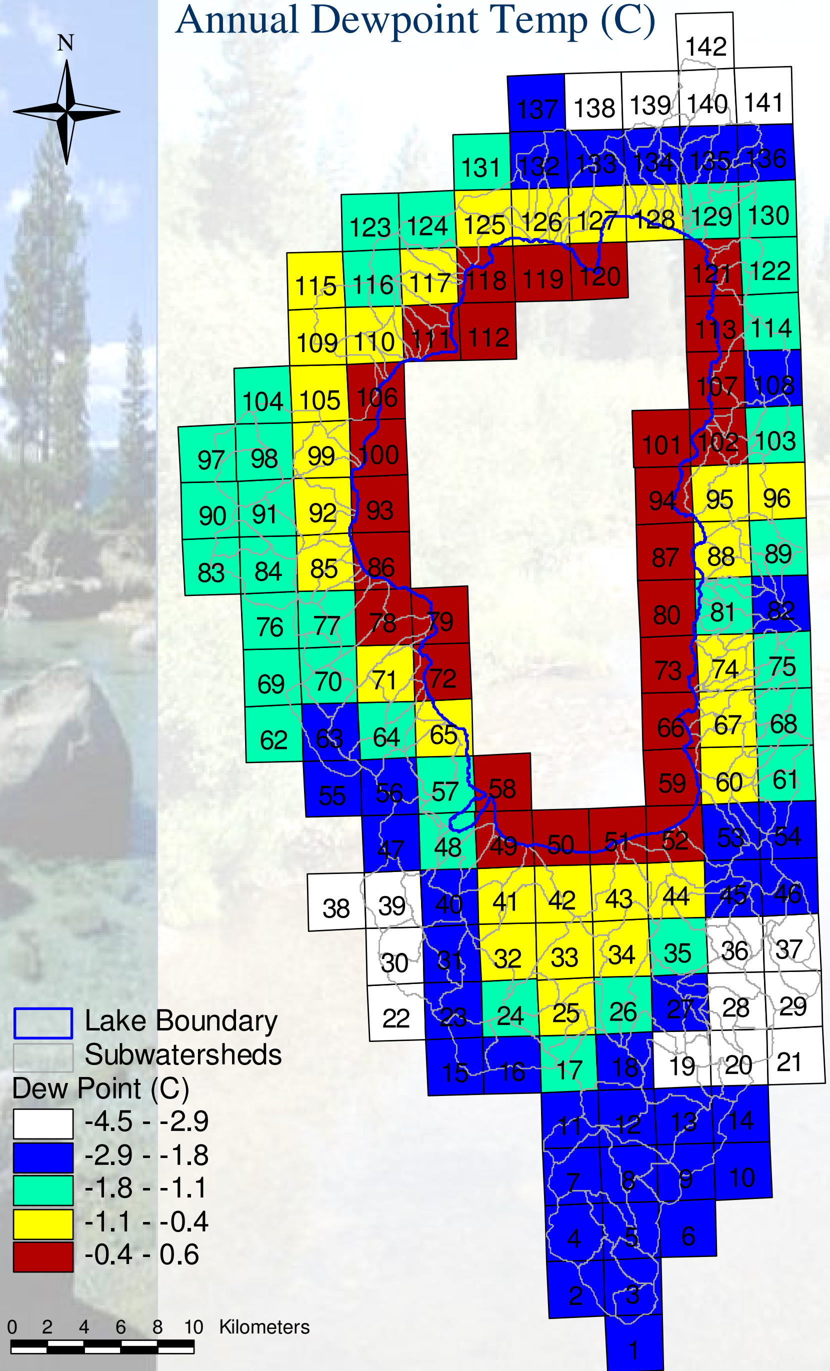
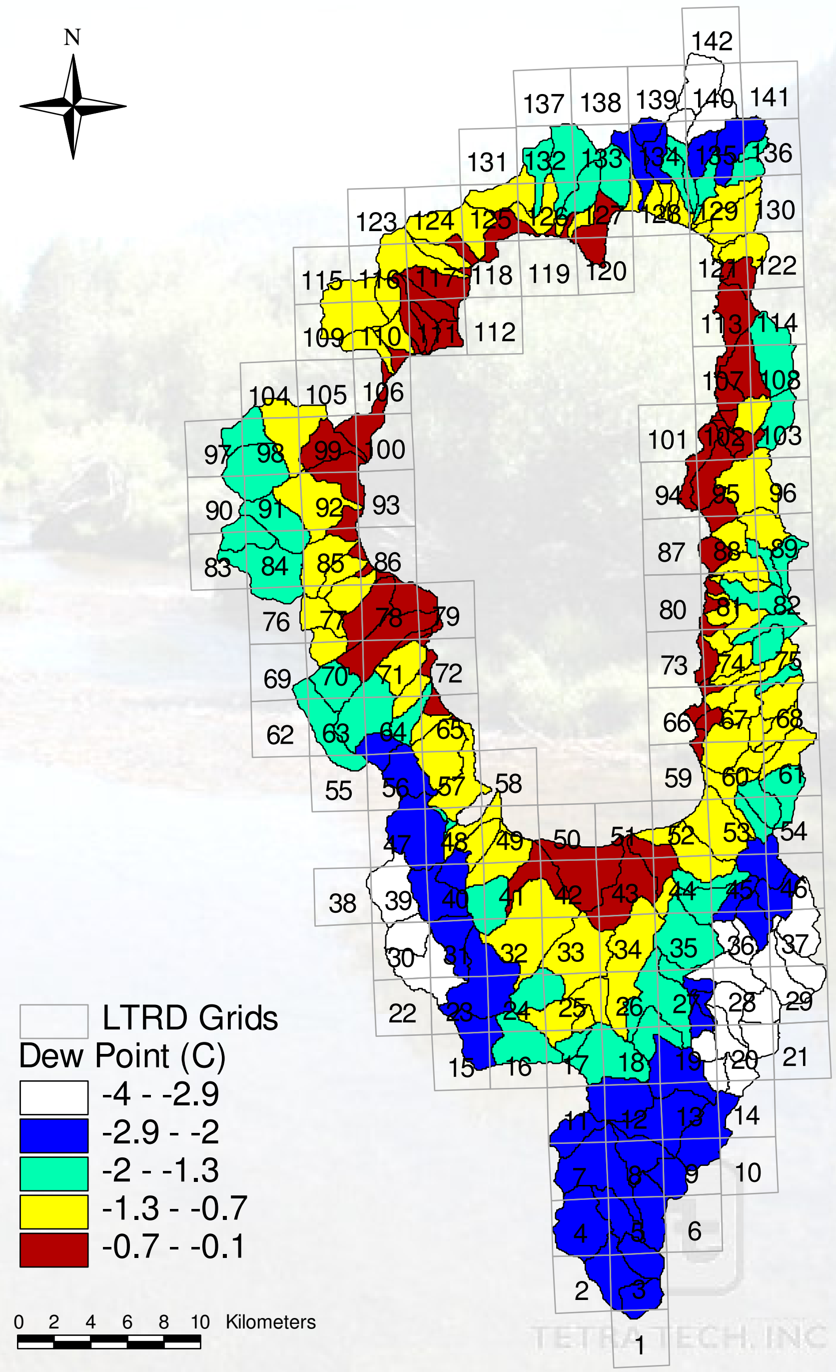
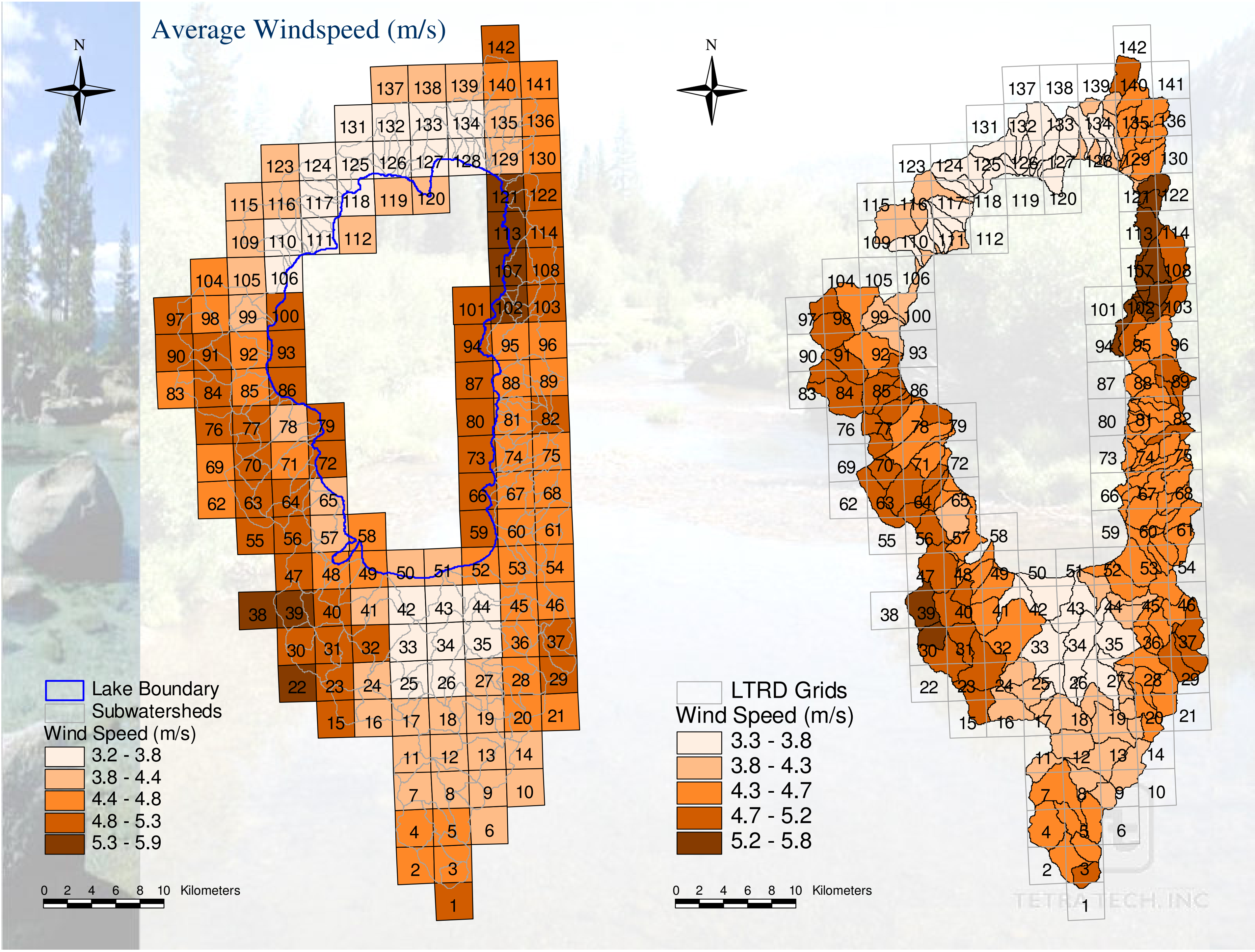
Annual Temperature (C)



Annual Dewpoint Temp (C)






Average Windspeed (m/s)
N
Lake Boundary
Subwatersheds
Wind Speed (m/s)
3.2 - 3.8
3.8 - 4.4
4.4 - 4.8
4.8 - 5.3
5.3 - 5.9
0 2 4 6 8 10 Kilometers
N
LTRD Grids
Wind Speed (m/s)
3.3 - 3.8
3.8 - 4.3
4.3 - 4.7
4.7 - 5.2
5.2 - 5.8
0 2 4 6 8 10 Kilometers
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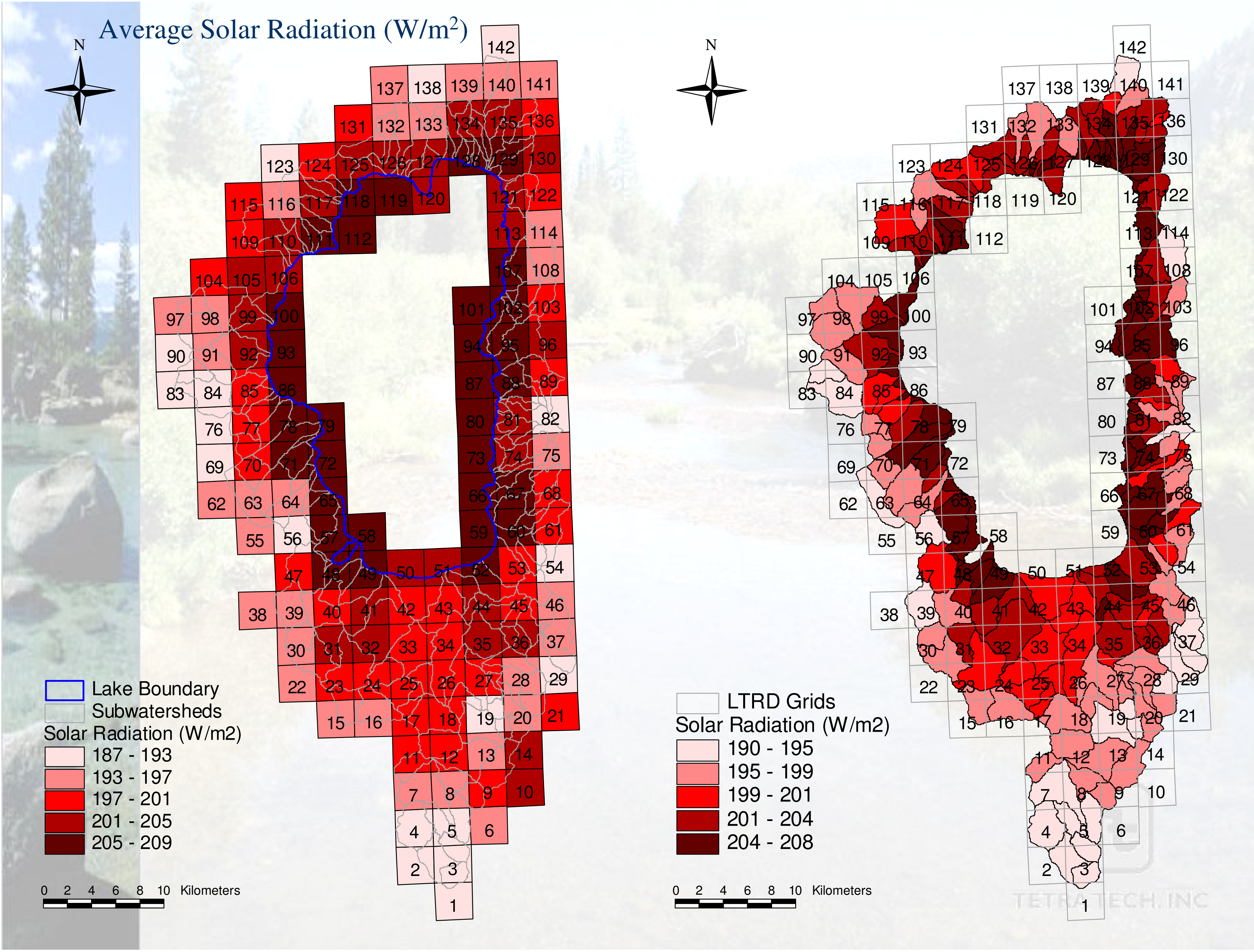
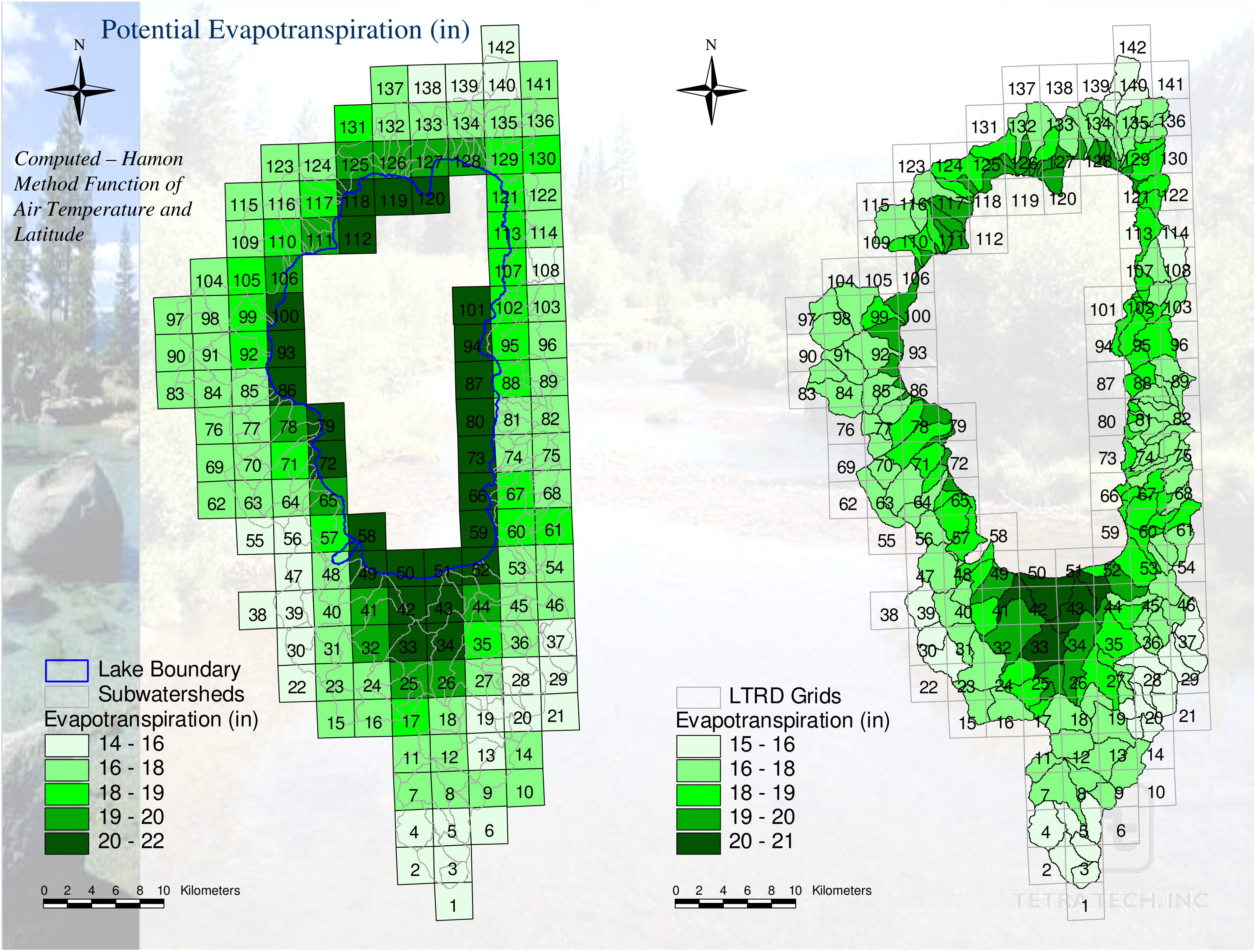

Average Solar Radiation (W/m²)
N
Lake Boundary
Subwatersheds
Solar Radiation (W/m2)
187 - 193
193 - 197
197 - 201
201 - 205
205 - 209
0 2 4 6 8 10 Kilometers
N
LTRD Grids
Solar Radiation (W/m2)
190 - 195
195 - 199
199 - 201
201 - 204
204 - 208
0 2 4 6 8 10 Kilometers
TETRA TECH, INC


Potential Evapotranspiration (in)
N
Computed – Hamon Method Function of Air Temperature and Latitude
Lake Boundary
Subwatersheds
Evapotranspiration (in)
14 - 16
16 - 18
18 - 19
19 - 20
20 - 22
0 2 4 6 8 10 Kilometers
N
LTRD Grids
Evapotranspiration (in)
15 - 16
16 - 18
18 - 19
19 - 20
20 - 21
0 2 4 6 8 10 Kilometers
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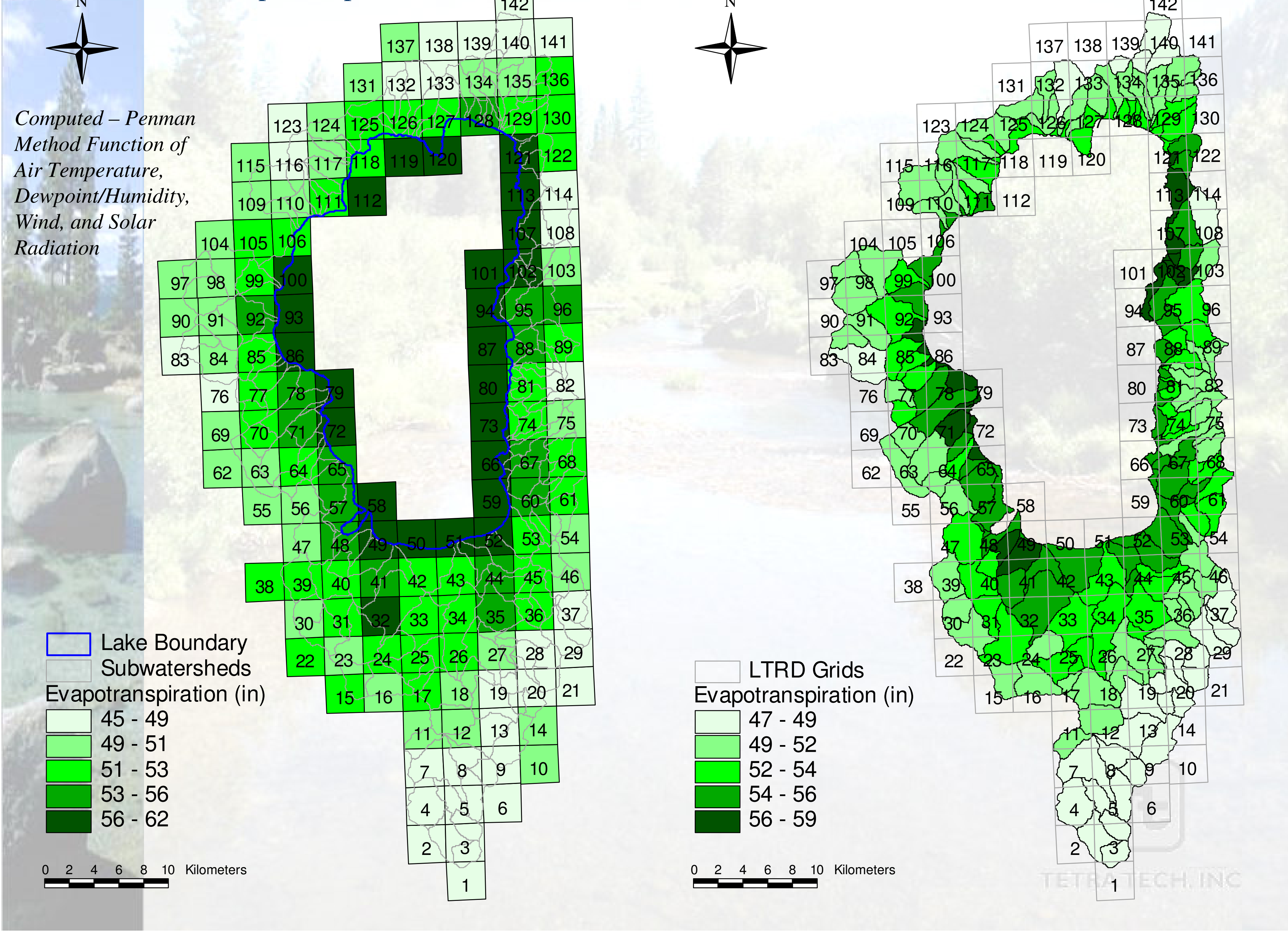
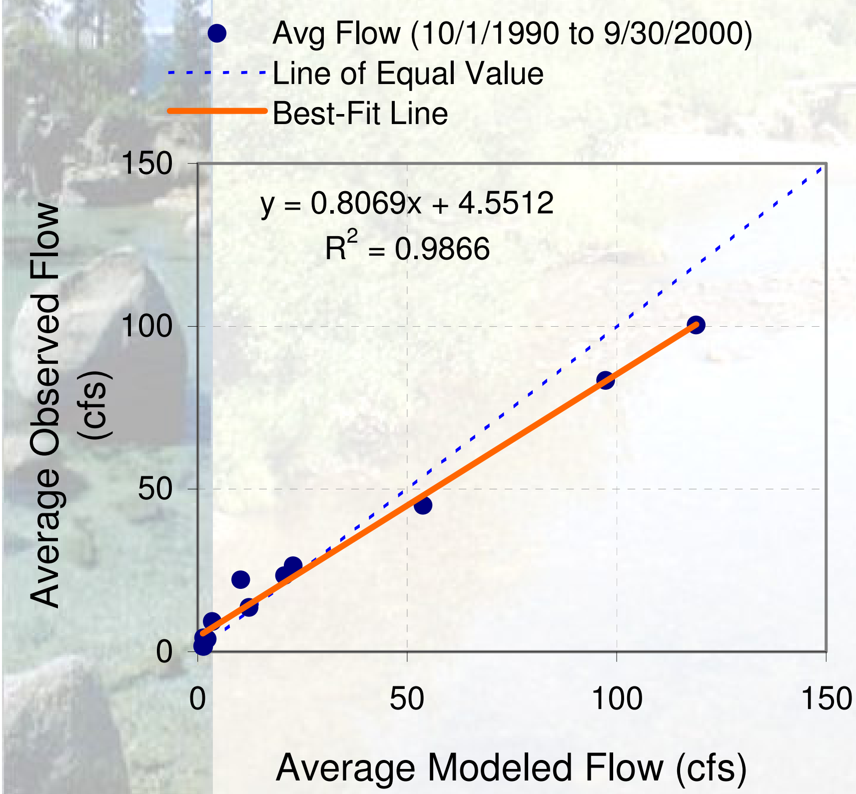
Potential Evapotranspiration (in)

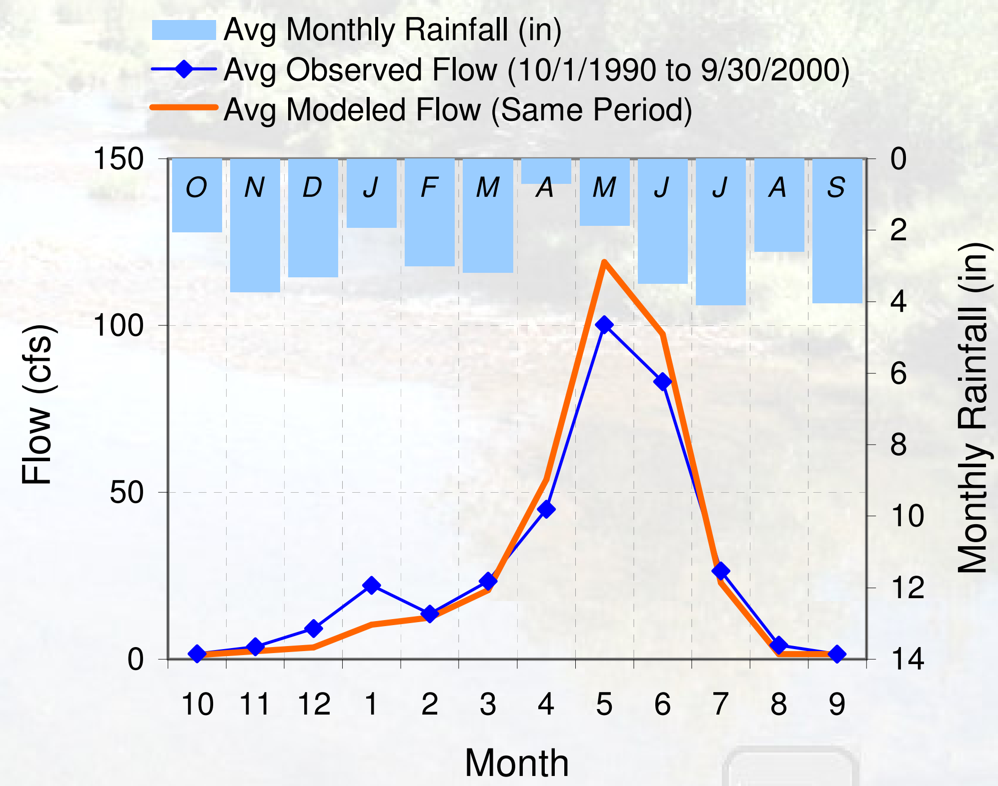


MM5 Meteorology in LSPC

- Precipitation
  - Good predictor of long-term totals and spatial variability
  - Underestimates water volume for snow events
- Temperature & Dewpoint
  - Excellent predictor for long-term and spatial variability
  - Sometimes over-predicts by a few degrees and misses snowfall events (snowfall simulation requires *precise* temperature data)
- Windspeed & Solar Radiation
  - Reasonable magnitude, though not enough observed data to validate

Ward Creek (10-Year Composite)





Model Test for Seasonality

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Model Testing, Calibration, Validation

Modeling Sequence

- Hydrology
  - Process and parameters
  - Snow simulation
  - Stream hydraulics
- Sediment
  - Erosion & sediment yield
  - Instream settling and resuspension
- Water Quality
  - Dissolved nutrients
  - Sediment associated nutrients

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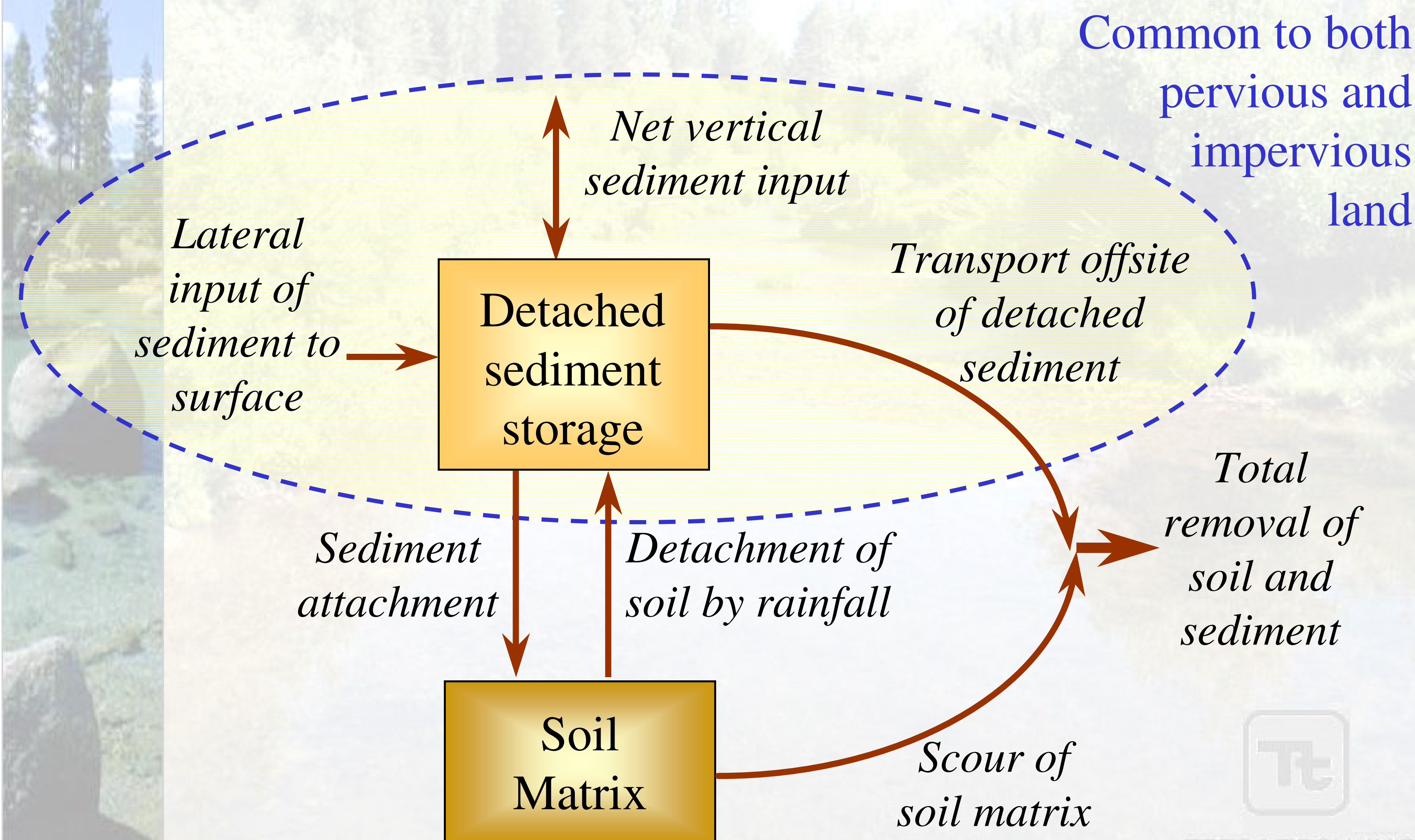
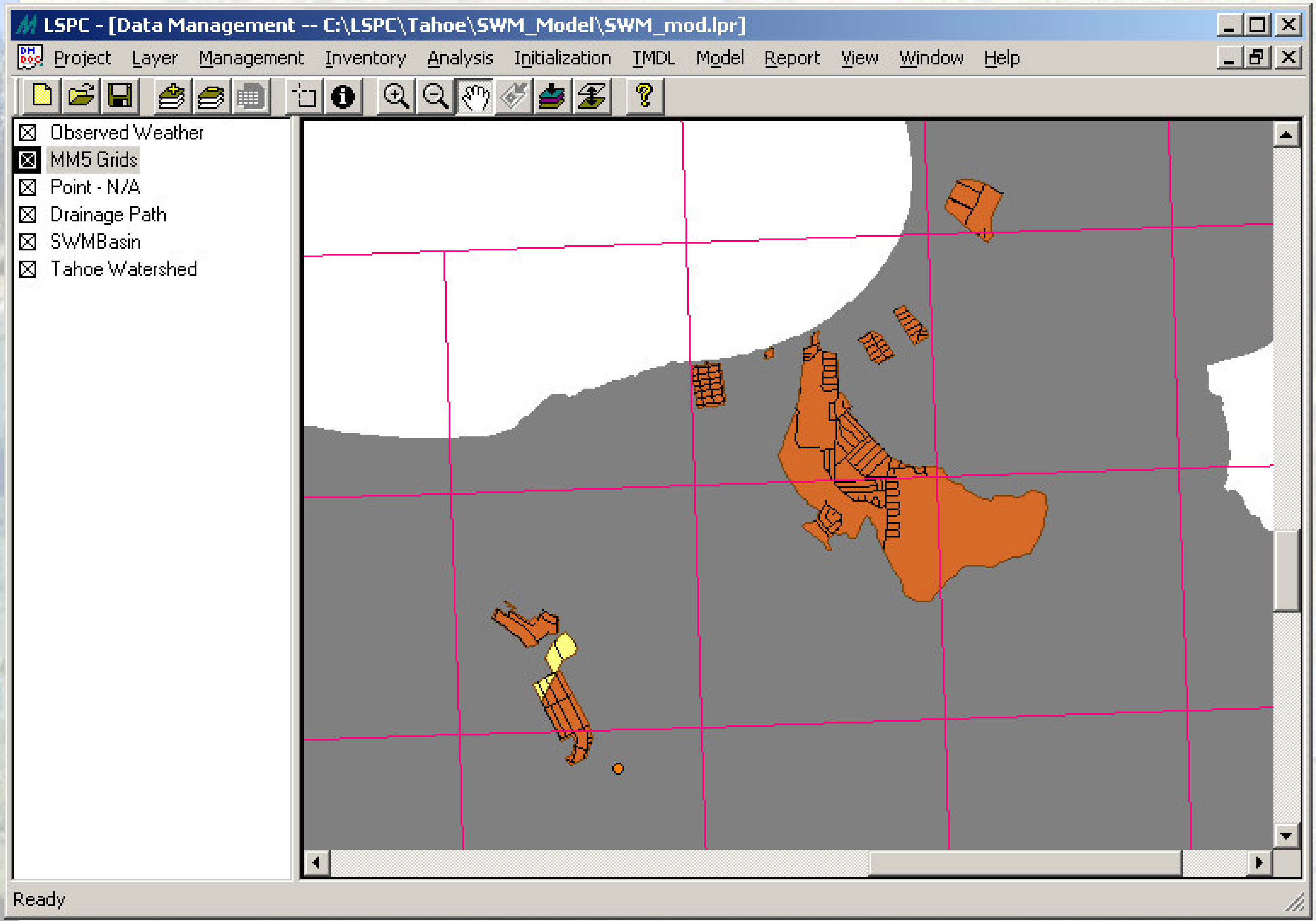
Sediment Processes



Sediment Budget and Transport

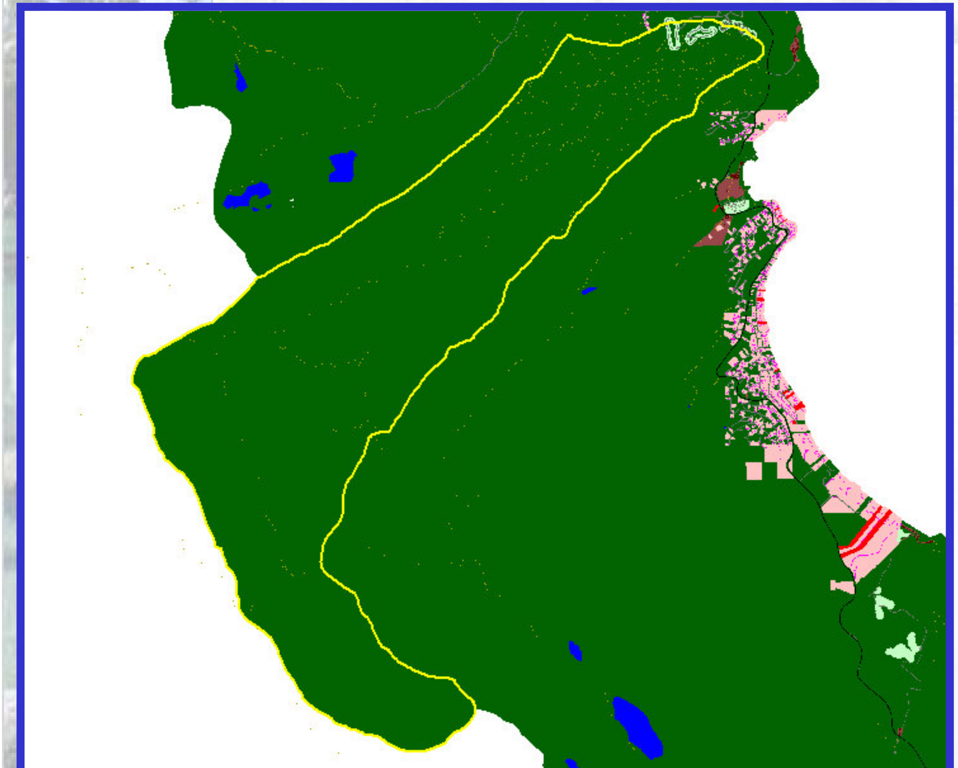
- Land Processes
  - Production and removal of sediment from land
    - Washoff of solids from impervious surfaces
    - Washoff of loose sediment from pervious surfaces
    - Scouring of soil matrix (pervious land)
- Stream Channel Processes
  - Transport, deposition and scour of sediment in the stream channels

TRG Stormwater Monitoring Dataset



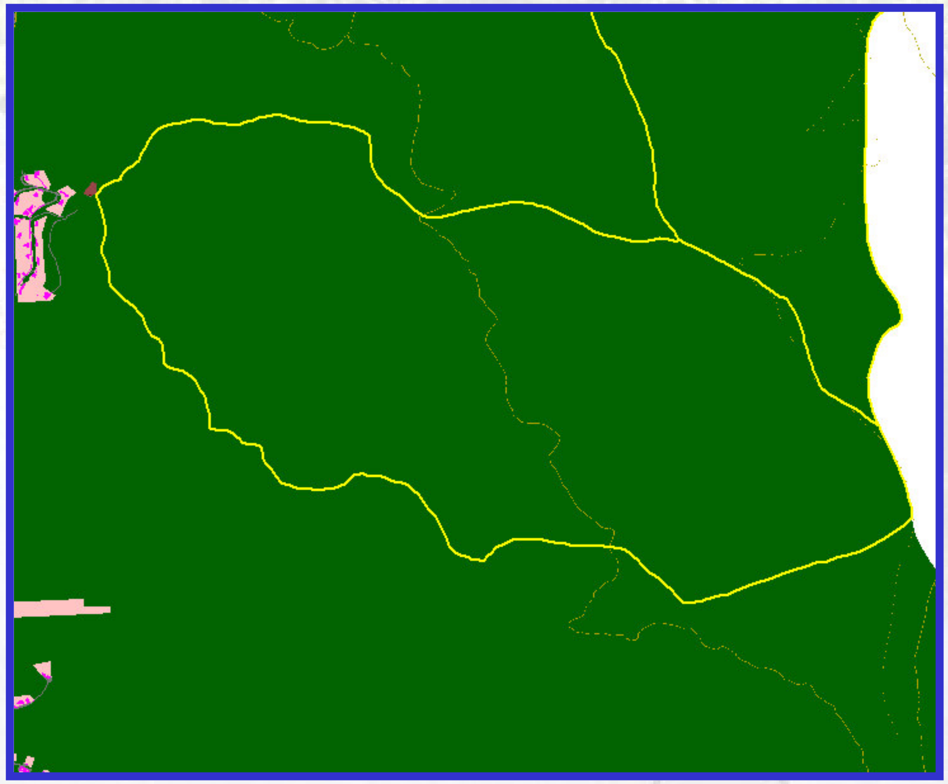
LTIMP Reference Sites

General Creek



Unimpacted vegetated land, some trails and campgrounds

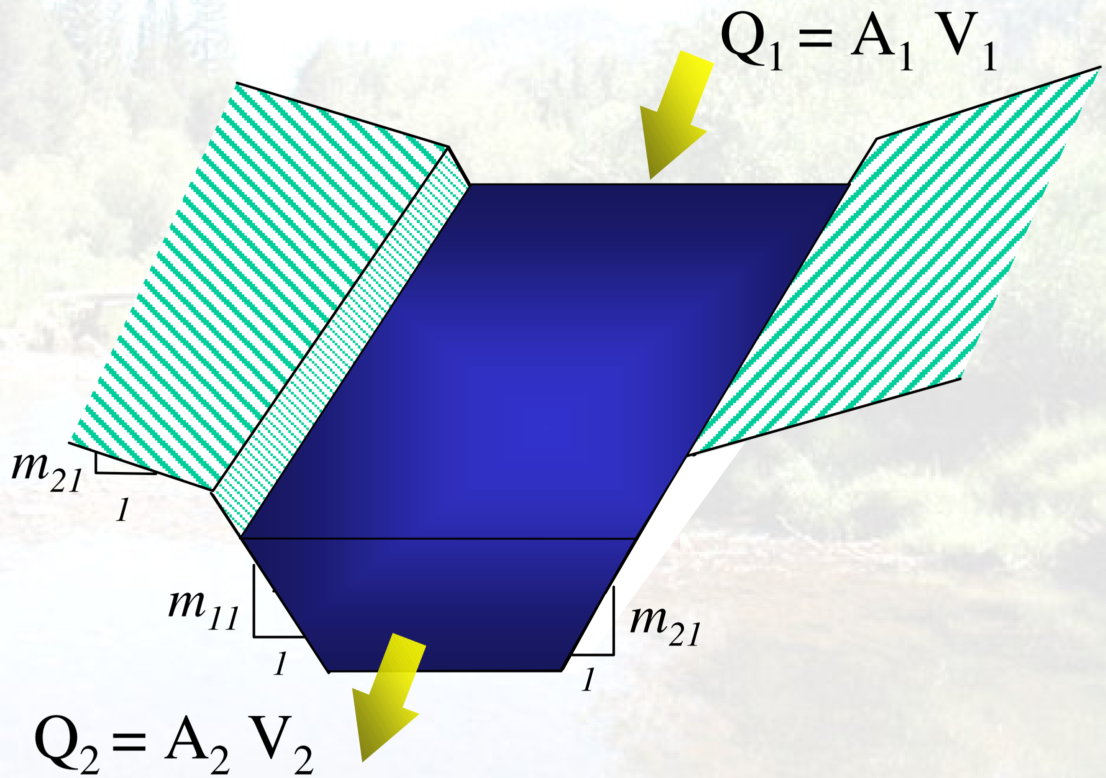
Logan House Creek



Unimpacted vegetated land, some trails

Function Table

- Area (surface) = Top width * length
- Volume = Cross sectional area * length
- Outflow can be withdrawal, spillway discharge or outflow at the downstream end of a reach
- Stream Flow = Cross sectional area * velocity

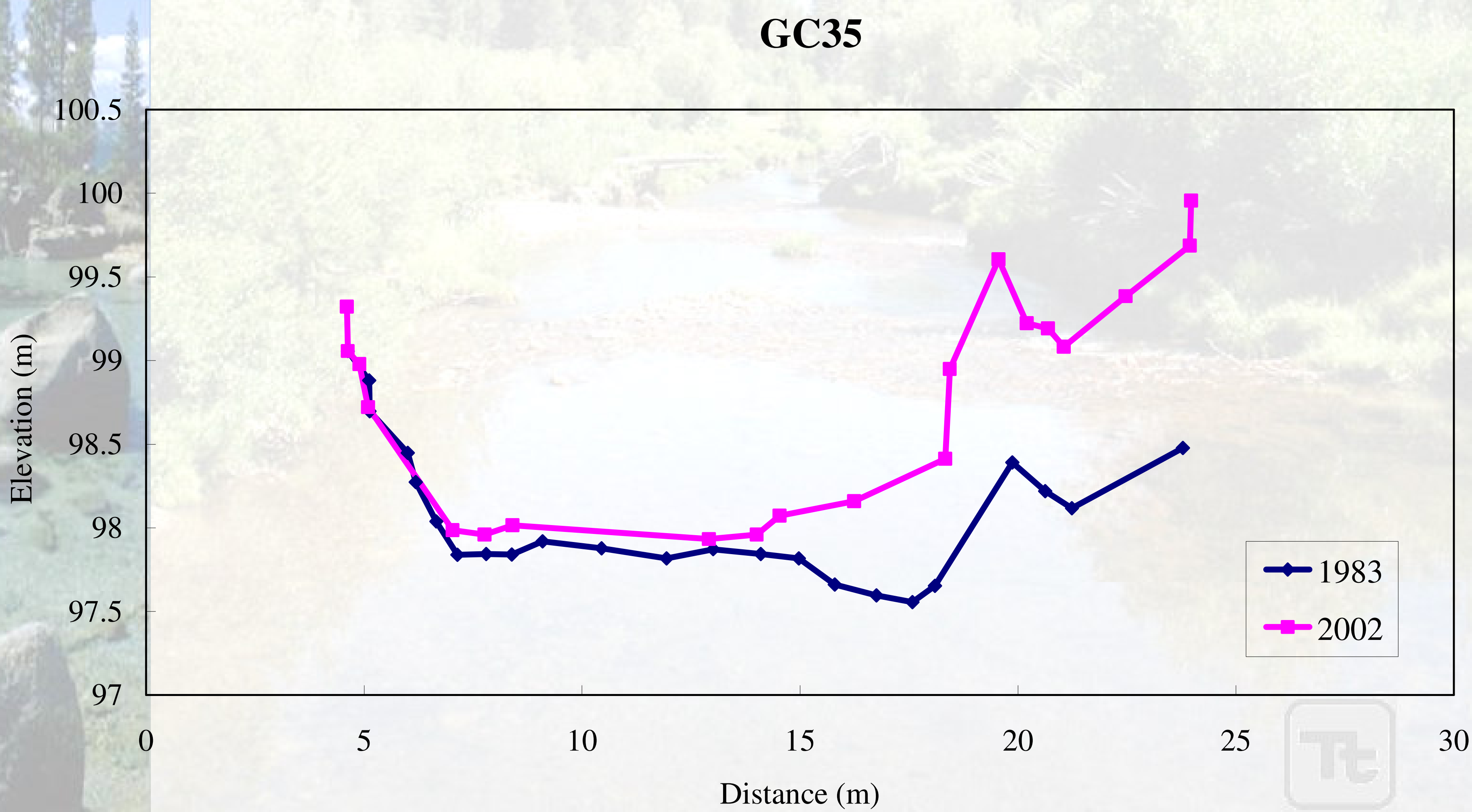


Depth	Area	Volume	Outflow
0.0	0.0	0.0	0.0
0.08	10.81	0.86	2.12
0.80	11.36	8.84	98.09
1.20	11.68	13.45	192.51

F-tables for Ungaged Streams

- General Creek and Logan House Creek were identified as reference streams with least stream channel erosion impact (Andrew Simon, 2004).
- Relationship between upstream drainage area and mean channel depth and width at downstream point established.
- Relationship factors, together with respective upstream drainage area, were applied to other streams to derive representative cross-sections and F-tables.

Sample General Creek Cross-Section*



* Provided by Andrew Simon

Cross-section Methodology

- Average bank-full dimensions:
  - Depth: 1 m (3.2 ft)
  - Width: 8 m (26.2 ft)
- Derived Relationship:
  - Depth = a_1 (Upstream Area) ^{b1}
  - Width = a_2 (Upstream Area) ^{b2}

Typical Factors:

	Exponent	Coefficient
Depth	0.28	1.50
Width	0.40	14.49

Best-Fit Factors:

	Exponent	Coefficient
Depth	0.464	1.559
Width	0.395	14.490

Summary and Next Steps

- Continue sediment & nutrient calibration
  - LTIMP sediment & nutrient
  - Heyvaert & Thomas: SWM sediment & nutrient
  - Bob Coats: Landuse-Water Quality Relationships
- Integrate parallel research
  - Andrew Simon: Stream channel erosion (CONCEPTS)
  - Eric Strecker: BMP evaluations
  - Chad Praul & Tom Gavigan: BMP inventory

TMDL Analysis Considerations

Loading Capacity for Lake to meet target(s)

Selected Load Allocation

TMDL

Potential Load Reductions under Various Scenarios

Future Planning Support

Implementation

Potential Load Reduction based on Management Opportunities.

Thank You

Questions?