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Engineer Research and Development Center

# Fundamentals of Water Quality & Sediment Monitoring

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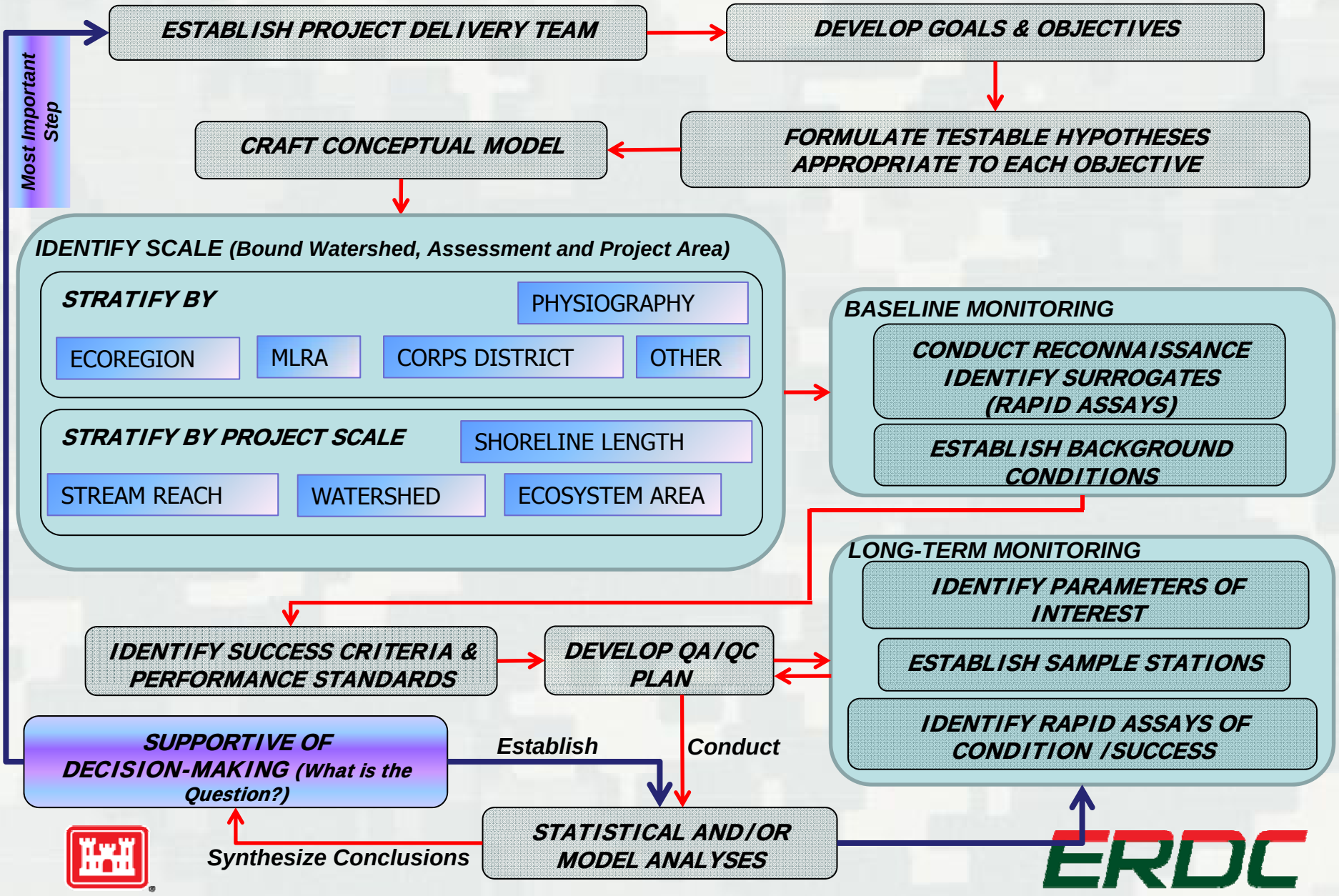
31 October 2013

WOTS

Water Operations Technical Support

# Webinar Outline / Objectives

- Water Quality / Sediment Monitoring in Your Plan
- The Driver – Hydrology → Water Quality Conditions and Sediment Yield
- Erosion and Sediment Processes
- Importance of Water Quality (Background)
- Water Quality / Sediment Monitoring in Your Plan
- Incorporation of Water Quality / Sediment Monitoring in Conceptual Modeling (Correspondence with Objectives, Hypotheses, Tasks, and Products)
- Pathogen / Sediment Case Study
- Corps Water Quality Guidance
- Rewind


Most Important Step
ESTABLISH PROJECT DELIVERY TEAM
DEVELOP GOALS & OBJECTIVES
FORMULATE TESTABLE HYPOTHESES APPROPRIATE TO EACH OBJECTIVE
CRAFT CONCEPTUAL MODEL
IDENTIFY SCALE (Bound Watershed, Assessment and Project Area)
STRATIFY BY
PHYSIOGRAPHY
ECOREGION
MLRA
CORPS DISTRICT
OTHER
STRATIFY BY PROJECT SCALE
SHORELINE LENGTH
STREAM REACH
WATERSHED
ECOSYSTEM AREA
BASELINE MONITORING
CONDUCT RECONNAISSANCE IDENTIFY SURROGATES (RAPID ASSAYS)
ESTABLISH BACKGROUND CONDITIONS
LONG-TERM MONITORING
IDENTIFY PARAMETERS OF INTEREST
ESTABLISH SAMPLE STATIONS
IDENTIFY RAPID ASSAYS OF CONDITION /SUCCESS
IDENTIFY SUCCESS CRITERIA & PERFORMANCE STANDARDS
DEVELOP QA/QC PLAN
SUPPORTIVE OF DECISION-MAKING (What is the Question?)
Establish
Conduct
STATISTICAL AND/OR MODEL ANALYSES
Synthesize Conclusions
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# Why Stratify/Classify?

- Great variety of aquatic ecosystems in United States

- Narrows the focus to a group of aquatic ecosystems that function similarly making it possible to:
  - Reduce the level of natural variability that must be considered
  - Identify and assess the functions most likely to be performed
  - Simplify the development of models
  - Reduce the amount of data that must be collected and analyzed

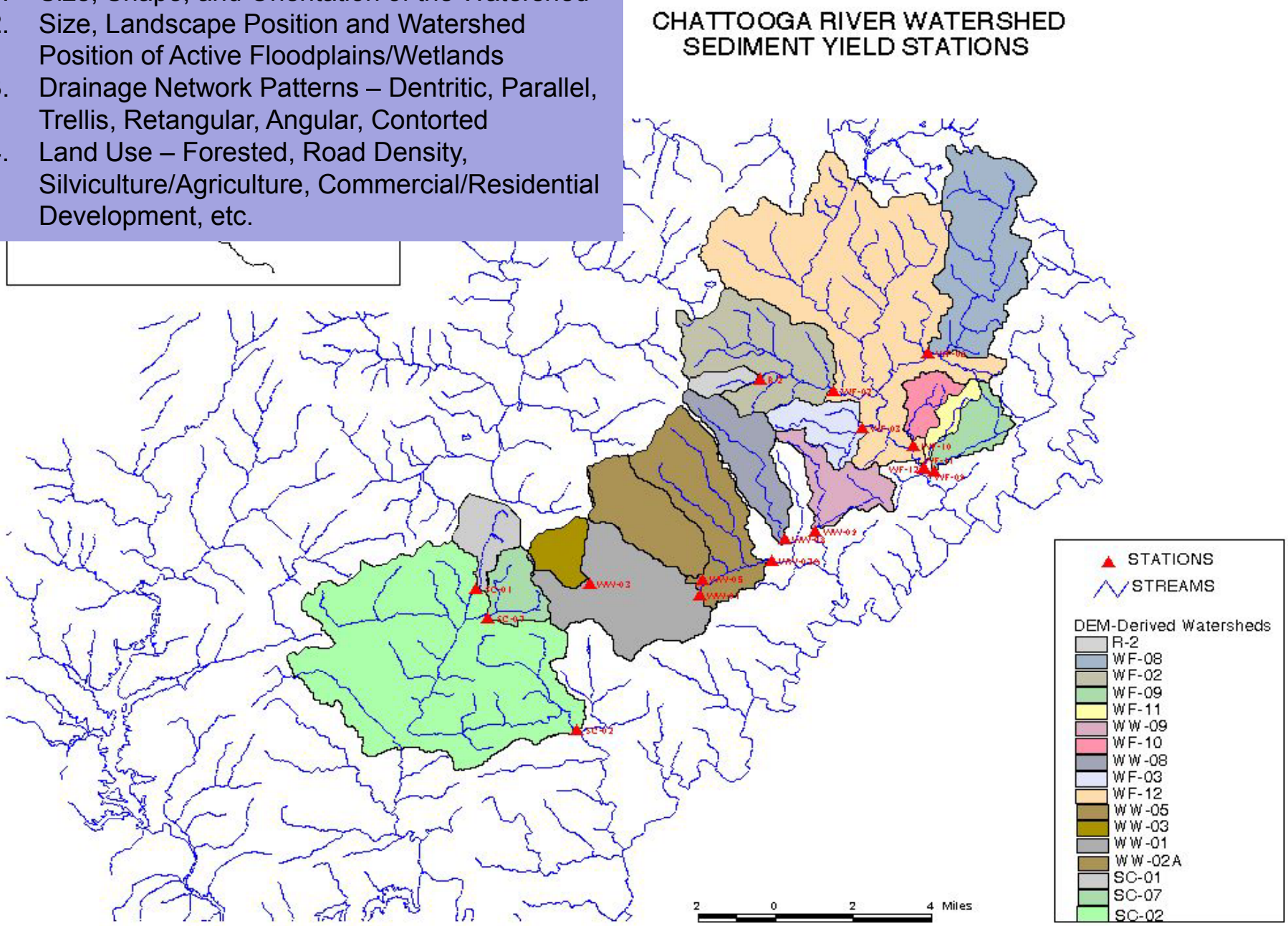
# Why Step Phasing?

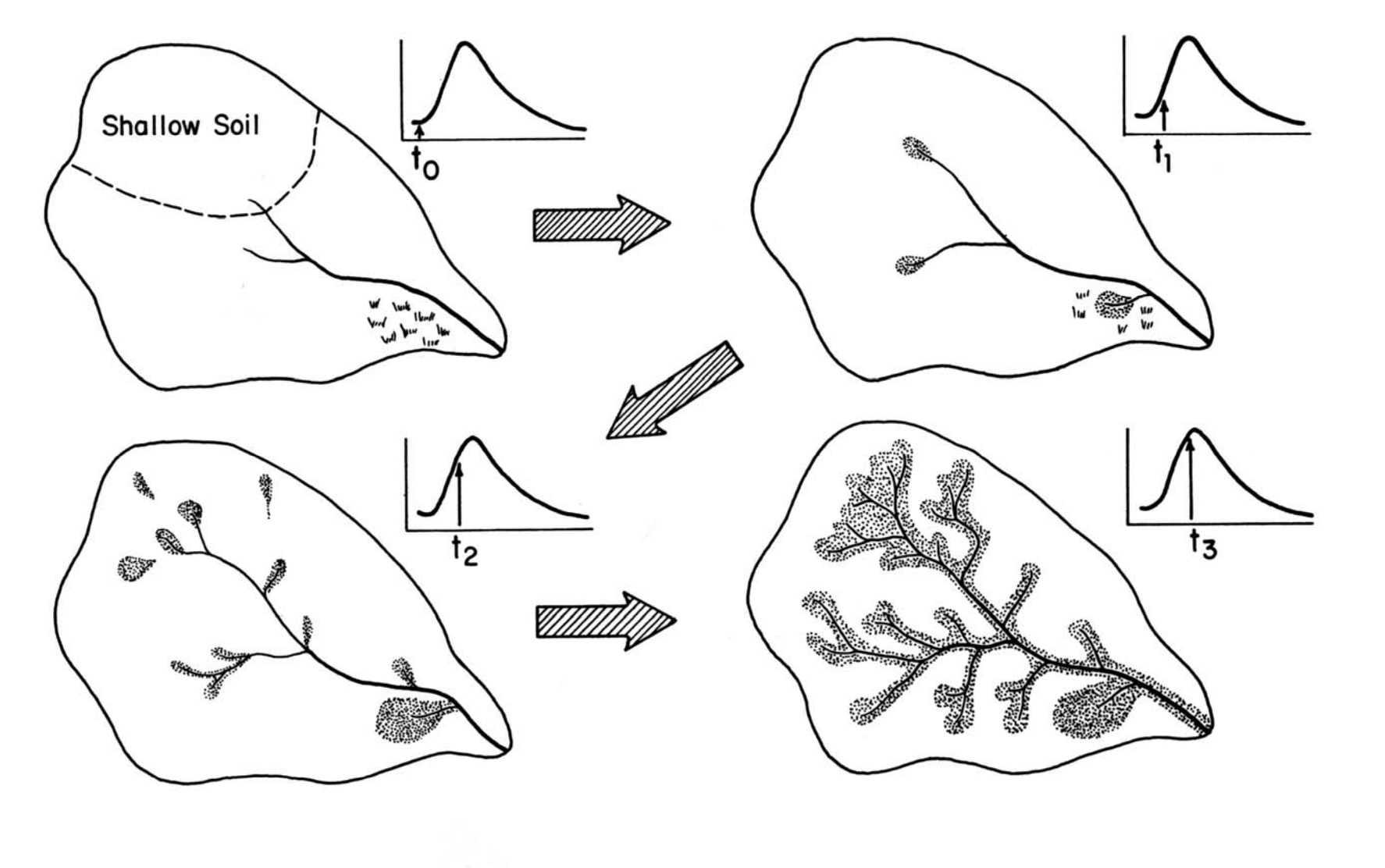
- Facilitates Adaptive Monitoring for intensive or long-term studies
- Promotes stratified systematic or random sampling
- Reduces the amount of data that must be collected and analyzed
- Establishes surrogates / proxies / metrics for correspondence with direct measures that can be extrapolated and applied to other watersheds / aquatic ecosystems
- Identifies boundary conditions of model segments
- Expedites and reduces cost of study

# Hydrology
# Watershed Scale

Watershed Yield Varies with:

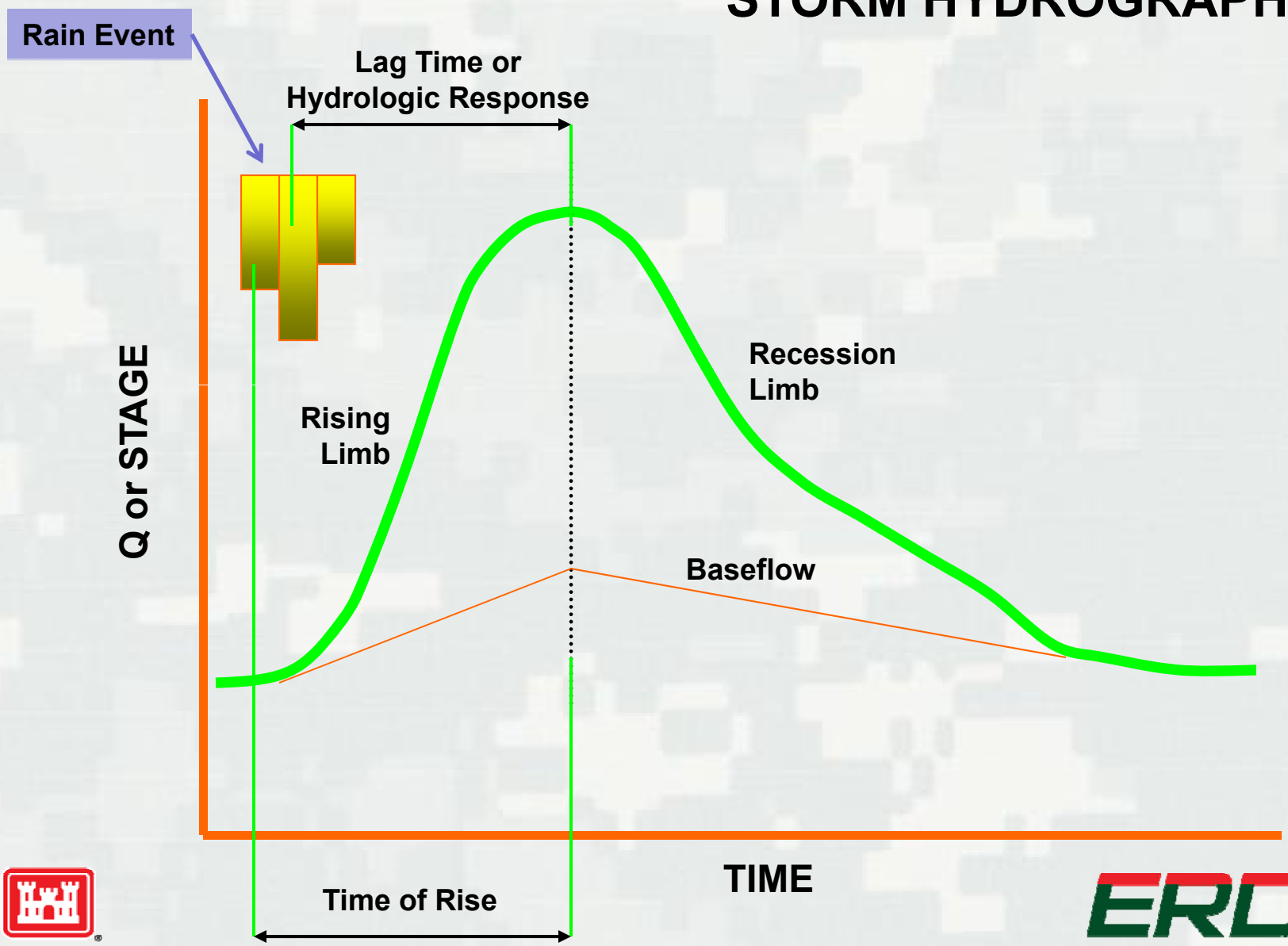
1. Size, Shape, and Orientation of the Watershed
2. Size, Landscape Position and Watershed Position of Active Floodplains/Wetlands
3. Drainage Network Patterns – Dentritic, Parallel, Trellis, Retangular, Angular, Contorted
4. Land Use – Forested, Road Density, Silviculture/Agriculture, Commercial/Residential Development, etc.

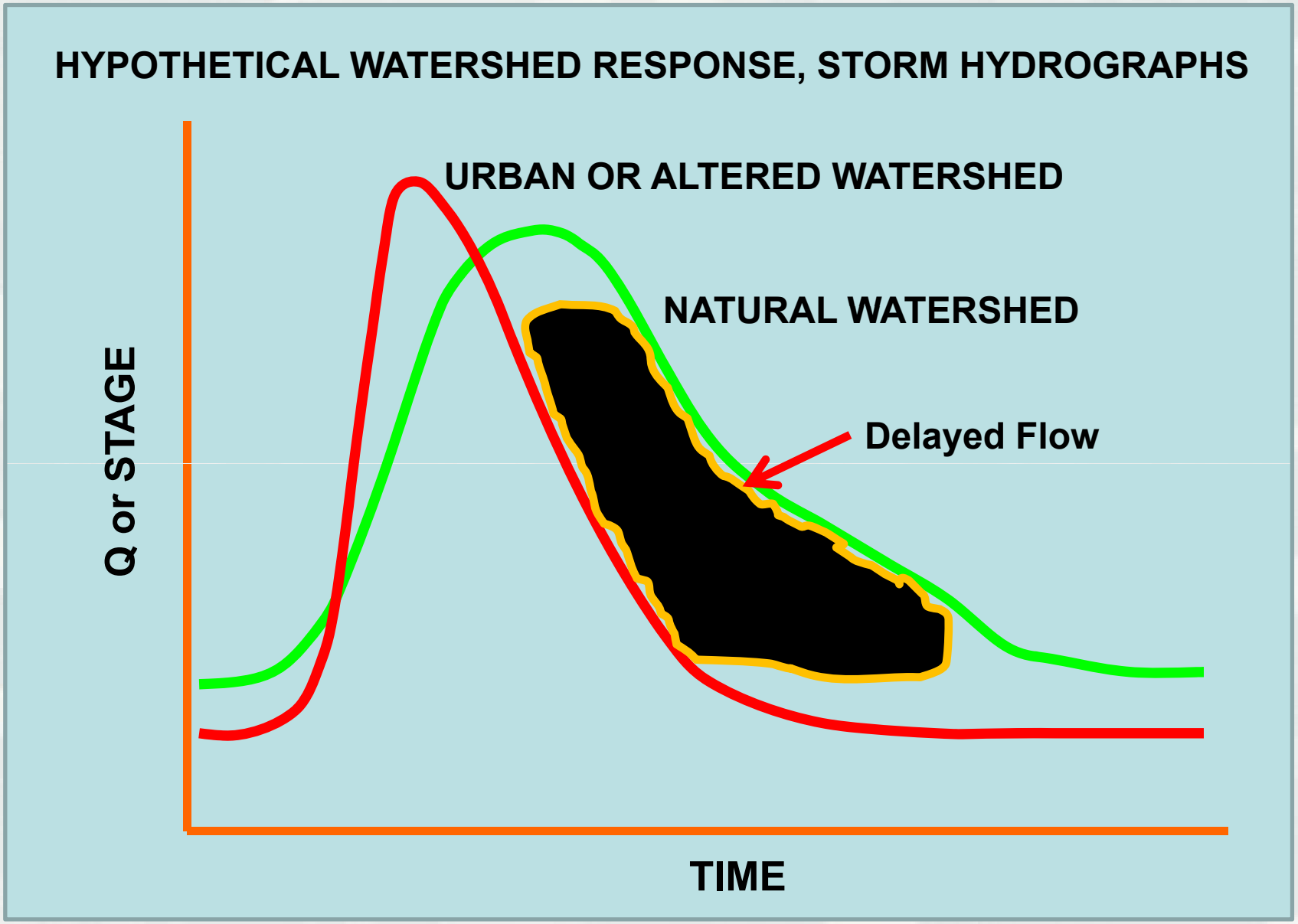




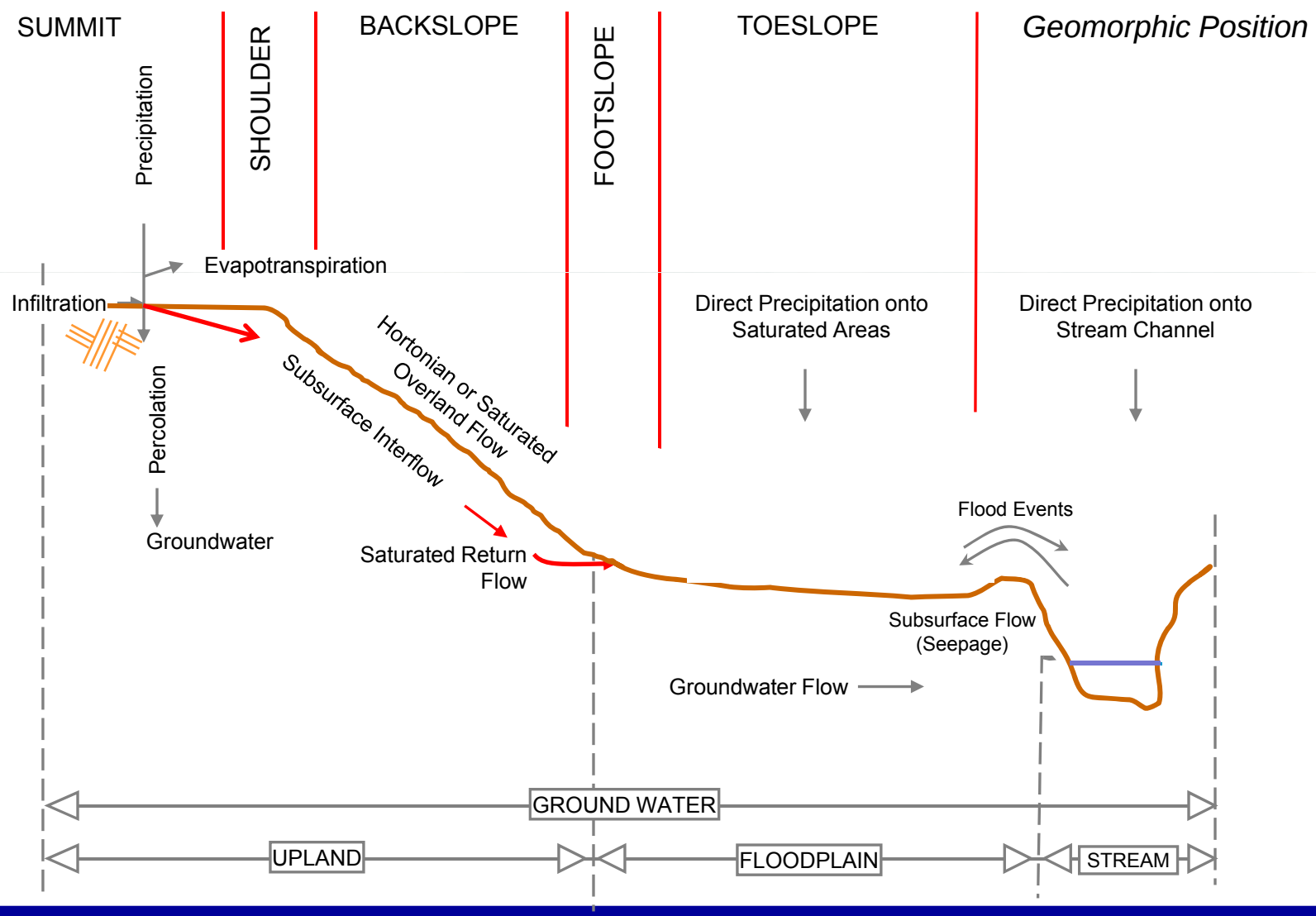

**Stormflow Production from a Small Vegetated Watershed**
**(Variable Source Area Concept)**

# STORM HYDROGRAPHS




HYPOTHETICAL WATERSHED RESPONSE, STORM HYDROGRAPHS
URBAN OR ALTERED WATERSHED
NATURAL WATERSHED
Delayed Flow
Q or STAGE
TIME

# Hillslope Hydrology: Geomorphic Position, Water Source, Hydrodynamics



## Capture and re-routing of Subsurface Interflow

Effects:

1) Reduces delayed flow
2) Routes surface water & sediment rapidly down road ditch, to a concave feature (e.g., ephemeral stream), and ultimately a perennial stream
3) “Starves” downslope riparian zone / wetlands of water source

# Hydrology to Sediment Transport
# Bridging the Gap

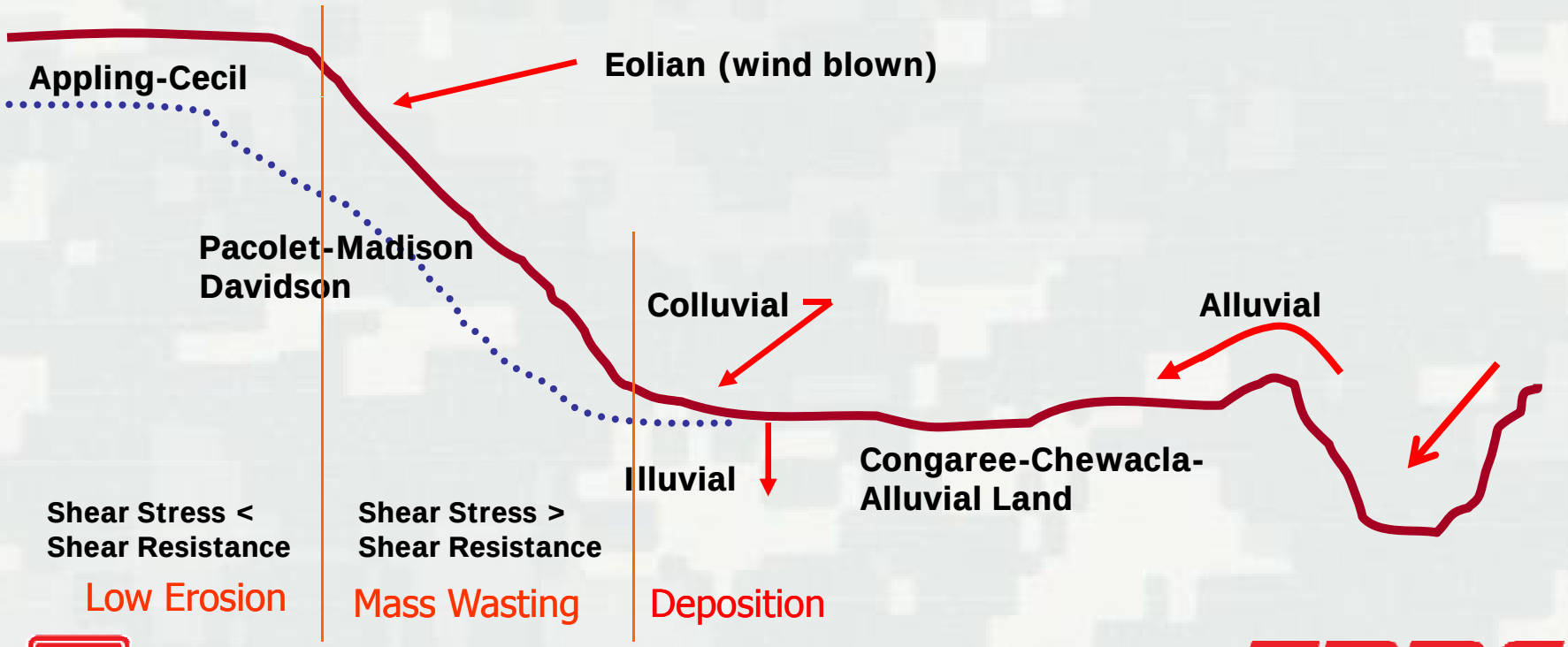
# RELATIONSHIP BETWEEN HILLSLOPE AND EROSION

1) **Shear Stress**

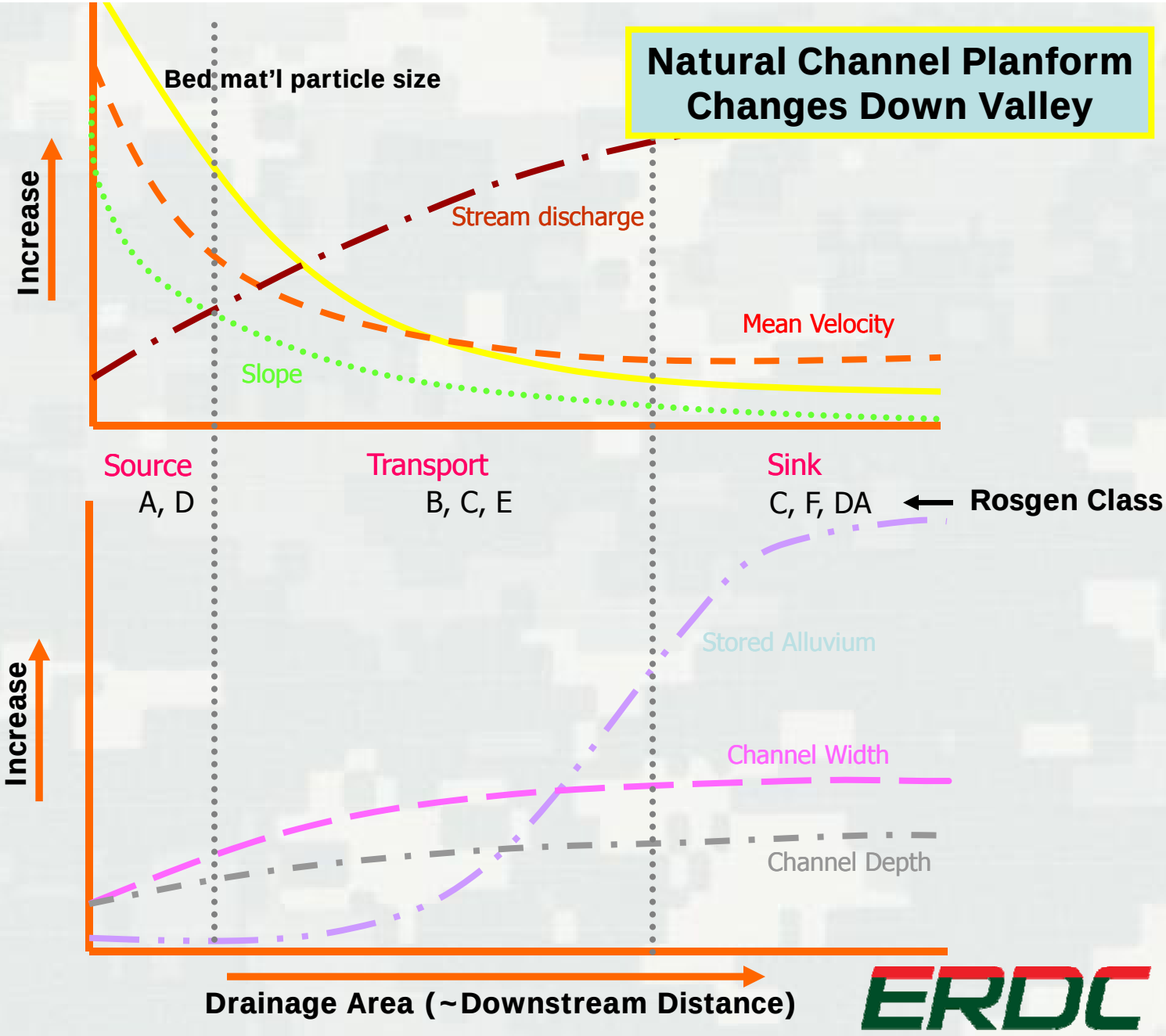
$$\tau = \gamma\, d \cos\theta \sin\theta$$

$\tau$ = shear stress
$\gamma$ = specific weight of water
$d$ = mean depth of flow
$\theta$ = local slope angle

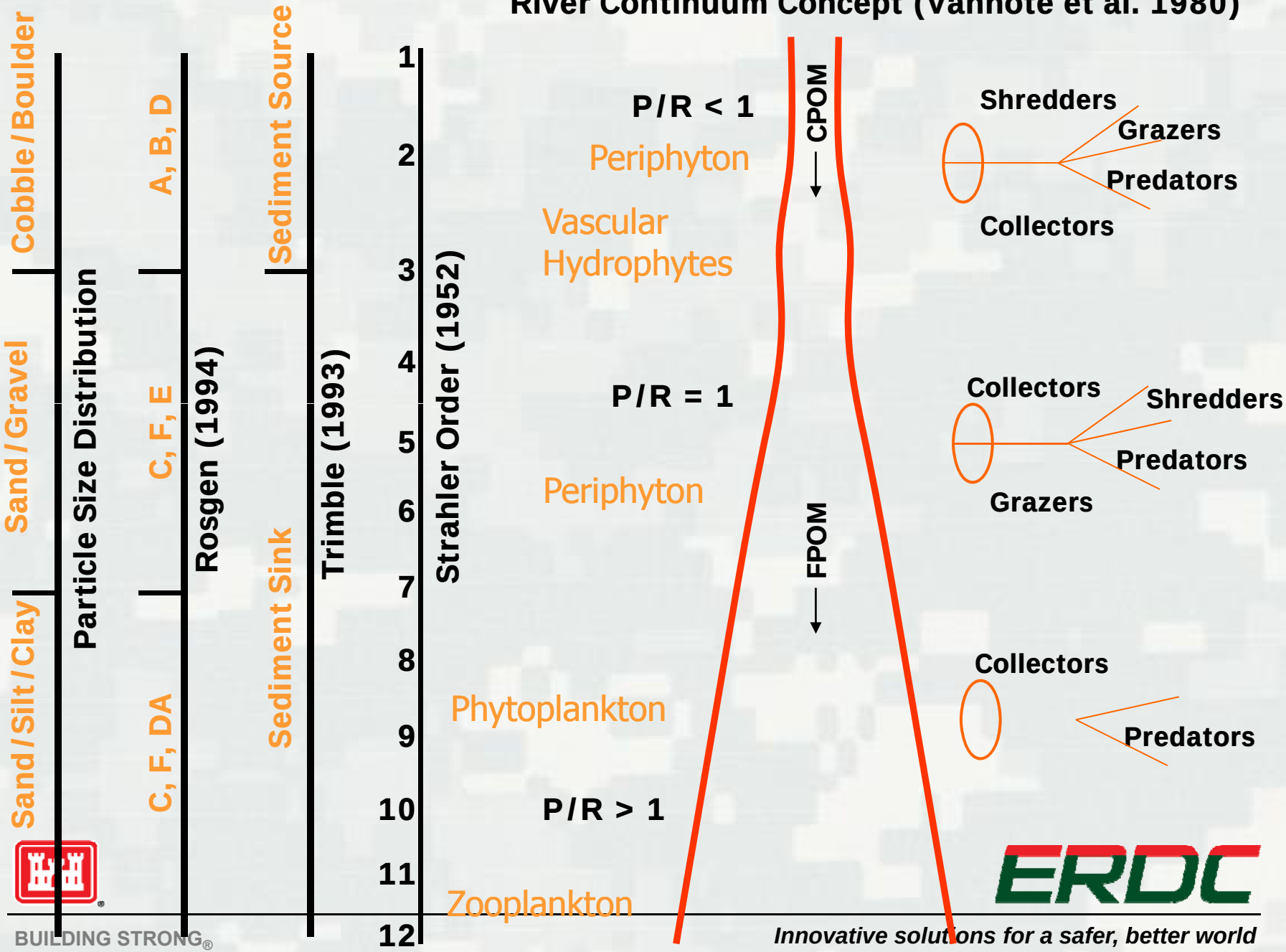
2) **R = Shear resistance of soil surface horizon**



# Natural Channel Planform Changes Down Valley



# River Continuum Concept (Vannote et al. 1980)

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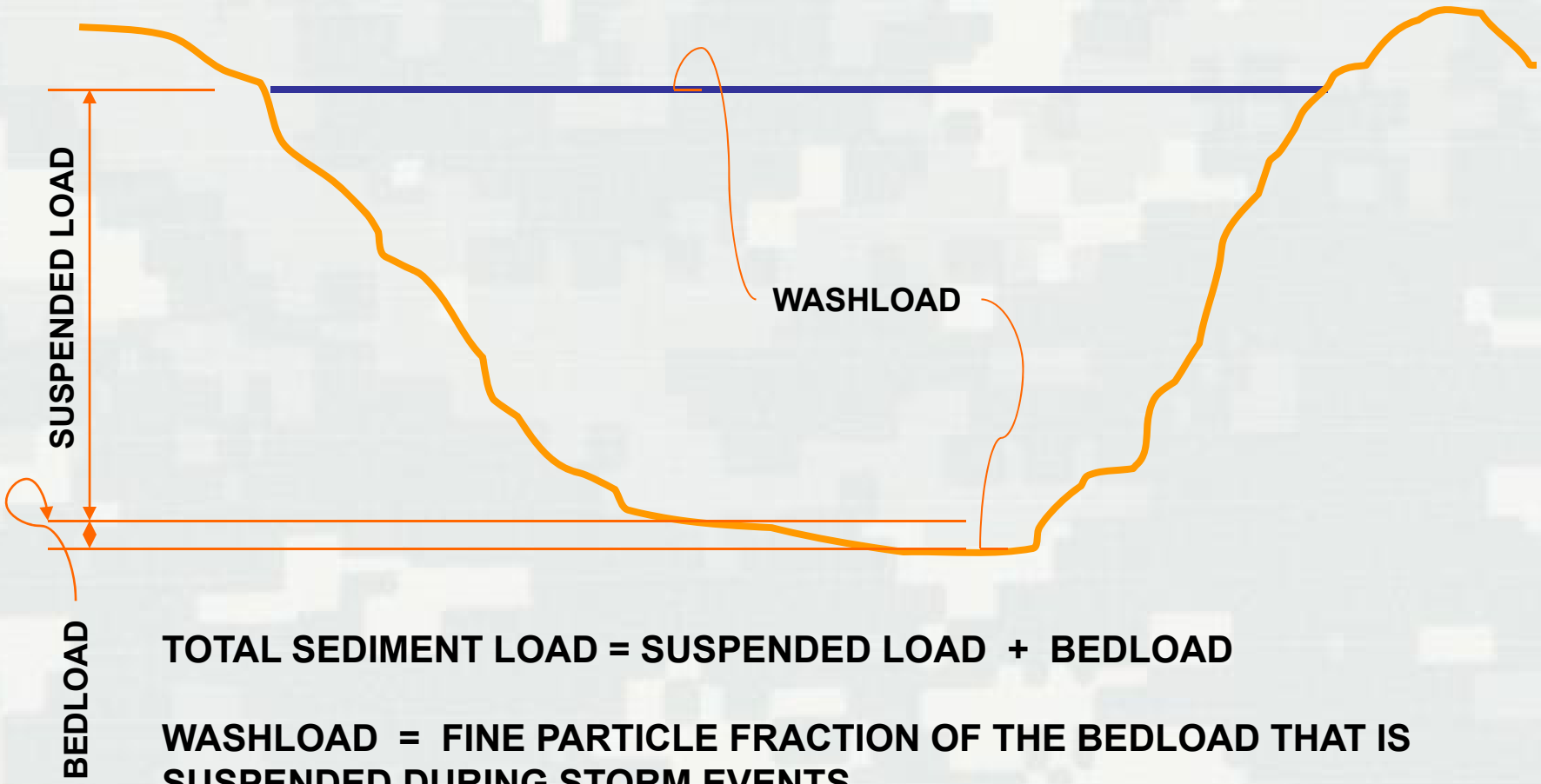
# SEDIMENT LOAD DEFINITION

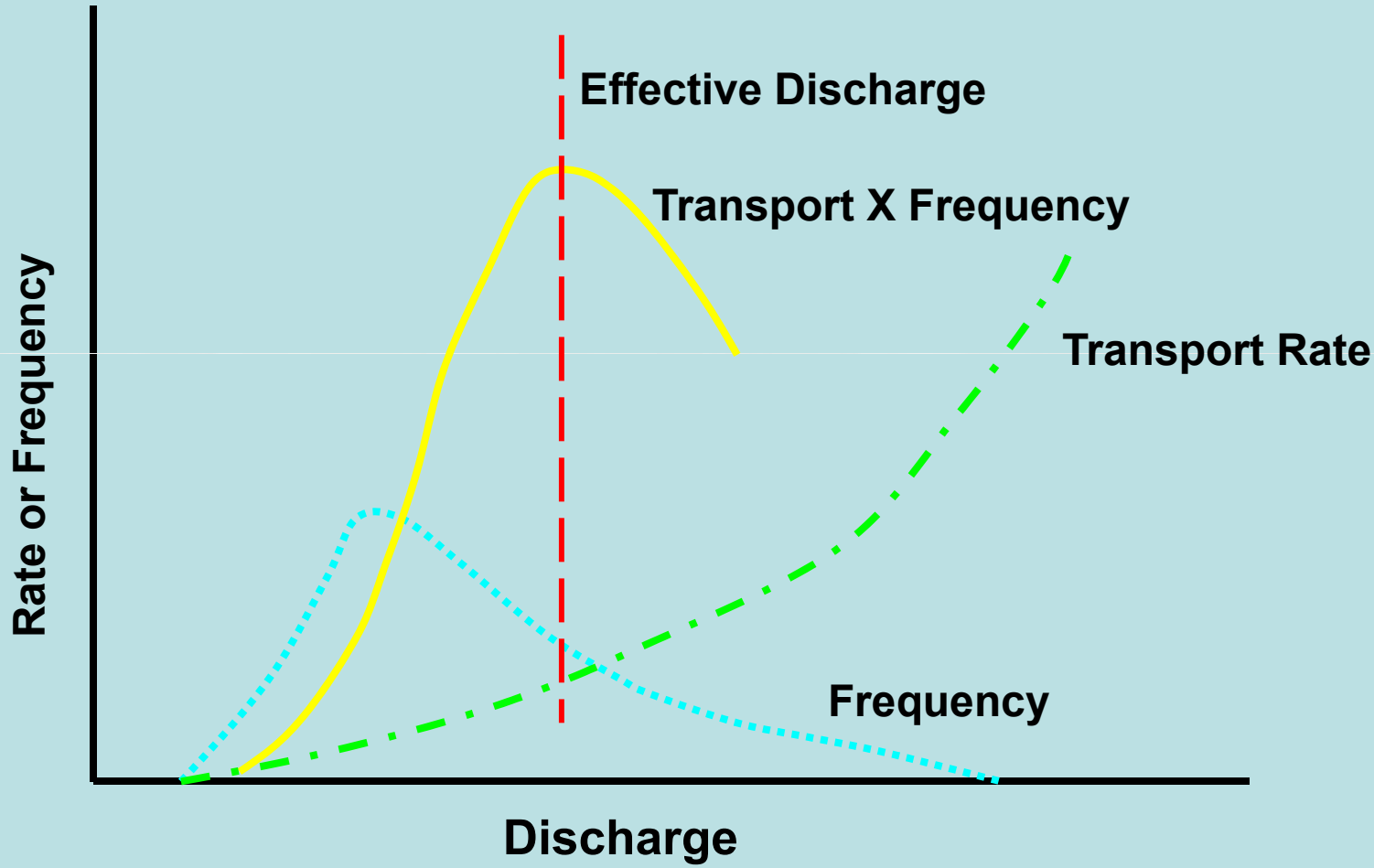



TOTAL SEDIMENT LOAD = SUSPENDED LOAD + BEDLOAD

WASHLOAD = FINE PARTICLE FRACTION OF THE BEDLOAD THAT IS SUSPENDED DURING STORM EVENTS (USUALLY THE SILT/CLAY FRACTION)

LOAD CALCULATION: M = Q X C

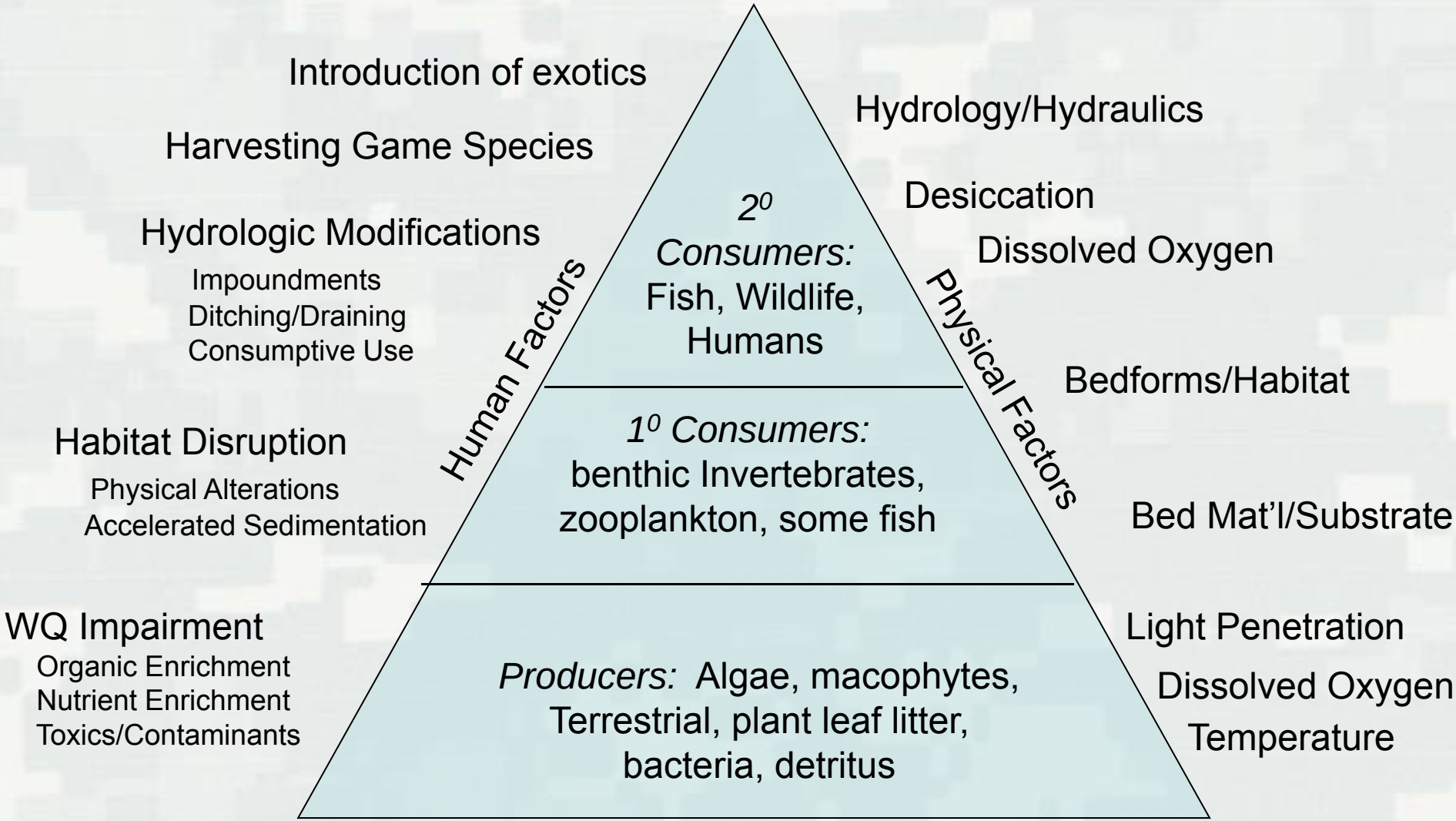
## Hydrology to Sediment: Bridging the Gap with a Metric




Hypothetic Relationship Between Effective or Bankfull Discharge and Cumulative Sediment Transport (Wolman and Miller 1960)

# Importance of Water Quality

## Factors affecting aquatic ecosystems depicted at trophic levels



# Types of Trophic States in Reservoirs and Lakes

| Trophic State | Water Quality Characteristics |
|---|---|
| Oligotrophic | Clear waters with extreme clarity, low nutrient concentrations, little organic matter or sediment, and minimal biological activity. |
| Mesotrophic | Waters with moderate nutrient concentrations and , therefore, more biological productivity. Waters may be lightly clouded by organic matter, sediment, suspended solids or algae. |
| Eutrophic | Waters extremely rich in nutrient concentrations, with high biological productivity. Waters clouded by organic matter, sediment, suspended solids, and algae. Some species may be eliminated. |
| Hypereutrophic | Very mucky, highly productive waters due to excessive nutrient loading. Many clearwater species cannot survive. |

# General Ranges of Primary Productivity of Phytoplankton and Related Characteristics of Lakes of Different Trophic Categories

| Trophic State ( -trophic) | Mean Primary Productivity (mg C/m$^2$/Day) | Phytoplankton Biomass (mg C / m$^3$) | Chlorophyll a (mg/m$^3$) | Dominant Phytoplankton (-phyceae) | Light Extinction Coefficients (η / m) | Total Organic Carbon (mg/L) | Total Phosphorus (µg / L) | Total Nitrogen (µg / L) | Total Inorganic Solids (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Oligo- | 50-300 | 20-100 | 0.3-3 | Chryso- | 0.05-1.0 | <1-3 | <1-5 | <1-250 | 2-15 |
| Meso- | 250-1000 | 100-300 | 2-15 | Bacillario- | 0.1-2.0 | <1-5 | 10-30 | 250-600 | 100-500 |
| Eu- | > 1000 | > 300 | 10-500 | Cyano- | 0.5-4.0 | 5-30 | 30-5000 | 500-15000 | 400-600 |

| Trophic State | Secchi Disk Depth (m) Average (Range) |
|---|---|
| Oligotrophic | 9.9 (5.4 – 28.3) |
| Mesotrophic | 4.2 (1.5 – 8.1) |
| Eutrophic | 2.45 (0.8 – 7.0) |



Pruitt 2010

# Nutrient Limitation

**Redfield Ratio (Developed for Deep Oceans)**

**C:N:P = 106:16:1**

**Freshwater Systems**

**N:P > 10, Phosphorus-limited system**

**N:P < 10, Nitrogen-limited system**

**In general,**

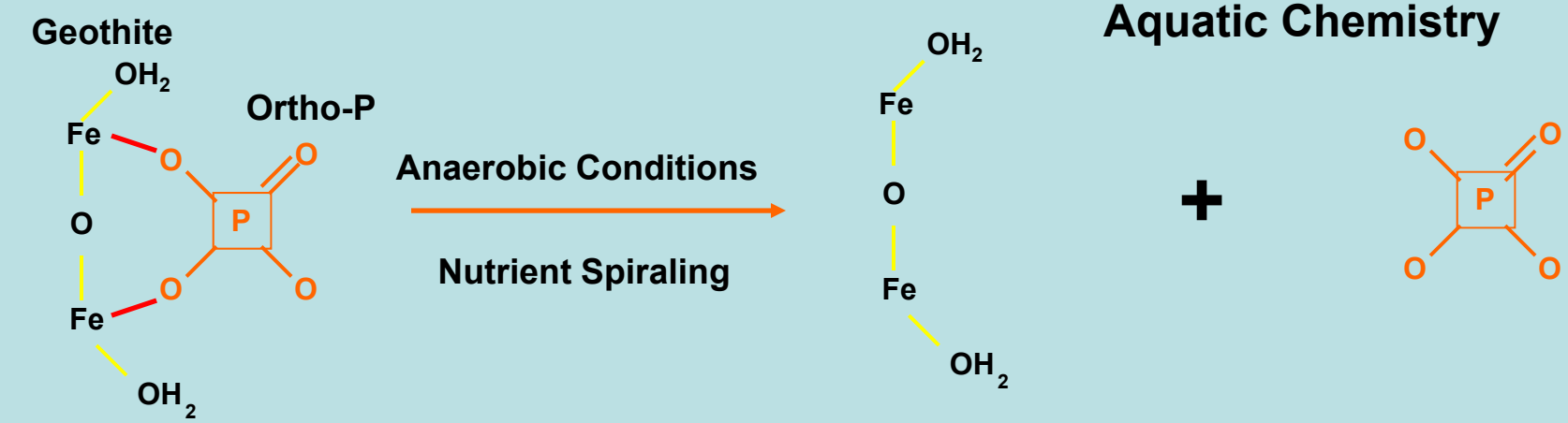
**Eastern water bodies: P-limited**

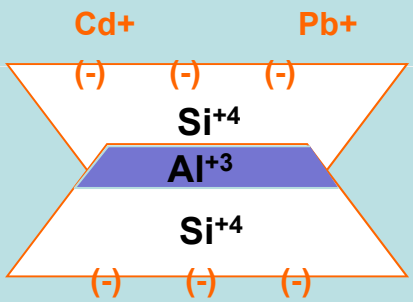
**Western water bodies: N-limited**

**Why is P limited in lakes?**

1. **Weathering of rock and parent material releases little biologically available phosphorus to streams and lakes (exception – many western physiographies).**
2. **Root zone in riparian zone intercepts and retains most soluble P.**
3. **Rainfall contains very little P (no gaseous phase in P-cycle).**
4. **Any soluble PO4 released into water is rapidly adsorbed onto particles or precipitated with other cpds**

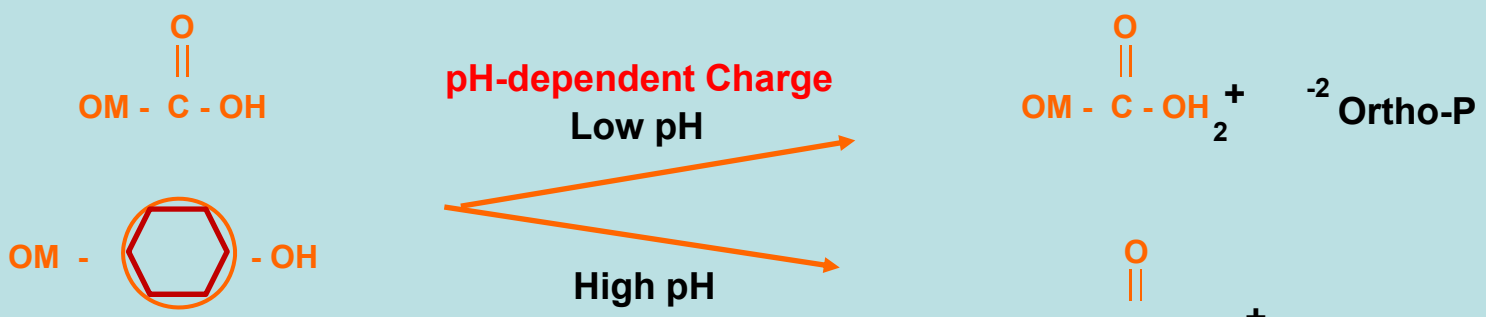
# Aquatic Chemistry




Net Negative Charge = High Cation Exchange Capacity or Metal Sequestration

Clay Phyllosilicate (e.g., mica, vermiculite)




Organic Matter Functional Groups

# Data Acquisition
# Fluvial Sediment

# INTEGRATED SUSPENDED SEDIMENT SAMPLER

# BEDLOAD SAMPLING (32 lb. with 3” orifice)

1) SELECT BEDLOAD SAMPLER SIZE BASED ON ANTICIPATED STREAM PSD

2) DEPLOY BL-84 @ PRE-SELECTED INTERVALS CROSS STREAM

3) TIME DEPLOYMENT ON EQUAL FREQUENCY @ EACH INTERVAL (USUALLY 20 MINS. TOTAL)

# Cable-Weigh System With Bedload Sampler

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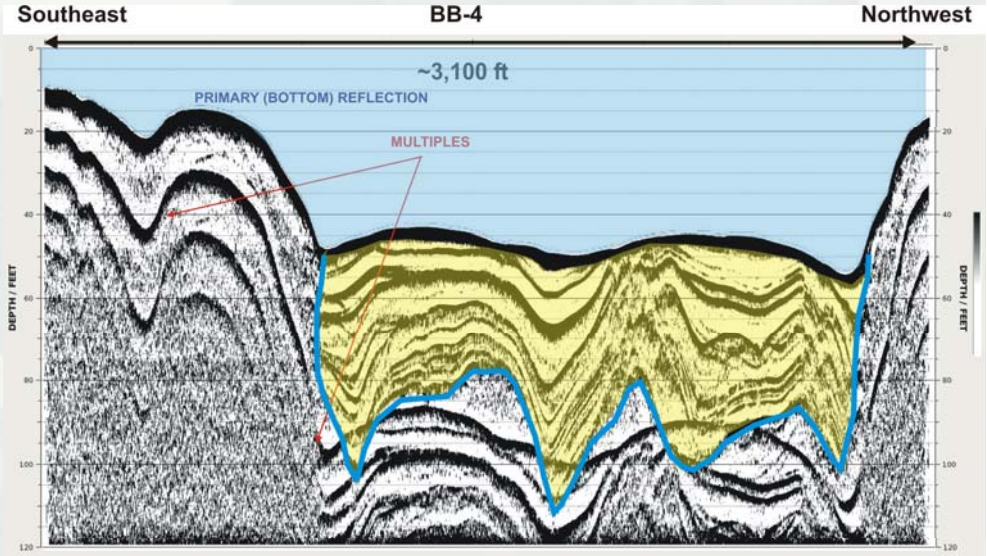
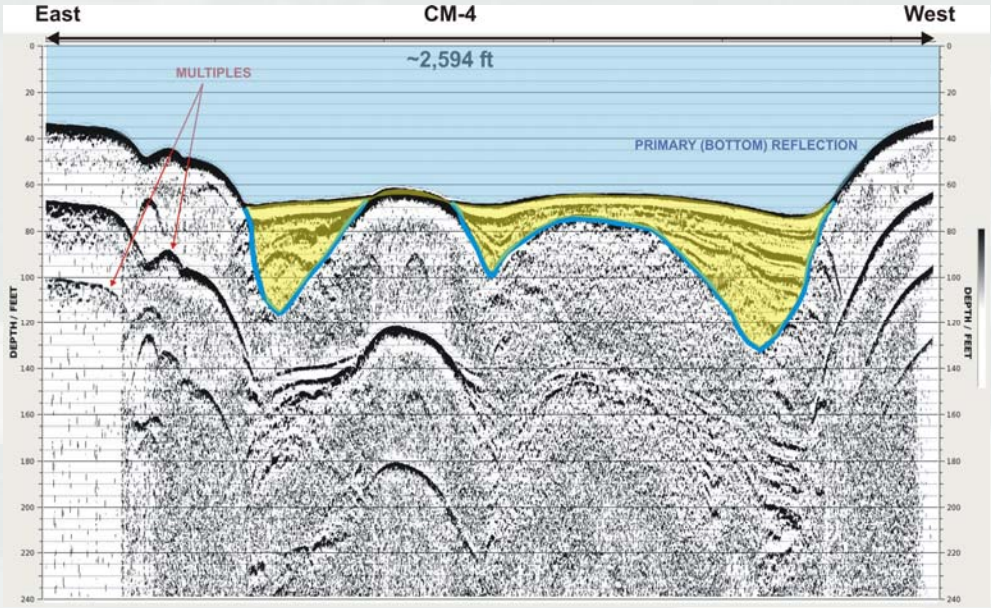
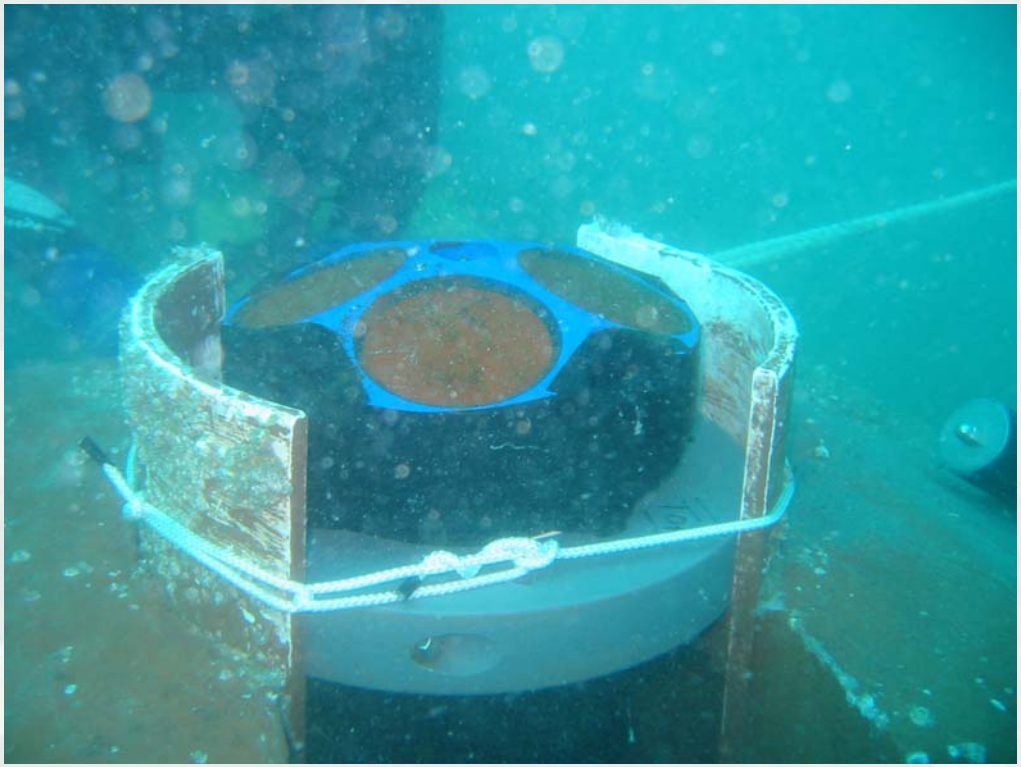


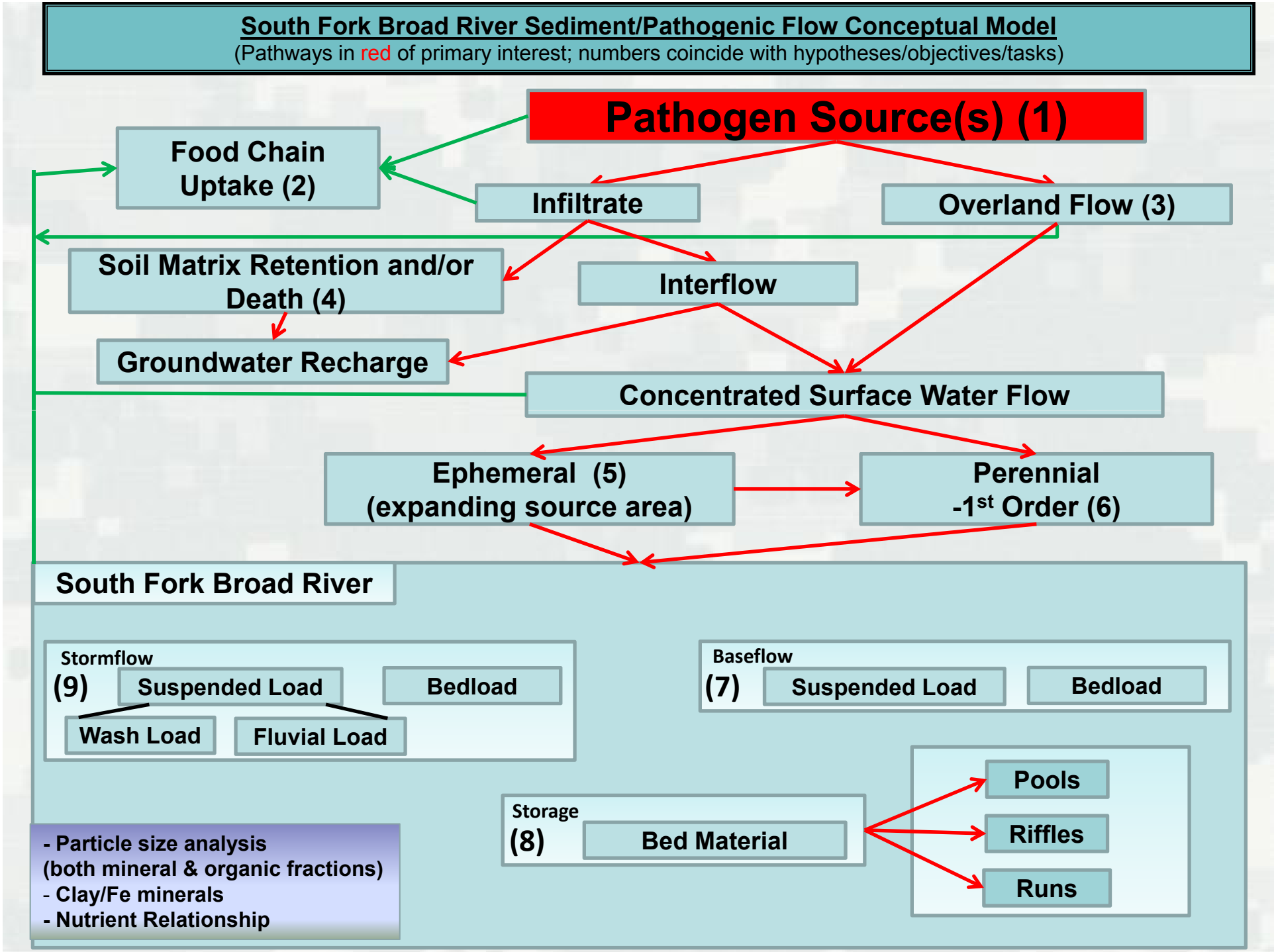

# Sub-Bottom Profiling



Acoustic Doppler Current Profiling

1) Measures velocity at multiple levels
2) Can be calibrated to measure suspended sediment

# Case Study 1:
# Pathogen / Sediment Study


South Fork Broad River Sediment/Pathogenic Flow Conceptual Model
(Pathways in red of primary interest; numbers coincide with hypotheses/objectives/tasks)
Pathogen Source(s) (1)
Food Chain Uptake (2)
Infiltrate
Overland Flow (3)
Soil Matrix Retention and/or Death (4)
Interflow
Groundwater Recharge
Concentrated Surface Water Flow
Ephemeral (5) (expanding source area)
Perennial -1st Order (6)
South Fork Broad River
Stormflow
(9)
Suspended Load
Bedload
Wash Load
Fluvial Load
Baseflow
(7)
Suspended Load
Bedload
Storage
(8)
Bed Material
Pools
Riffles
Runs
- Particle size analysis
(both mineral & organic fractions)
- Clay/Fe minerals
- Nutrient Relationship

# Project Objectives

| CM No. | Objective | LOE | Priority |
|---|---|---|---|
| 1 | Determine pathogen taxa & concentration – Source(s) | Mod | High |
| 2 | Determine direct food chain uptake | High | Low |
| 3 | Determine transport via overland flow | High | Mod |
| 4 | Establish removal via infiltration [soil matrix] | Mod | Low |
| 5 | Identify pathogens in concentrated flow – Ephemeral Flow | High | High |
| 6 | Identify pathogens in concentrated flow – Perennial Flow | Mod | High |
| 7 | Determine suspended load & pathogen concentration during baseflow conditions | Mod | High |
| 8 | Establish pathogen sinks in bedforms (pools vs. riffles vs. runs) | Mod | High |
| 9 | Determine suspended, bed, wash load & pathogen concentration during stormflow conditions | High | High |

**CM No. = Conceptual Model Number; LOE = Level of Effort**

# Testable Hypotheses

| CM No. | Hypothesis (Landscape/Stream-Reach Scale) | Priority |
|---|---|---|
| 1 | Pathogen taxa & concentration can be determined at the source (can we discriminate between various sources) | High |
| 2 | Food chain uptake of pathogens can be established | Low |
| 3 | Pathogens can be identified in overland flow surface water | High |
| 4 | Pathogens can be retained in the soil matrix & removed from the biosphere | Low |
| 5 | Pathogens can be identified in ephemeral concentrated flow | High |
| 6 | Pathogens can be identified in perennial concentrated flow | High |
| 7a | Pathogens can be identified during baseflow conditions in the water column of the SFBR (seasonal variability possible) | High |
| 7b | Pathogens can be identified during baseflow conditions in the sediment of the SFBR (seasonal variability possible) | High |
| 8 | Pathogens can be identified in the bed material; Pathogens are stored in different concentrations depending on bedform type, organic & mineral fractions | High |
| 9 | Same as 7a and 7b during stormflow conditions; can we discriminate between organic & mineral fractions in fluvial sediment | Mod |
| **CM No.** | **Hypothesis (Watershed Scale)** | **Priority** |
| 1, 3, 5, 6 → 8 | There is a relationship between location of stored pathogens and sources (e.g., Point and Non-Point Sources, GIS land use vs. concentration/taxa, etc.) | Mod |
| 1, 3, 5, 6,9 → 8 | There is distance limit from the pathogen source | High |
| 1, 3, 5, 6,9 → 8 | There is a source dependent relationship the pathogen type and transport down stream | Mod |

**CM No. = Conceptual Model Number**

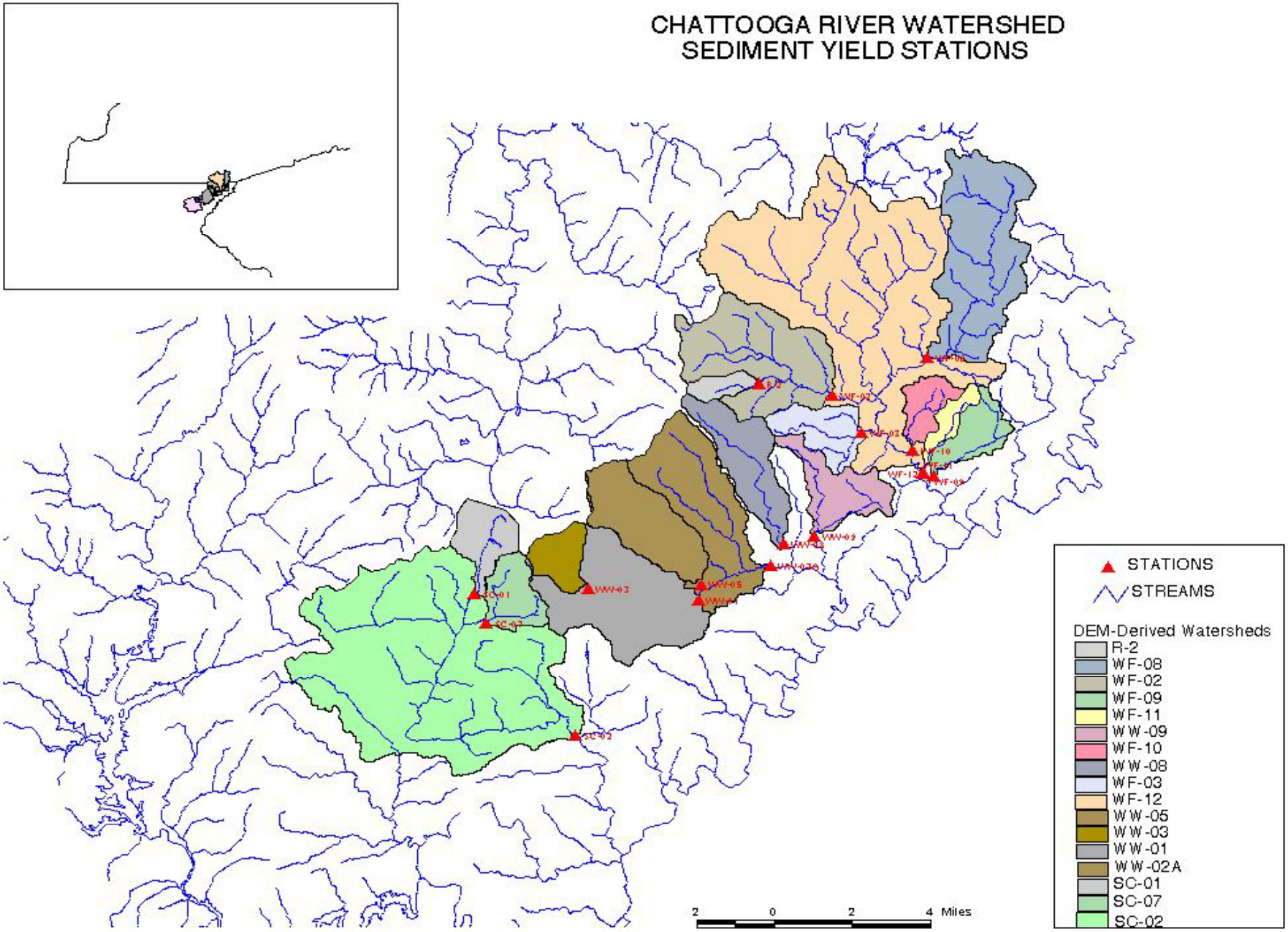
# Tasks / Deliverables

| Priority | CM No. | Task (Recommended Stepwise Order) | LOE |
|---|---|---|---|
| 1 | 7, 8 | Characterize (physical) a representative reach to establish geomorphic features and sediment properties at each specified sample point | High |
| 1 | 7, 8 & 9 | Sample water column & sediment in bedforms within representative reach for specific pathogens & markers | High |
| 1 | 1, 2, 3, 4 | Collect soil samples at the source (baseflow vs. stormflow) for specific pathogens & markers | Mod |
| 2 | 7, 8 | Establish means of discriminating between “free” bacteria in sediment water vs. attached (e.g., whole cores extraction, pore water, etc.) | High |

| CM No. | Product/Deliverable | Time Frame |
|---|---|---|
| 1 thru 6 | Identify major sources/sinks, transport pathway(s), mechanism(s) & fate of pathogens of concern | LT |
| 7 & 9 | Establish relationship b/t turbidity & stage (including seasonal variation) | ST/LT |
| 1 thru 6 | Develop correspondence b/t landuse & Pathogen location and concentration | ST |
| 7 & 9 | Establish relationship b/t TSS or SSC & turbidity | ST/LT |
| 7, 8 & 9 | Develop, test & validate surrogates for bedload | LT |
| 7, 8 & 9 | Develop correspondence b/t sediment yield & stream condition | LT |
| 7, 8 & 9 | Compare sediment yield against available sediment databases | LT |

**CM No. = Conceptual Model Number; LT = Long Term; ST = Short Term; TSS = Total Suspended Solids; SSC = Suspended Sediment Concentration**

# Case Study 2: Chattooga River Sediment / Ecological Investigation

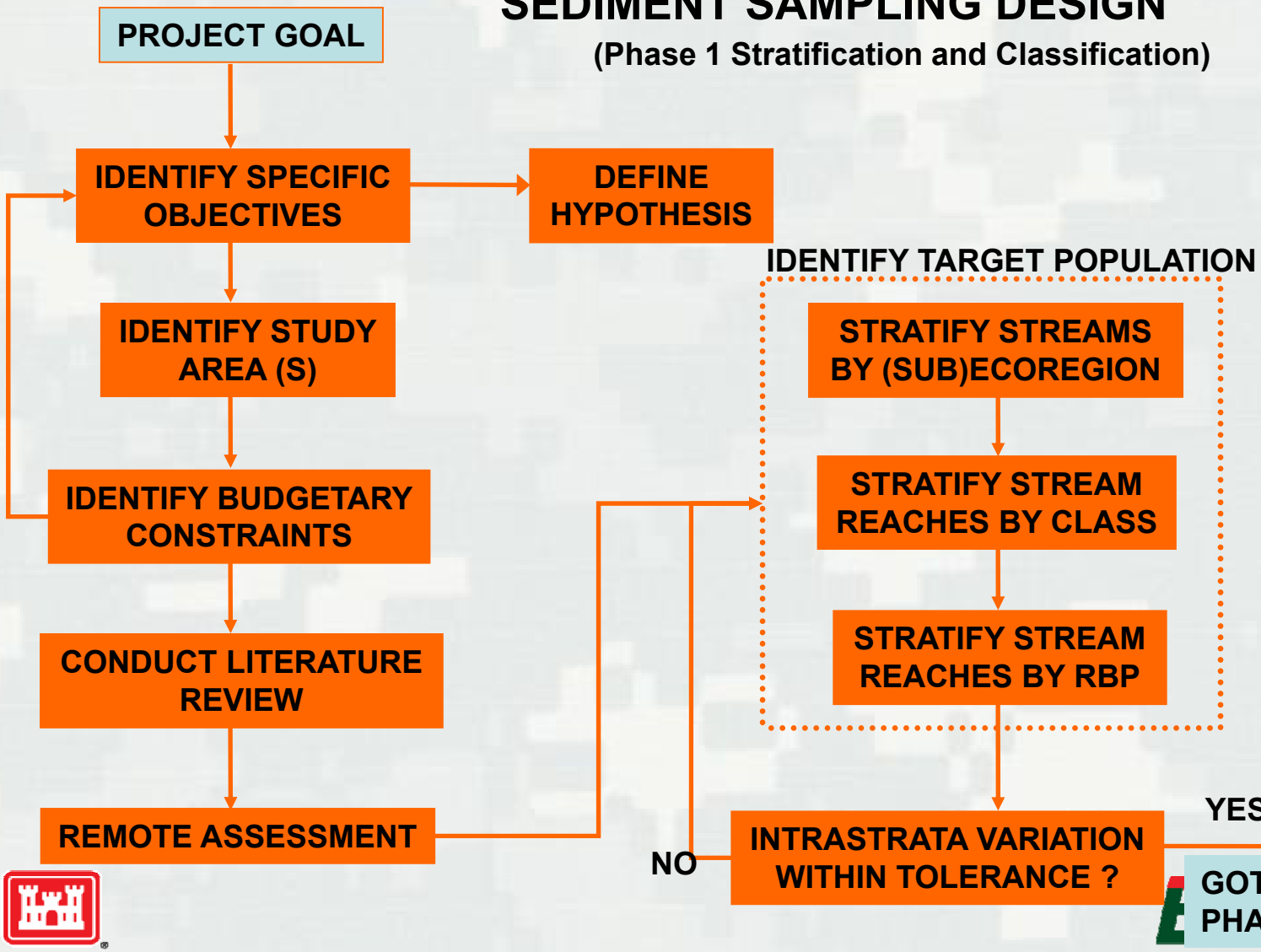

CHATTOOGA RIVER WATERSHED
SEDIMENT YIELD STATIONS
STATIONS
STREAMS
DEM-Derived Watersheds
R-2
WF-08
WF-02
WF-09
WF-11
WW-09
WF-10
WW-08
WF-03
WF-12
WW-05
WW-03
WW-01
WW-02A
SC-01
SC-07
SC-02
2 0 2 4 Miles

# OBJECTIVES

- Develop Sediment Protocol for Sampling and Data Analysis
- Integrate Sediment Protocol with Aquatic Ecology
- Develop Standards Protective of Stream Functions and Beneficial Uses

# SEDIMENT SAMPLING DESIGN

(Phase 1 Stratification and Classification)



# STRATIFY BY RAPID BIOASSESSMENT PROTOCOL (RBP)

- Assessed 59 Sites

(3 ID'ed as Reference)

- 17 Metrics Tested

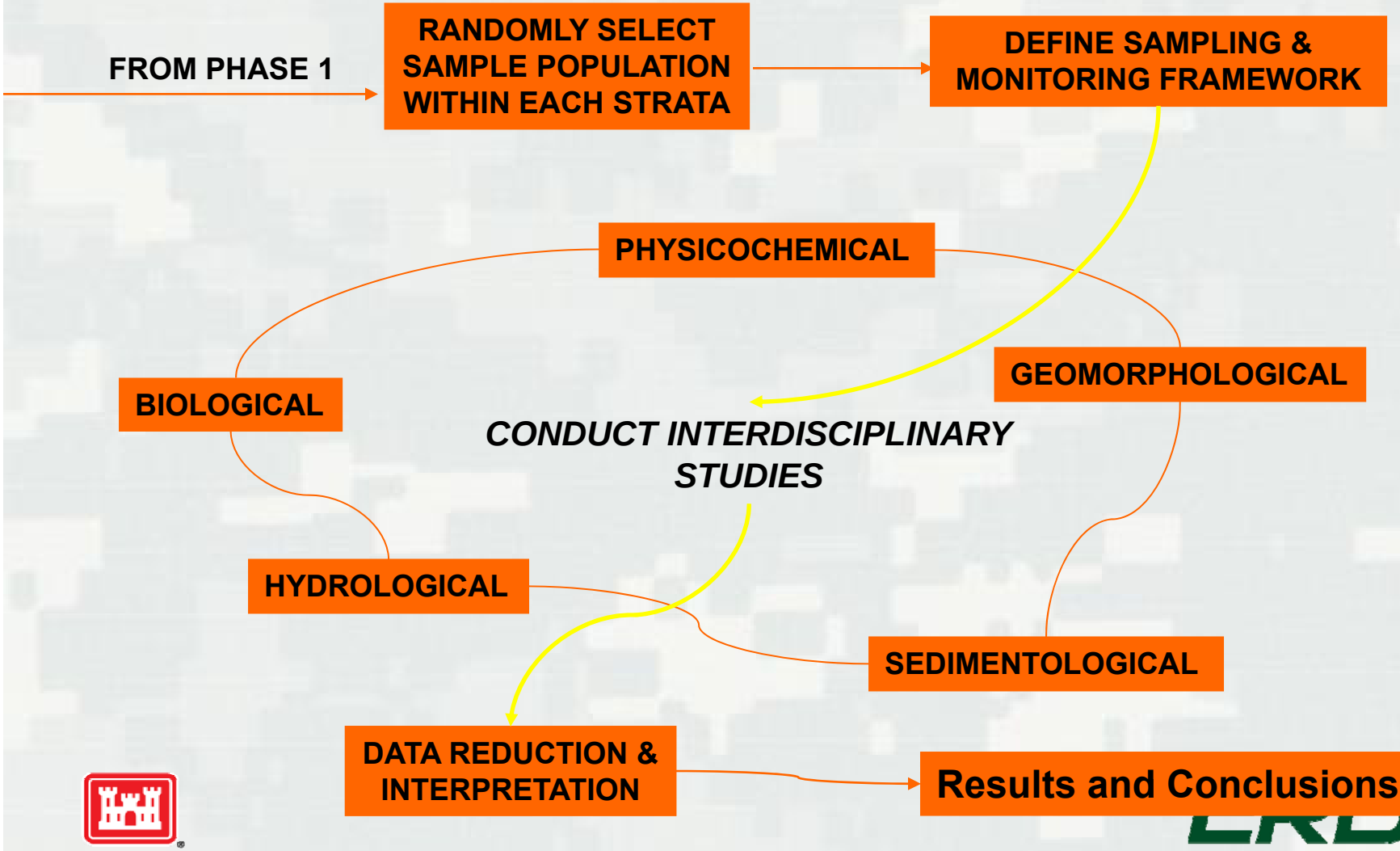
(5 Sensitive to Sed. Impairment –

EPT, %EPT, %Dom Taxa, NCBI, Clingers

- Very Good
- Good
- Fair
- Poor
- Very Poor

# SEDIMENT SAMPLING DESIGN

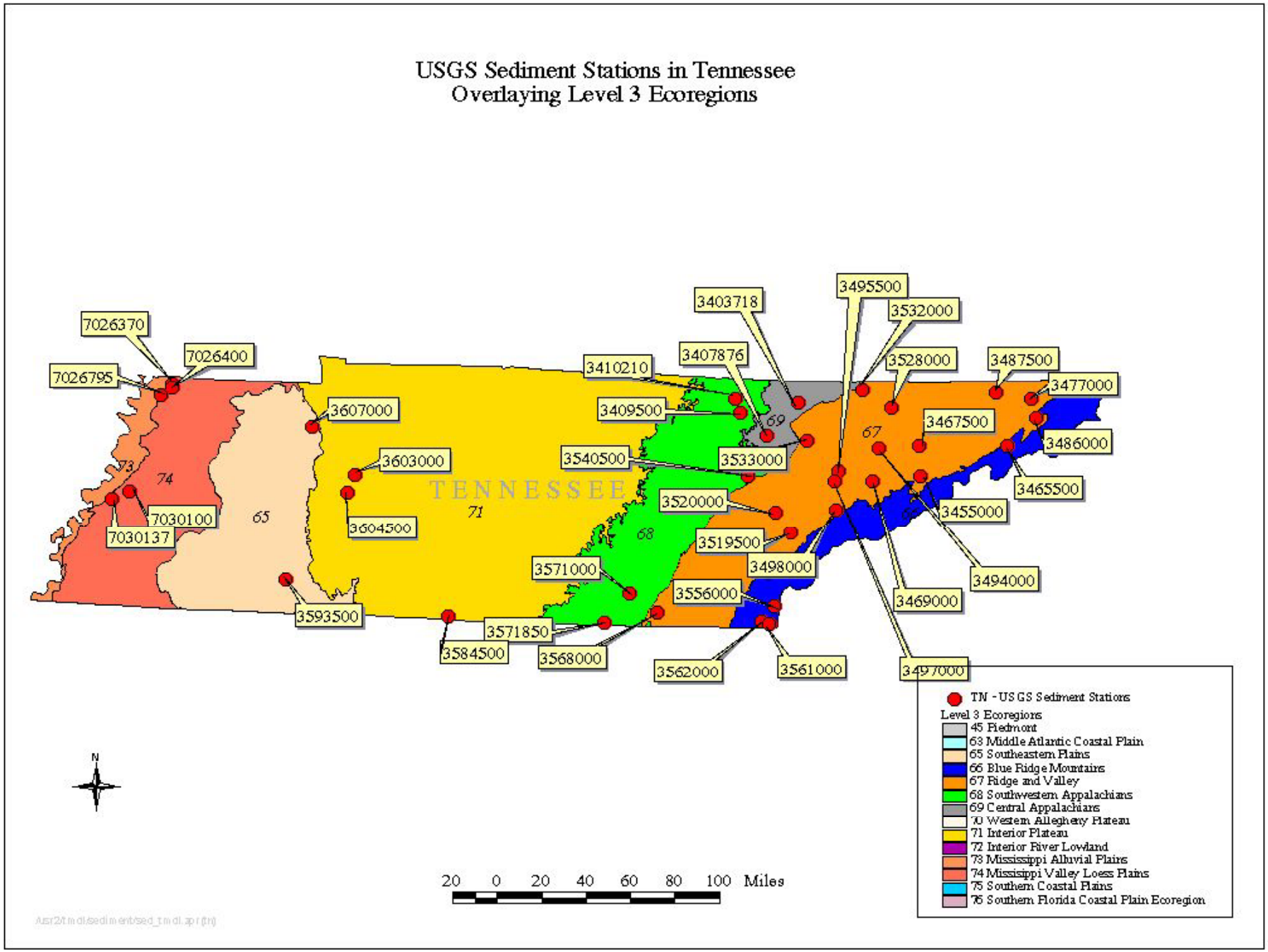
(Phase 2: Project Sampling Design)



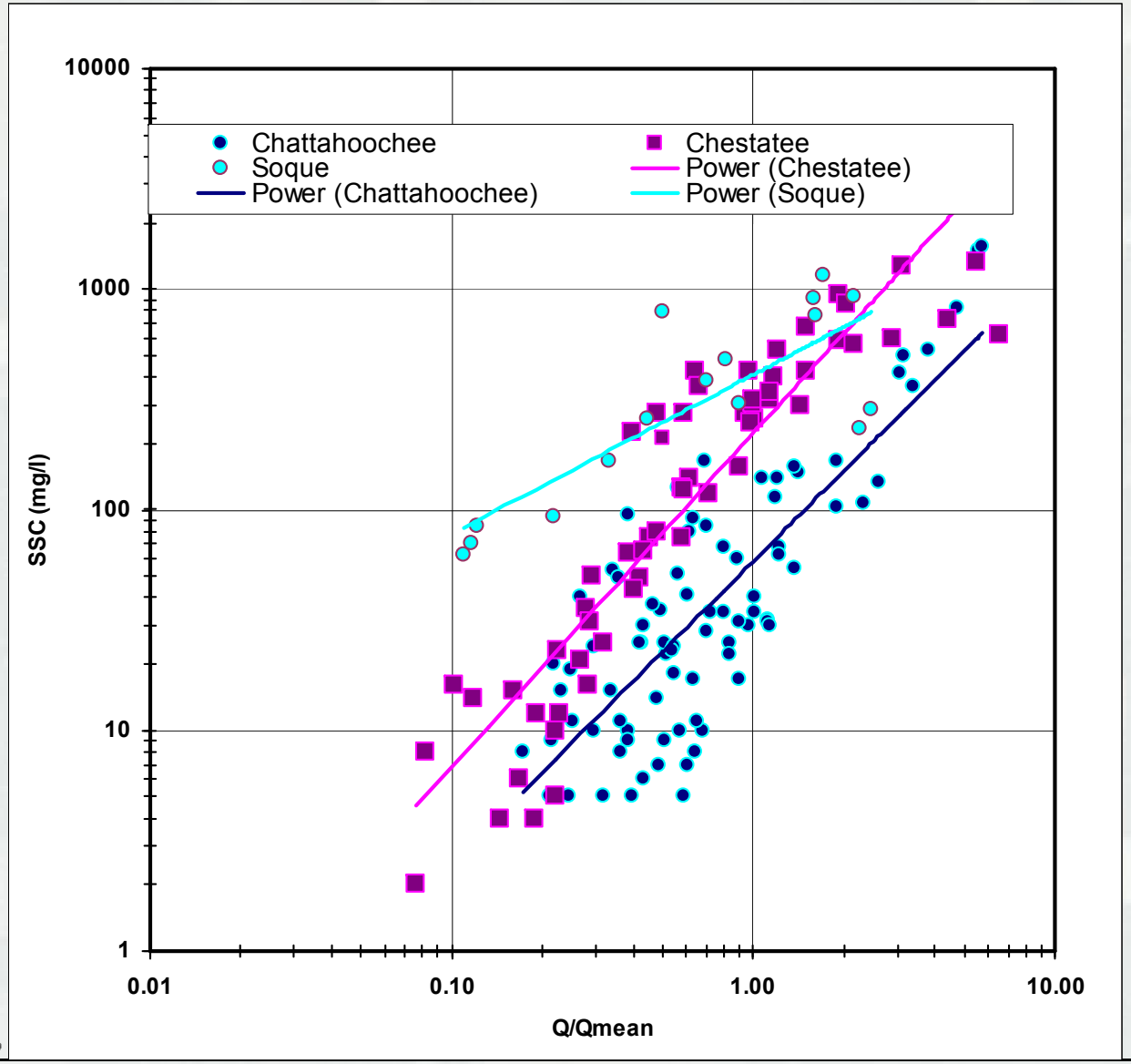
# *In-Situ* SEDIMENT SUSPENDED LOAD SAMPLING

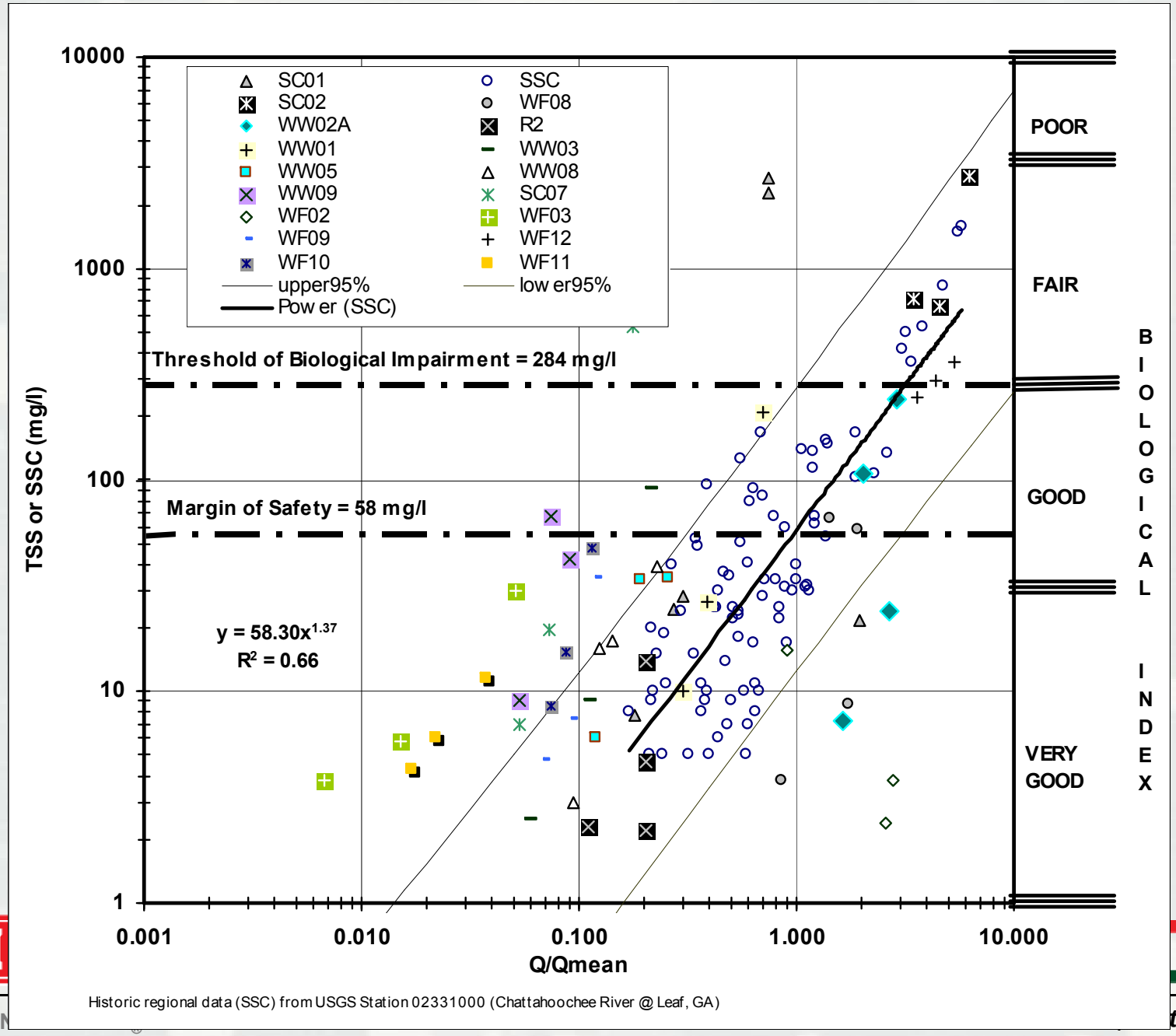
**SINGLE-STAGE SAMPLER/MULTIPARAMETER PROBE**

**AUTOMATED, STAGE-ACTUATED SAMPLER**


USGS Sediment Stations in Tennessee
Overlaying Level 3 Ecoregions
TENNESSEE
7026370
7026400
7026795
3607000
3603000
3604500
7030100
7030137
3593500
3584500
3571850
3568000
3571000
3410210
3409500
3407876
3403718
3540500
3533000
3520000
3519500
3498000
3556000
3562000
3561000
3495500
3532000
3528000
3487500
3477000
3467500
3486000
3465500
3455000
3494000
3469000
3497000
73
74
65
71
68
69
67
TN - USGS Sediment Stations
Level 3 Ecoregions
45 Piedmont
63 Middle Atlantic Coastal Plain
65 Southeastern Plains
66 Blue Ridge Mountains
67 Ridge and Valley
68 Southwestern Appalachians
69 Central Appalachians
70 Western Allegheny Plateau
71 Interior Plateau
72 Interior River Lowland
73 Mississippi Alluvial Plains
74 Mississippi Valley Loess Plains
75 Southern Coastal Plains
76 Southern Florida Coastal Plain Ecoregion
N
20 0 20 40 60 80 100 Miles

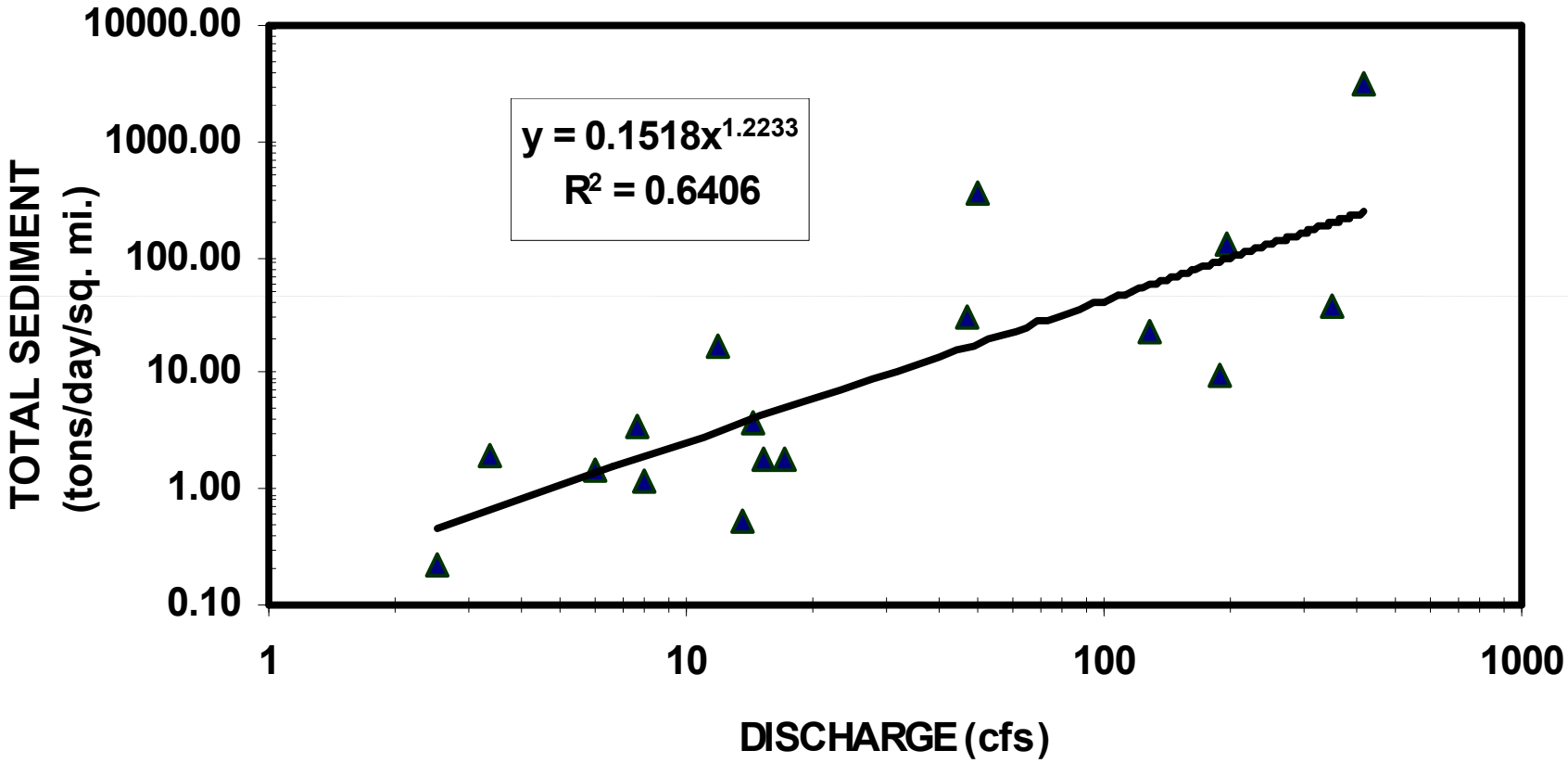
# Selection of Background Sediment Dataset

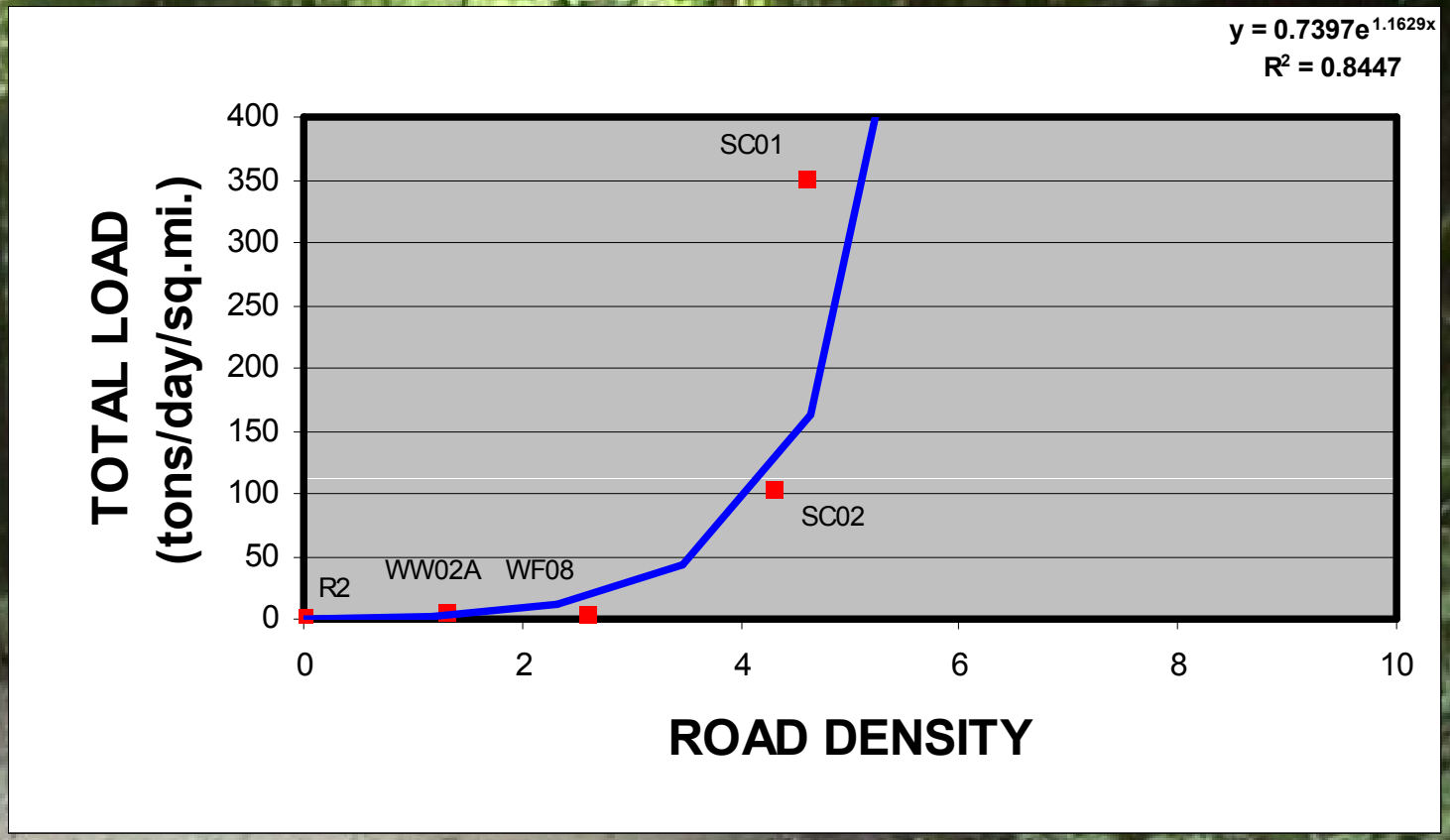





Historic regional data (SSC) from USGS Station 02331000 (Chattahoochee River @ Leaf, GA)

## FIGURE 4. TOTAL SEDIMENT RATING CURVE (All Stations)

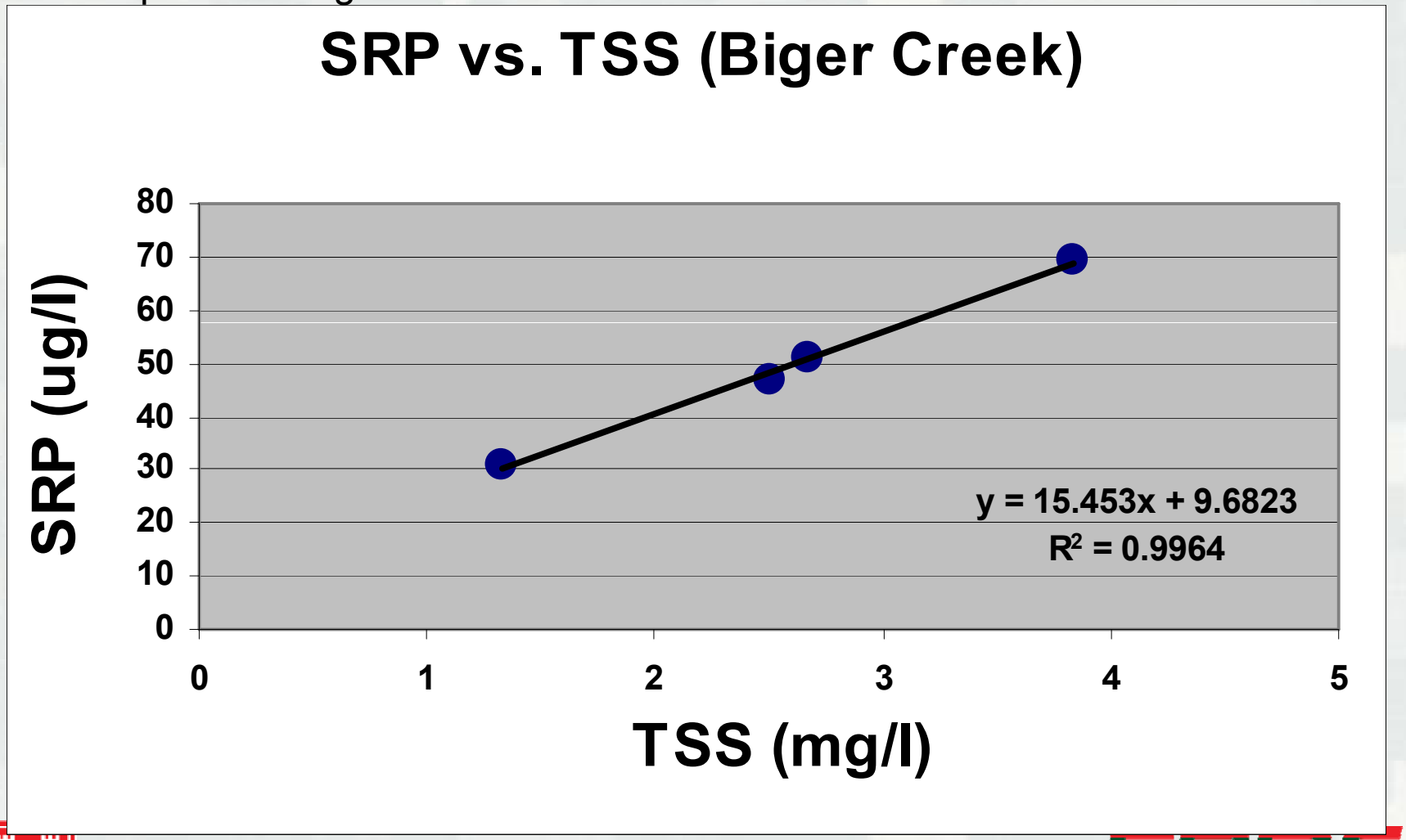





Road density = Length of road divided by the corresponding watershed area

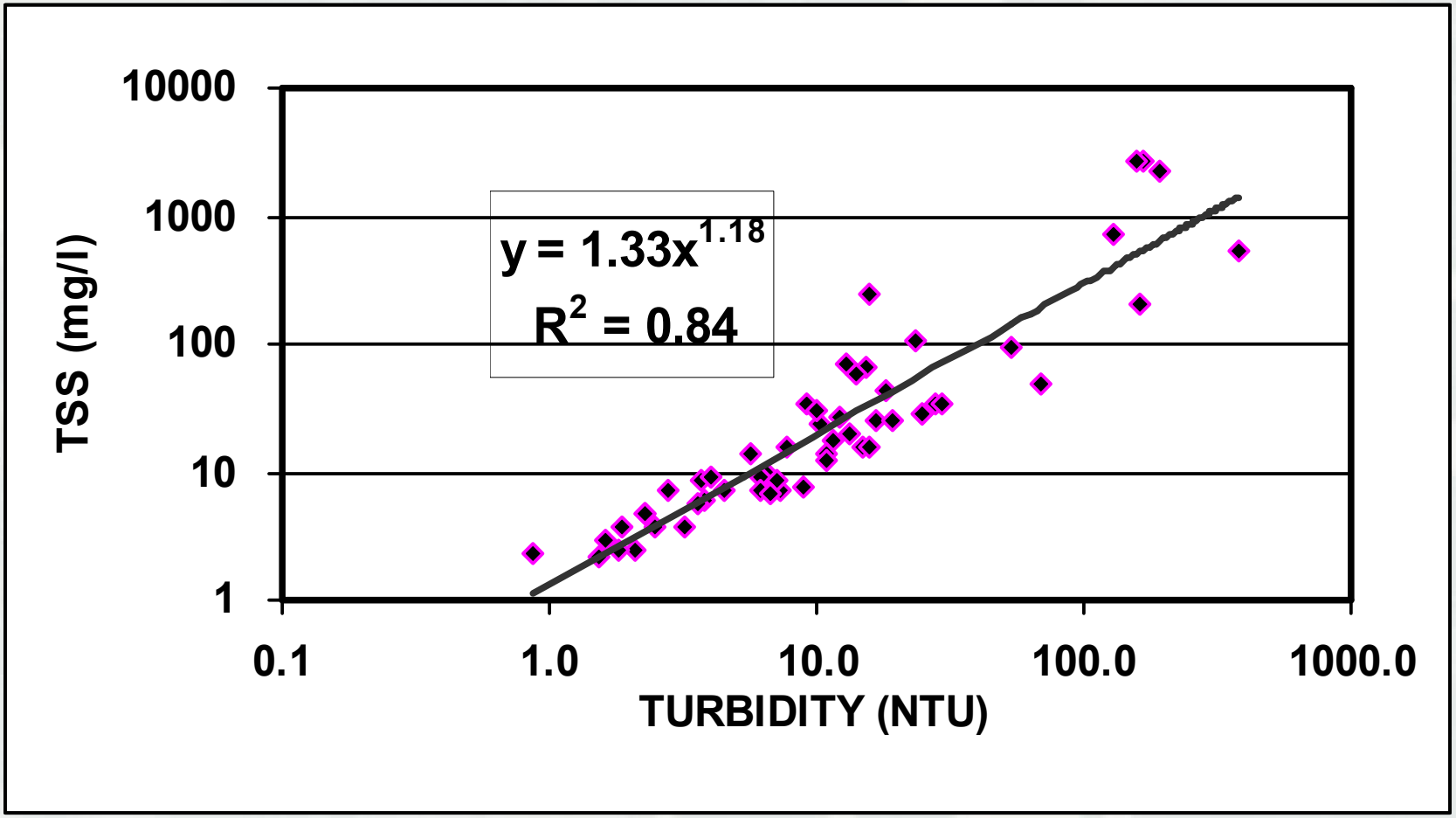
# SOLUBLE REACTIVE PHOSPHORUS vs. TSS

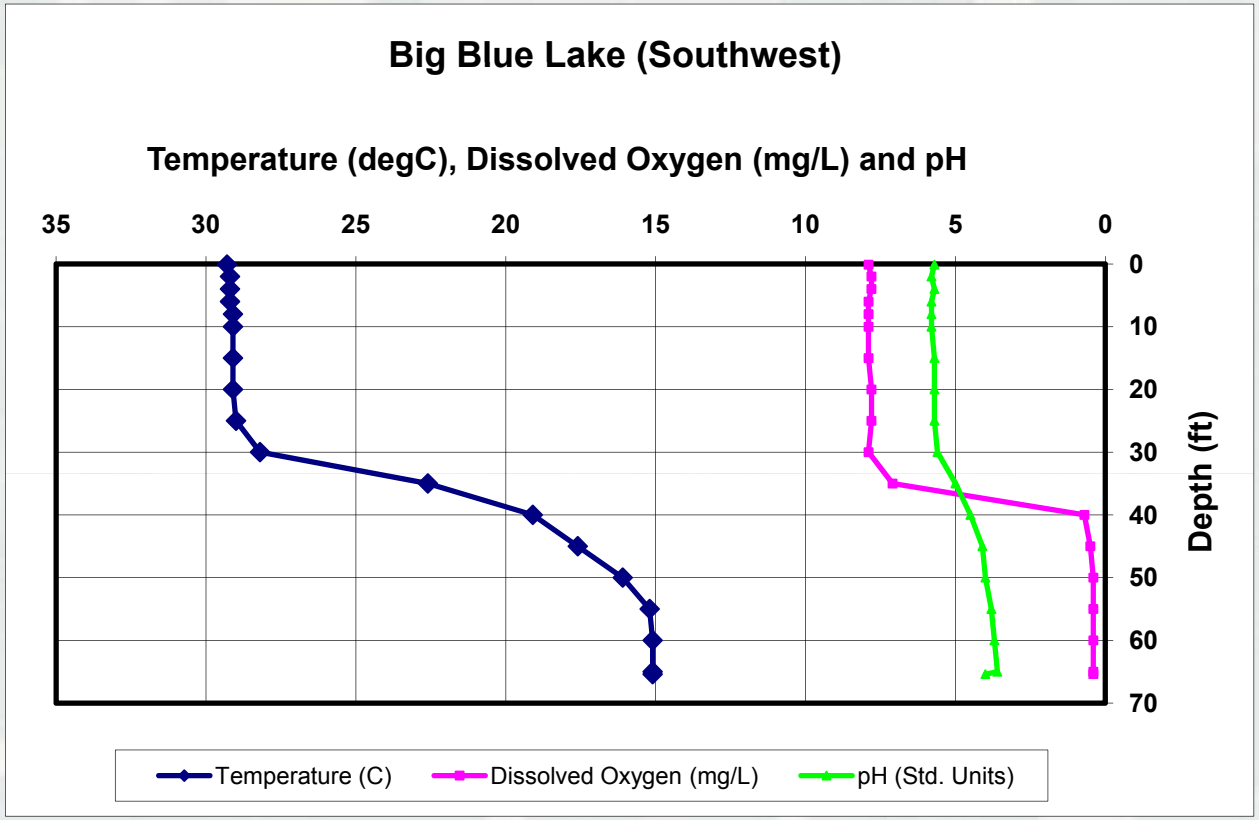
Develop the Surrogate!



# TOTAL SUSPENDED SOLIDS vs. TURBIDITY

Develop the Surrogate!




Big Blue Lake (Southwest)
Temperature (degC), Dissolved Oxygen (mg/L) and pH
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
Depth (ft)
Temperature (C)
Dissolved Oxygen (mg/L)
pH (Std. Units)

# CONCLUSIONS

- Good Correspondence Observed Between Biological Index and Normalized Suspended Load
- [TSS] > 284 mg/l Adversely Affected Aquatic Biological Structure
- [TSS] < 58 mg/l During Stormflow Provides Adequate MOS (Protective of Aquatic Life and Supportive of Beneficial Uses)
- Corresponding Turbidity Limits of 69 and 22 NTUs Establish the Thresholds of Biological Impairment and MOS, Respectively

# RECOMMENDATIONS

- DEVELOP *NUMERIC* STANDARDS THAT INTEGRATE TOTAL SEDIMENT LOADING AND BIOLOGICAL ENDPOINTS
- BASE STANDARDS ON DISCHARGE AND/OR STAGE UTILIZING A *SLIDING SCALE* (DIMN. SED. RATING CURVE, BIO-SED CURVE)
- ESTABLISH SURROGATES: TSS vs. NTU; BEDLOAD vs. 1/3 LOWER BAR; EMBEDDEDNESS vs. BEDLOAD; SEDLOAD vs. PFANKUCH; SEDLOAD vs. BANK STABILITY
- IDENTIFY SOURCES AND SINKS
- IMPLEMENT REGS, POLICY, BMP's, AND RESTORATION PROTECTIVE OF STREAM FUNCTION AND BENEFICIAL USES

# REWIND

1. Understand the question, need, and the decision that needs to be made.
2. Identify goals and objectives, formulate testable hypotheses, and develop a water quality and sediment monitoring plan which supports the decision-making process
3. Project scale, stratification, classification
4. Conceptual model
5. Hydrologic and aquatic geochemical processes ~ water quality, sediment issues, and development of a monitoring plan
6. Correspondence between direct measures and laboratory analyses and surrogates
7. Other

## Suggested References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# Questions and Feedback

**Presentation recording:**
http://el.erdc.usace.army.mil/wots/wots.html

**Next Presentation:** 7 November 2013, 10:30AM:
Geomorphic, Hydrologic and Hydraulic Surveys,
Sarah Miller, ERDC-EL

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