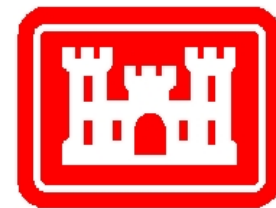
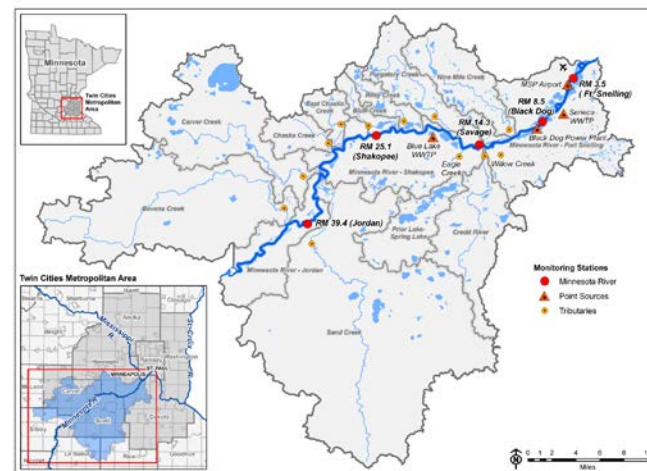
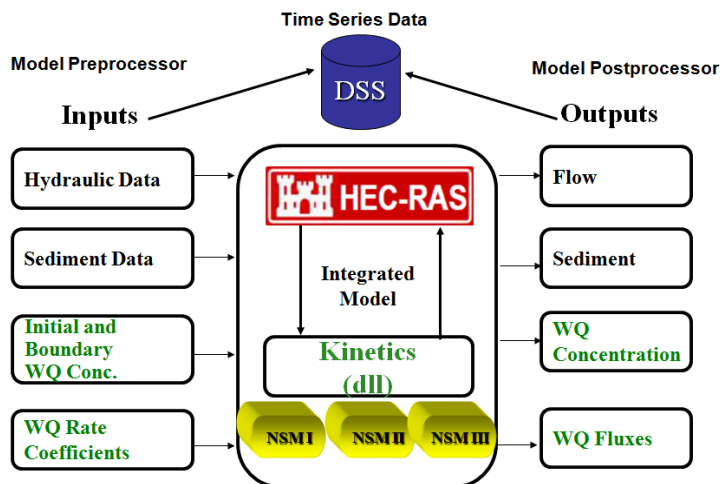
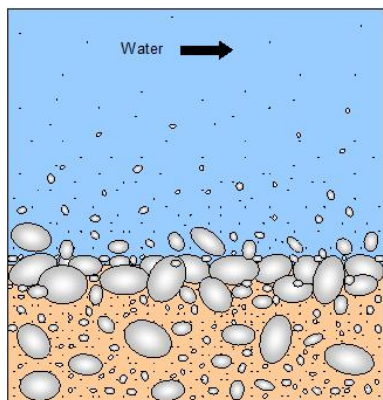
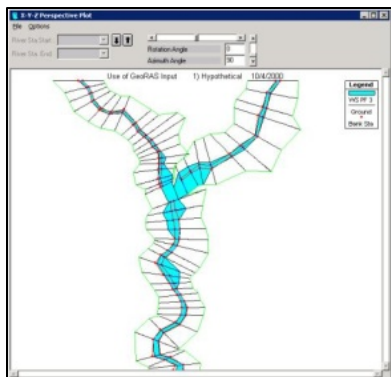




Nutrient Modeling Capabilities within HEC-RAS



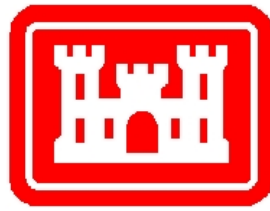
EMRRP Webinar Series



Billy Johnson, and Zhonglong Zhang
April 1, 2014



Nutrient Modeling Development and Integration with HEC-RAS



Product Development Team:

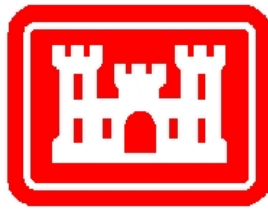
Billy Johnson (EL) – PDT Team Lead

Zhonglong Zhang (BTS) – NSM development

Mark Jensen, Cindy Lowney (HEC) – GUI and Model Integration



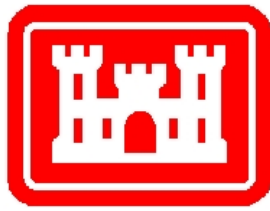
Problems to Address



- Riverine eutrophication
- Total Maximum Daily Load (TMDL) program
- Ecosystem management and restoration
- Other regulatory and non-regulatory decisions

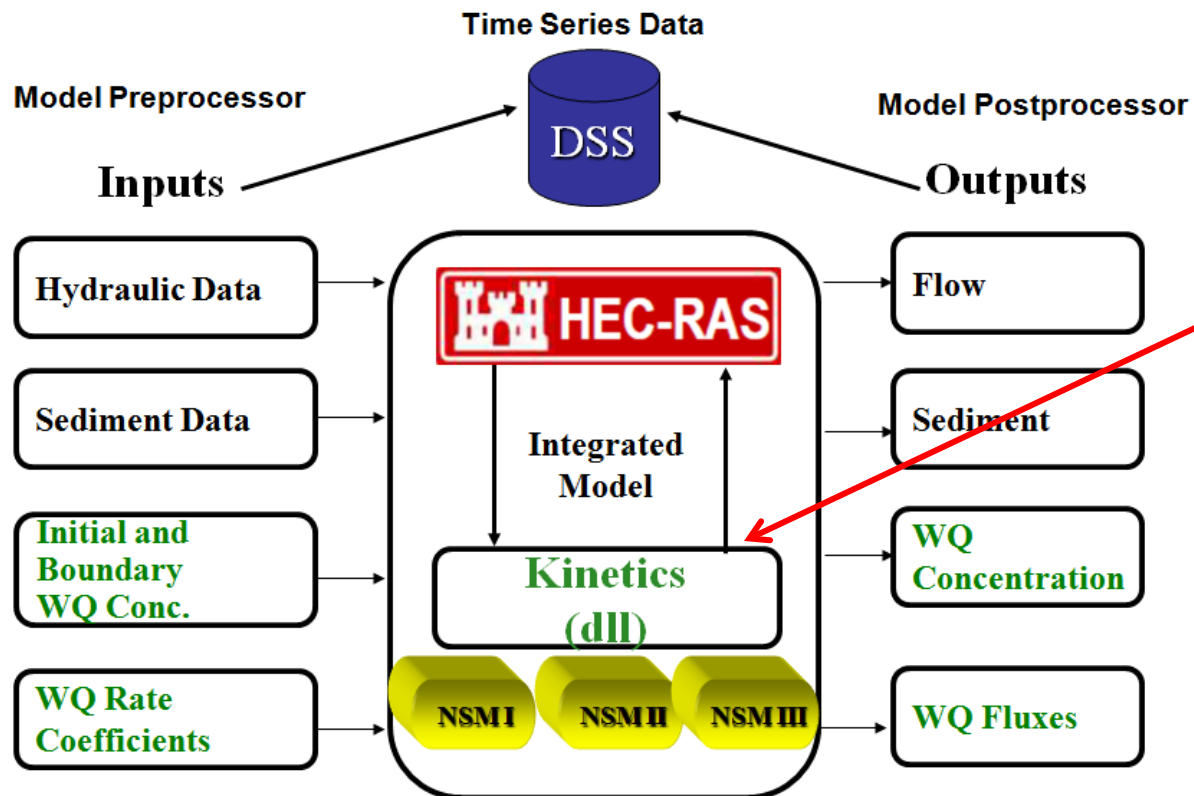
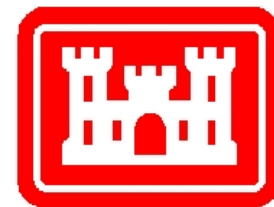


Purposes



- Improved and developed a set of state-of-the-art nutrient simulation modules (NSM)
- Integrated NSM into HEC-RAS to create an integrated 1D hydraulic, sediment and water quality model

R&D Approach

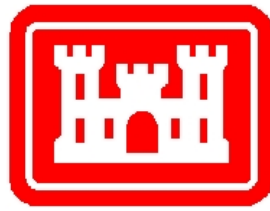


NSM

Nutrient Simulation Modules (NSM) – Is a three tiered nutrient modeling system that adds varying levels of modeling fidelity for nutrients in the water column and bed sediments.



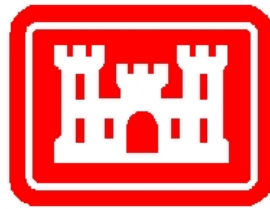
HEC-RAS (River Analysis Systems)



- One-Dimensional (1D) hydraulics program
- Computes river velocities, stages, profiles, and inundated areas (with GeoRAS) given streamflow and geometry
- Steady, Unsteady Flow, and Quasi-Unsteady (for Sediment analysis)
- HEC-RAS simulates sediment transport/movable beds resulting from scour and deposition
- Graphical User Interface
- Data storage/management
- Graphics, Tabular Output & Reporting
- GeoRAS – GIS pre and postprocessor

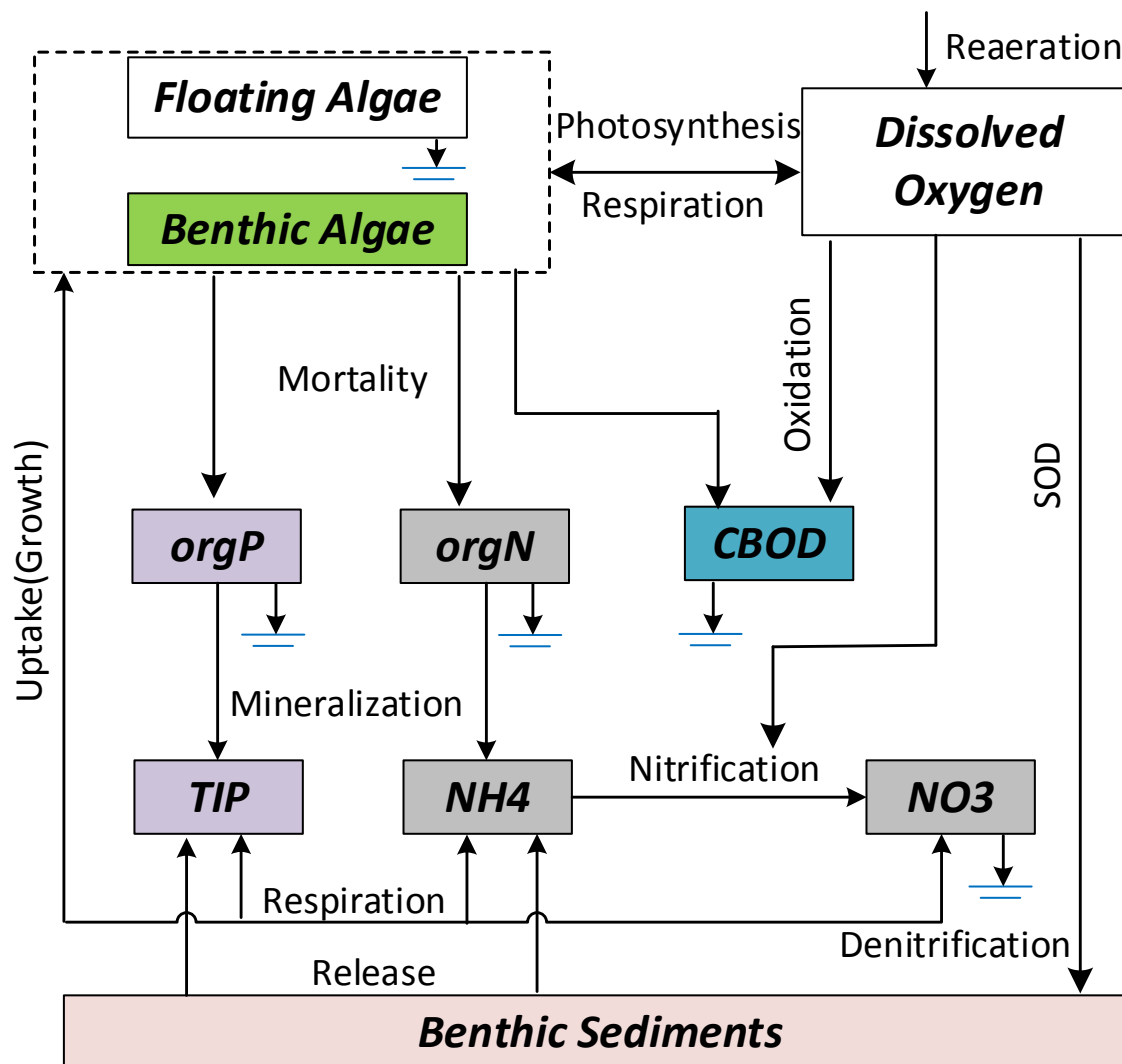
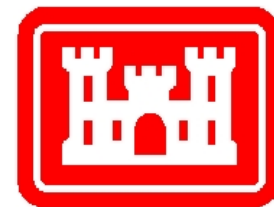


Nutrient Simulation Modules (NSM)



- Level I (NSMI.dll)
 - ▶ State variables: Floating Algae, Organic Nitrogen, Ammonia, Nitrate, Organic Phosphorus, Total Inorganic Phosphorus, CBOD, DO, Benthic Algae
 - ▶ Derived outputs: Chlorophyll-a, DIN, TKN, TN, DIP, TP, CBOD5
- Level II (NSMII.dll)
 - ▶ State variables: Algae, NO₃, NH₄, DON, LPON, RPON, TIP, DOP, LPOP, RPOP, DIC, LDOC, RDOC, LPOC, RPOC, DO, Benthic Algae, COD, Pathogen, Alkalinity
 - ▶ Derived outputs: Chlorophyll-a, DIN, TKN, TN, DIP, TP, DOC, POC, TOC, CBOD5, pH
- Level III (NSMIII.dll – NSM-II with a DiToro's bed sediment diagenesis model)
 - ▶ State variables: same as NSM II
 - ▶ Bed sediment variables

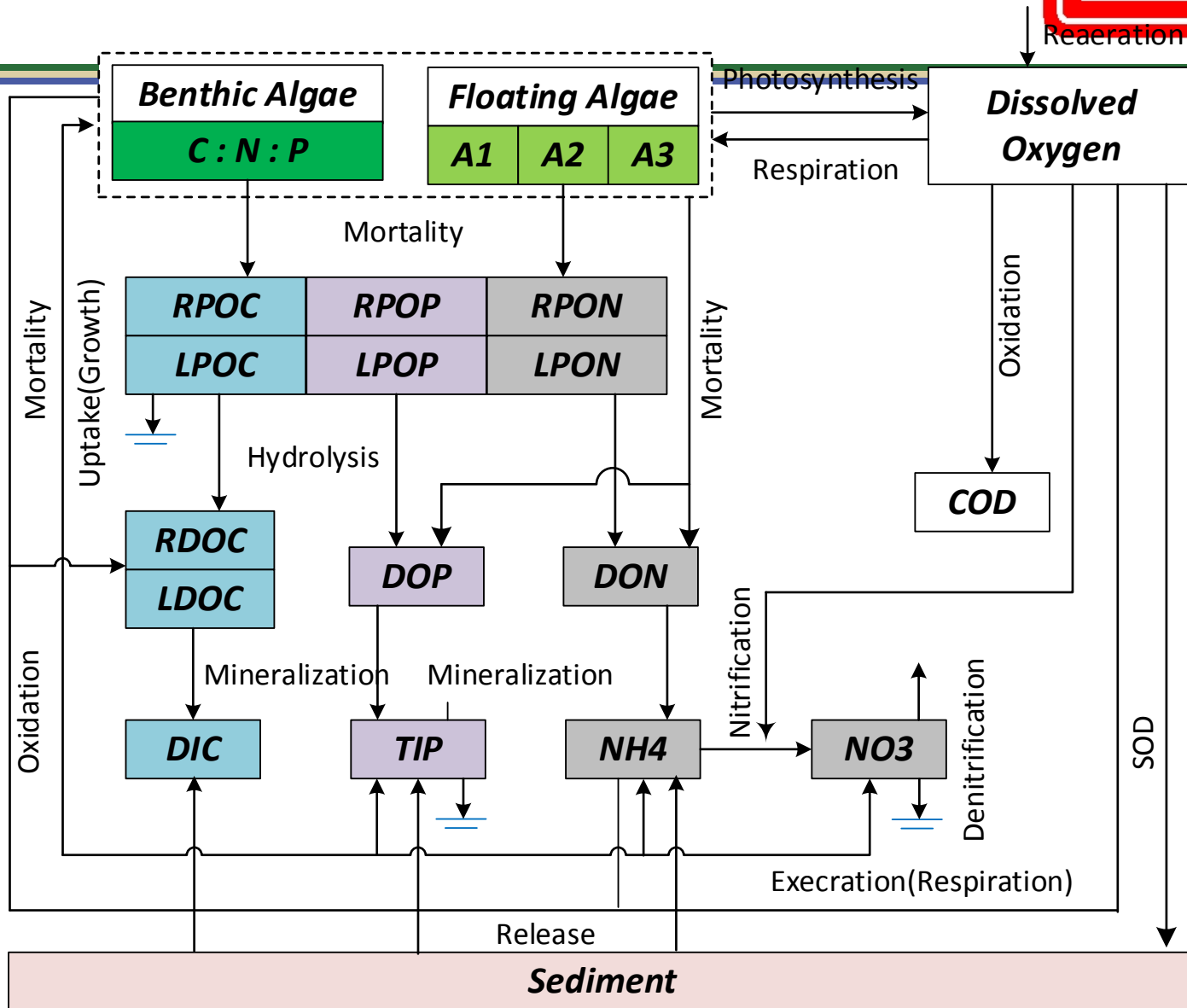
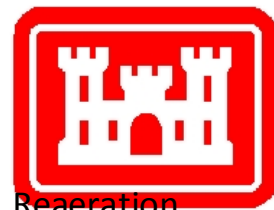
Nutrient Simulation Module – NSM-I



Reference: QUAL2E,
CE-QUAL-RIV1



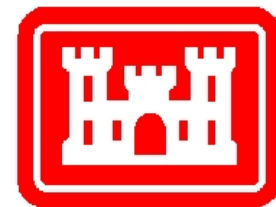
Nutrient Simulation Module – NSM-II



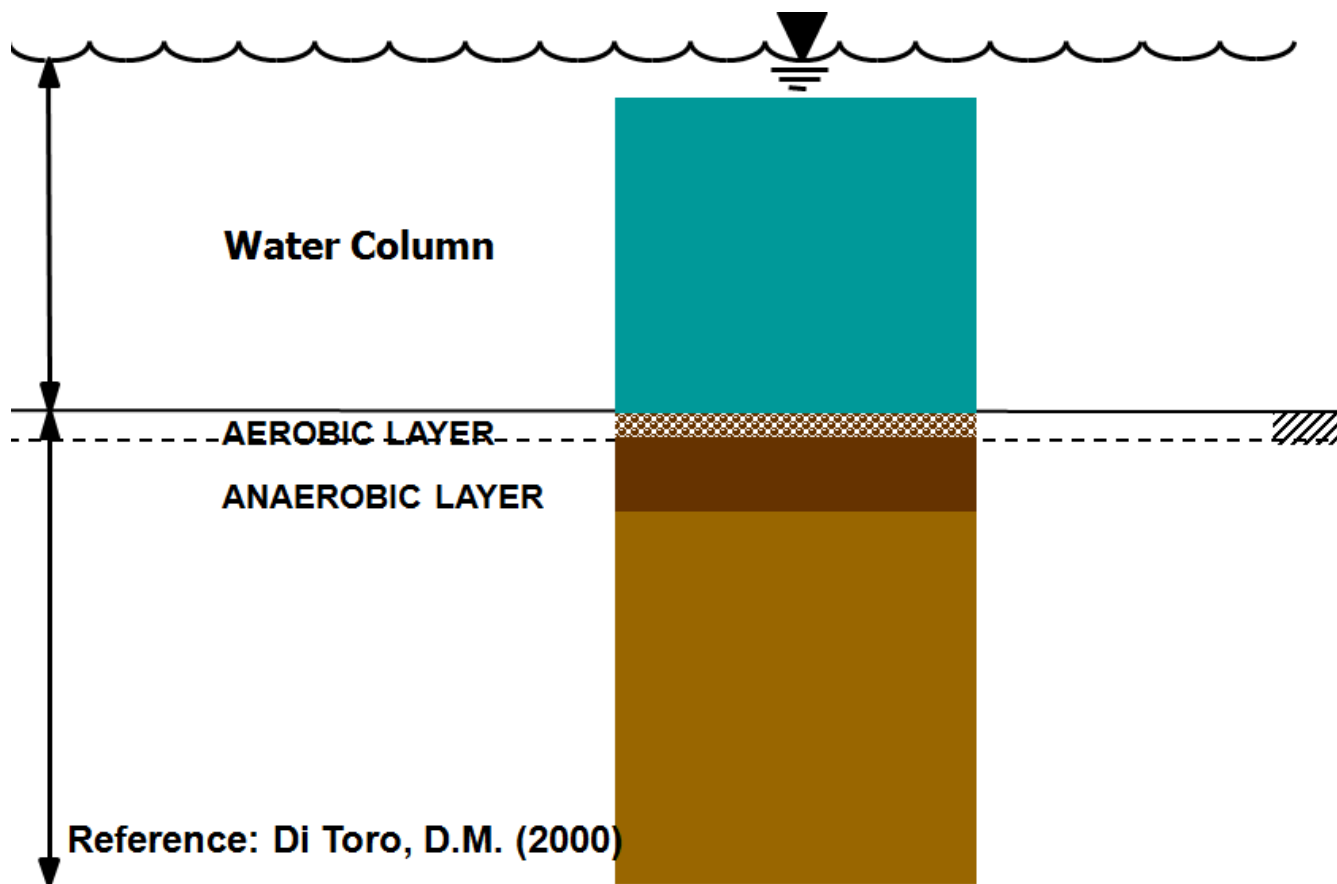
Reference: CE-QUAL-W2, ICM, QUAL2K, etc.



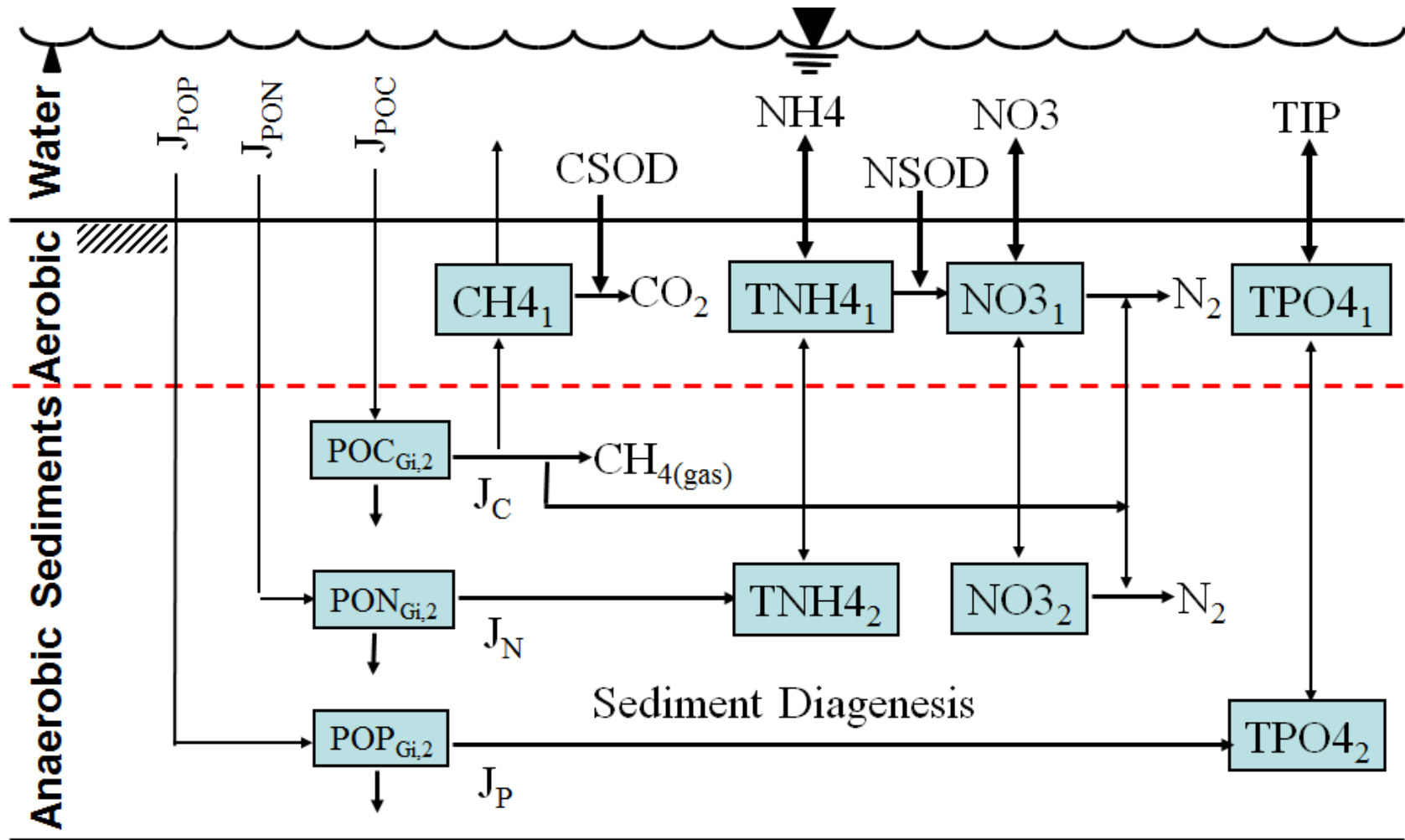
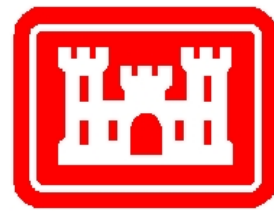
Nutrient Simulation Module – NSM-III



Sediment-water Processes ***“The Missing Link of Water-quality Modeling”***

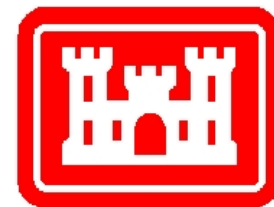


Nutrient Simulation Module – NSM-III

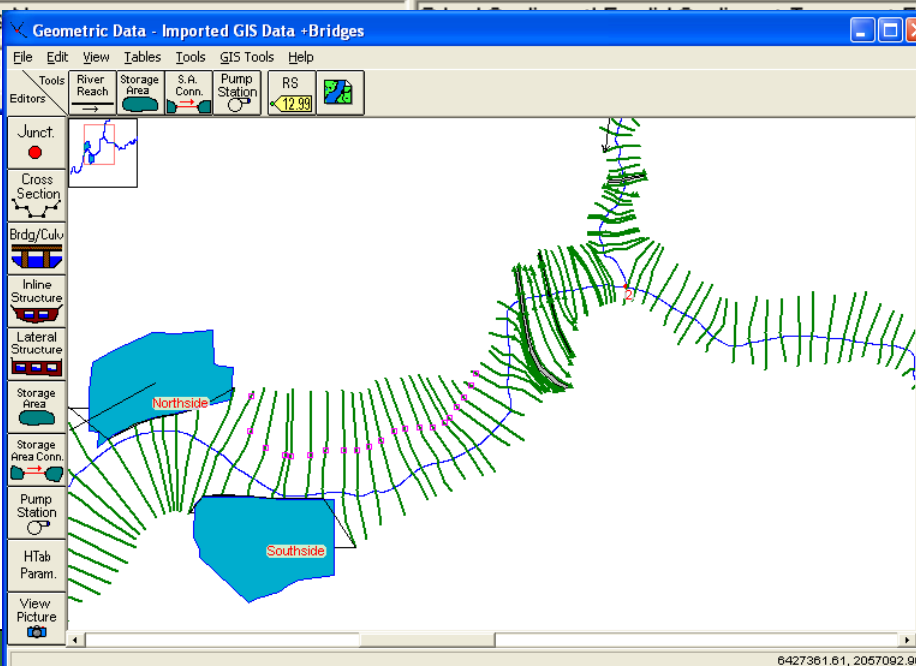
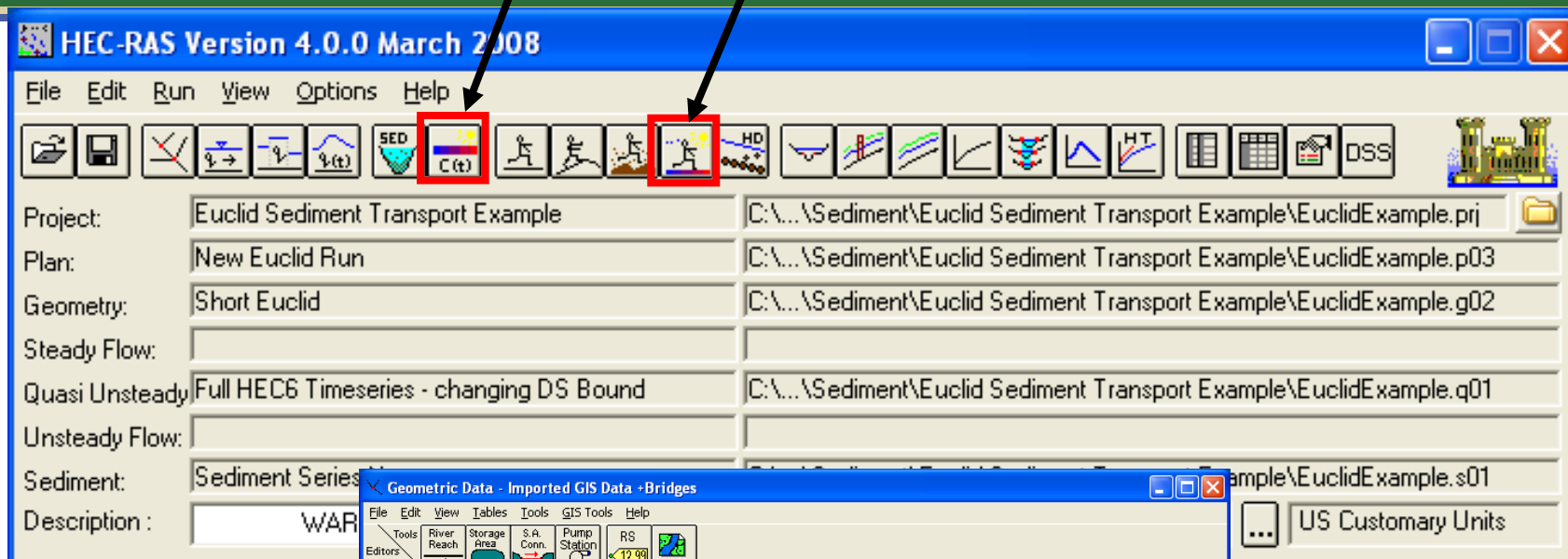




HEC-RAS User Interface

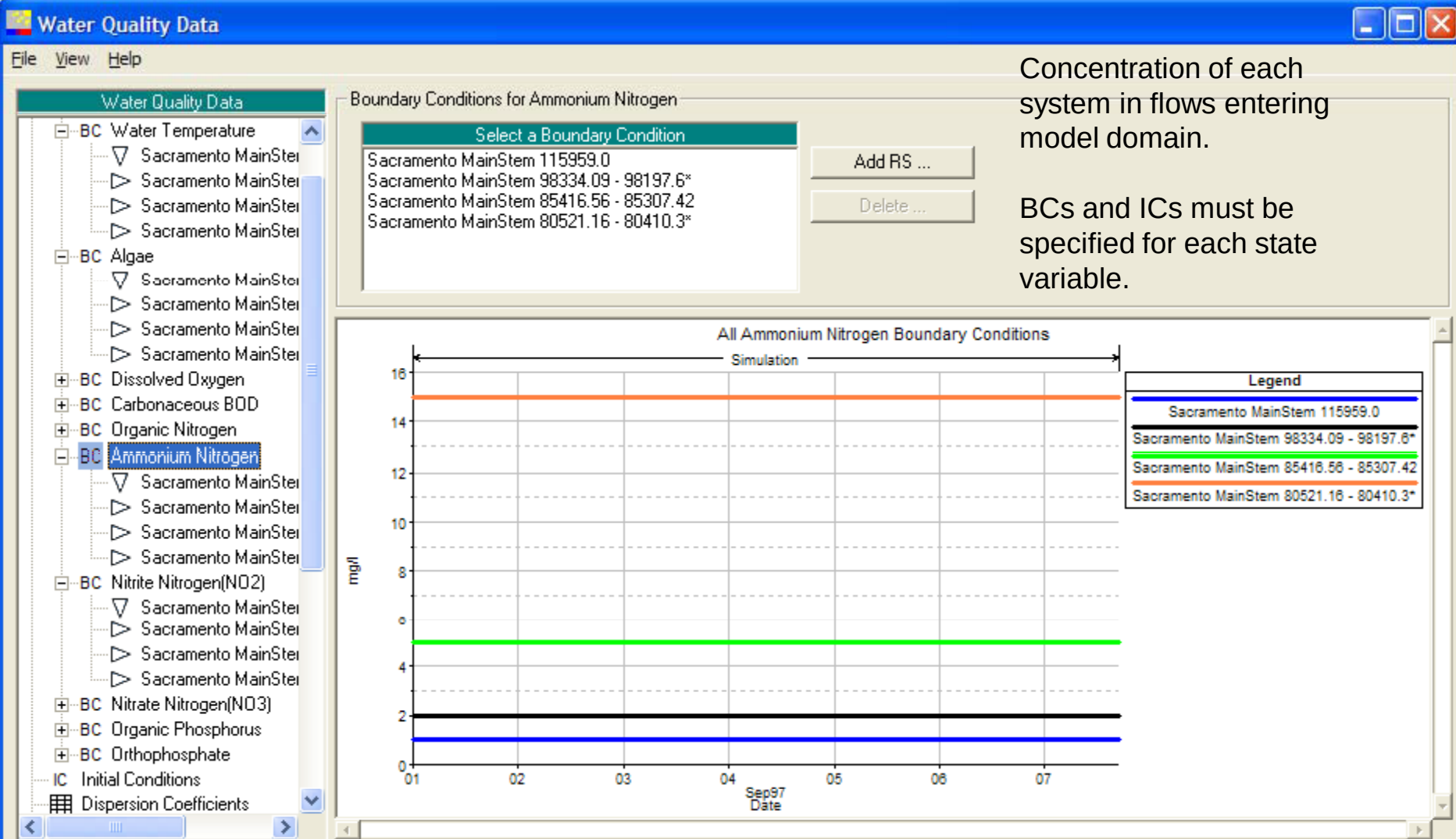
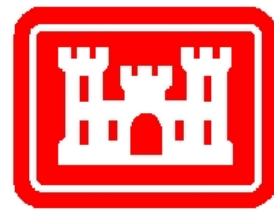


Water Quality Water Quality
Data Analysis





HEC-RAS NSM-I User Interface





Water Quality Data

File View Help

Water Quality Data

New Water Quality File

- BC Boundary Conditions
 - BC Water Temperature
- IC Initial Conditions
- Dispersion Coefficients
- Meteorology Datasets
- Nutrient Parameters
- Mass Injection
- Observed Data
 - Water Temperature
- Reference Values

Nutrient Modeling Parameters

Restore Default Values... ☒ View Both Table and Schematic ☐ View Table only ☐ View Schematic only

Algal local specific growth rate formulation: Multiplicative

Variable	Value	θ
Algae		
α_0 Biomass (Chl-a ratio)	ugCha/mgA	10
α_1 Biomass (Nitrogen Fraction)	mgN/mgA	0.07
α_2 Biomass (Phosphorus Fraction)	mgP/mgA	0.01
μ_{max} Maximum Growth Rate	day ⁻¹	1 1.047
ρ Respiration Rate	day ⁻¹	0.05 1.047
P_N Nitrogen Preference		1
K_L Growth Limitation (light)	W m ⁻²	4
K_N Growth Limitation (N)	mgN/L	0.01
K_P Growth Limitation (P)	mgP/L	0.001
λ_0 Light Extinction (non-algal)	m ⁻¹	0.03
λ_1 Light Extinction (linear algal)	m ⁻¹ (ugCh/L) ⁻¹	0.007
λ_2 Light Extinction (non-linear algal)	m ⁻¹ (ugCh/L) ^{-2/3}	0.05
σ_1 Settling Rate	m day ⁻¹	0.1 1.024
Dissolved Oxygen		
α_3 Production per unit algal growth	mgO/mgA	1.4
α_4 Uptake per unit algal respired	mgO/mgA	1.6
α_5 Uptake per unit NH4 oxidized	mgO/mgN	3
α_6 Uptake per unit NO2 oxidized	mgO/mgN	1
K_2 Atmospheric Reaeration	day ⁻¹	1 1.024
K_4 Sediment Demand	day ⁻¹	0 1.06
CBOD		
K_1 Decay Rate	day ⁻¹	0.02 1.047
K_3 Settling Rate	day ⁻¹	0 1.024
Nitrogen		
β_3 OrgN→NH4	day ⁻¹	0.02 1.047
β_1 NH4→NO2	day ⁻¹	0.1 1.083

NSM v1.0

Disso

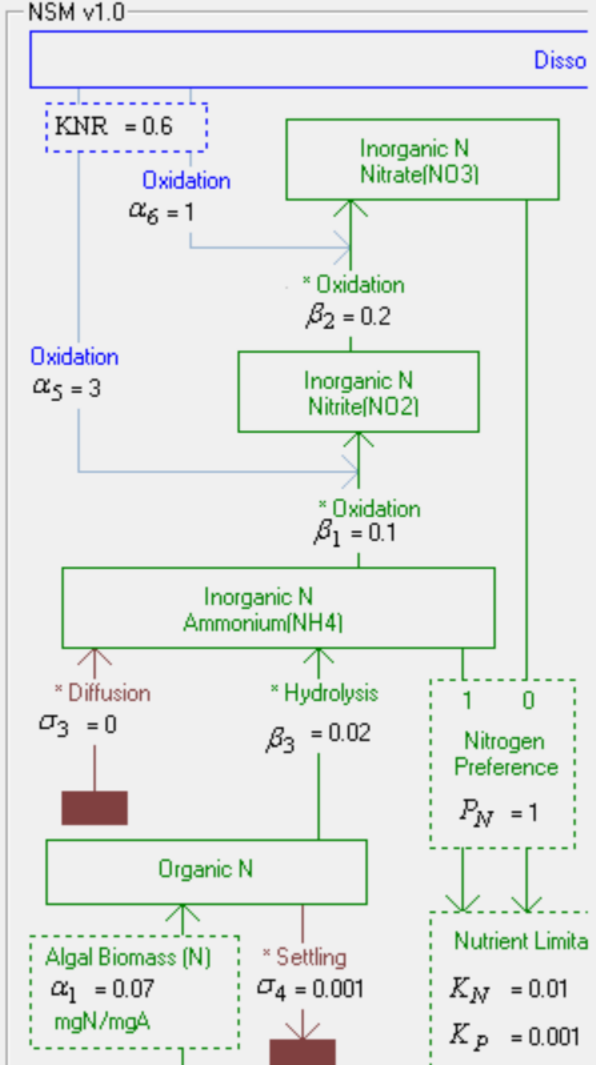
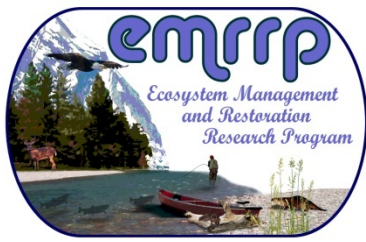
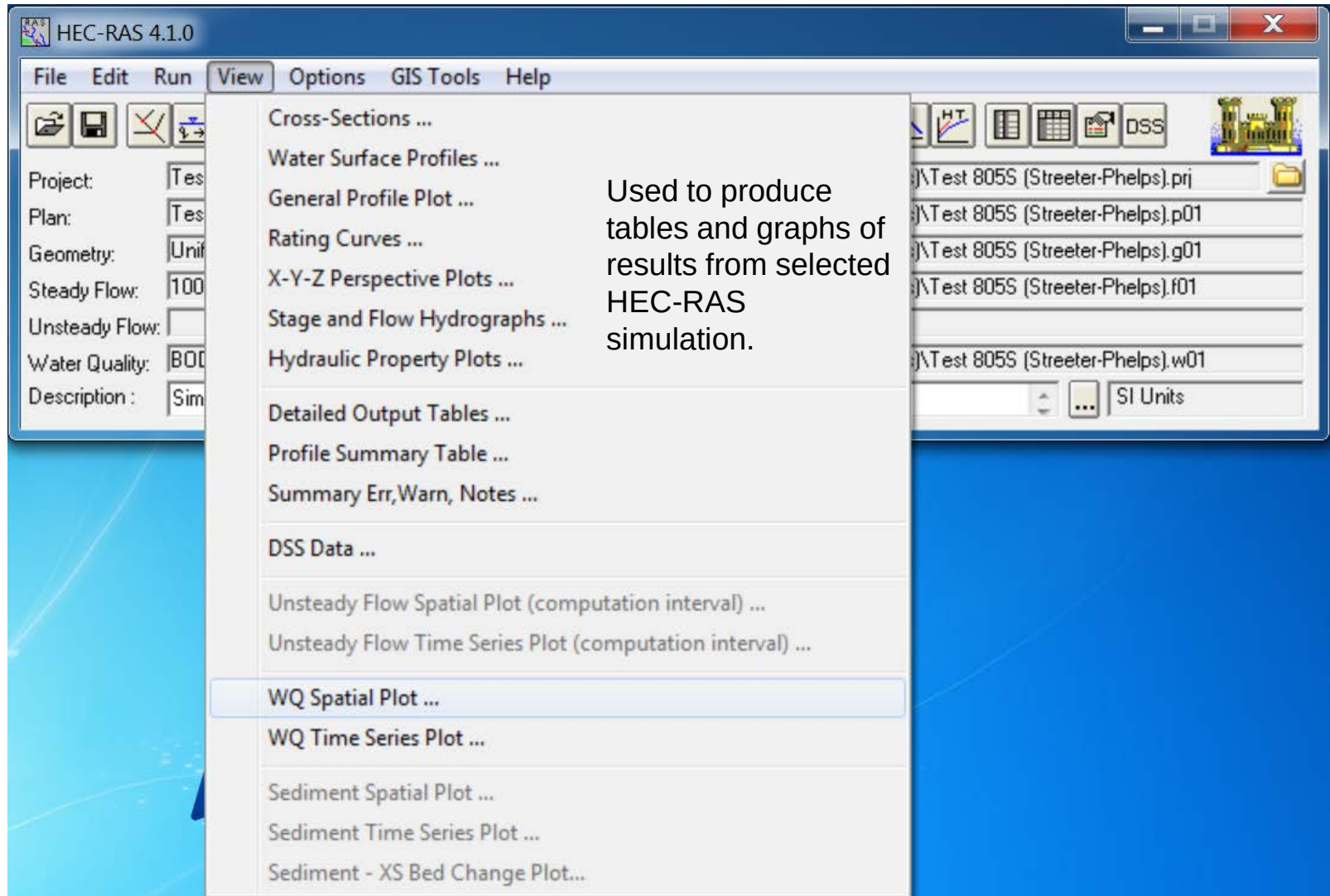
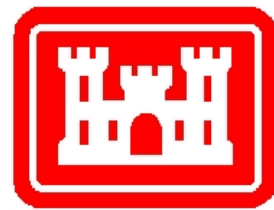


Diagram illustrating the Nitrogen (N) cycle and its relationship to other parameters:

- Algal Biomass (N)** (dashed box) with $\alpha_1 = 0.07$ mgN/mgA.
- Organic N** (solid box) with $\sigma_4 = 0.001$ (Settling).
- Inorganic N Ammonium (NH4)** (solid box) with $\sigma_3 = 0$ (Diffusion) and $\beta_3 = 0.02$ (Hydrolysis).
- Inorganic N Nitrite (NO2)** (solid box) with $\beta_1 = 0.1$ (Oxidation) and $\alpha_5 = 3$ (Oxidation).
- Inorganic N Nitrate (NO3)** (solid box) with $\alpha_6 = 1$ (Oxidation) and $\beta_2 = 0.2$ (Oxidation).
- Nitrogen Preference** (dashed box) with $P_N = 1$.
- Nutrient Limita** (dashed box) with $K_N = 0.01$ and $K_P = 0.001$.
- KNR = 0.6** (dashed box) with $\alpha_6 = 1$ (Oxidation).

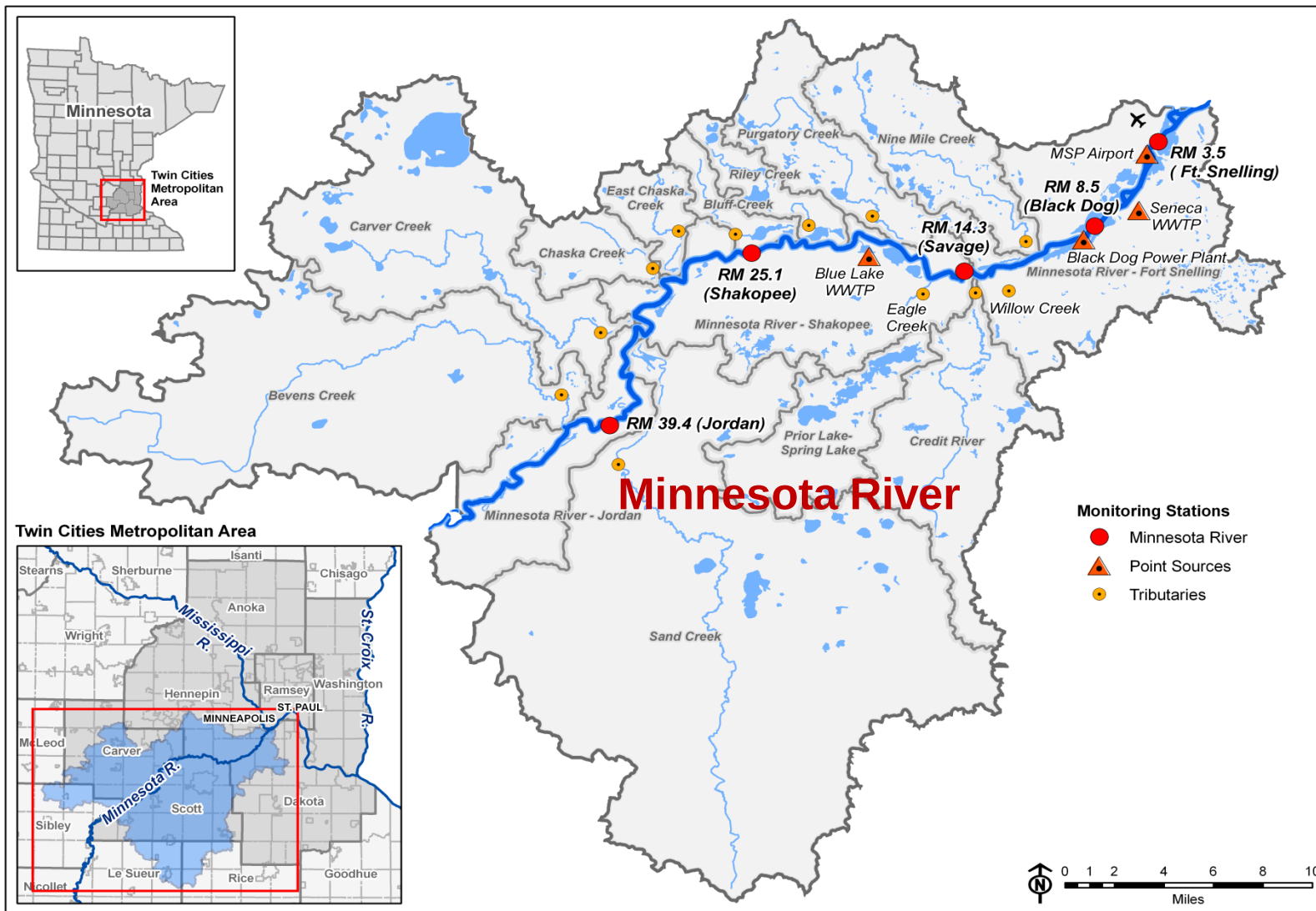
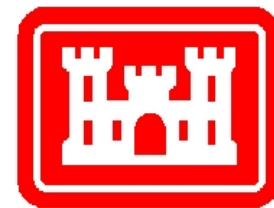


HEC-RAS NSM-I User Interface



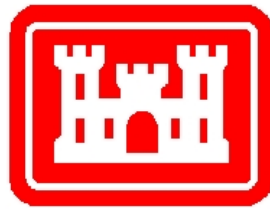


HEC-RAS – NSM-I Application and Evaluation





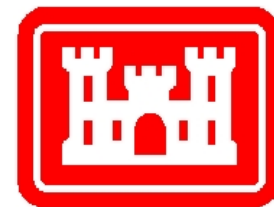
Lower Minnesota River (LMNR)



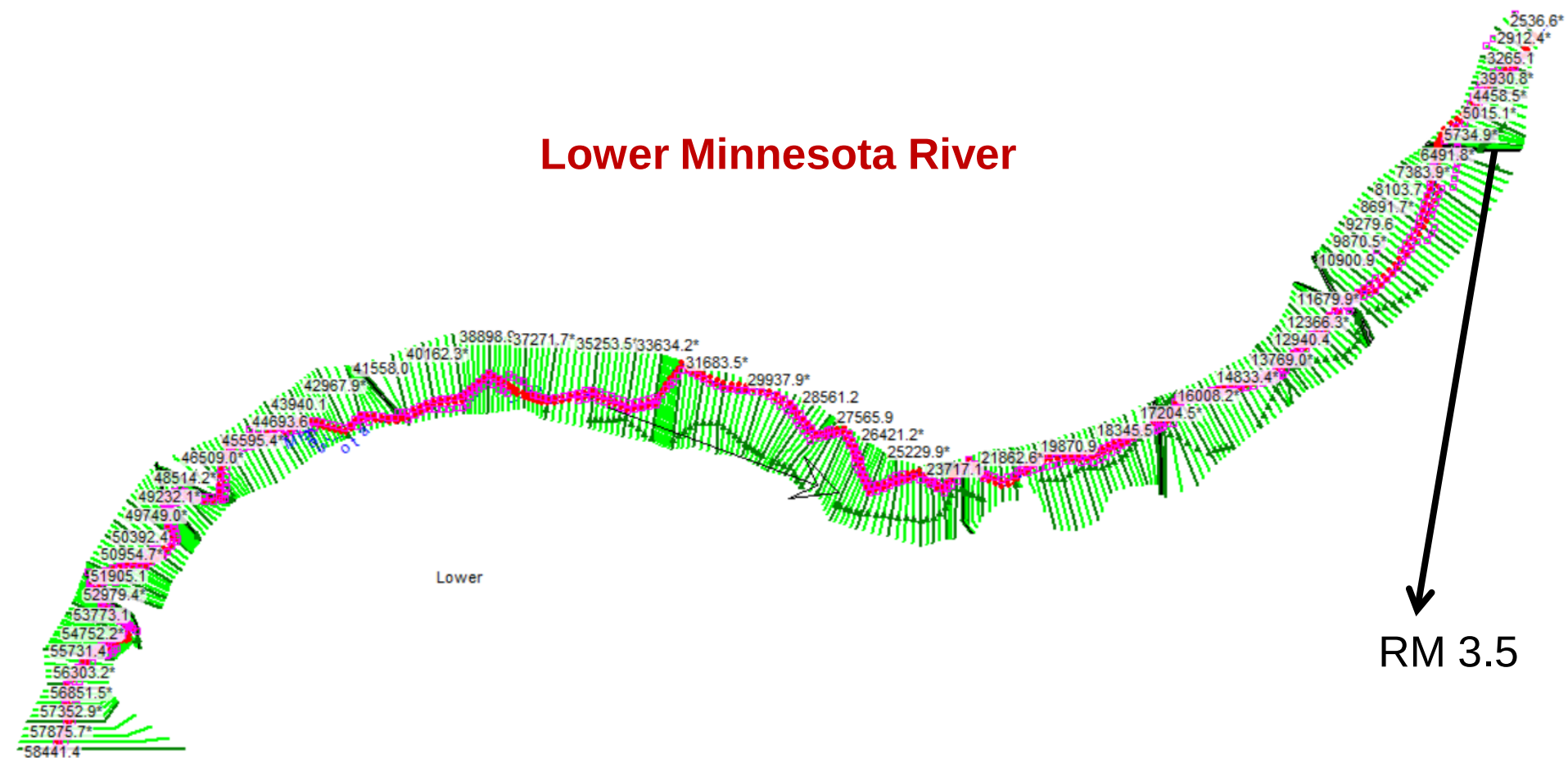
- A LMNR's CE-QUAL-W2 model has been developed by ERDC-EL for Minnesota Pollution Control Agency (MPCA) and Metropolitan Council Environmental Services (MCES).
- ERDC Report: Modeling the hydrodynamics and water quality of the Lower Minnesota River using CE-QUAL-W2.
- Six water years (2001 – 2006) data were available along the LMNR for the model calibration and verification.
 - ▶ Flow
 - ▶ Sediments
 - ▶ Nutrients (N, P)
 - ▶ CBOD
 - ▶ DO
 - ▶ Algae, Chl-a
- The HEC-RAS model was run for six year simulation periods from 2001 through 2006.



HEC-RAS Hydraulic Model

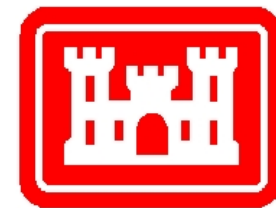


Lower Minnesota River

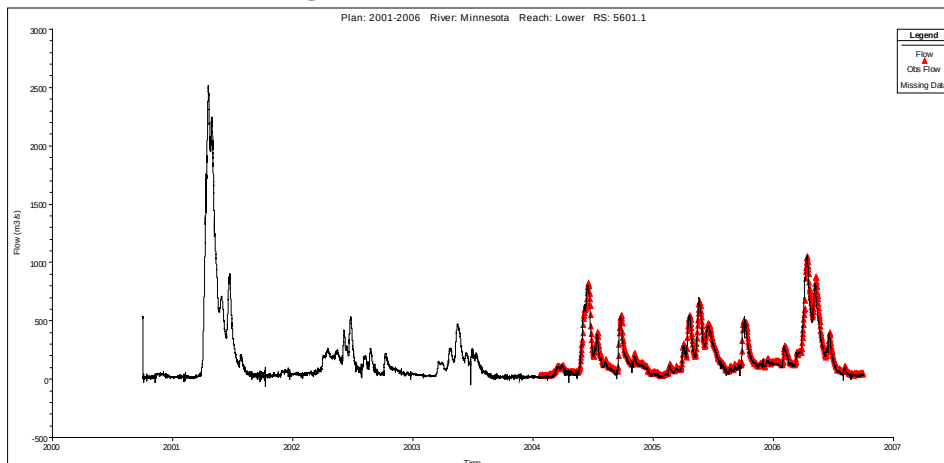




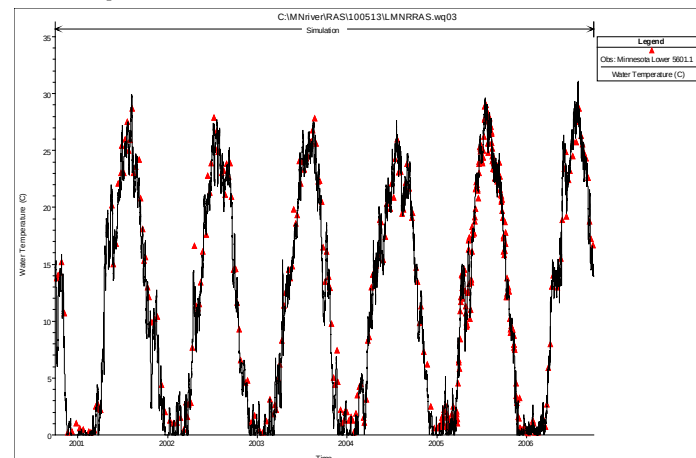
Comparison of Modeled Outputs and Observed Data at RM 3.5



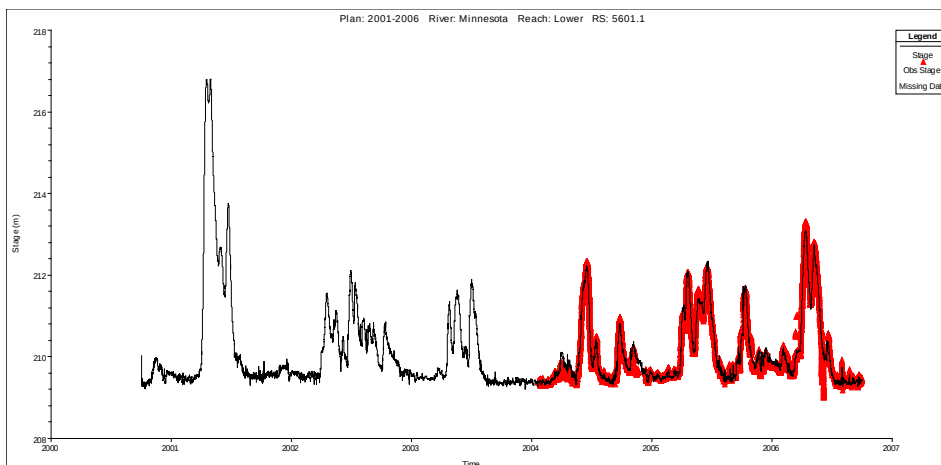
Flow discharge



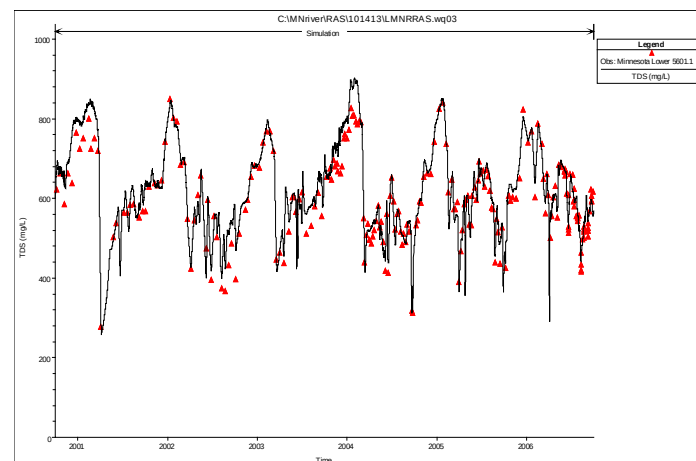
Temperature



Water elevation

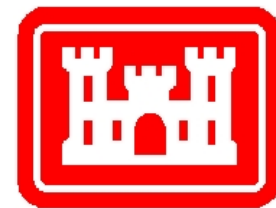


Total dissolved solids

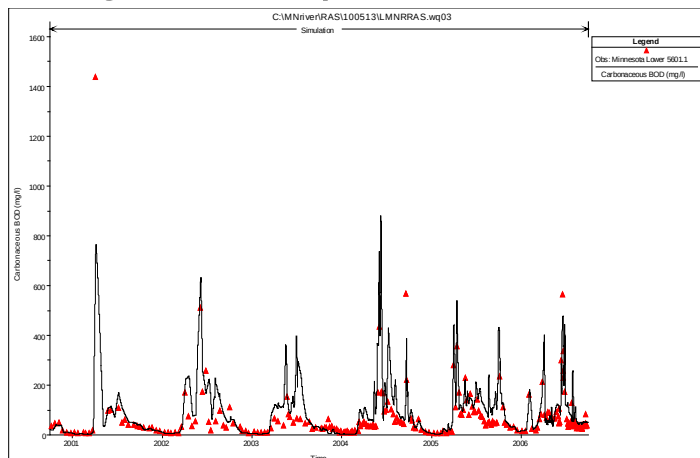




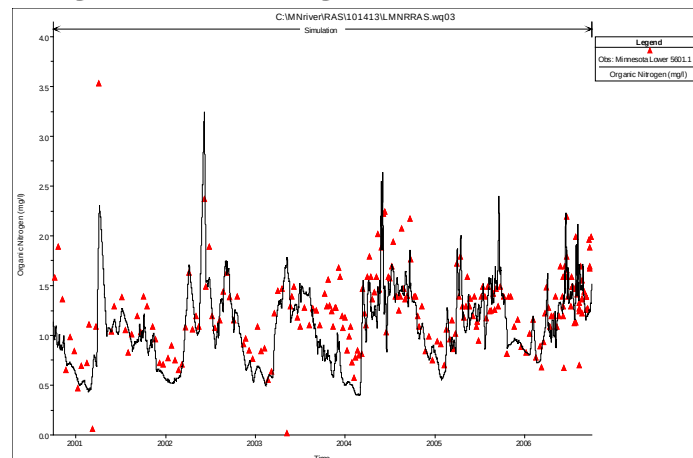
Comparison of Modeled Outputs and Observed Data at RM 3.5



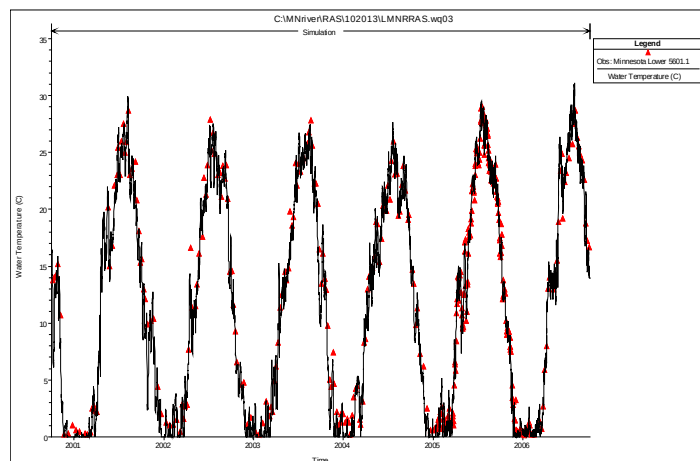
Inorganic suspended solids



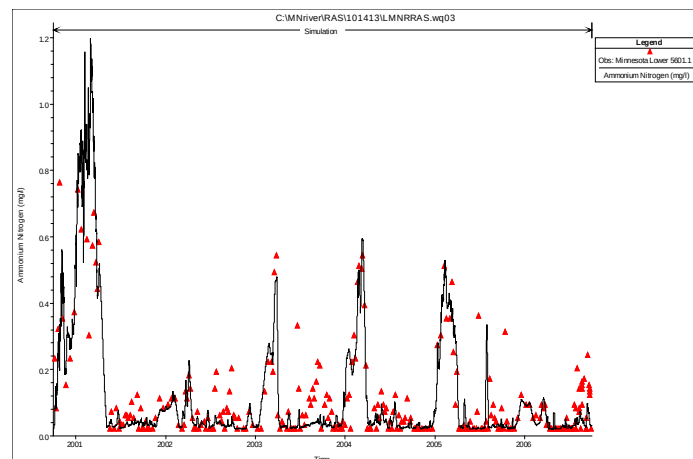
Organic nitrogen



Algal biomass

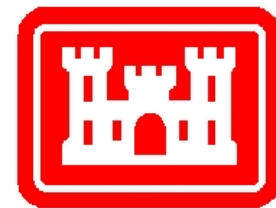


Ammonium nitrogen

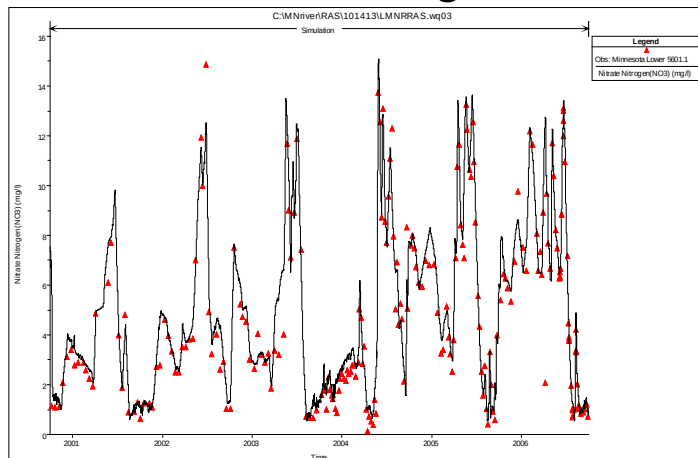




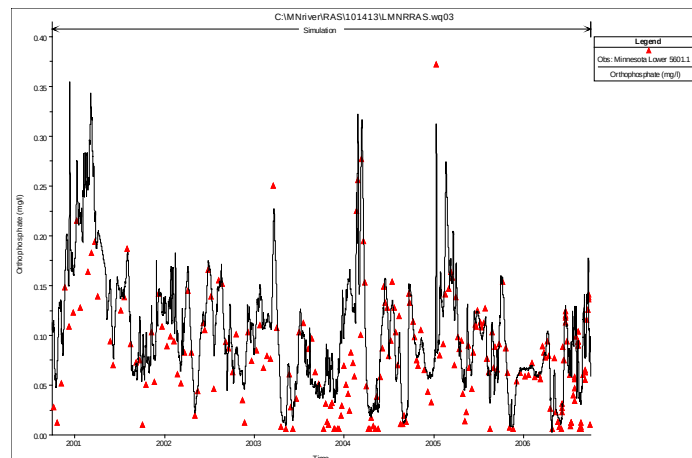
Comparison of Modeled Outputs and Observed Data at RM 3.5



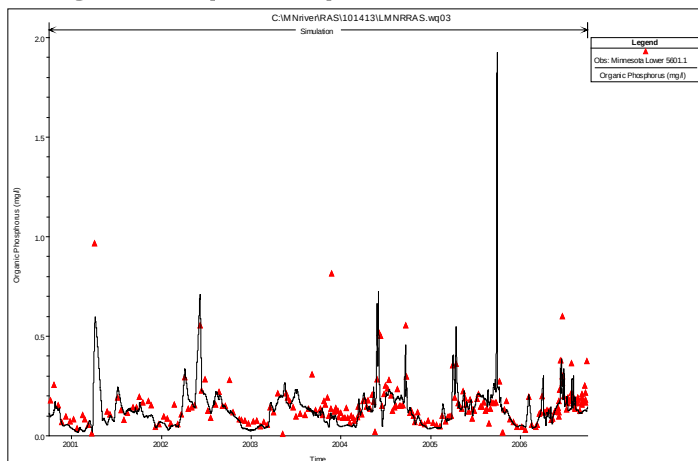
Nitrate-Nitrite nitrogen



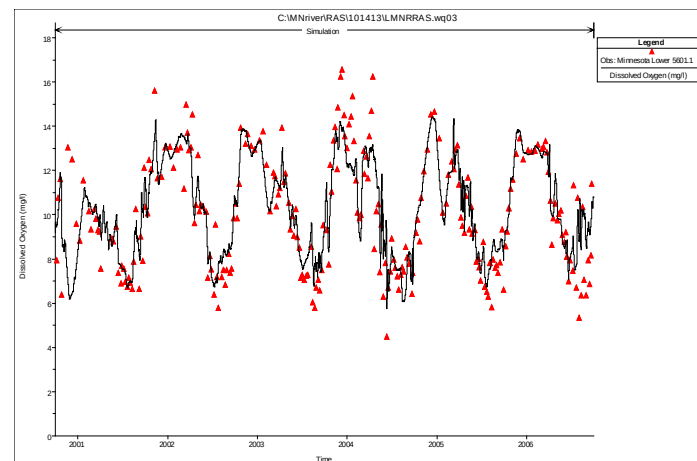
Dissolved inorganic phosphorous



Organic phosphorous

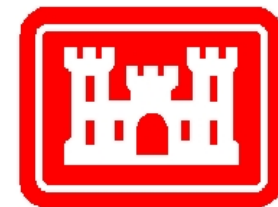


Dissolved oxygen





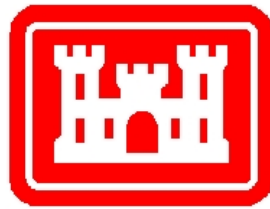
Comparison of Modeled Outputs and Observed Data at RM 3.5



	H	Q	ISS	TDS	T	orgN	NH4	NOx	orgP	PO4	Algae	DO	CBOD
	m	m ³ /s	mg/L	mg/L	°C	mg-N/L	mg-N/L	mg-N/L	mg-P/L	mg-P/L	mg-A/L	mg-O ₂ /L	mg-O ₂ /L
Station at RM 25.1													
R ²	-	-	0.75	0.97	0.97	0.84	0.89	0.98	0.80	0.97	0.89	0.88	0.73
NSE	-	-	0.57	0.97	0.96	0.83	0.89	0.98	0.78	0.97	0.89	0.88	0.68
PBIAS (%)	-	-	34	0.1	-2.6	-1.1	0.0	0.9	1.2	1.8	-2.4	1.2	-11.5
Station at RM 14.3													
R ²	-	-	0.70	0.93	0.98	0.67	0.92	0.98	0.50	0.81	0.71	0.77	0.43
NSE	-	-	0.64	0.92	0.97	0.58	0.92	0.98	0.46	0.71	0.70	0.76	0.29
PBIAS (%)	-	-	26	1.3	-3.8	-5.4	-0.9	4.5	-3.6	23.0	0.1	2.4	-16.1
Station at RM 8.5													
R ²	-	-	-	0.94	0.98	0.70	0.76	0.87	0.73	0.82	0.68	0.85	0.48
NSE	-	-	-	0.92	0.98	0.65	0.74	0.86	0.72	0.75	0.66	0.83	0.33
PBIAS (%)	-	-	-	2.1	-4.1	-4.7	-14	6.3	-3.9	18.6	1.16	3.2	15.4
Station at RM 3.5													
R ²	0.98	0.98	0.54	0.92	0.98	0.47	0.76	0.92	0.47	0.71	0.61	0.76	0.04
NSE	0.97	0.98	0.39	0.89	0.98	0.29	0.66	0.91	0.45	0.54	0.58	0.76	-4.3
PBIAS (%)	0	-1.5	48	3.0	-2.7	-9.0	-6.1	8.6	-9.4	27.5	1.18	1.9	37.4



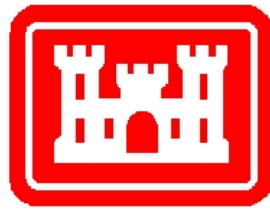
Summary



- HEC-RAS – NSM-I model was able to predict observed water quality concentration along the LMNR. A greater degree of spatial resolution of water quality was obtained than would otherwise have been possible, due to the relatively complex hydraulics of HEC-RAS.
- NSM-I is a simplified eutrophication model. A major advantage of NSM-I is that it demands less input data and computational effort.
- NSM-I is not detailed enough for the investigation of water quality phenomena involving specific types of algae and the effects of different CBOD groups, namely, the inability to reproduce the observed data. This leads us to apply HEC-RAS - NSM-II to the LMNR in the future.
- An existing hydraulic HEC-RAS model can quickly be adapted to model water quality. Thus the overall cost to stake-holders interested in water quality modeling is dramatically reduced.



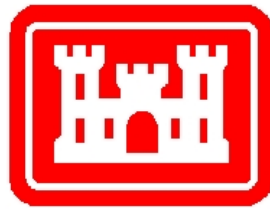
Capabilities to USACE



- This effort provides cost-effective, science-based riverine water quality impact assessment capabilities in support of the USACE ecosystem restoration and management mission.



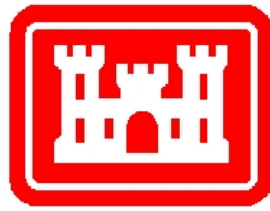
Products



- Software
 - ▶ NSMI.dll
 - ▶ NSMII.dll
 - ▶ NSMIII.dll
 - ▶ HEC-RAS with NSM (-I, -II, -III)
- Reports
 - ▶ Zhang, Z., Johnson, B.E. (2014). Aquatic Nutrient Simulation Modules (NSM) Developed for Hydrologic and Hydraulic Models. *ERDC/EL TR-14-X*, U.S. Army Engineer Research and Development Center, Vicksburg, MS.
 - ▶ Zhang, Z., Johnson, B.E. (2014). Application and Evaluation of HEC-RAS – NSM-I Model to the Lower Minnesota River. *ERDC TN-EMRRP-14-X*, U.S. Army Engineer Research and Development Center, Vicksburg, MS.



Model Certification



- HEC-RAS – NSM (-I, -II, -III) will be certified and released from HEC. ERDC-EL will prepare necessary testing and verification study materials and documentations to support HEC for the model certification.