Development of a Distributed Watershed Water Quality Model

Joint 8th Federal Interagency Sedimentation Conference and
3rd Federal Interagency Hydrologic Modeling Conference
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Discussion Items

- System-Wide Water Resources Program (SWWRP)
- Gridded Surface Sub-surface Hydrologic Analysis (GSSHA) model
- SWWRP-NSM Kinetic Modules
- Model Validation Studies
- Future Development Activities

SWWRP Nutrient Module Development

Research Effort

As Environmental Problems have become more complex and system oriented, it has become necessary to describe nutrient fate and transport on a more physical basis.

In order to evaluate individual projects in sufficient detail and at the same time evaluate projects on a system wide basis, complex models have to be able to exchange information with each other.

SWWRP Nutrient Module Development
Research Effort

To have a full system-wide water quality and contaminant capability in SWWRP, the different hydrologic and hydraulic engines must utilize a common water quality and contaminant approach to prevent the arbitrary portioning of constituents.

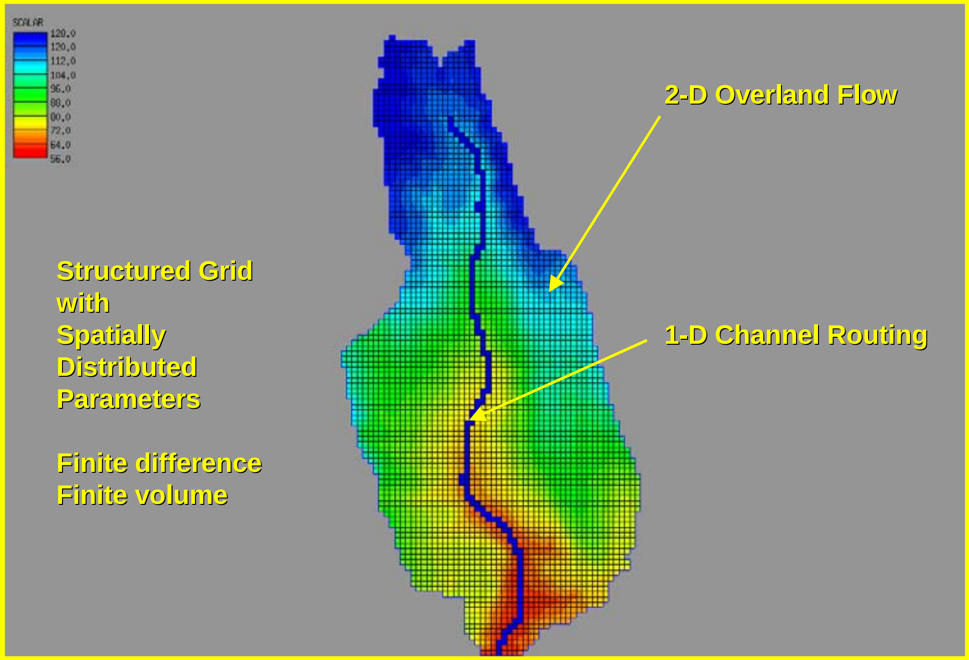
The goal of this research effort is to upgrade existing hydrologic and hydraulic models (i.e., water engines) using a common water quality approach in order to facilitate their linkage and application on a system wide basis.

SWWRP Nutrient Module Development

Gridded Surface Sub-surface Hydrologic Analysis (GSSHA) Model

GSSHA Flow and Sediment Modules

- **Spatial distribution of precipitation**
- **2D Overland flow (Diffusive Wave)**
- **1D Channel flow (Diffusive Wave)**
- **Infiltration (Green-Ampt, Green-Ampt Redistribution, and Richard's Eq.)**
- **Evapo-transpiration (Penman-Monteith and Deardorff)**
- **2D/3D Lateral groundwater flow**
- **Surface water/Groundwater Interaction**
- **Snow accumulation and melting**
- **Overland and channel sediment transport**



SWWRP Nutrient Module Development

GSSHA Modeling Sessions

For Additional Information on GSSHA Flow and Sediment Modules

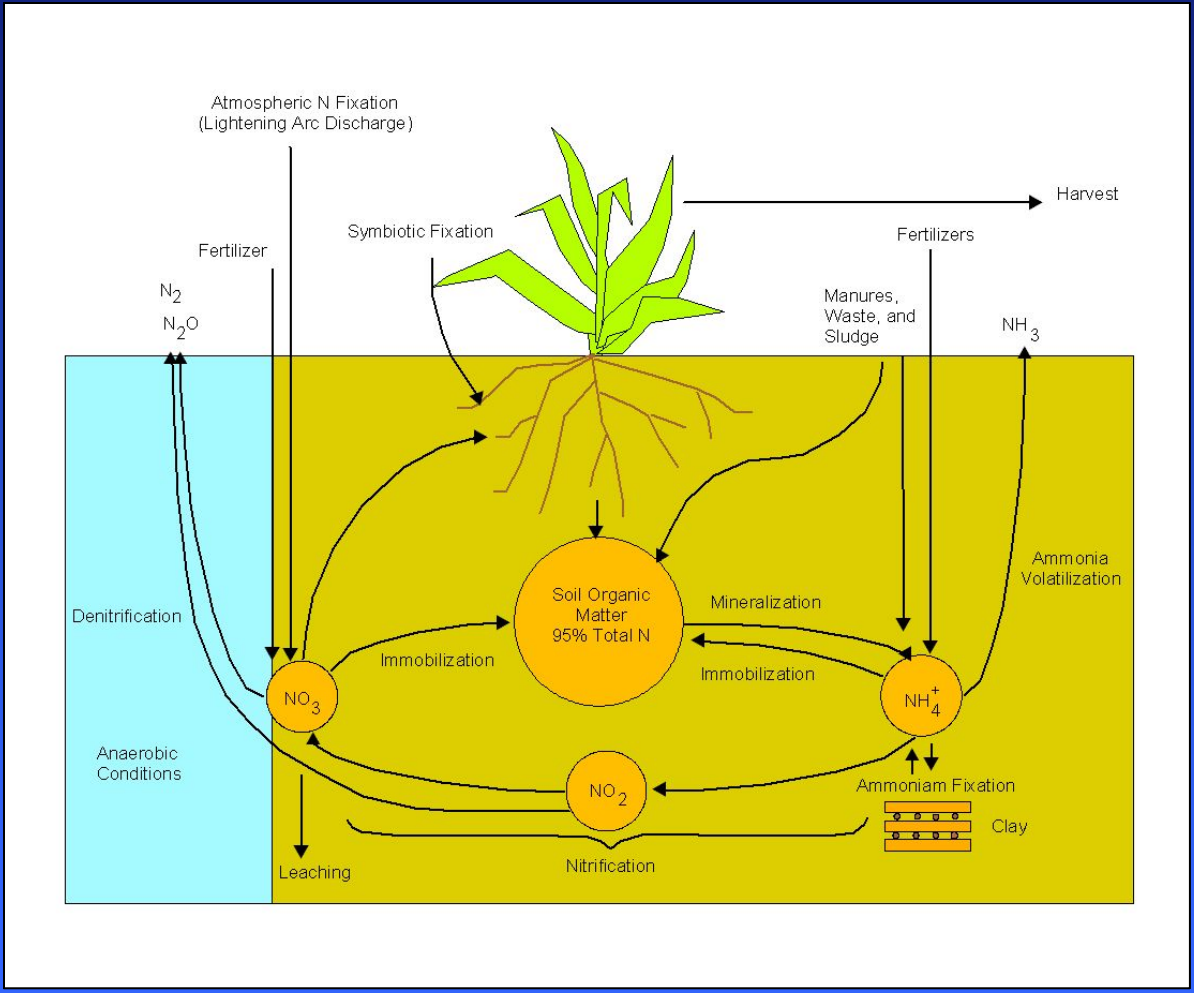
Session 1A (2:30 pm) - FRAMEWORK OF YEARLY STREAM SEDIMENT INPUT: Aaron Byrd

Session 2D (4:30 pm) - MODELING WETLANDS IN A MULTI-DIMENSIONAL HYDROLOGIC MODEL: Aaron Byrd, Fred L. Ogden, Robbie Jenkins, Justin Niedzialek, and E. James Nelson

Session 9F (2:10 pm) - MODELING STORM AND TILE DRAINS IN A MULTI-DIMENSIONAL HYDROLOGIC MODEL: Aaron Byrd, Justin Niedzialek, and Fred L. Ogden

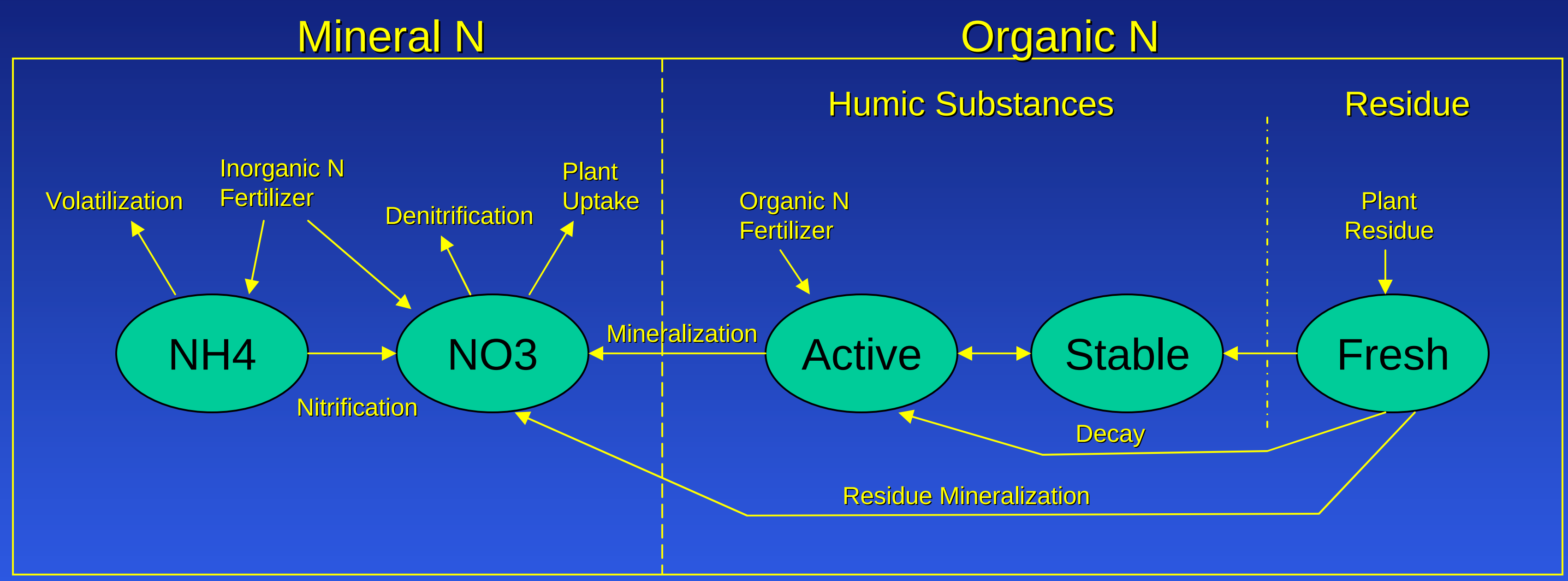
SWWRP Nutrient Module Development

Plant/Soil Nitrogen Cycle



SWWRP Nutrient Module Development

Nitrogen Partitioning



$$\frac{d(orgN_{frs})}{dt} = (-N_{minf} - N_{dec} - N_{ersf} + N_{extf})$$

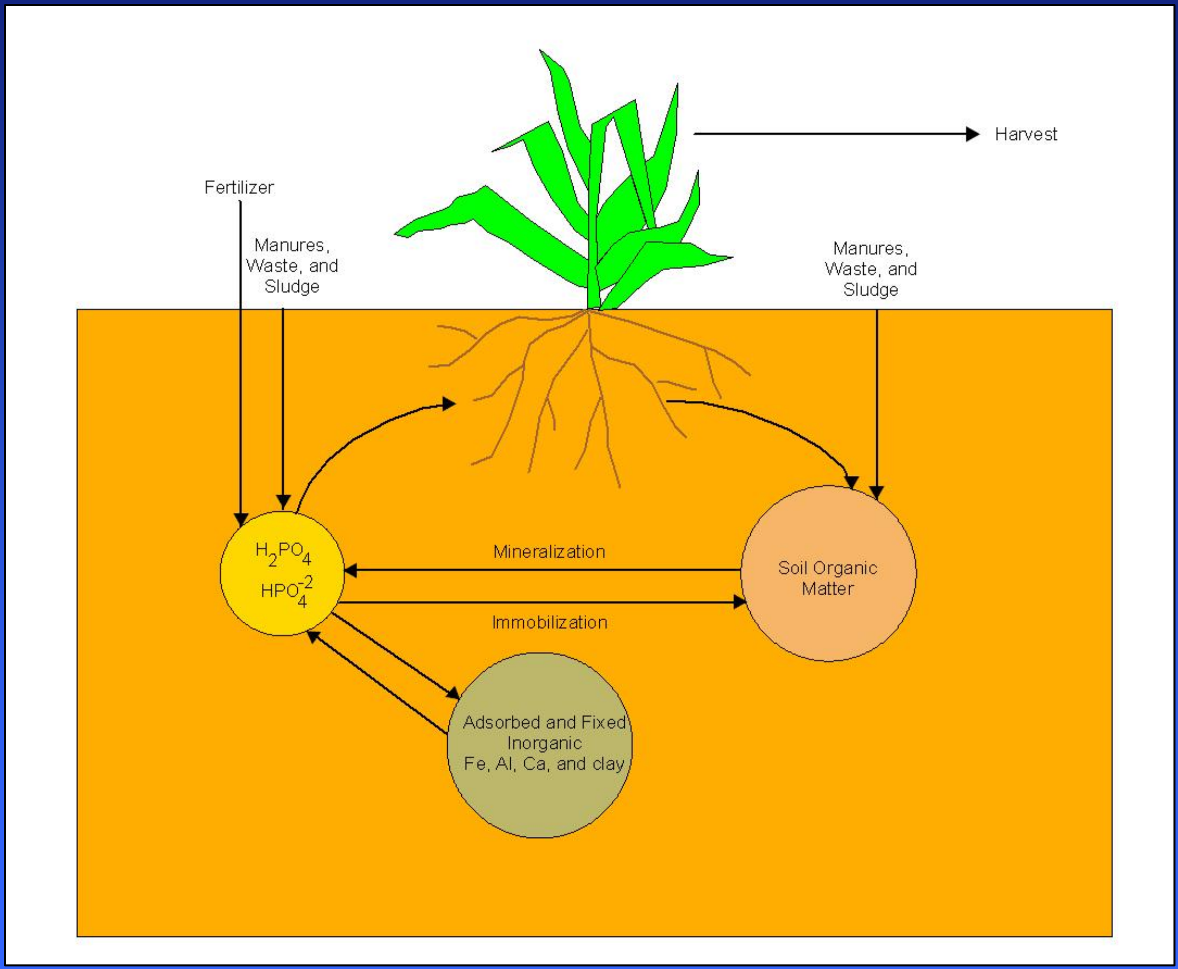
$$\frac{d(NH_4^+)}{dt} = (N_{\min} - N_{nit|vol} - N_{up4} - N_{ers4} + N_{ext4})$$

$$\frac{d(orgN_{act})}{dt} = (N_{dec} + N_{trn} - N_{mina} - N_{ersa} + N_{exta})$$

$$\frac{d(NO_3^-)}{dt} = (N_{nit} - N_{dnit} - N_{up3} - N_{\inf} + N_{ext3})$$

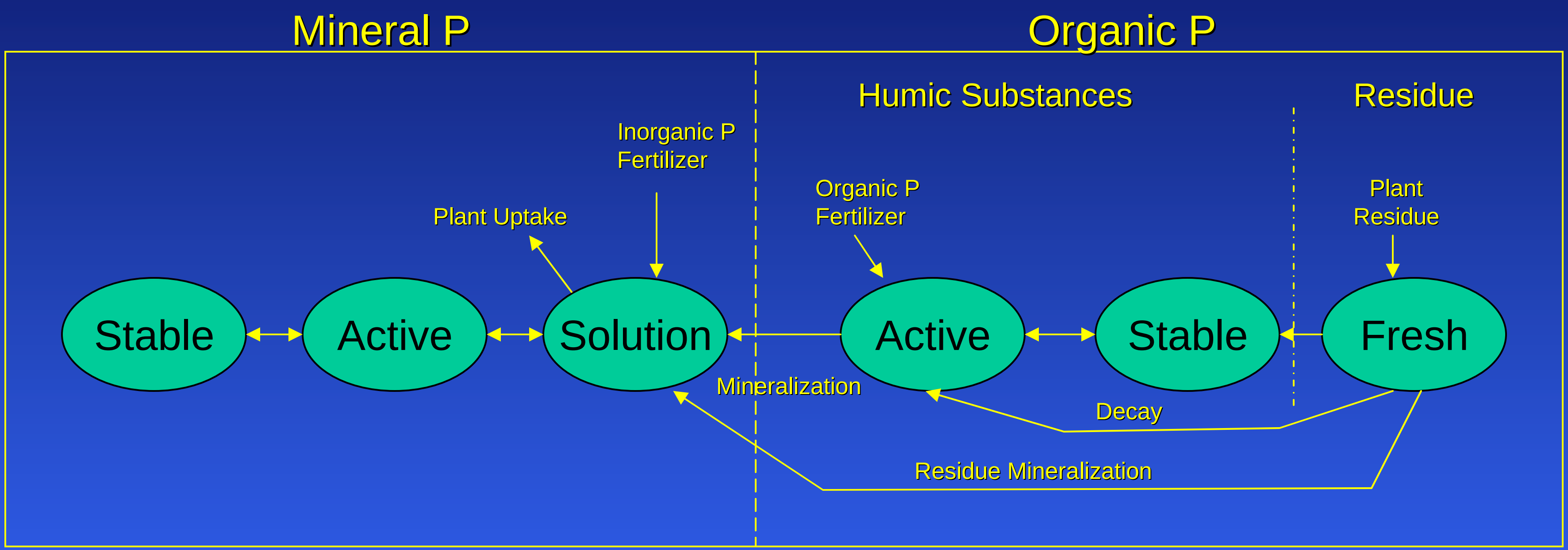
SWWRP Nutrient Module Development

Plant/Soil Phosphorus Cycle



SWWRP Nutrient Module Development

Phosphorus Partitioning



$$\frac{d(orgP_{frs})}{dt} = -P_{minf} - P_{dec} - P_{ersf} + P_{extf}$$

$$\frac{d(minP_{act})}{dt} = -P_{sol|act} + P_{act|sta} - P_{ersa} + P_{exta}$$

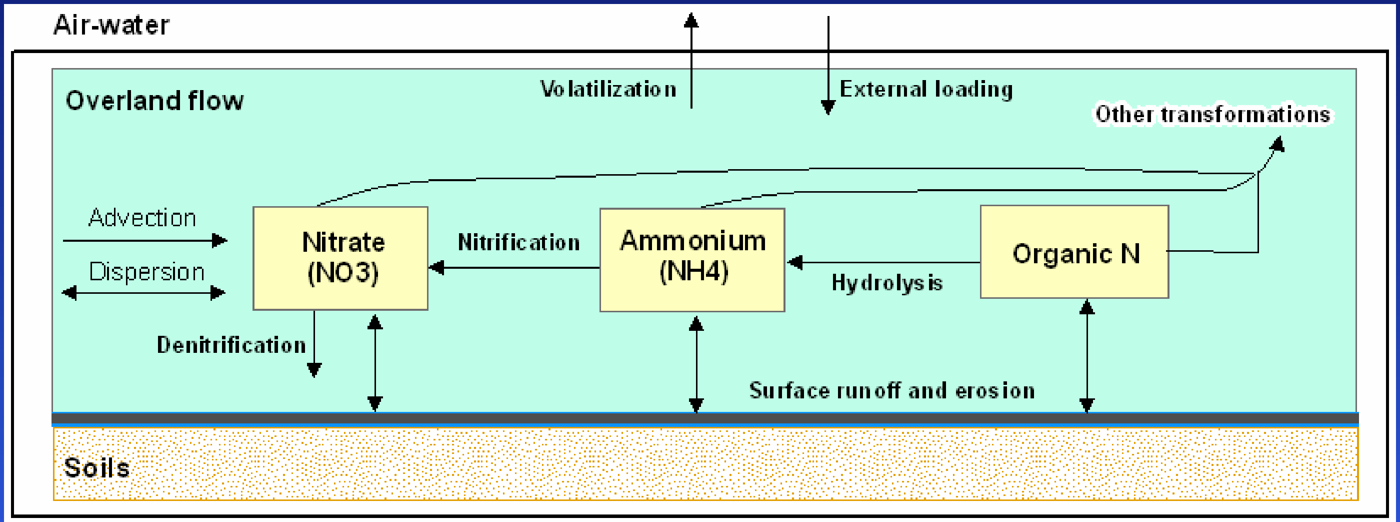
$$\frac{d(orgP_{act})}{dt} = P_{dec} - P_{mina} - P_{ersa} + P_{exta}$$

$$\frac{d(solP)}{dt} = P_{\min} + P_{sol|act} - P_{up} - P_{\inf} + P_{extd}$$

$$\frac{d(minP_{sta})}{dt} = -P_{act|sta} - P_{erss} + P_{exts}$$

SWWRP Nutrient Module Development

Overland Nitrogen Processes



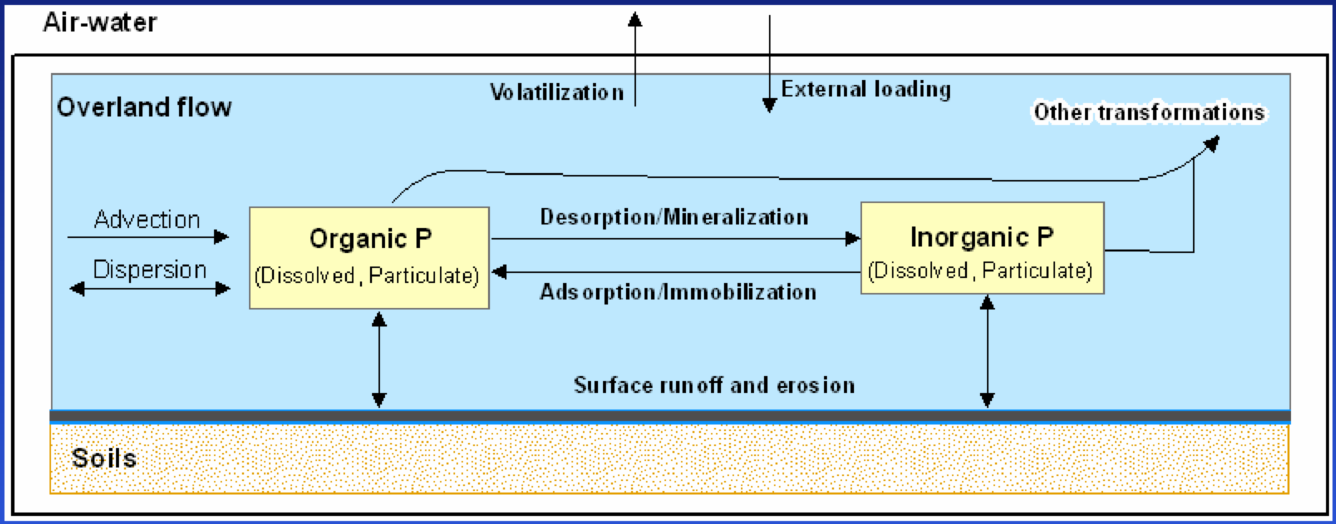
$$\frac{\partial(h\cdot orgN_{ov})}{\partial t}+\frac{\partial N_{x,org}}{\partial x}+\frac{\partial N_{y,org}}{\partial y}=-N_{dep,org}+N_{ers,org}+N_{alg}-N_{hyd}+N_{ext,org}$$

$$\frac{\partial(h\cdot NH_{4\ ov}^{+})}{\partial t}+\frac{\partial N_{x,NH}}{\partial x}+\frac{\partial N_{y,NH}}{\partial y}=-N_{dep,NH}+N_{ers,NH}+N_{hyd}-N_{nit}+N_{ext,NH}$$

$$\frac{\partial(h\cdot NO_{3\ ov}^{-})}{\partial t}+\frac{\partial N_{x,NO}}{\partial x}+\frac{\partial N_{y,NO}}{\partial y}=-N_{dep,NO}+N_{ers,NO}+N_{nit}-N_{dnit}+N_{ext,NO}$$

SWWRP Nutrient Module Development

Overland Phosphorus Processes



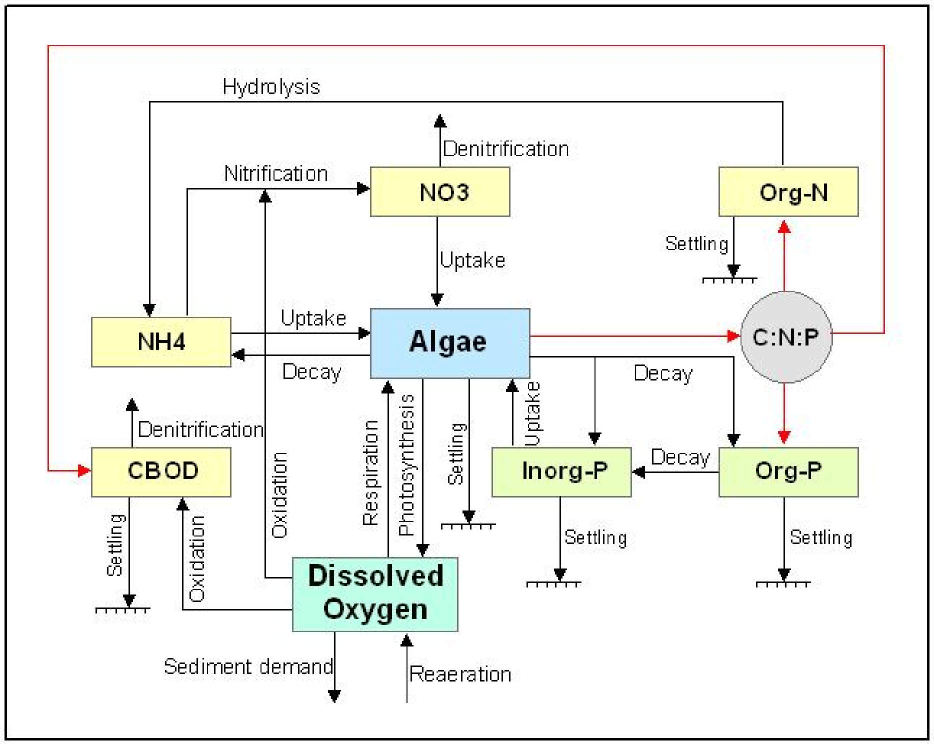
$$\frac{\partial(h \cdot irgP_{ov})}{\partial t} + \frac{\partial P_{x,irg}}{\partial x} + \frac{\partial P_{y,irg}}{\partial y} = -P_{dep,irg} + P_{ers,irg} + P_{sol|irg} + P_{\min} + P_{ext,irg}$$

$$\frac{\partial(h \cdot orgP_{ov})}{\partial t} + \frac{\partial P_{x,org}}{\partial x} + \frac{\partial P_{y,org}}{\partial y} = -P_{dep,org} + P_{ers,org} - P_{\min} + P_{ext,org}$$

$$\frac{dDO_{ch}}{dt} = \kappa_2 \cdot \left(DO_{sat} - DO_{ch}\right) + \left(\alpha_3 \cdot \mu_a - \alpha_4 \cdot \rho_a\right) \cdot alg_{ch} - \kappa_1 \cdot CBOD_{ch}$$

SWWRP Nutrient Module Development

Channel Water Quality Processes



$$\frac{dDO_{ch}}{dt} = \kappa_2 \cdot \left(DO_{sat} - DO_{ch}\right) + \left(\alpha_3 \cdot \mu_a - \alpha_4 \cdot \rho_a\right) \cdot alg_{ch} - \kappa_1 \cdot CBOD_{ch}$$

$$- \frac{\kappa_4}{1000 \cdot D} - \alpha_5 \cdot \beta_{N,1} \cdot NH_{4\,ch}^{+} - \alpha_6 \cdot \beta_{N,2} \cdot NO_{3\,ch}^{-}$$

SWWRP Nutrient Module Development

Current Status

Currently, there exists overland and channel kinetics modules (SWWRP-NSMv1.0).

These modules allow for the input of: NO2, NO3, NH4, Organic Nitrogen, PO4, and Organic Phosphorus.

These modules allow for the output of: NO2, NO3, NH4, Org. N, PO4, Org. P, Algae, CBOD, and DO.

Constituents will be allowed to exist as dissolved, adsorbed, and/or solid phase where applicable.

SWWRP Nutrient Module Development

Current Status

Overland and Channel Nutrient Kinetic modules are being linked with the GSSHA model.

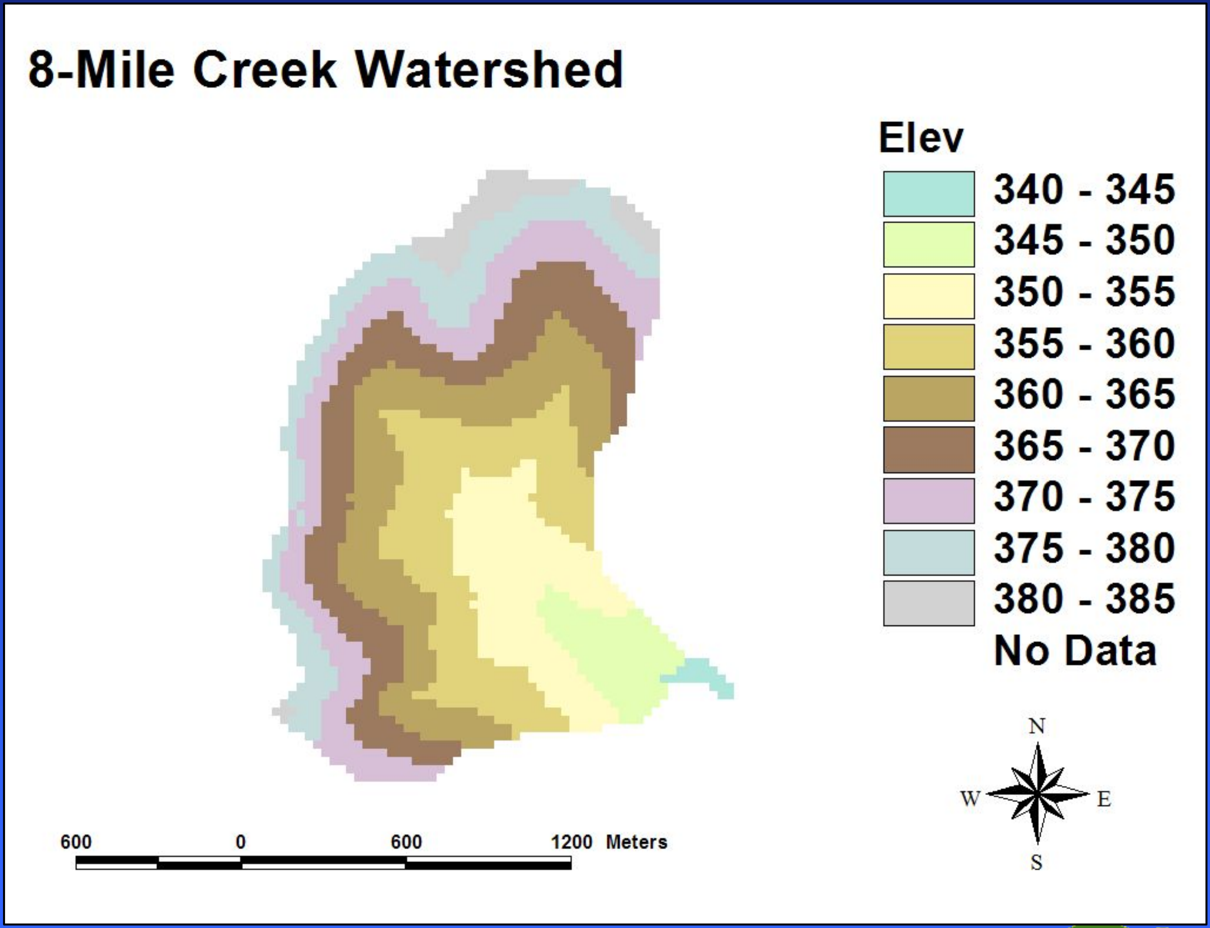
Channel Nutrient Kinetic module is being linked with Hydrologic Engineer Center – River Analysis System (HEC-RAS).

SWWRP Nutrient Module Development
Validation Sites

- Eight Mile Creek Watershed (~1 mi^2) – WI.
- Eau Galle Watershed (~40 mi^2) – WI.
- ARS Research Watershed (??? mi^2) – OH.

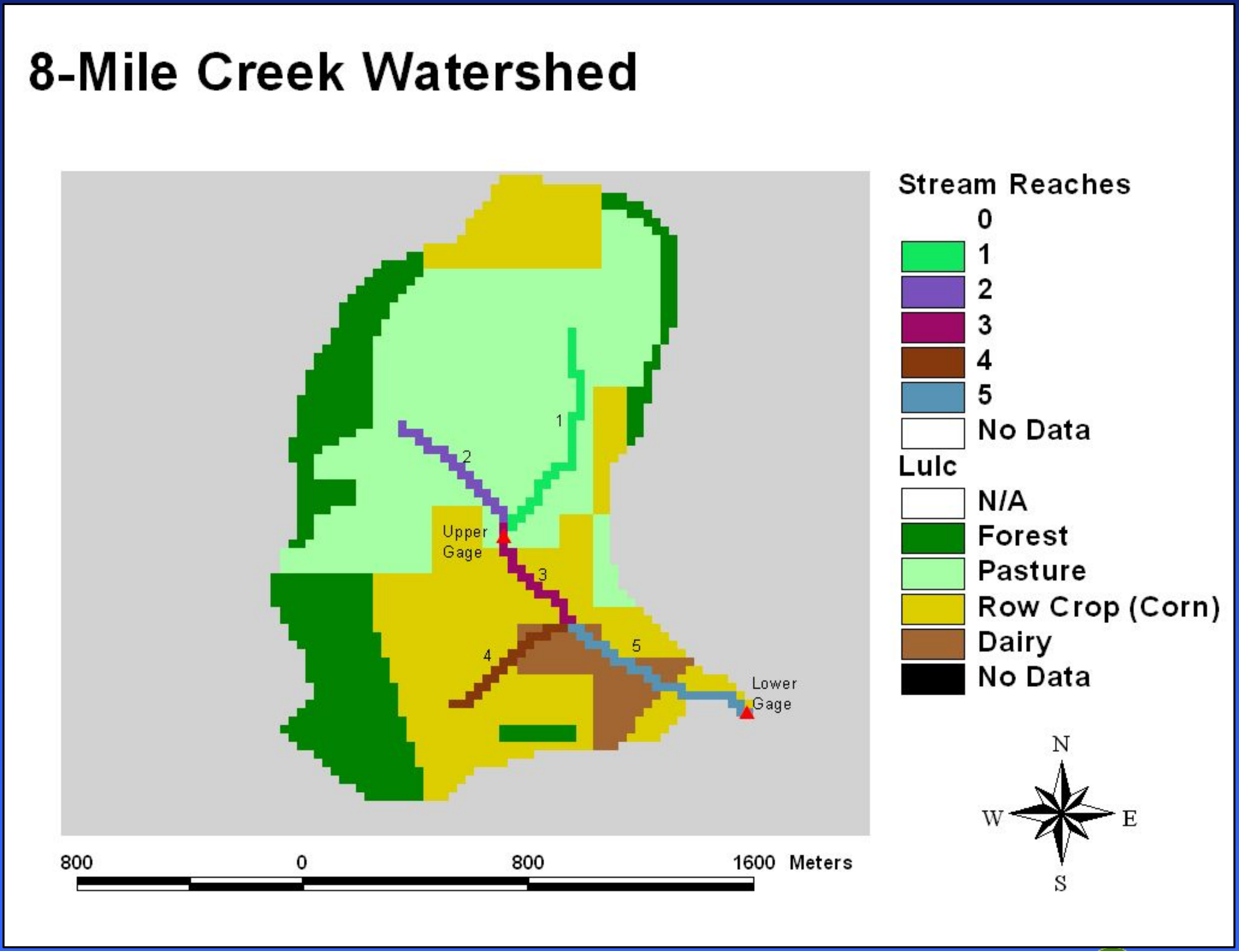
SWWRP Nutrient Module Development
Validation Site: 8-Mile Creek Watershed

Drainage Area = 2.43 km^2 (0.88 mi^2)



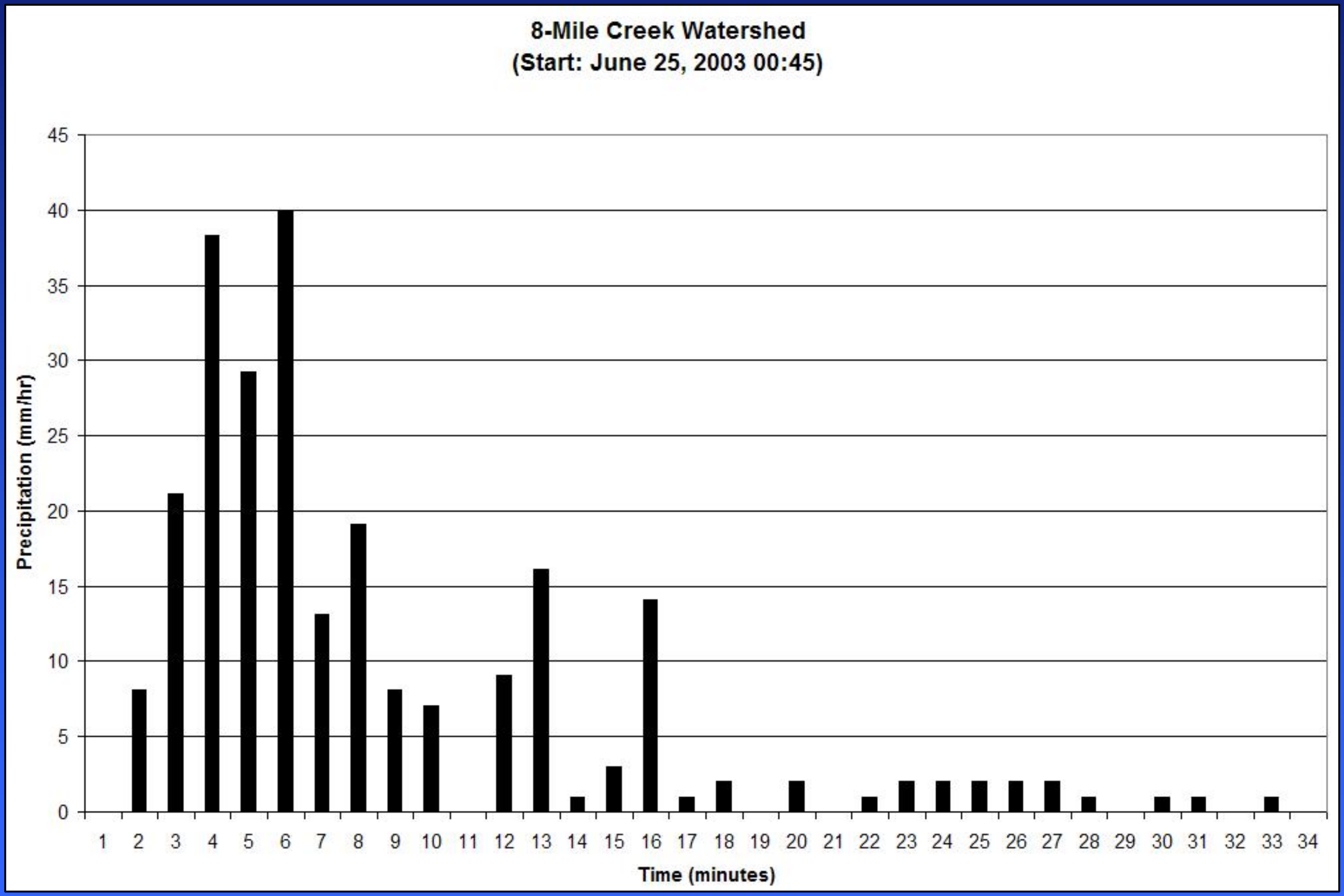
SWWRP Nutrient Module Development
Validation Site: 8-Mile Creek Watershed

Soil Texture is <u>Silt Loam</u> and is assumed to be uniform throughout the sub-area.



SWWRP Nutrient Module Development

Validation Site: 8-Mile Creek Watershed



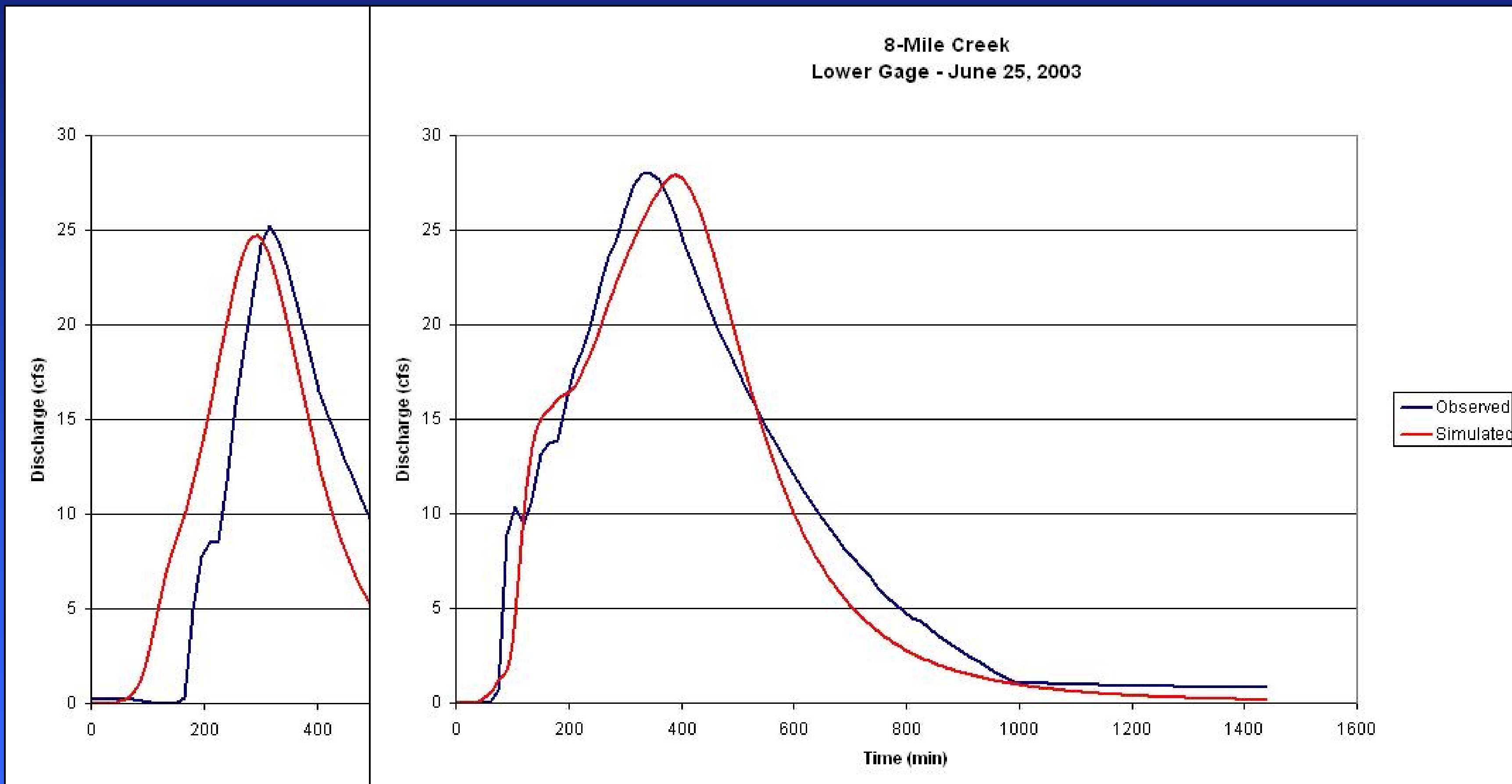
SWWRP Nutrient Module Development

Validation Site: 8-Mile Creek Watershed

Flow Results

Runoff Volume (m^3)		% Difference
Observed Lower Gage	21074.3	-7.6
Simulated Lower Gage	19463.8	
Observed Upper Gage	11448.5	-5.6
Simulated Upper Gage	10811.1	
Time to Peak (min)		**% Difference**
Observed Lower Gage	345	13.0
Simulated Lower Gage	390	
Observed Upper Gage	315	-7.9
Simulated Upper Gage	290	
Peak Flow (m^3/s)		**% Difference**
Observed Lower Gage	0.79	0.0
Simulated Lower Gage	0.79	
Observed Upper Gage	0.72	-2.8
Simulated Upper Gage	0.70	

SWWRP Nutrient Module Development
Validation Site: 8-Mile Creek Watershed



SWWRP Nutrient Module Development

Validation Site: 8-Mile Creek Watershed
Nitrogen and Phosphorus Loading

Landuse	Soluble N (g)/(grid cell)
Dairy	192.6
Pasture	3.6
Corn	4.1
Forest	5.1

Landuse	Soluble P (g)/(grid cell)
Dairy	11.10
Pasture	0.67
Corn	0.95
Forest	0.24

- Assumed 95% of TN was Organic N.
- Assumed 0.1 cm effective depth for soil porewater.
- Assumed 1% of Organic N would be soluble.
- Assumed Specific Wt. of Soil would be 2650 kg/m^3.

- Used Sharpley's Slightly Weathered Equation to compute Labile P. Labile P = 0.56*BP+5.1 in ppm.
- Assumed a Kd value of 175 to compute Soluble P.

SWWRP Nutrient Module Development

Validation Site: 8-Mile Creek Watershed

Nitrogen and Phosphorus Model Results

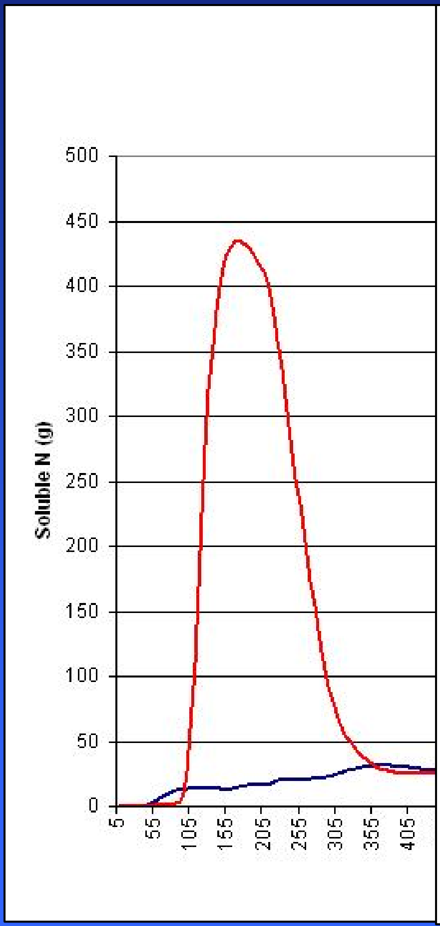
Lower Gage	Soluble N (kg/d)
Total Observed Soluble N	163.8
Total Computed Soluble N	250.4
Upper Gage	**Soluble N (kg/d)**
Total Observed Soluble N	15.0
Total Computed Soluble N	20.8

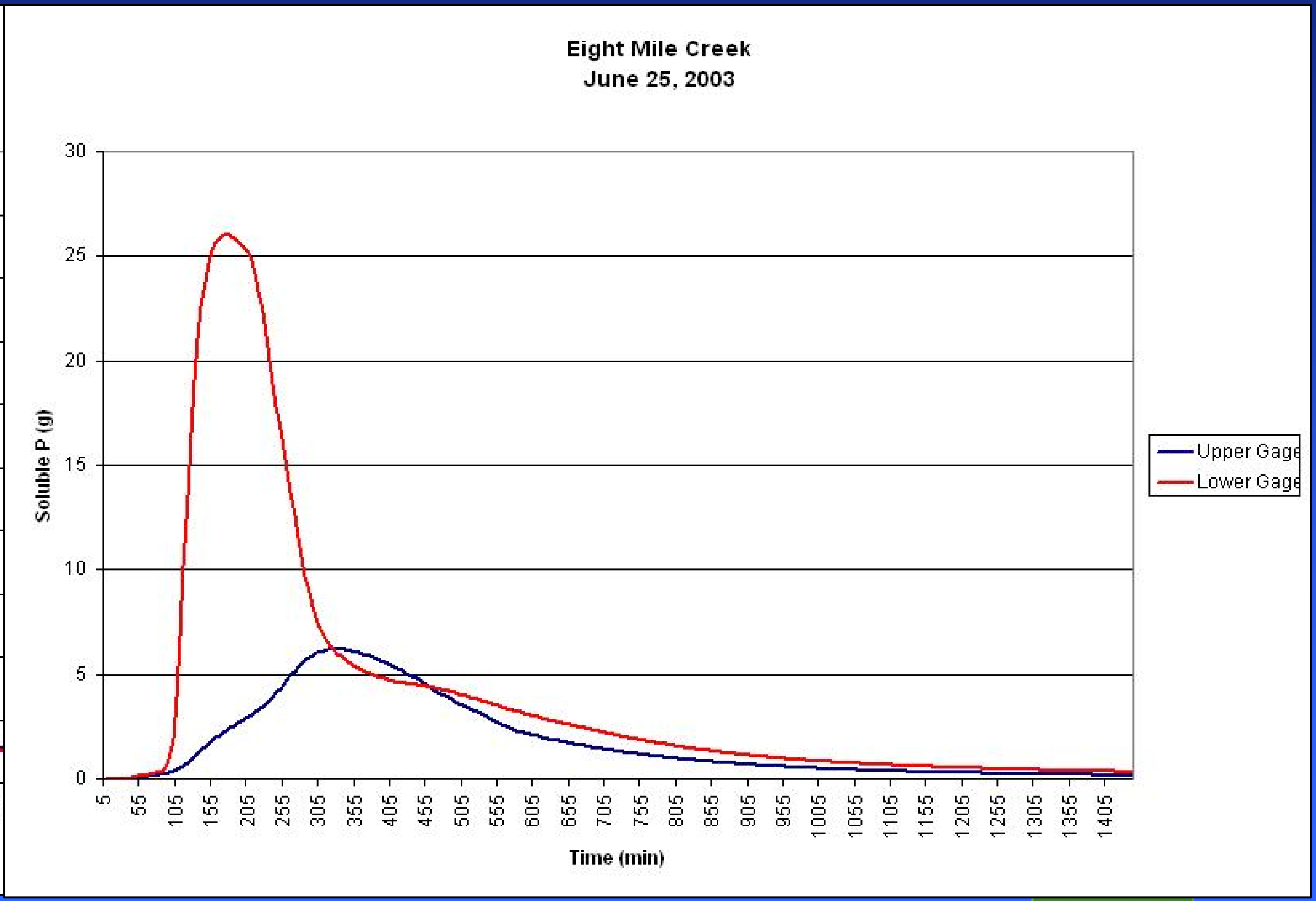
Lower Gage	Soluble P (kg/d)
Total Observed Soluble P	12.4
Total Computed Soluble P	14.9
Upper Gage	**Soluble P (kg/d)**
Total Observed Soluble P	4.0
Total Computed Soluble P	3.5

SWWRP Nutrient Module Development

Validation Site: 8-Mile Creek Watershed

Nitrogen and Phosphorus Model Results

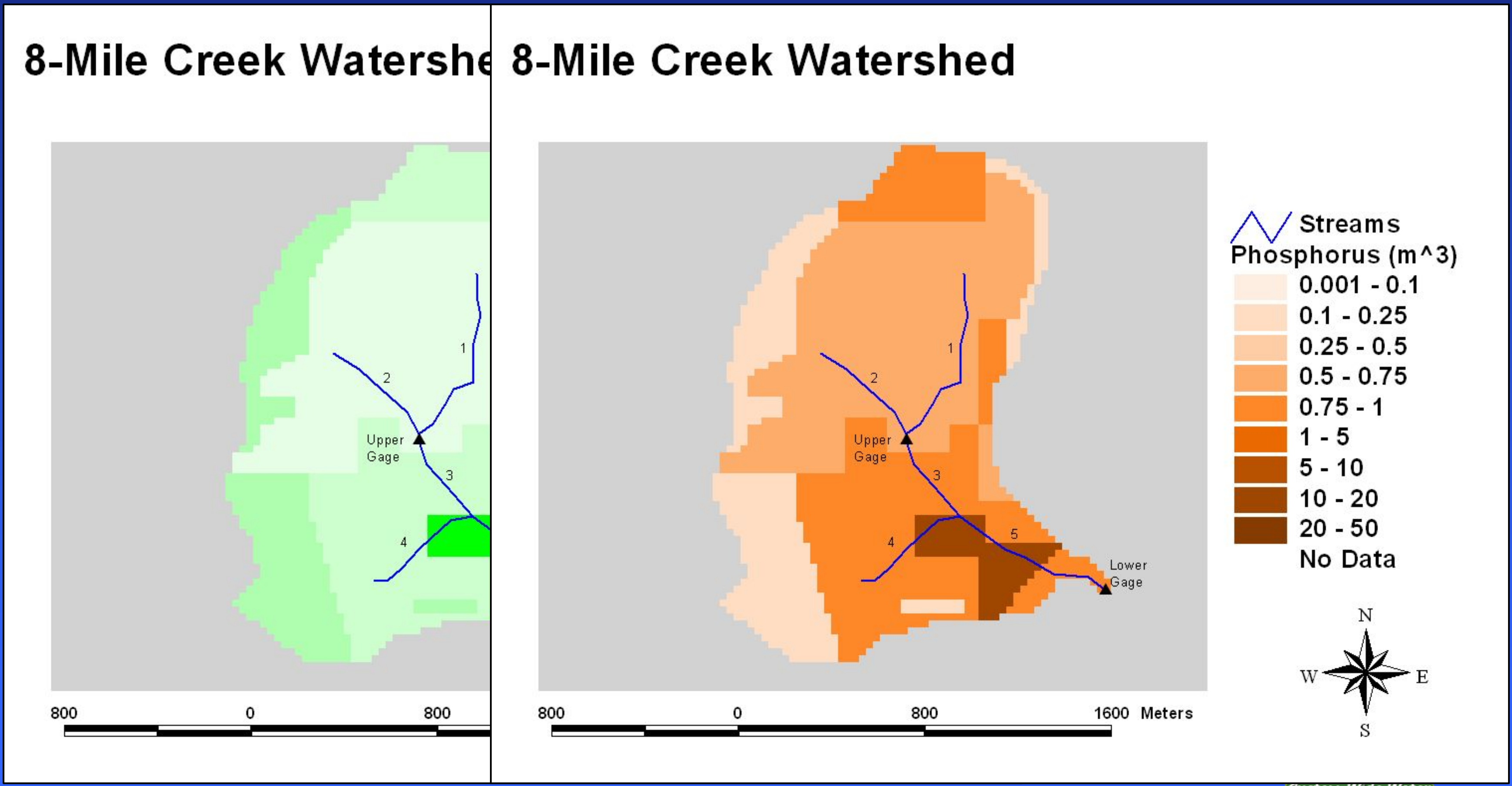




System-Wide Water Resources Program

SWWRP Nutrient Module Development

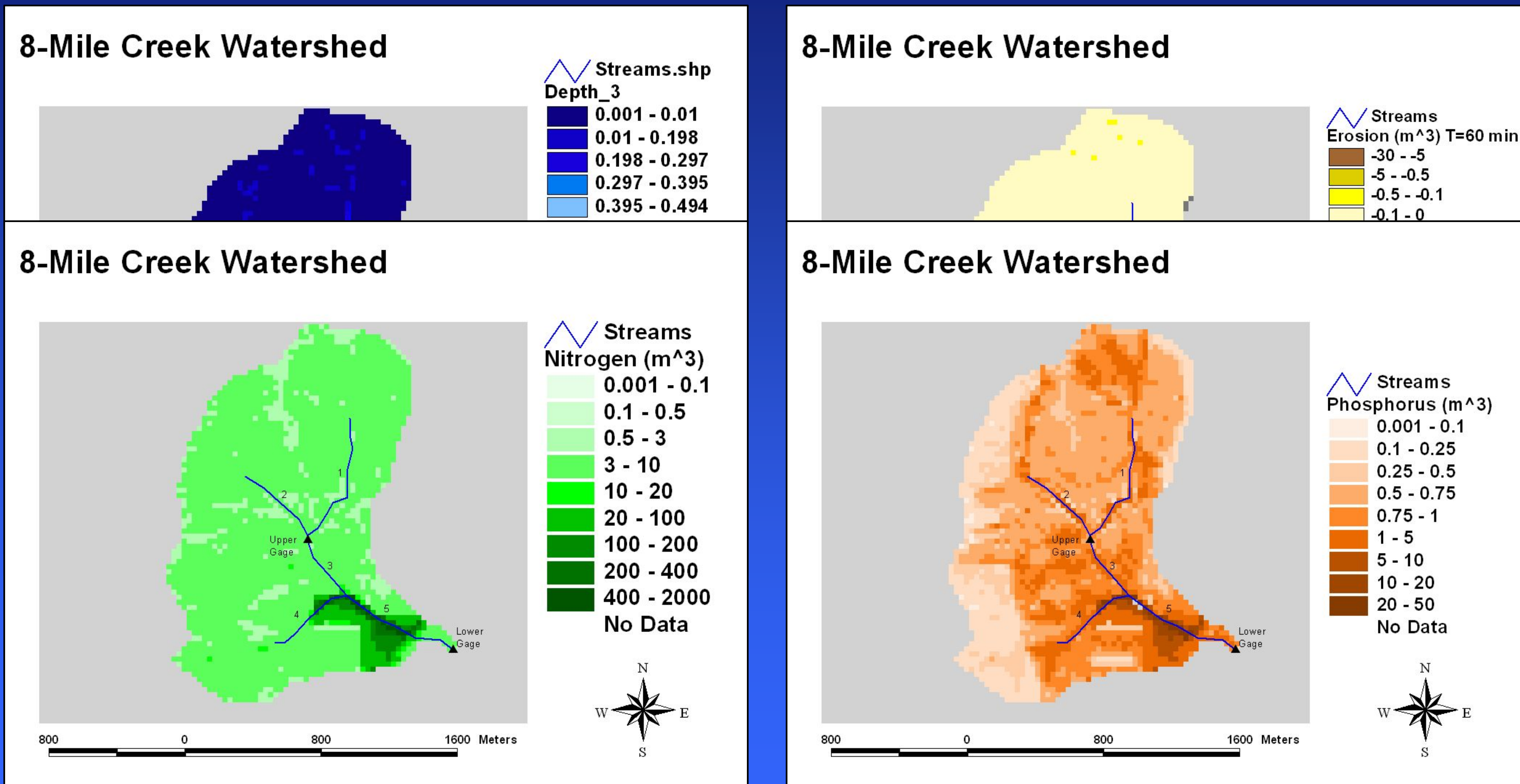
Validation Site: 8-Mile Creek Watershed
Nitrogen and Phosphorus Mass Loading Grids



Eight Mile Creek Watershed

June 25, 2003

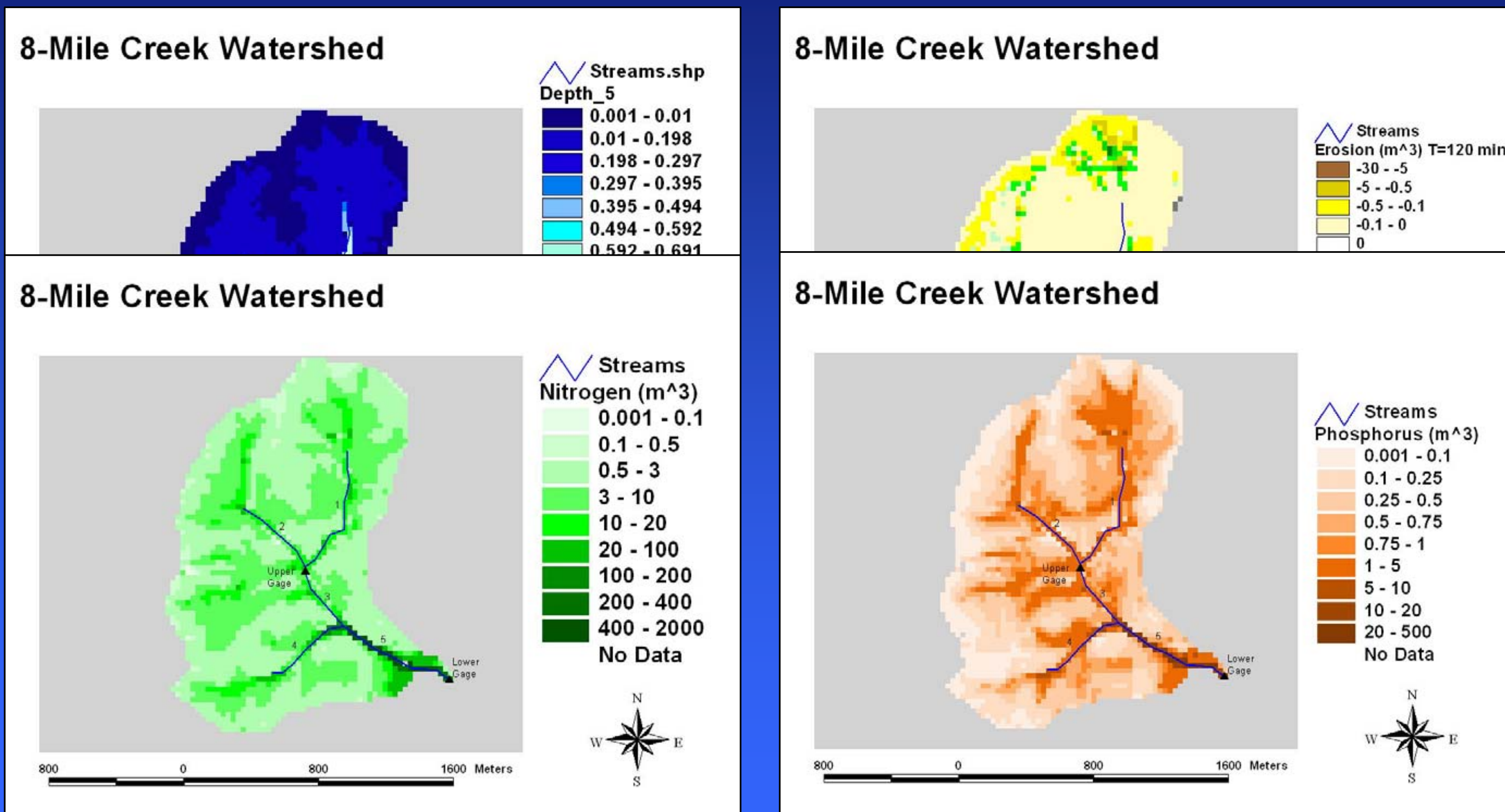
T = 60 minutes



Eight Mile Creek Watershed

June 25, 2003

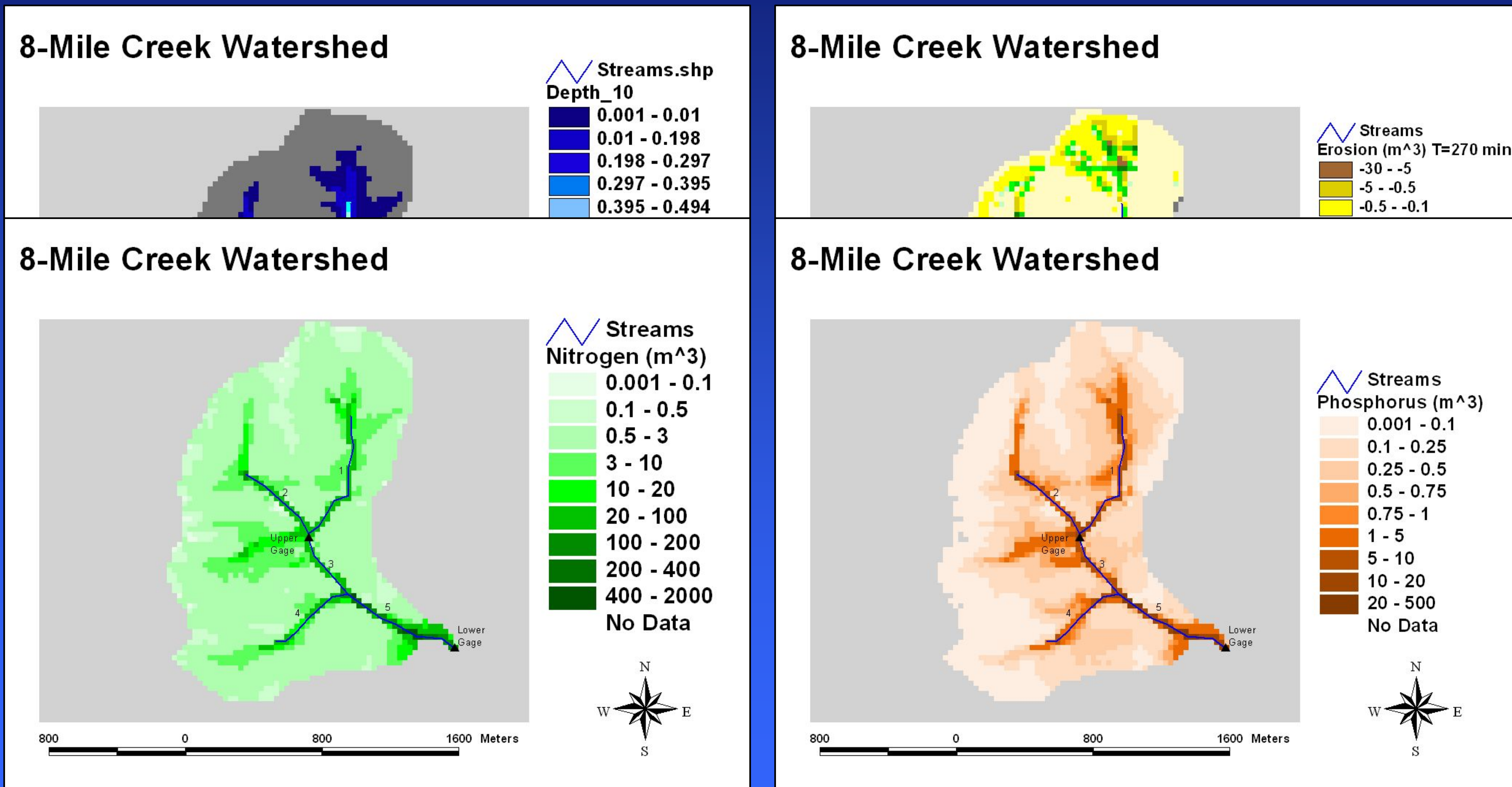
T = 120 minutes



Eight Mile Creek Watershed

June 25, 2003

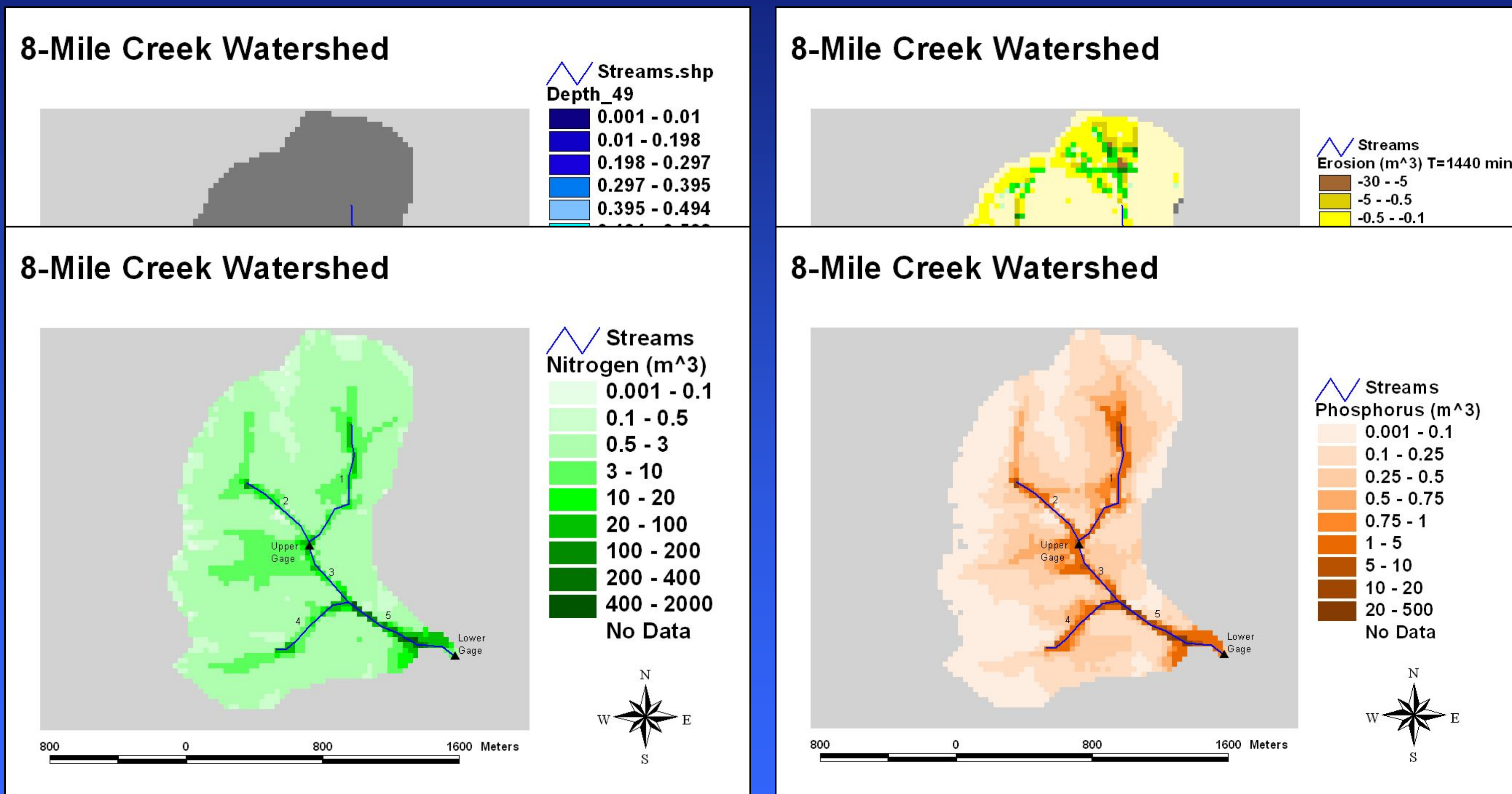
T = 270 minutes



Eight Mile Creek Watershed

June 25, 2003

T = 1440 minutes



ERDC Engineer Research and Development Center

System-Wide Water Resources Program

System-Wide Water SWWRP Resources Program

SWWRP Nutrient Module Development
Future Development Activities

- Develop Plant/Soil Module
  - EPIC/SWAT Plant Formulations (4/06)
  - EDYS Formulations (Terrestrial and Aquatic) (9/06) – *joint effort with Montgomery-Watson-Harza (MWH)*
- Upgrade Channel Kinetics to include RIV1, CE-QUAL-W2 and CE-QUAL-ICM formulations where appropriate
- Develop Carbon Cycle – *joint effort with ARS-Fort Collins*
- Link SWWRP-NSM with HEC-HMS
- Link SWWRP-NSM with ADH (<u>AD</u>aptive <u>H</u>ydraulics Model)