Identifying Stressors, Sources, and Needed Pollutant Load Reductions

Stephen Carter, PE

Pollutant Sources and Impacts

Pollutants
- Nutrients
- Sediment
- Pathogens
- Temp
- Salt
- Metals
- Pesticides
- Organics

Point Sources
- WWTP
- Urban runoff
- Industry

Nonpoint Sources
- Forest/natural runoff
- Streambank erosion
- Reduced shading
- Atmospheric deposition
- Abandoned mines
- Construction
- Agriculture
  - Cropland
  - CAFOs

Impacts
- Aquatic life
- Habitat
- Fishing & swimming
- Human health
- Nuisance odors
- Algal blooms

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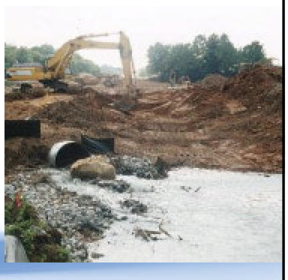

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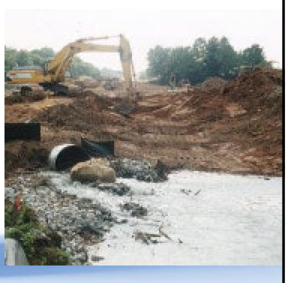

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The Technical Approach

Establish a link between watershed sources and receiving water responses to represent cause-effect relationships

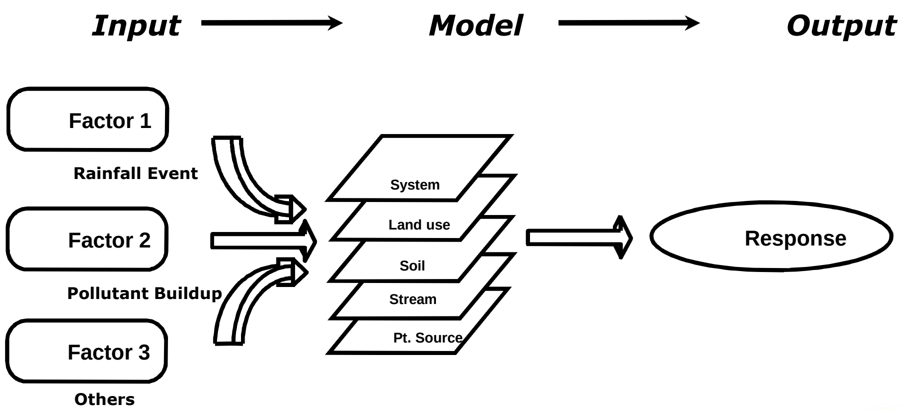
Keep in mind…it's not the approach itself, but how you put it all together that achieves the objectives.

What is a Model?

- A theoretical construct,
- together with assignment of numerical values to model parameters,
- incorporating some prior observations drawn from field and laboratory data,
- and relating external inputs or forcing functions to system variable responses

* Definition from: Thomann and Mueller, 1987

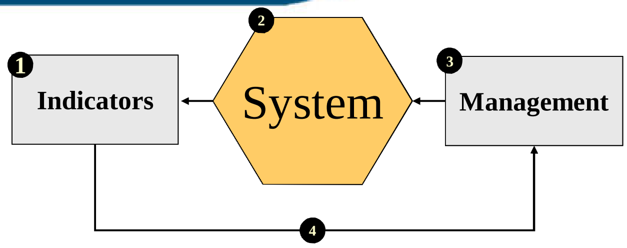
What Constitutes a Model?



Common Questions Regarding the Use of Models

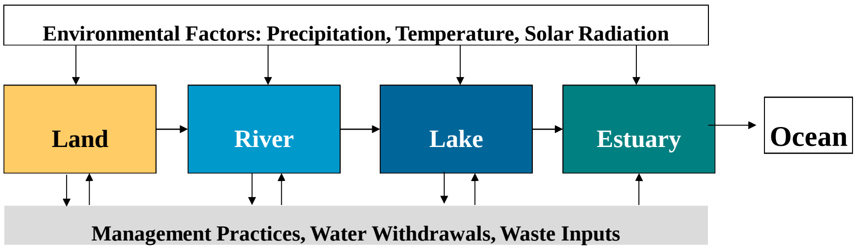
- Is a model necessary?
- Which model should I use?
- What are the trade-offs between using simple and complex models?
- Which features of the system should the modeling efforts focus on?
- How can modeling results be integrated into the overall watershed planning framework?
- How can complex model results be effectively transmitted to the public?
- What else, besides models, can I use?

Role of Modeling in Decision Making



- Alternatives evaluation/design support
- TMDLs
- Watershed management
- Permits
- Hazardous waste remediation
- Harbors
- Stormwater
- New development

Modeling in Decision Making



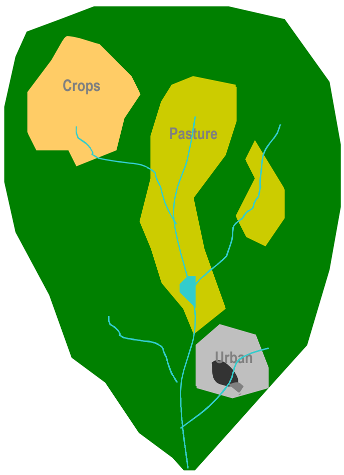
- Types of analysis
  - Waterbody Type
  - Inputs

Model Categories

- Landscape/Loading models
  - Runoff of water and dissolved materials on and through the land surface
  - Erosion of sediment and associated constituents from the land surface
- Receiving water models
  - Flow of water through streams and into lakes and estuaries
  - Transport, deposition, and transformation in receiving waters
- Watershed models
  - Combination of landscape and receiving water models

Model Categories

- Landscape/ Loading models
- Receiving water models
- Watershed models



Model Basis

- Empirical Formulations
  - mathematical relationship based on observed data rather than theoretical relationships
- Deterministic Models
  - mathematical models designed to produce system responses or outputs to temporal and spatial inputs

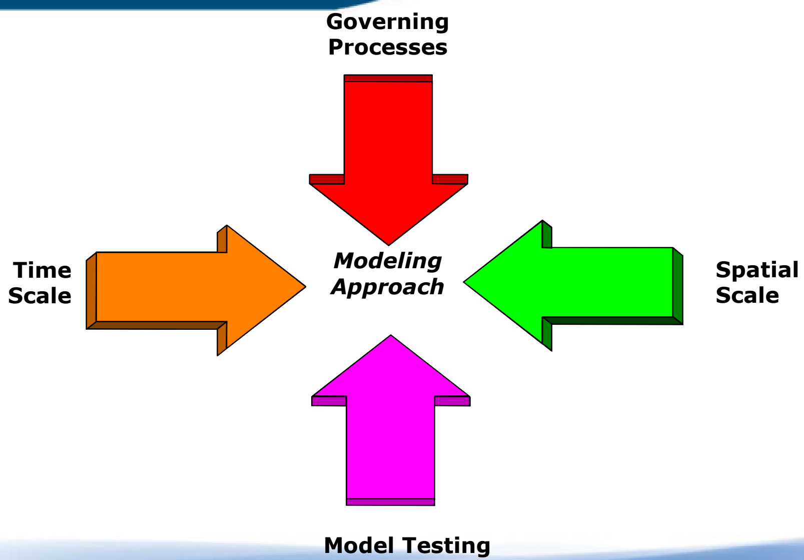
Level of Complexity – Landscape Models

- Export Coefficients
  - average annual unit area loads based on landuse type
- Loading Functions
  - simplified erosion and water quality loading combined with basic representation of hydrologic processes
- Dynamic Models
  - mechanistic (process-based), time-variable representation of watershed processes, including hydrology, erosion, and water quality

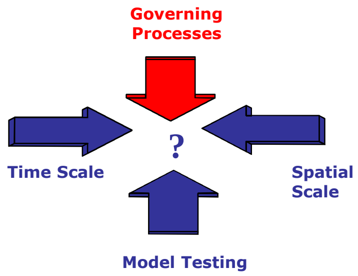
Level of Complexity - Receiving Water Models

- Steady-state Models
  - fate and transport model that uses constant values of input variables to predict constant results (under a representative condition)
- Quasi-dynamic Models
  - similar to steady-state formulations, but may include diurnal representation
- Dynamic Models
  - mathematical formulation describing the physical behavior of a waterbody and its temporal variability
    - Hydrodynamic - circulation, transport, deposition
    - Water Quality - nutrients, toxics, pathogens, etc.

The Modeling Dilemma



Governing Processes



Input — **Algorithms** — **Output**

Time series
Meteorology
Streamflow
WQ sampling

Spatial/Landscape
Soils
Topography
Land cover
Pollutant characteristics

Receiving Waters
Physical data
Kinetics data
Fate & transport

Landscape/ Watershed Models
Hydrology
Buildup
Washoff
Erosion
Overland transport
Fate & transport

Receiving Water Models
Hydraulics
Hydrodynamics
Fate & transport
Scour & deposition
Chemical interactions

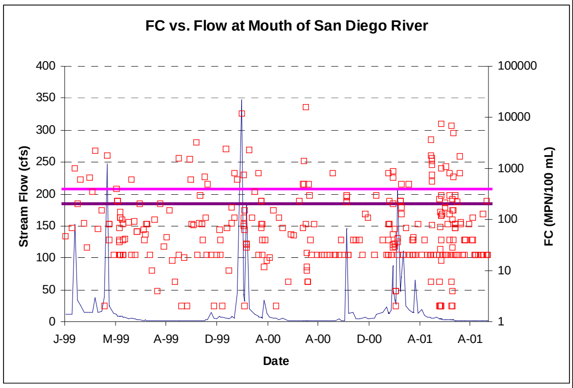
Time series
Summary statistics
% change/ Improvement
Violations
Classification maps
Impact maps

Governing Processes
How to reduce the level of effort?

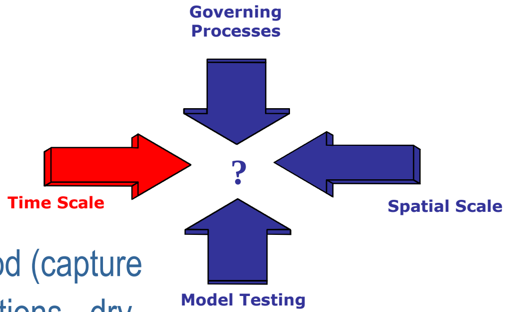
- Structured selection should lead to the simplest model
- Simplification of processes
  - Preserve the sensitivity of the model
  - Preserve the response of cause-effect relationships
- Level of calibration
  - Gross estimates
  - Comparative analyses
  - Design

Governing Processes
Wet vs. Dry Conditions

- Wet conditions
  - Episodic
  - Dynamic
- Dry conditions
  - Sustained flows over dry periods (e.g., urban runoff, POTW effluent)
  - Requires modeling assumption (e.g., steady state)



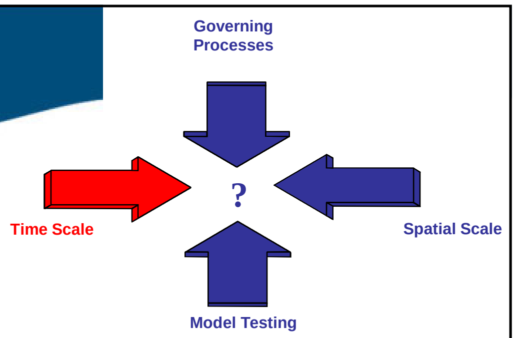
Time Scale
Watershed Model



Landscape/Watershed

- Representative time period (capture range of hydrologic conditions - dry and wet years, critical events)
- Representative time step
  - Long-term seasonal and annual averages
  - Relative comparison analysis
  - Assimilative capacity and standards

Time Scale
Receiving Water Model



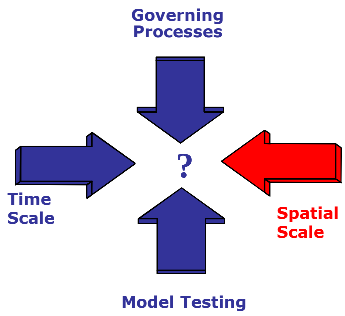
Receiving Water

- Representative time period (capture range of hydrodynamic conditions – dry/wet years, critical events)
- Representative time step
  - Model processes (eutrophication, sediment diagenesis)
  - Relative comparison analysis
  - Assimilative capacity and standards

Spatial Scale Considerations

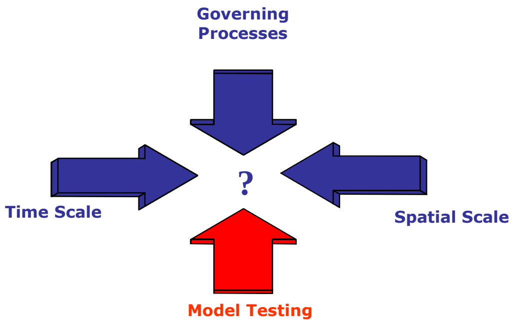
Scale

- Regional (R)
- Watershed (WS)
- Sub-watershed (SWS)
- Small area mgmt (SAM)
- Stream segment/ receiving water (RW)



Basin-wide loading estimates	R/WS/SWS
"Program" development and implementation	WS/SWS/SAM
Pollution control design	SAM
Analysis of receiving water quality impairment	RW, SAM
Credits for BMP implementation	SAM, RW

Model Testing

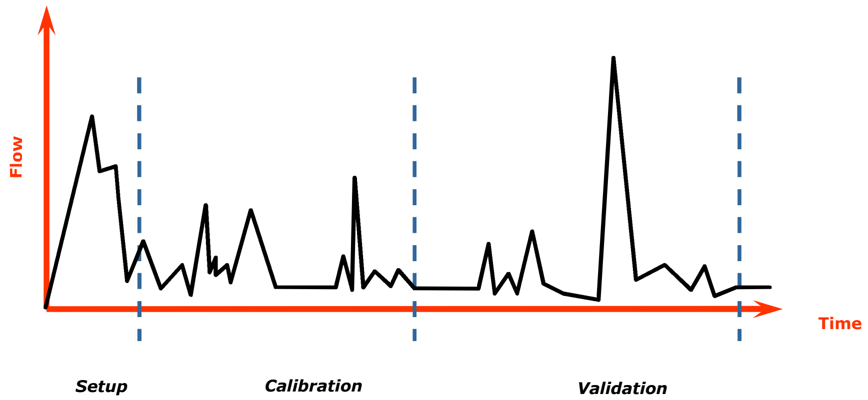


1. CALIBRATION: model parameter adjustment or fine-tuning to reproduce observation data
2. VALIDATION: testing of calibration adequacy through application of parameters to an independent data set (without further adjustment)
3. VERIFICATION: examination of the numerical technique in the computer code to ascertain that it truly represents the conceptual model and that there are no inherent numerical problems

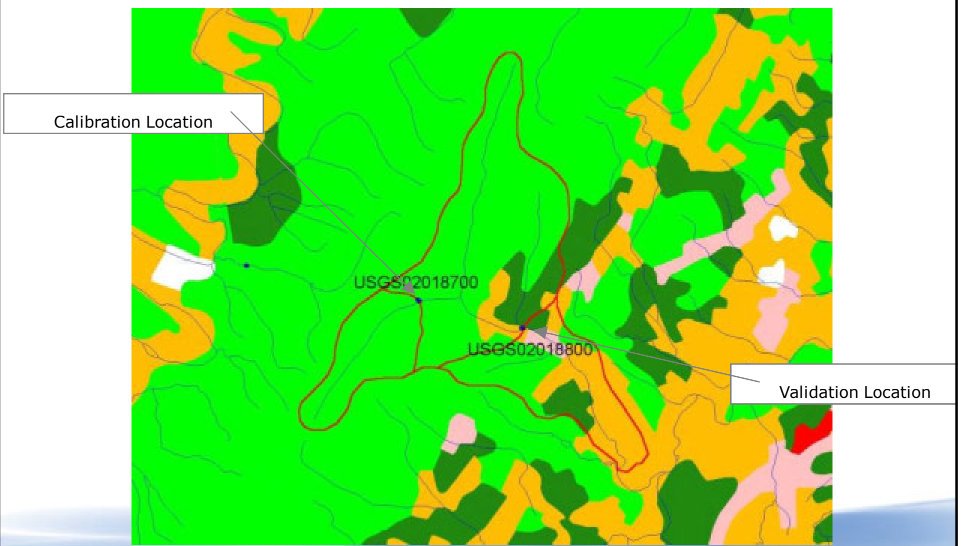
Location and Time Period Selection

- Calibration
  - monitoring data availability
  - proximity to area of interest
  - range of hydrologic and water quality-associated conditions
- Validation
  - separate time period
  - different location
  - monitoring data availability

Example: Calibration/Validation Time Period Selection



Example: Calibration/Validation Location Selection - Watershed Model



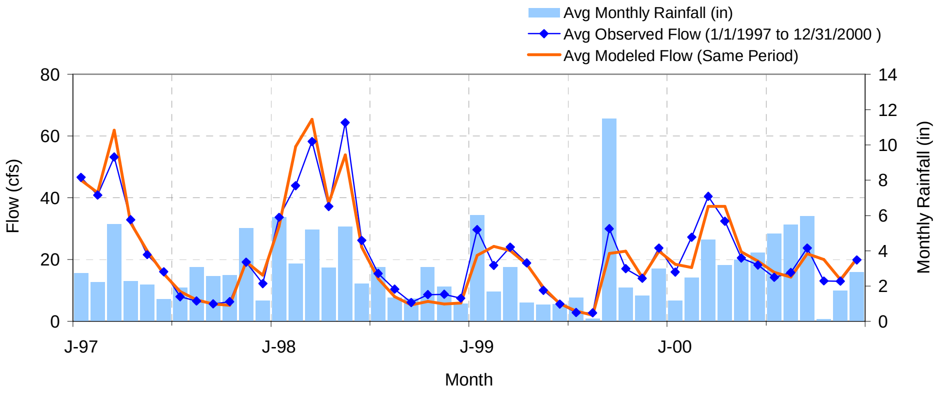
Uncertainty in Modeling Analysis

Data limitations

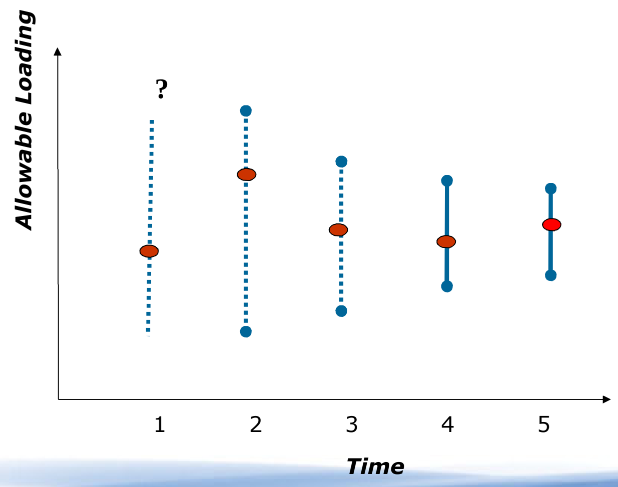
Science limitations

+ Cost & Time Constraints = Model Uncertainty

Measures of Analysis Uncertainty



Challenges in Evaluating Uncertainty



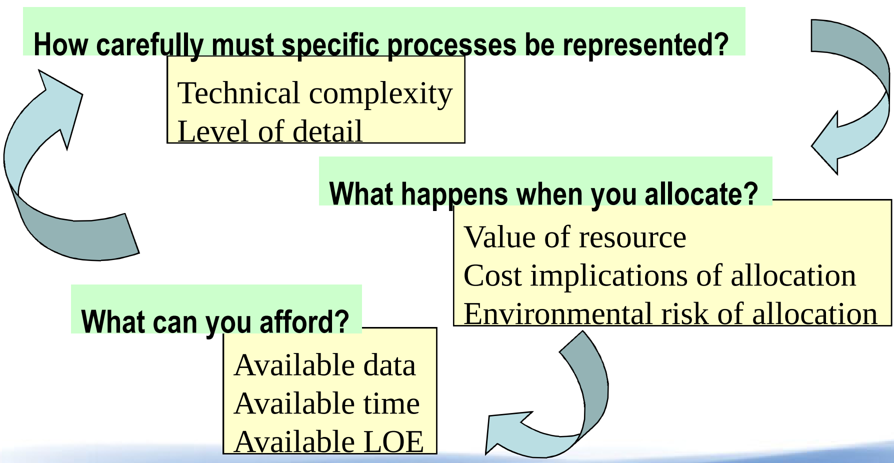
Typical Points of Contention

- ***Don't like the conclusions***
- Speed/time insufficient to comment or provide input
- Concerns over data quality/data sufficiency
- "bad" science
- Inability of agency to respond to comments
- Equity of management cost responsibilities
- Clarity of conditions for future adaptation or update

Tools for Resolution

- Early buy-in on methods
- Engaged stakeholders
- Targeted data collection
- Communication
- Proactive response to comments
- Consideration of alternative allocations
    - Consideration of cost
- Flexibility in schedule
- Clear options for update or future revision

Factors to Consider in Selecting Level of Analysis



Considerations—Pollutant/Stressor

- Eutrophication/Algal Bloom
- Nutrient enrichment
- Oxygen depletion
- Sediment diagenesis of organic matter
- Sediment transport problems
- Toxic contamination
- Pathogen contamination
- Thermal problems
- Others

Each issue requires different analytical techniques

Considerations—Waterbody Type

- Rivers and Streams
  - relatively fast flowing
  - variable residential time
  - transport processes are usually dominant
- Lakes and Reservoirs
  - slow moving water
  - deposition and accumulation processes
  - recycling processes
  - both acute and delayed responses
- Estuaries
  - reversal flows and tidal influences

Considerations—Sources

- Constant loading: A large wastewater plant
- Variable or intermittent loading: An industrial facility
- Randomly occurring loading: Rainfall driven loads - NPS, stormwater

Each source requires different modeling techniques

Considerations—Water Quality Standards

- Numeric endpoint
- Narrative criteria
- Seasonal variation
- Dependency on another constituent
- Averaging period (chronic versus acute)

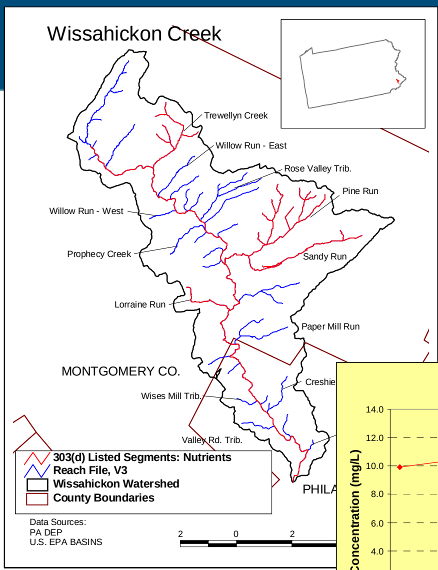
Considerations—Impairment Conditions

- Steady State condition
- Cumulative condition
- Episodic condition

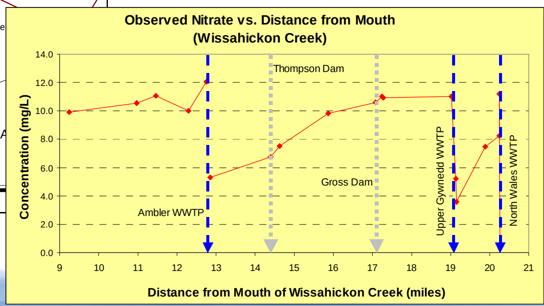
Steady State Condition

- Prolonged response
- Critical condition can be represented by constant flow rate (design flow)
- Impairment usually occurs at low flow
- Represent well most PS problems

Steady State Example



- Occurs under low flow conditions
- For example : Nutrient Impairment – Low DO

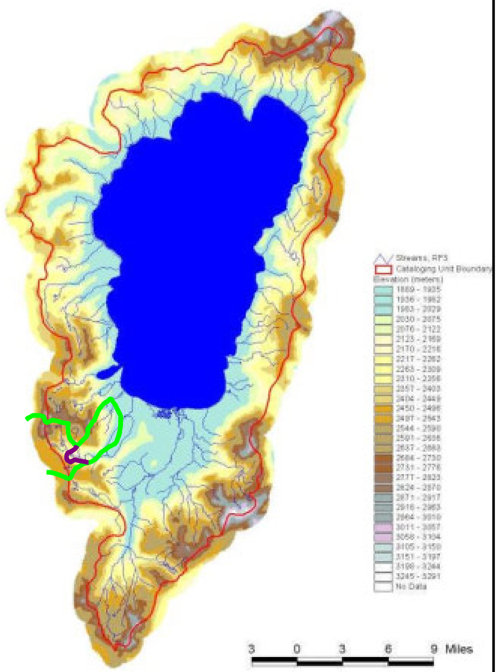


Cumulative Condition

- Impairment results under specific conditions (climatic)
- Same inflows may not create an immediate response
- Fraction of loading inflows may accumulate in the system and became a source under certain condition
- Impairment may results from long-term loading accumulation

Cumulative Example
Lake Tahoe

- Lake or Estuary
- Loadings accumulate and cause delayed effect
- All sources contribute

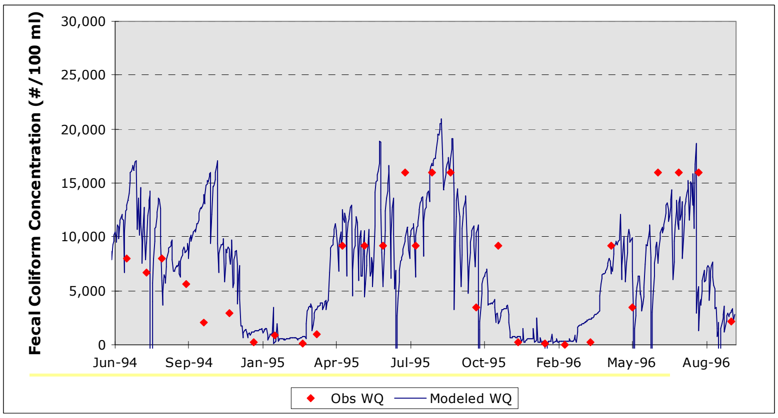


Episodic Condition

- Impairment occurrence varies rapidly with time
- Impairment may follow a random process
  - accidental release/spills/bypass
  - wet-weather and rainstorm dependent
  - Stormwater, Combined Sewer Overflows, Sanitary Sewer Overflows are also key sources
  - Atmospheric Deposition
- Nonpoint sources may be a major contributors

Wet Weather Example

Fecal Coliform (Muddy Creek)

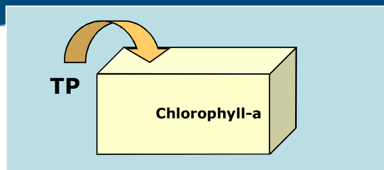


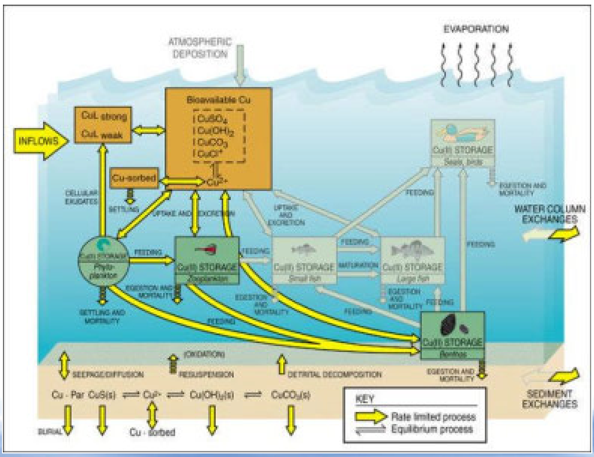
Waterbody Response Categories

	Steady State	Cumulative	Episodic
River/ Stream	I	II	III
Lakes/ Reservoir	IV		V
Estuaries	VI		

Conceptual Models…

Simplified





Detailed

Model/Methods Selection Inputs

- WQ Targets
- Conceptual Model
- Data Inventory
- Management Options

DP — Decision Point

Review and Evaluation

- Spatial/Temporal Scales of Targets
- Available data (inputs/calibration)
- Physical/Chemical/Biological Processes
- Implementation Recommendations

Available Models/Resource Needs Assessment

- Process/Constituent Representation
- Spatial/Temporal Capabilities
- Model Resource Needs
- MSD Computational Resources/Preferences

Model Selection Criteria Defined (DP)

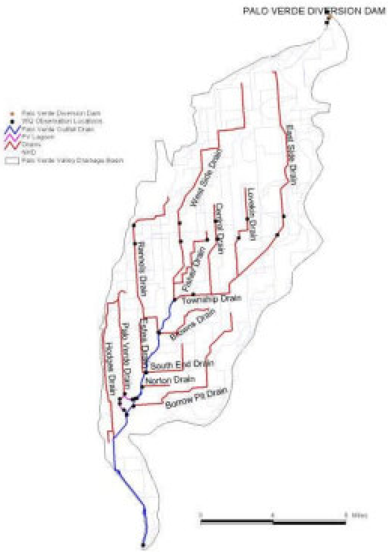
Preferred Models Selected (DP)

Model Resource Needs (DP)

Model Application and Configuration Plan

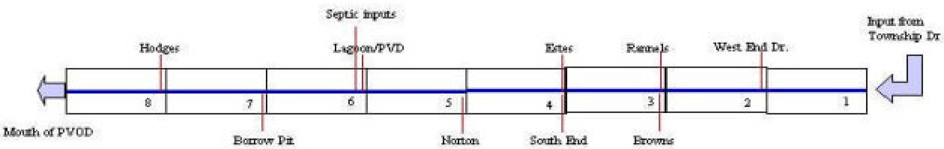
Palo Verde Outfall Drain, CA Bacteria TMDL

- Agricultural irrigation supply canal system
- Flow controlled by a Colorado River diversion
- Minimal flow and bacteria monitoring data
- Arid region – dry flow considered critical
- Range of nonpoint and point sources



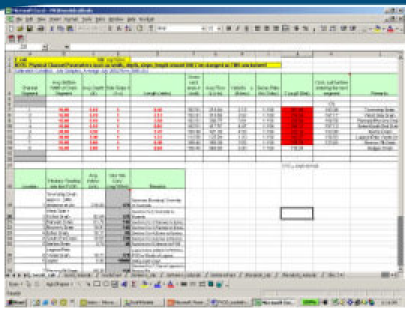
Palo Verde Outfall Drain Modeling Approach

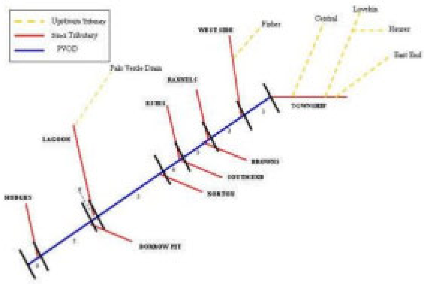
- Performed detailed source analysis and identified septic systems and wildlife as major contributors
- Developed a mass-balance spreadsheet model
  - Represented main stem with tributary inputs
  - Series of plug-flow reactors
  - Used channel geometry, flow estimates, and bacteria observations
  - Predicted the change in bacteria concentration for E.coli, fecal coliform bacteria, and enterococcus throughout the main-stem



Palo Verde Outfall Drain Model

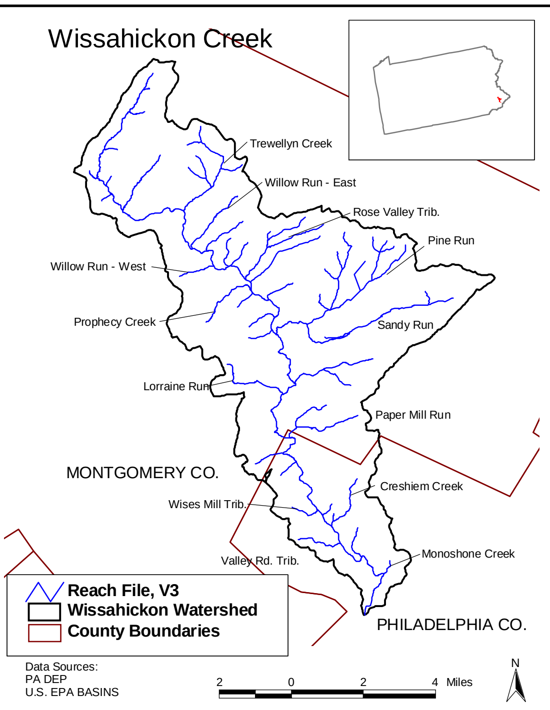
- Completed model and TMDL development in less than 4 months
- Provides a flexible basis for the Regional Board to evaluate bacteria source-response scenarios





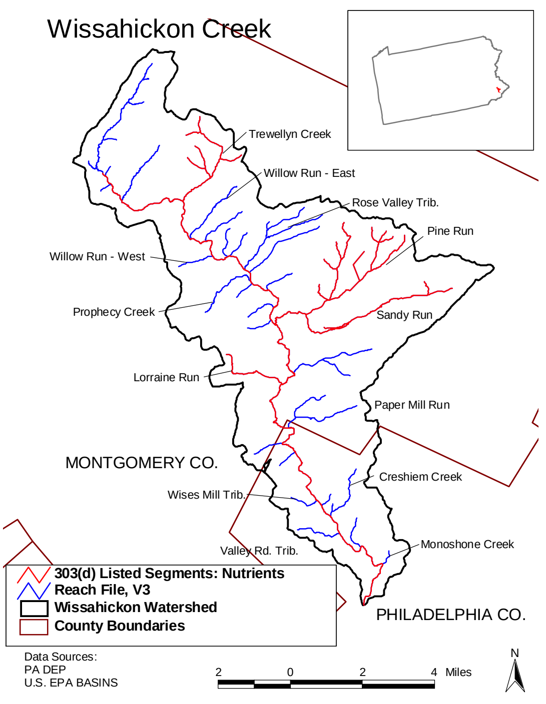
Wissahickon Creek Watershed

- Drains approximately 64 sq. miles (41,000 acres)
- Approximately 24.1 miles long
- Dominant land uses include industrial, residential, agricultural, undeveloped woodlots, and recreational
- Impaired due to sediment and nutrients



Nutrient TMDL Objectives

- Reduce reoccurrence of DO violations
- Reduce nuisance algal growth (periphyton)



Nutrient TMDL
Analytical Framework

- Steady state model for simulation of critical conditions (low flow)
  - EFDC hydrodynamic model
  - Modified version of WASP to simulate periphyton growth processes
- Processes linking nutrients and DO
  - Periphyton growth processes
  - Considered additional impacts on DO due to SOD
- Nonpoint sources on a case-by-case basis (e.g., golf courses, sediments behind dams)
- Focus attention on point sources

Nutrient TMDL
Model Development

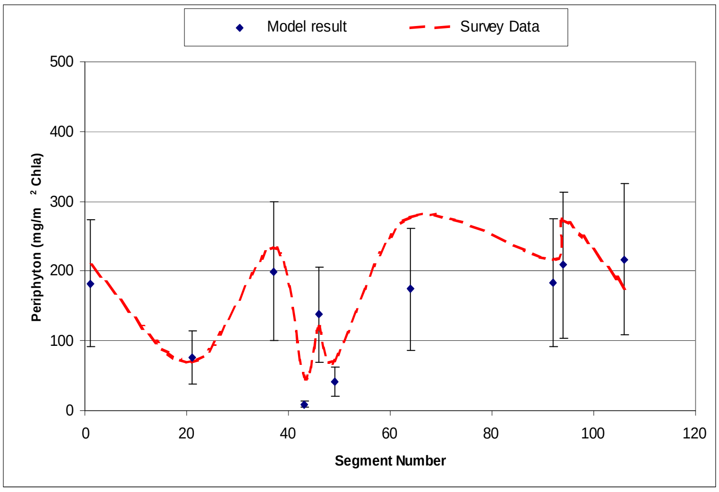
Model Calibration

- Hydrodynamic model (EFDC) calibrated to “time-of-travel” study
- Water quality model (WASP) calibrated to instream water quality data and periphyton data

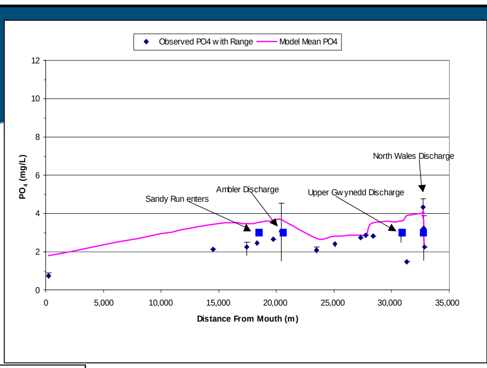
Model Configuration of Critical Conditions

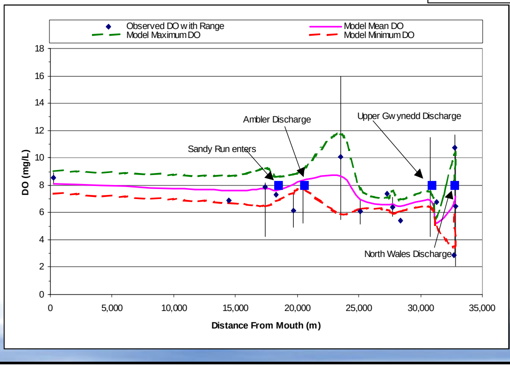
- Modeling system configured to critical conditions
  - 7Q10 background flows
  - Discharge design flows
- Target based on instream DO criteria for Trout Stocking and Warm Water Fishes
- WLAs developed for NH3-N, NO3+NO2-N, ortho PO4-P, and CBOD5

Nutrient TMDL - Calibration to Periphyton Biomass



Nutrient TMDL Calibration





Nutrient TMDL - Load Reductions

- WLAs reported for two effluent DO scenarios
- Reductions relaxed with increase in DO

Major Dischargers' Effluent DO at 6.0 mg/L

		TMDL Percent Reduction			
Name	NPDES	CBOD5	NH3-N	NO3+NO2-N	Ortho PO4
North Wales Boro	PA0022586	90.0	88.0	20.0	90.0
Upper Gwynedd Township	PA0023256	89.0	80.0	15.1	88.0
Ambler Boro	PA0026603	26.0	35.3	0.0	58.3
Abington Township	PA0026867	88.0	70.0	34.0	77.0
Upper Dublin Township	PA0029441	75.0	70.0	10.1	80.0

A - Calculated from NPDES permit limit
B - Calculated from average of summer 2002 monitoring

Major Dischargers' Effluent DO at 7.0 mg/L

		TMDL Percent Reduction			
Name	NPDES	CBOD5	NH3-N	NO3+NO2-N	Ortho PO4
North Wales Boro	PA0022586	60.0	58.0	10.0	60.0
Upper Gwynedd Township	PA0023256	72.0	65.0	15.1	70.0
Ambler Boro	PA0026603	14.0	10.0	0.0	58.3
Abington Township	PA0026867	71.0	65.0	10.0	70.0
Upper Dublin Township	PA0029441	57.9	40.0	10.1	40.1

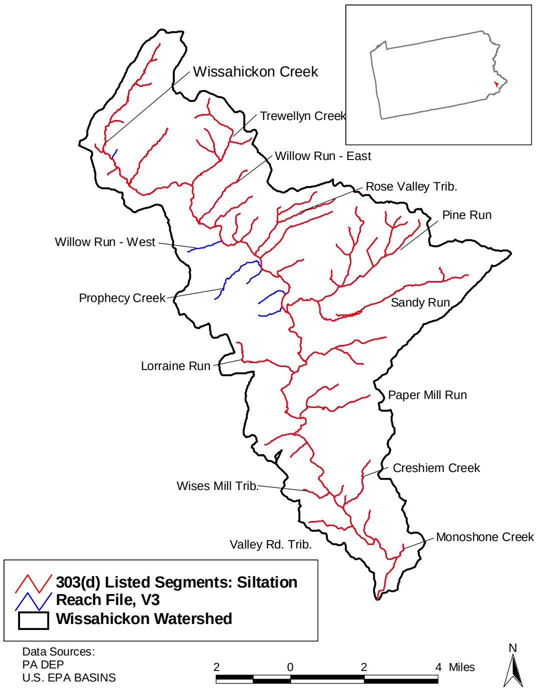
A - Calculated from NPDES permit limit
B - Calculated from average of summer 2002 monitoring

Siltation TMDL Objectives

- Impairments due to siltation
- Sources:
  - Urban runoff/storm sewers
  - Habitat modification

Endpoint

- No water quality criteria available for siltation



Siltation TMDL Analytical Framework

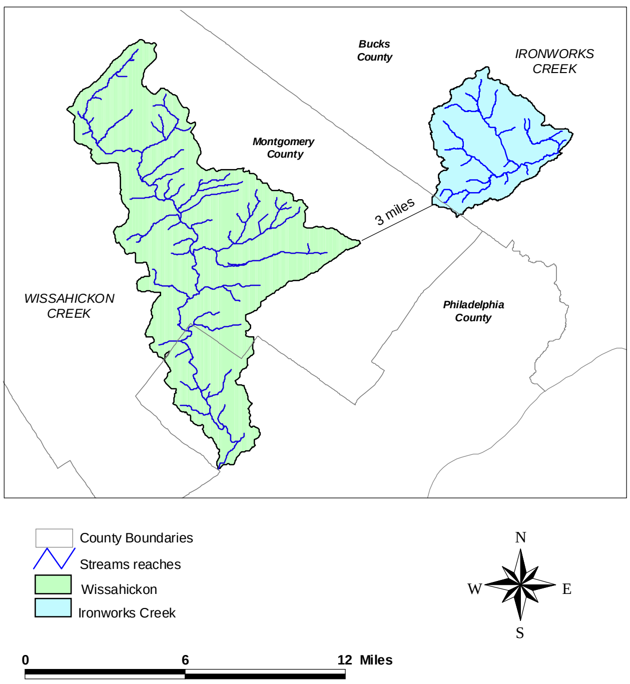
Reference Watershed approach

- No numeric instream criteria for siltation in PA
- Reference watershed used to set endpoints for TMDL development
- AVGWLF model developed for both the Wissahickon Creek and reference watersheds for comparison of siltation loads
  - Overland load form storm runoff
  - Streambank erosion

Siltation TMDL
Reference Watershed Selection

- Goal: Identify similar, unimpaired watersheds to be used to develop siltation TMDL endpoints.
- Data used:
  - Ecoregion coverages
  - Topography
  - Soils
  - Surface Geology
  - Land use distribution
  - Watershed size
  - Point source inventory

Reference Watershed – Ironworks Creek



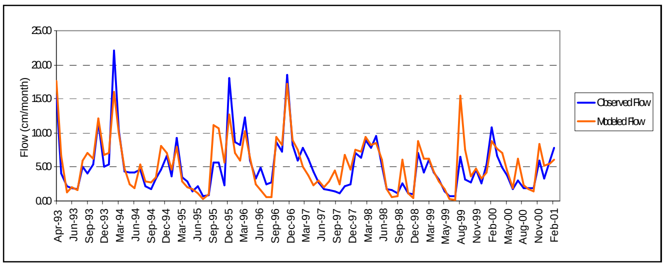
Comparison of Wissahickon Creek to Ironworks Creek

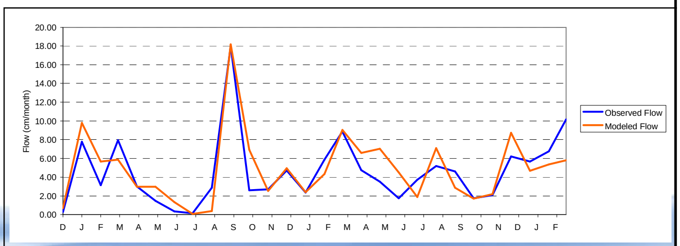
- Good match between most categories that impact siltation
  - Landuse is key
  - Soils and ecoregion also critical
  - Point sources are insignificant loads
- Difference in watershed size could be addressed in model approach

Stream	Wissahickon Creek	Ironworks Creek
Watershed Type	Impaired Watershed	Reference Watershed
Watershed Size (acres)	40,928	11,114
Geologic Province	Piedmont	Piedmont
Dominant Rock Types	Sandstone/ Metamorphic-Igneous/ Shale/ Carbonate	Sandstone/ Metamorphic-Igneous
Dominant Soils	C & B	C & B
Ecoregions	Triassic Lowlands Piedmont Uplands Piedmont Limestone Dolomite Lowlands	Triassic Lowlands Piedmont Uplands
Percent Slope of Watershed	0.25%	0.63%
Point Sources	14	0
Percent Urban	43%	44%
Percent Forested	40%	31%
Landuse Types:	% Landuse	% Landuse
Low Intensity Development	34.10%	39.80%
High Intensity Development	8.50%	4.20%
Hay/Pasture	7.10%	11.70%
Cropland	8.90%	10.90%
Conifer Forest	2.40%	1.80%
Mixed Forest	10.20%	10.30%
Deciduous Forest	28.00%	19.60%
Quarry	0.30%	0.00%
Coal Mine	0.02%	0.00%
Transitional	0.40%	0.10%

Siltation TMDL - Hydrology Calibration

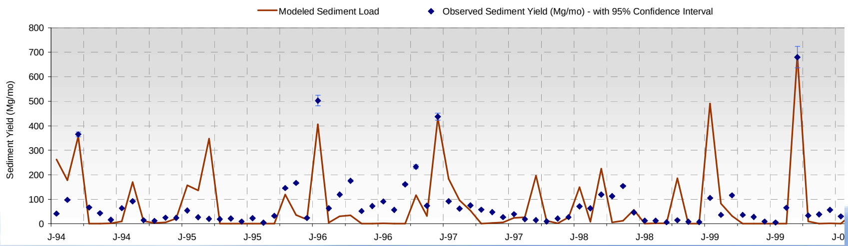
- Monthly hydrology calibration performed on both the Wissahickon and reference watersheds





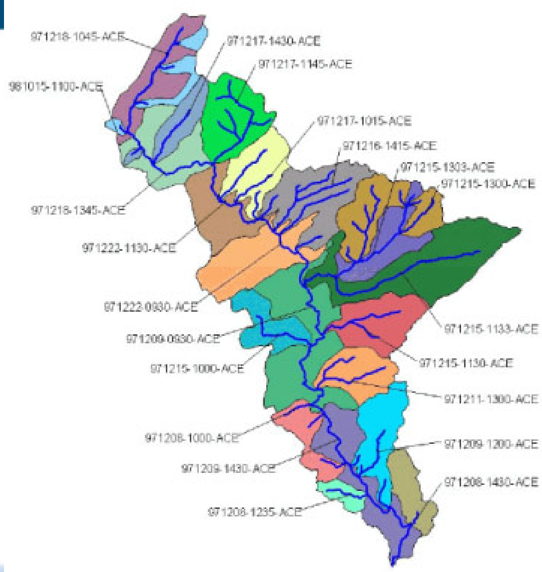
Siltation TMDL - Water Quality Calibration

- Calibration less of issue due to empirical aspect of model
- “Validation” of model using water quality data at mouth of Wissahickon Creek
- Validation limited due to limited water quality data for storm flows
- Monthly sediment loads validated



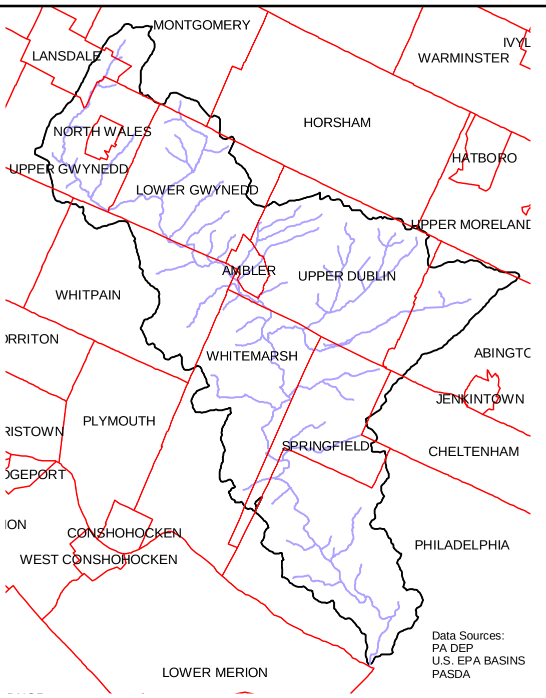
Siltation TMDL Calculation

- Watershed was divided into subwatersheds for each 303(d) listed stream segment
- TMDLs were calculated for each stream segment
- TMDL components:
  - LAs to upstream loads
  - WLAs to dischargers and stormwater permits (MS4s)
  - 10% margin of safety

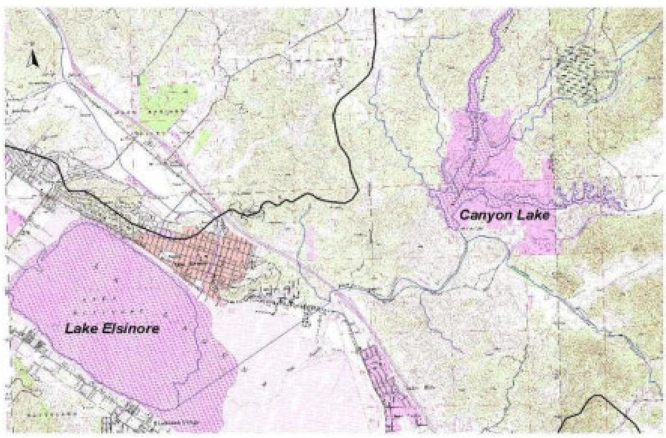


Siltation TMDL MS4 Permits

- MS4s required WLAs
- Each municipality holds its own MS4 permit
- WLAs include:
  - Overland load from runoff
  - Streambank erosion

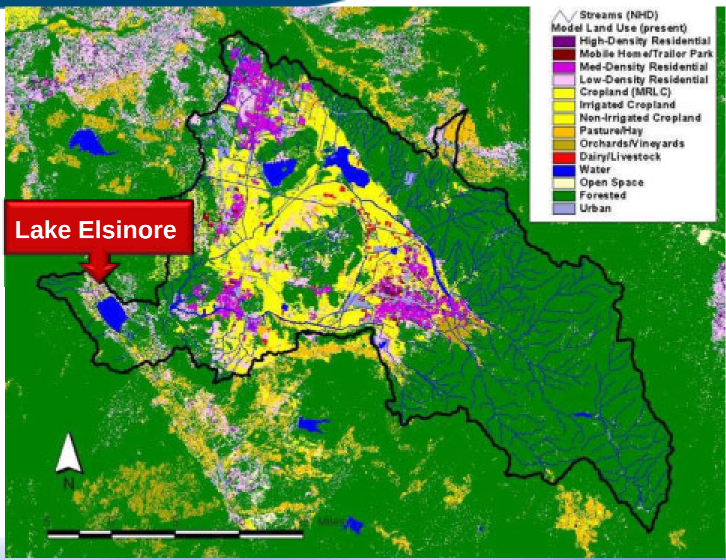


Lake Elsinore Eutrophication



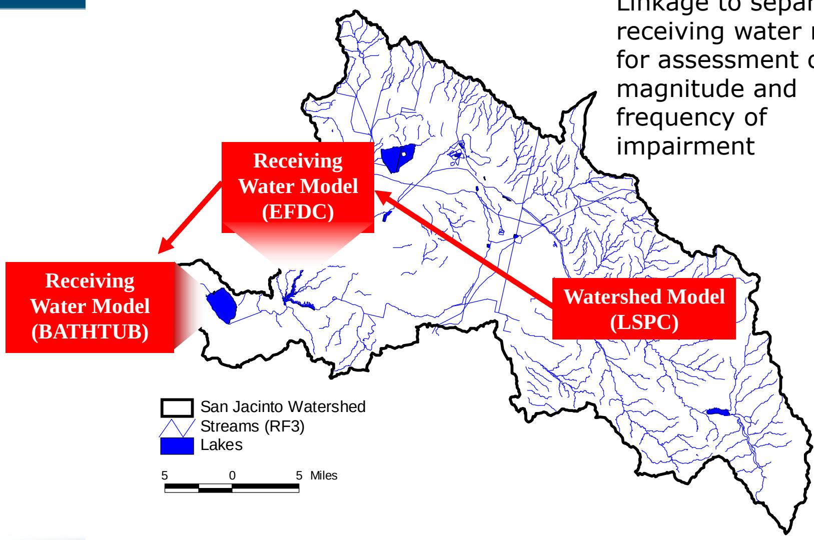
Lake Elsinore and Canyon Lake: USGS Topography (1:24K)

Lake Elsinore Eutrophication



Model Representation

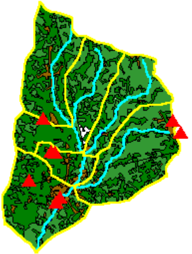
Linkage to separate receiving water models for assessment of magnitude and frequency of impairment



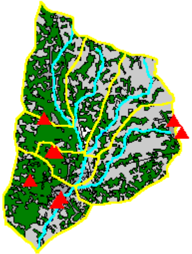
Spatial Scale: Watershed Model

- Which landuse category/breakdown should be considered? (Level of effort and detail)

Lumped → **Distributed**



Anderson Level 1



Anderson Level 2

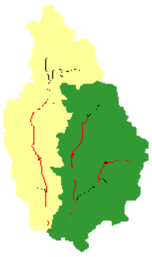
Factors to Consider

- Predominant Landuse
- Type of Impacts
- Future Land Use Conversion
- Data Availability
- Resources

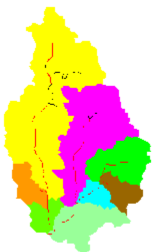
Spatial Scale: Watershed Model

- Need to define a suitable level of segmentation

Lumped → **Distributed**



2 Segments



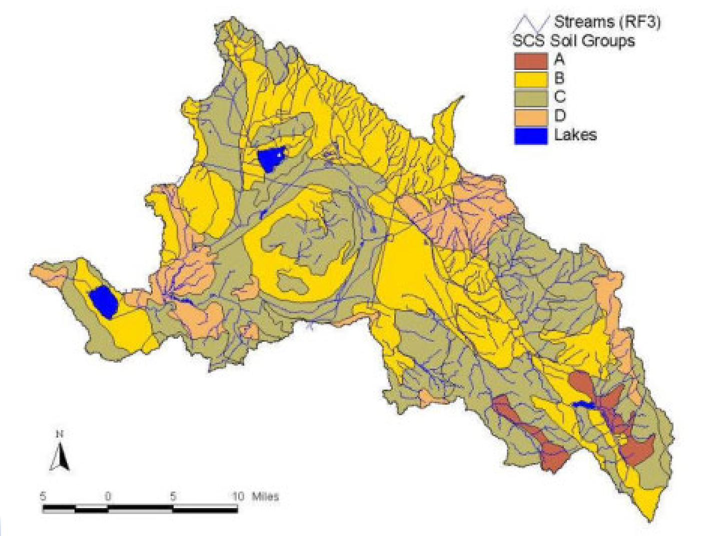
8 Segments

Factors to Consider

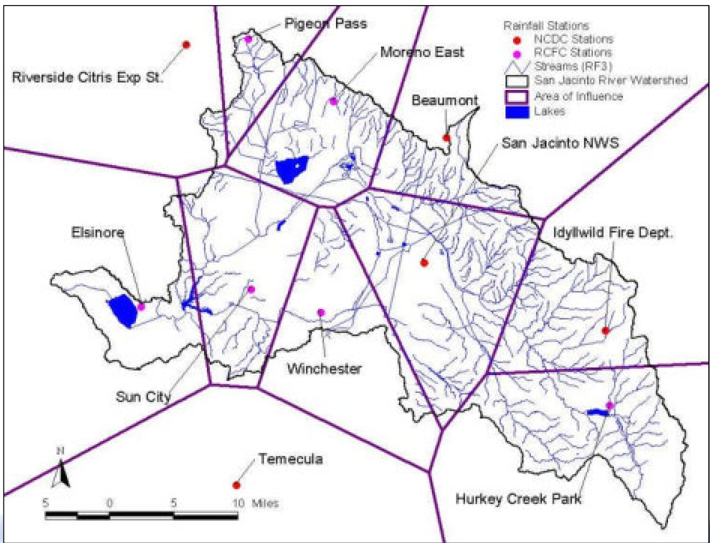
Watershed
- Land Use distribution
- Soils
- Topo/weather station location
- Data (weather, PS)

Management
- Planning
- Regulatory
- Impact
- Alternative analysis

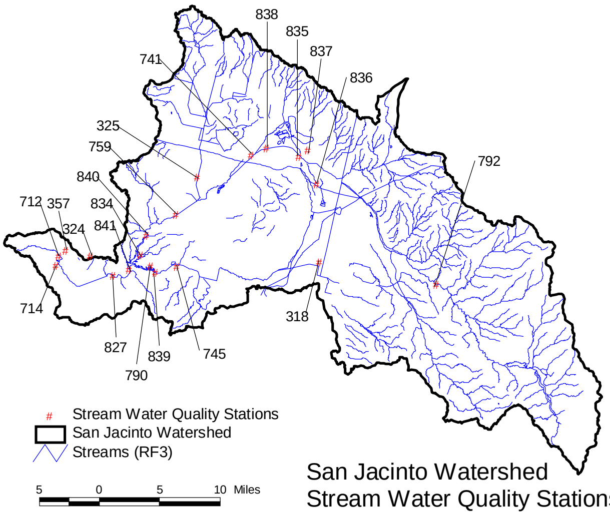
Considerations for Watershed Model Configuration – Hydrologic Soil Groups



Representation of Rainfall Based on Observed Data

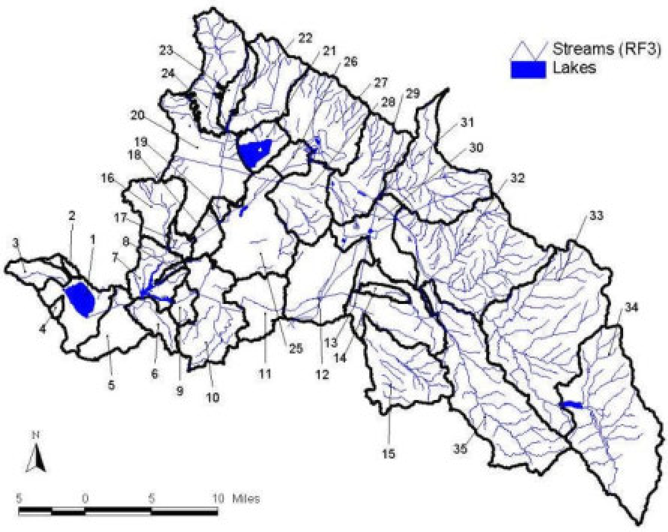


Considerations for Watershed Model Configuration – Monitoring Stations

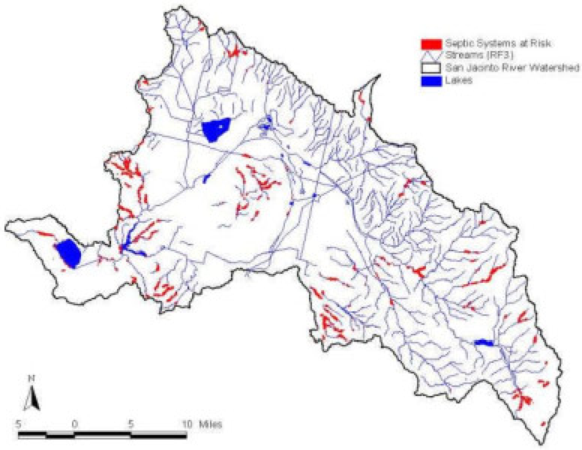


San Jacinto Watershed
Stream Water Quality Stations

Sub-Watershed Delineation and Model Representation

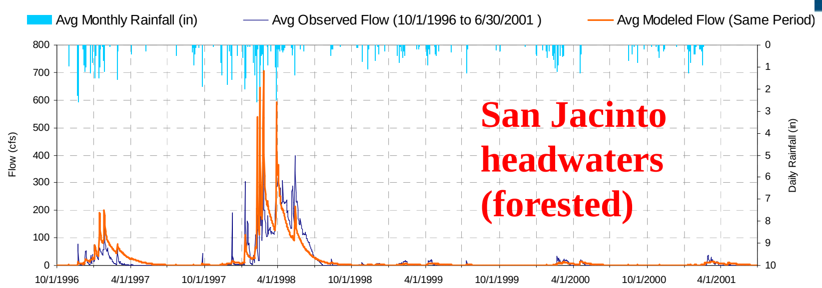


Representing Septic Loads



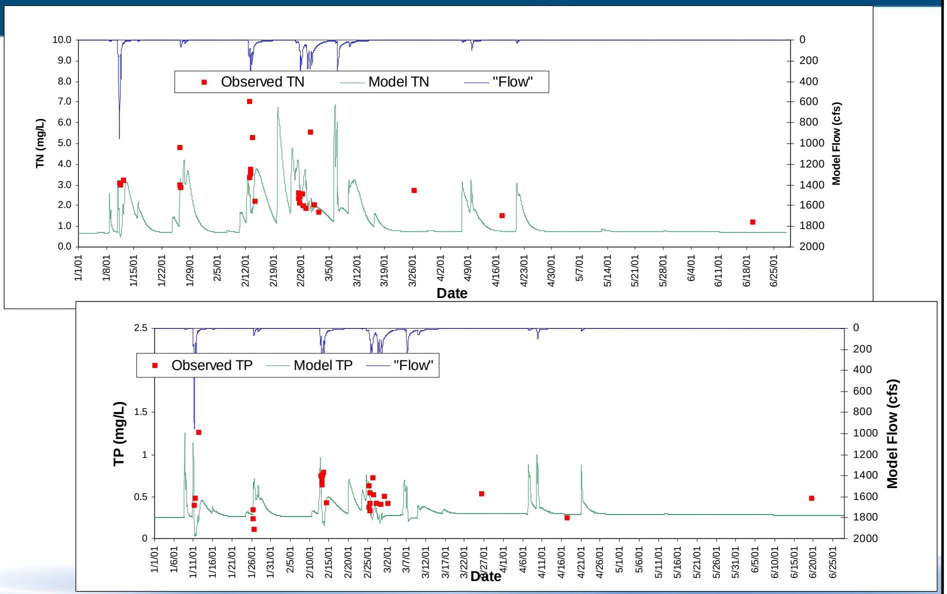
- Load estimates based on assumptions for per capita load, nutrient concentrations, and failure rates of systems.
- Loading represented dynamically in LSPC model and driven by rainfall

Hydrology Calibration



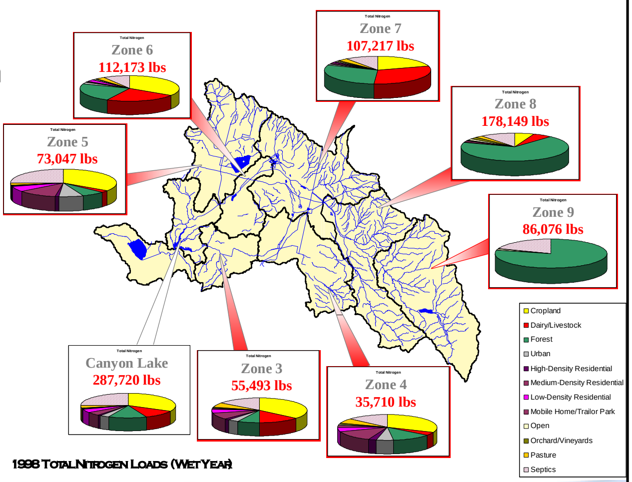
LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 33 4.75-Year Analysis Period: 10/1/1996 - 6/30/2001 Flow volumes are (inches/year) for upstream drainage area		**USGS 11069500 San Jacinto River Near San Jacinto** Riverside County, California	
Total Simulated In-stream Flow:	**11.39**	Total Observed In-stream Flow:	**11.16**
Total of simulated highest 10% flows:	**9.52**	Total of Observed highest 10% flows:	**9.56**
Total of Simulated lowest 50% flows:	**0.00**	Total of Observed Lowest 50% flows:	**0.01**
Simulated Summer Flow Volume (months 7-9):	**0.03**	Observed Summer Flow Volume (7-9):	**0.16**
Simulated Fall Flow Volume (months 10-12):	**0.35**	Observed Fall Flow Volume (10-12):	**0.41**
Simulated Winter Flow Volume (months 1-3):	**7.58**	Observed Winter Flow Volume (1-3):	**5.10**
Simulated Spring Flow Volume (months 4-6):	**3.44**	Observed Spring Flow Volume (4-6):	**5.49**
Errors (Simulated-Observed)	*Current Run (n)*	*Recommended Criteria*	
Error in total volume:	2.04	10	
Error in 10% highest flows:	-0.40	15	

Water Quality Calibration – Mixed Land Use



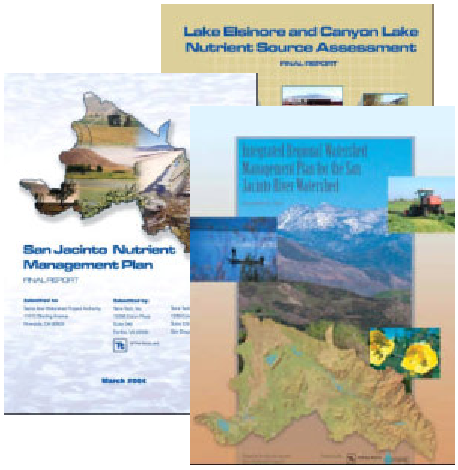
Interpretation of Model Results

- Management Strategies Identified for Each Source/ Landuse
  - Urban
  - Hydraulic/ riparian modifications
  - Agricultural
  - Other (e.g., pollutant trading studies, continued monitoring)

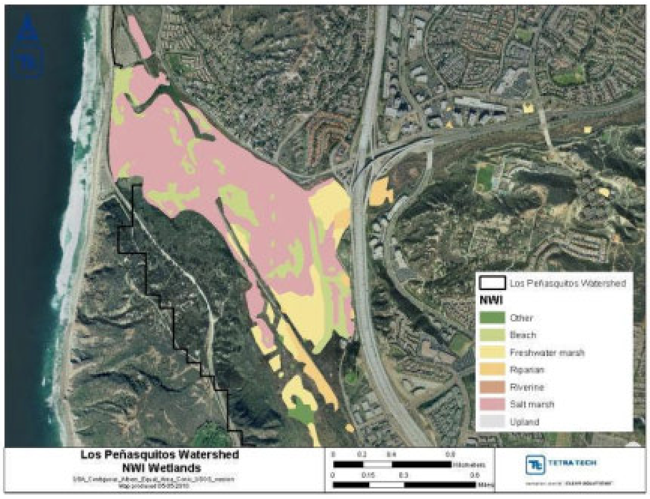


Supporting Planning Efforts

- Lake Elsinore and Canyon Lake Nutrient Source Assessment
  - Stakeholder led
  - Supported RWQCB TMDL development
- San Jacinto Nutrient Management Plan
  - Options for load reductions (land use based)
- IRWMP
  - Specific projects identified
- Septic Mgt. Plan



Los Penasquitos Lagoon - 1985



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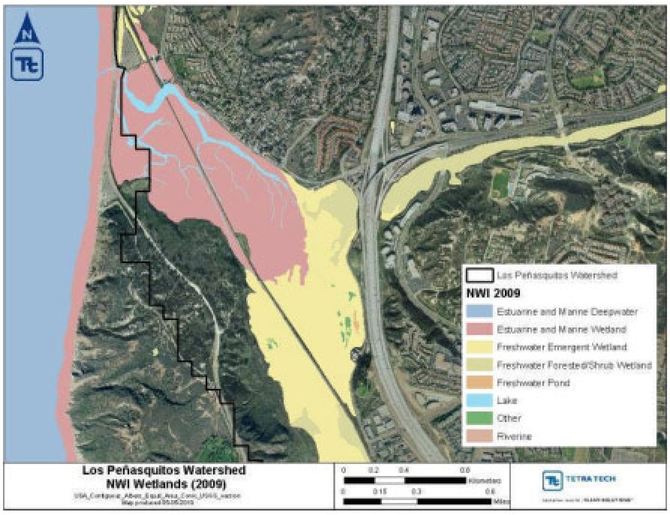
Los Penasquitos Lagoon - 2009



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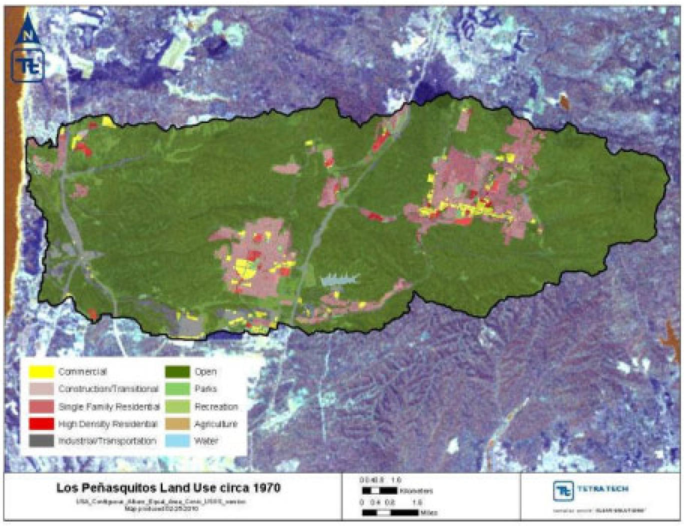
Los Penasquitos Watershed – 1970s



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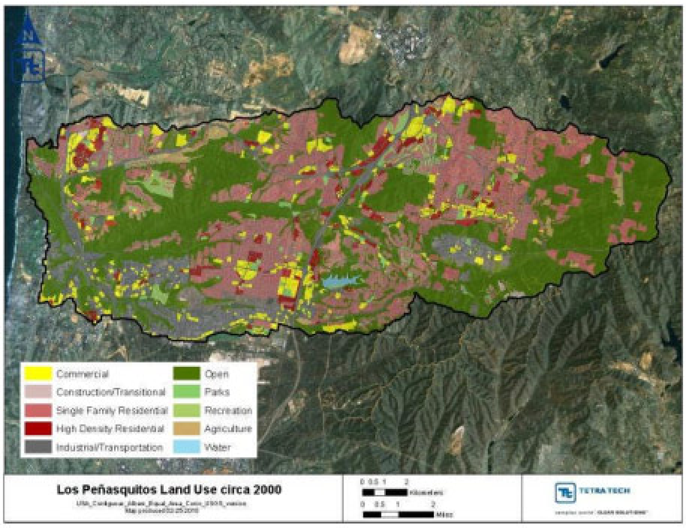
Los Penasquitos Watershed - Existing Land Use



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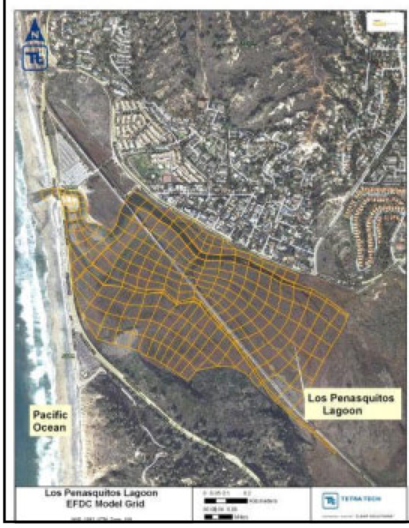
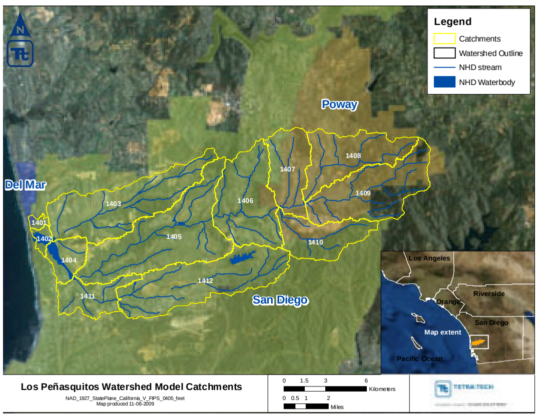
Model Development

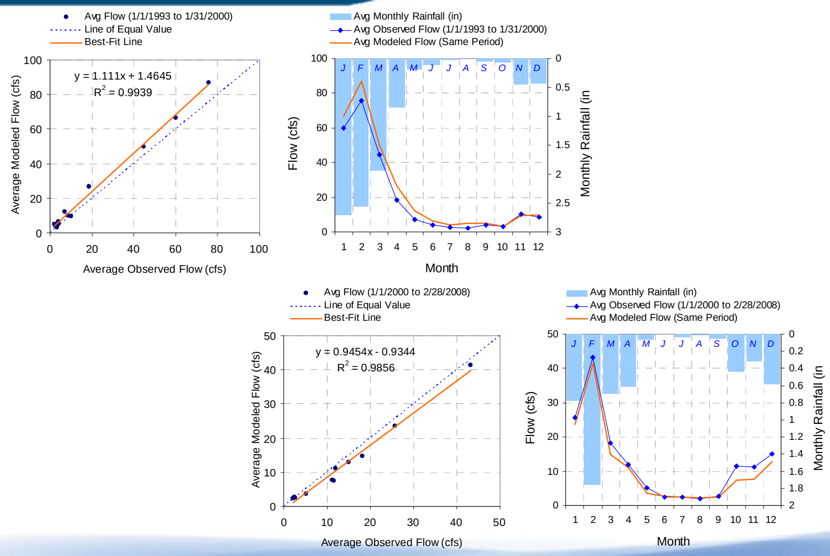
EFDC Model of Lagoon



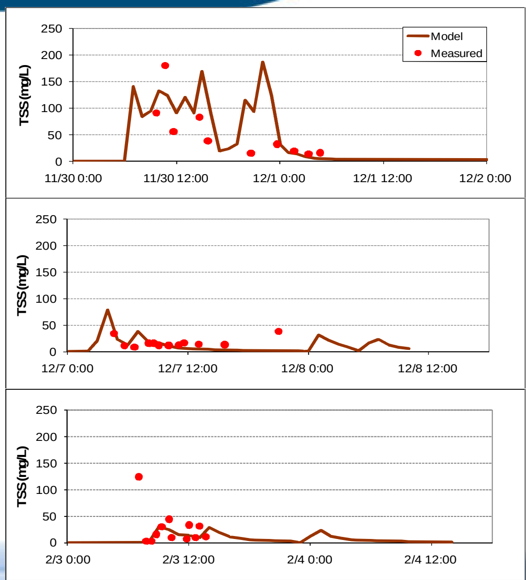
LSPC Model of Watershed



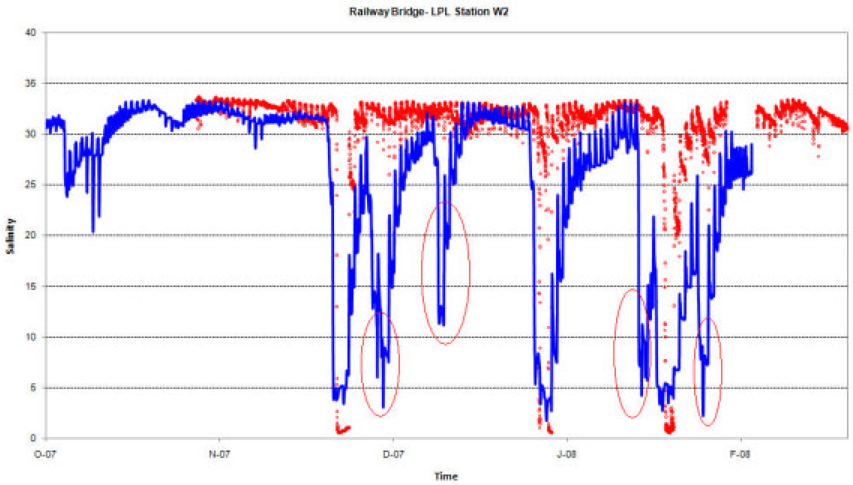
Watershed Model Calibration/Validation



Watershed Model Calibration/Validation



Lagoon Model Salinity Calibration



How is the Model Used?

- Key decisions:
  - No numeric target for sediment/siltation
  - Establishing link between watershed loading and lagoon sedimentation
- Variables
  - Watershed loading
  - Lagoon flushing
  - Lagoon vegetation

Establishing a Target

- Document historical changes in lagoon condition
  - Research available literature
  - Identify unimpaired time period
- Correlate with land use changes over time
- TMDL numeric target based on unimpaired time period
  - Estimate watershed sediment contribution (from historic landuse)
  - Calculate total based on watershed model output

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Decision

- LSPC modeled watershed loads:
  - 1975 land use (assumed unimpaired conditions in lagooon)
  - 2009 land use
- Requires 70% watershed load reduction

Note the lagoon model wasn't needed!

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Questions
WARNING
RUNOFF/STORM DRAIN WATER
MAY CAUSE ILLNESS
AVOID CONTACT WITH PONDED OR
FLOWING RUNOFF AND THE AREA WHERE
RUNOFF ENTERS THE OCEAN
AVISO