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New Advances in Modeling Water Quality and Targeted Conservation Effects at Field to Watershed Scales

2013 Heartland Regional Water Conference

April 15 – 17, 2013
Sheraton, Overland Park, KS

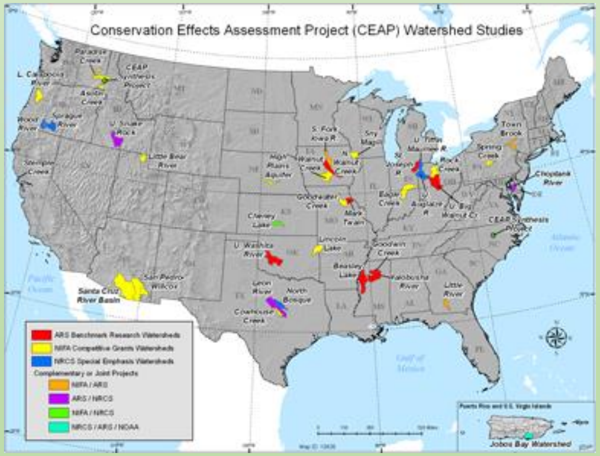
Presentation Themes

1. CEAP Cropland Conservation Impacts
2. Modeling Conservation Practices – SWAT and AnnAGNPS
3. The AgES-W Modeling System
4. New Modeling Technologies
5. Future Modeling Challenges

CEAP (Conservation Effects Assessment Project)

- **Quantify the environmental effects of conservation practices and programs**
- **Develop the science base for managing the agricultural landscape for environmental quality**
- **Guide USDA conservation policy and program development**
- **Help conservationists, farmers, and ranchers make more informed conservation decisions**

Watershed Assessments



ARS Benchmark Watersheds,
Special Emphasis Watersheds,
NIFA Competitive Grants Watersheds

Cropland

Wetlands

Regional and National

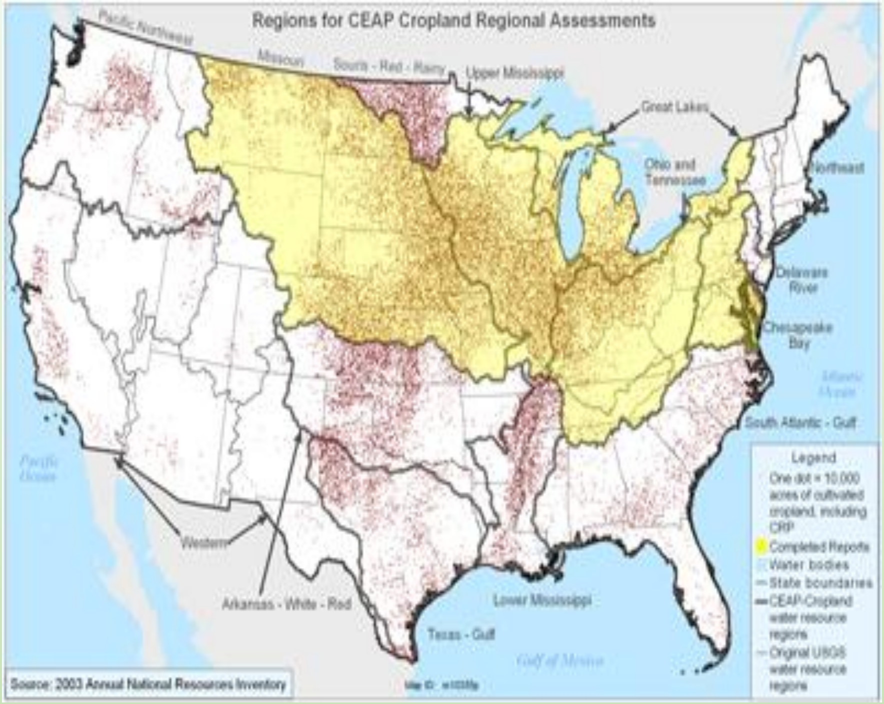
Wildlife

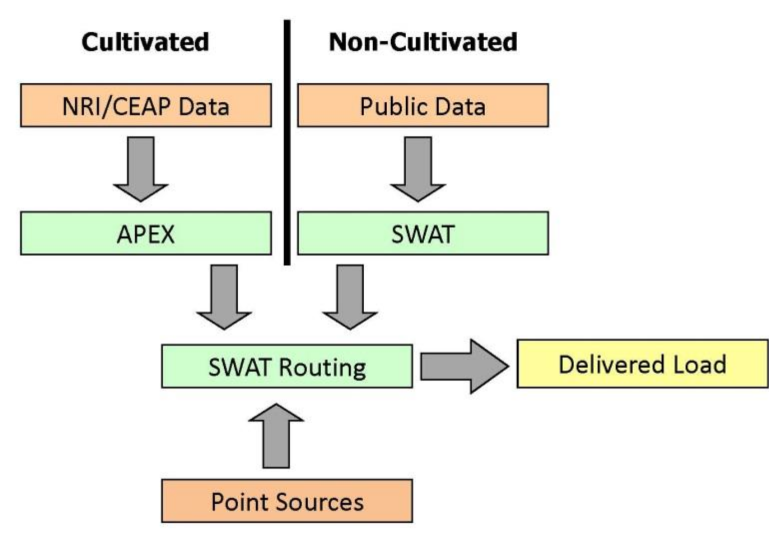
Grazing Lands

CEAP Cropland National Assessment

River Basin Cropland Modeling Study Reports

Upper Mississippi River Basin
Ohio-Tennessee River Basin
Missouri River Basin
Arkansas-White-Red River Basins
Texas Gulf Water Resource Region
Lower Mississippi River Basin
Great Lakes Water Resource Region
Souris-Red-Rainy Water Resource Region
South Atlantic-Gulf Water Resource Region
Mid-Atlantic Water Resource Region (including separate reports for the Chesapeake Bay and Delaware River watersheds)
New England Water Resource Region
Pacific Northwest Water Resource Region
Western Water Resource Regions





Cultivated

Non-Cultivated

NRI/CEAP Data

Public Data

APEX

SWAT

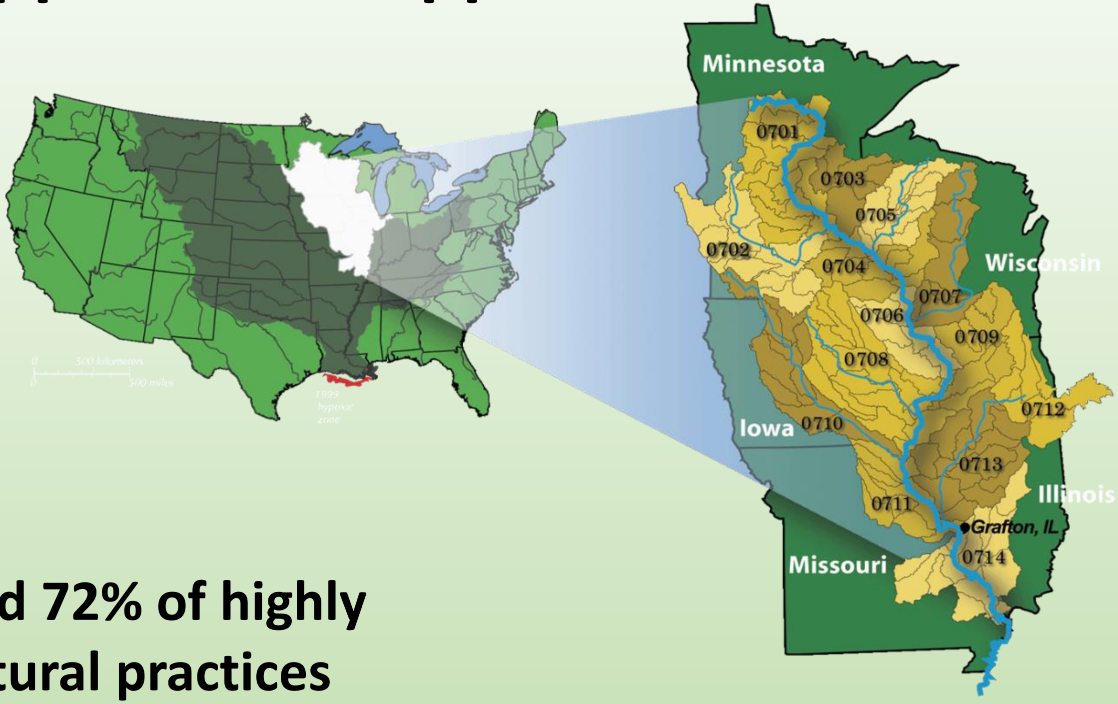
SWAT Routing

Delivered Load

Point Sources

Latest Report:
Missouri River Basin (released August 30, 2012

CEAP Cropland - Upper Mississippi River Basin



Significant Progress Made in Reducing Sediment, N, and P Losses

- 45% of the cropland and 72% of highly erodible land has structural practices
- 95% of the cropland has reduced tillage, 71% is no-till or mulch till
- Edge of field sediment loss reduced by 69%, P by 45%, and N by 18%
- In-stream sediment reduced by 37%

Maresch, et al., 2008, JSWC Vol. 63, No. 6, pp. 198A-203A.

Upper Mississippi Basin - Targeting Conservation Increases Impact

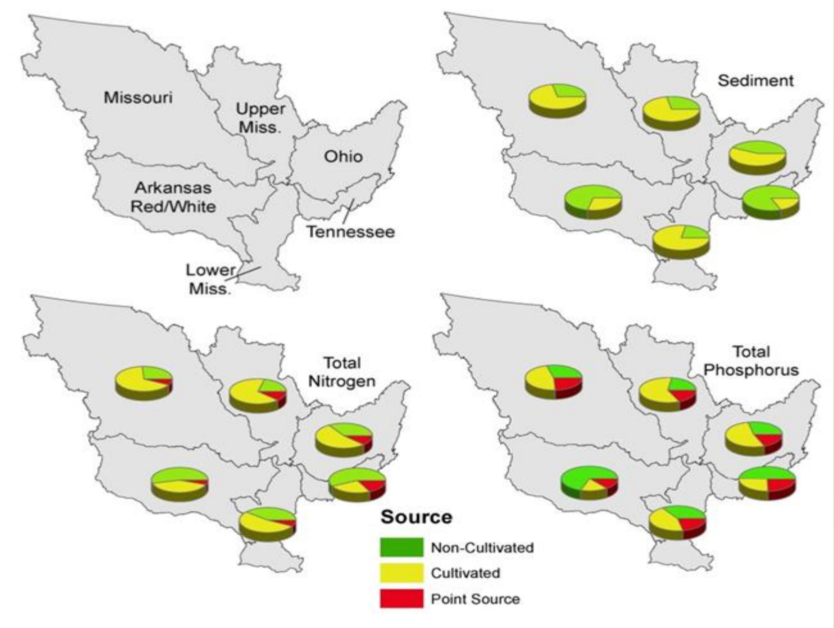
- 36 million acres (62%) are under-treated for sediment, N or P loss
- Treating 36 million acres of under-treated would cut N loss in subsurface flow from 21.8 to 11.4 lb/acre (48%); total N reduction of 43%; and total P reduction of 51%
- 8.5 million acres (15%) are critically under-treated for sediment, N or P loss
- Treating 8.5 million acres of critically under-treated would cut sediment loss from 1.0 to 0.6 t/acre (40%); N reduction from 8.6 to 6.1 lb/acre (29%); and P reduction from 3.0 to 2.4 lb/ha (22%)

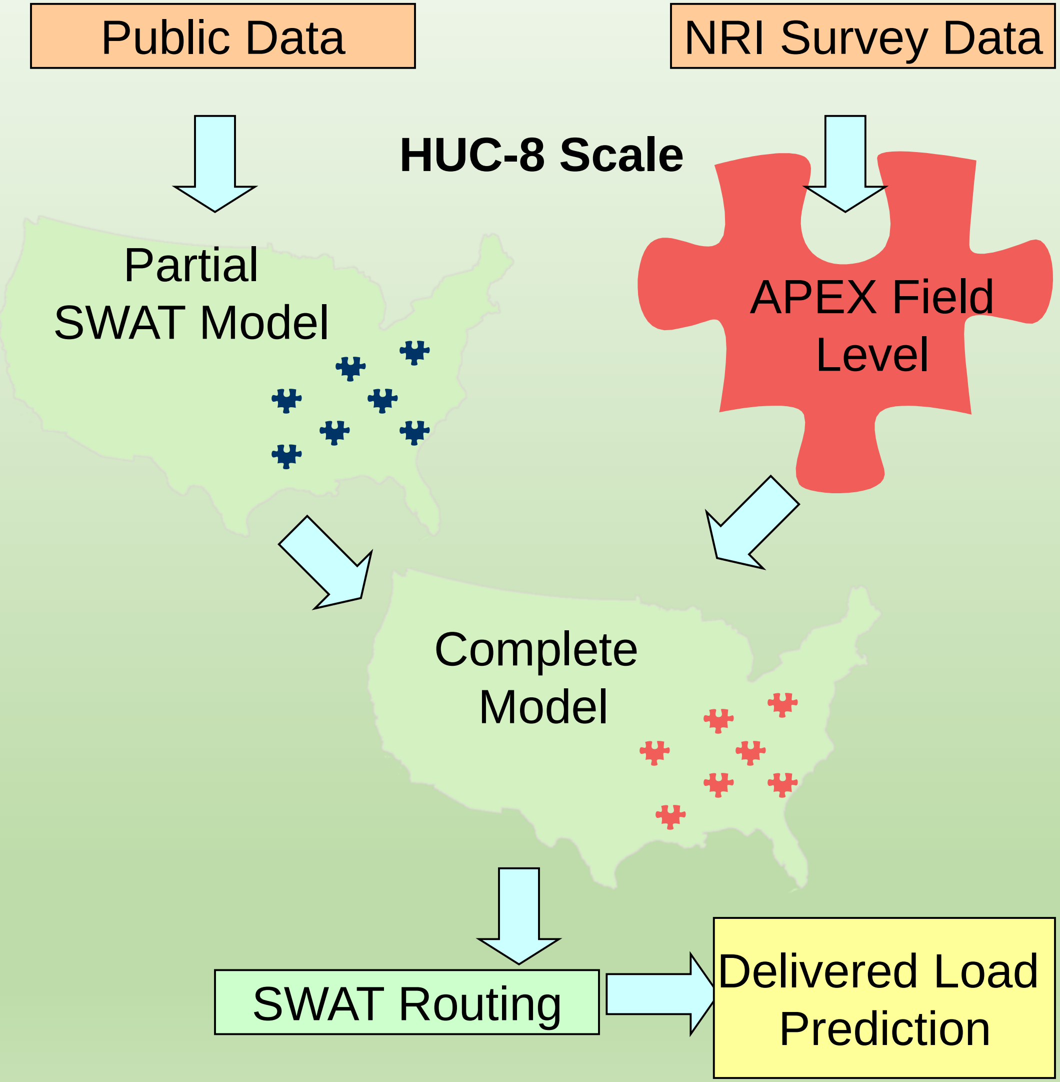
Key Question: What future role(s) will models play in targeting conservation practice implementation at various spatial scales?

White, M. et al. 2013. Nutrient delivery from the mississippi river to the Gulf of Mexico and effects of cropland conservation. JSWC. In Press.

US National Assessments

- **Justify US conservation expenditures (about 2 billion annually) for CEAP**
- **Quantitative predictions of water quality improvements**
- **18 river basins simulated using SWAT and APEX**





Public Data

NRI Survey Data

HUC-8 Scale

Partial SWAT Model

APEX Field Level

Complete Model

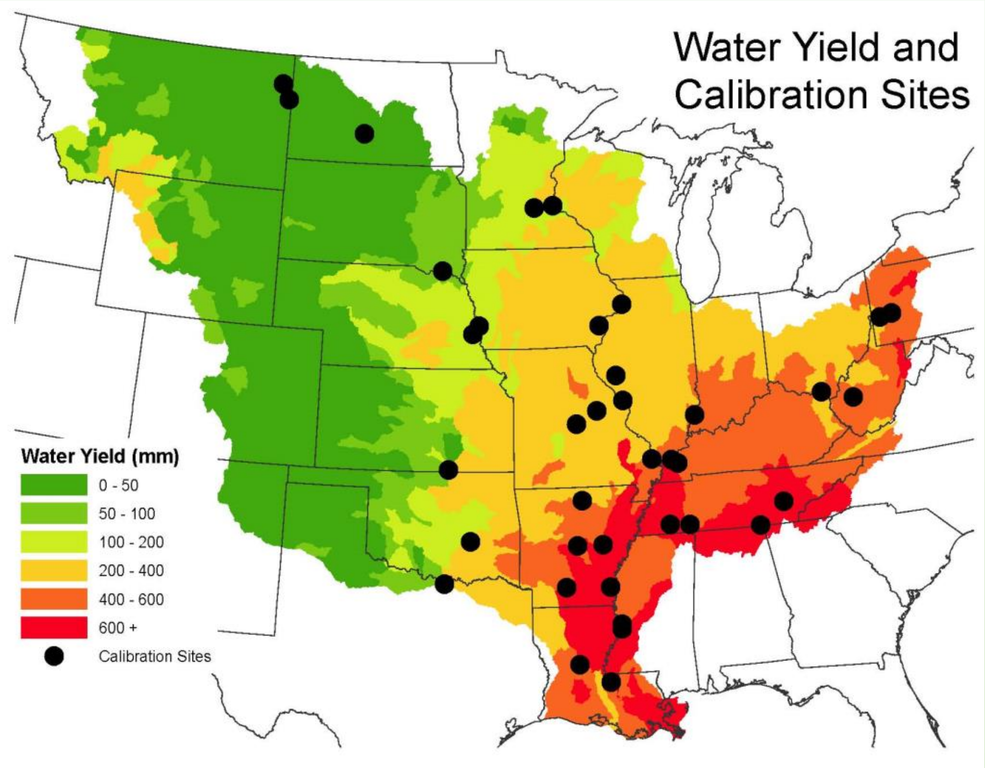
SWAT Routing

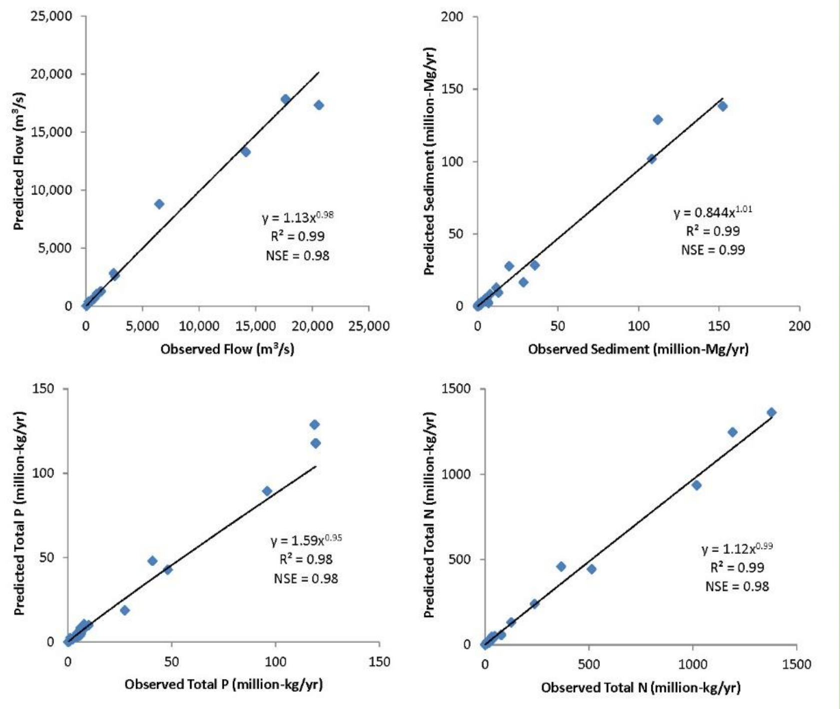
Delivered Load Prediction

CEAP Framework

CEAP Framework Calibration

- **Streamflow (surface runoff and baseflow)**
  - **Calibrated at the 8 digit level to USGS estimated runoff**
  - **Automated calibration using autocalibration software**
- **Sediment and Nutrients**
  - **Calibrated to individual estimated loads at 38 sites**
  - **Automatic calibration using heuristic algorithms**



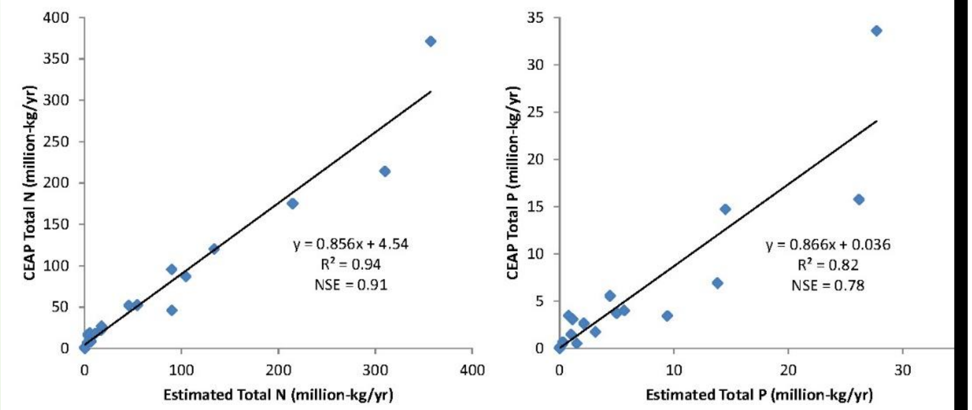


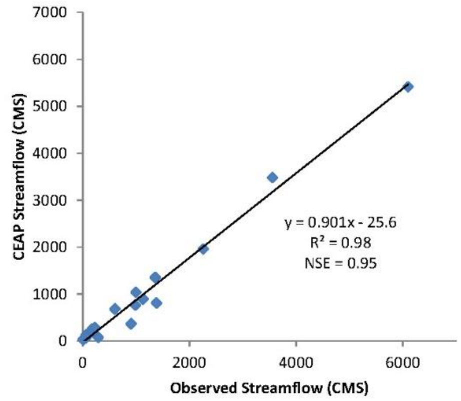
Relative Errors

Flow: -3.9% to 15.8% (median = -1.1%)
Sediment: 99% to 64% (median = 5.9%)
Total P: -140% to 35% (median = -1.8%)
Total N: -90% to 36% (median = -0.8%)

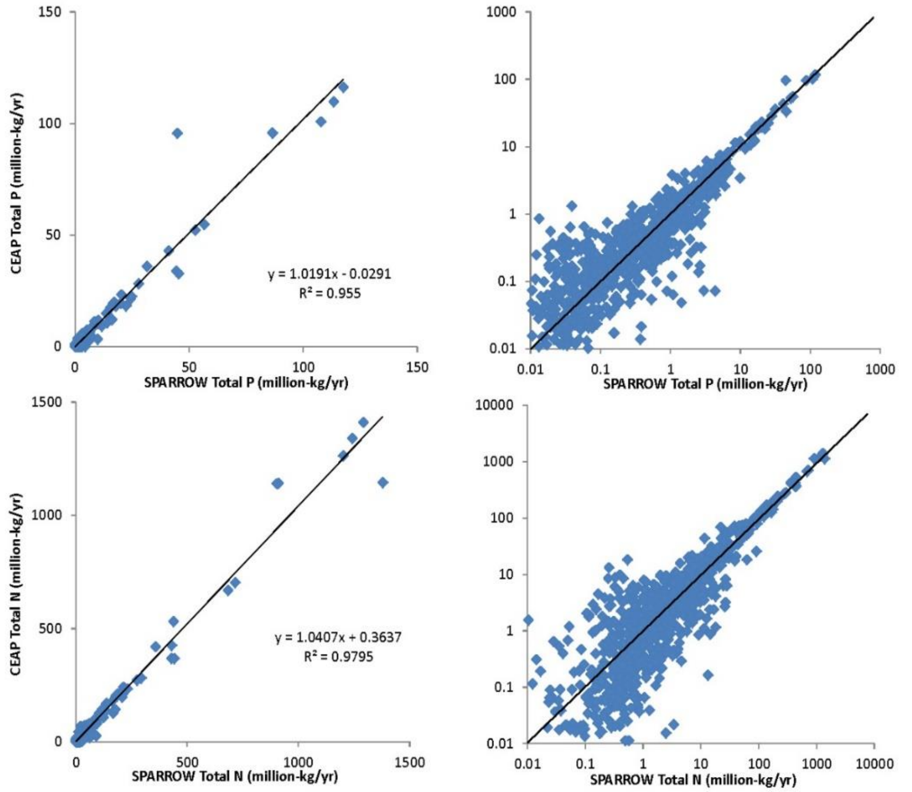
Coefficient of determination (R^2) and NSE ranged from 0.98 to 0.99 across parameters

CEAP Framework Validation





Validation period: 1970-2007

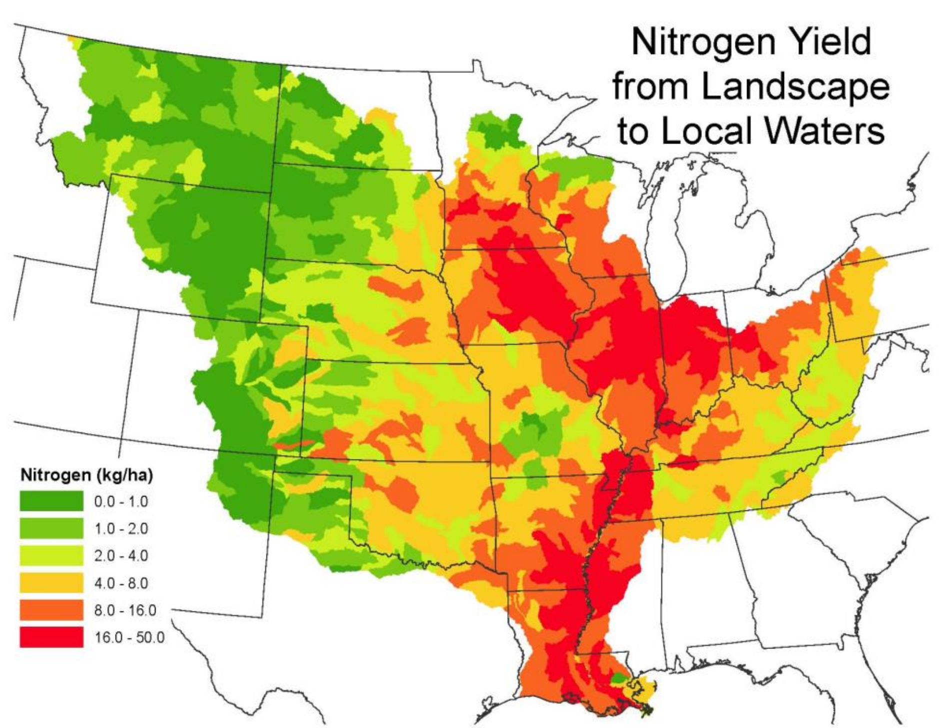


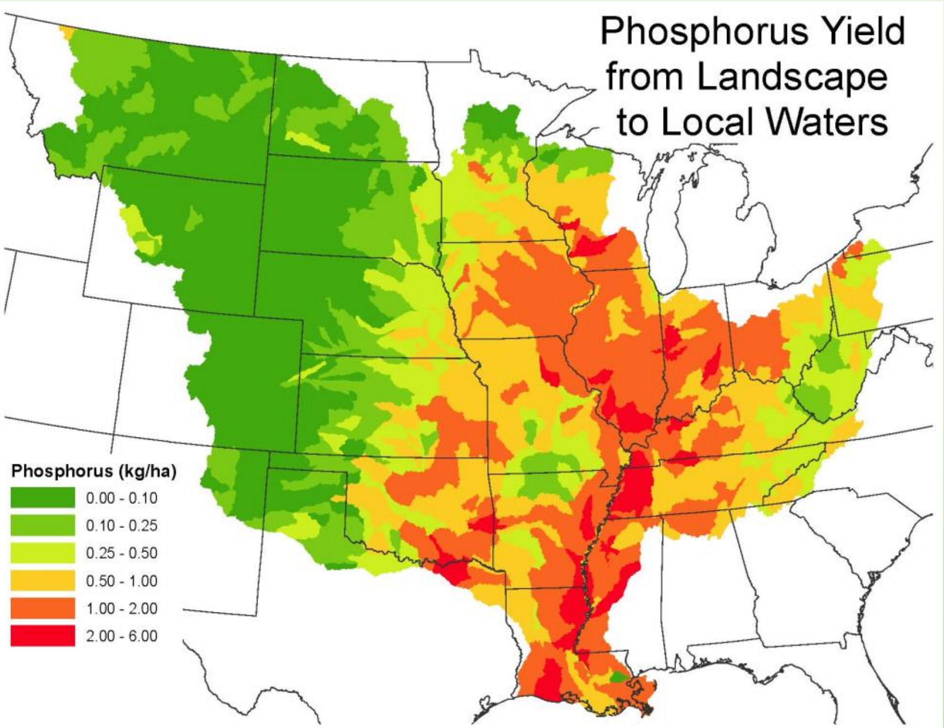
- **17 sites as reported in Saad et al. (2011) with flow, total N and total P**

- **R^2 values ranged from 0.82 to 0.98 and NSE ranged from 0.78 to 0.95**

- **CEAP and SPARROW nutrient predictions as scatter plots in both log and real domains**
- **Comparisons in real space are highly correlated (r^2 >0.95) with slopes near unity**

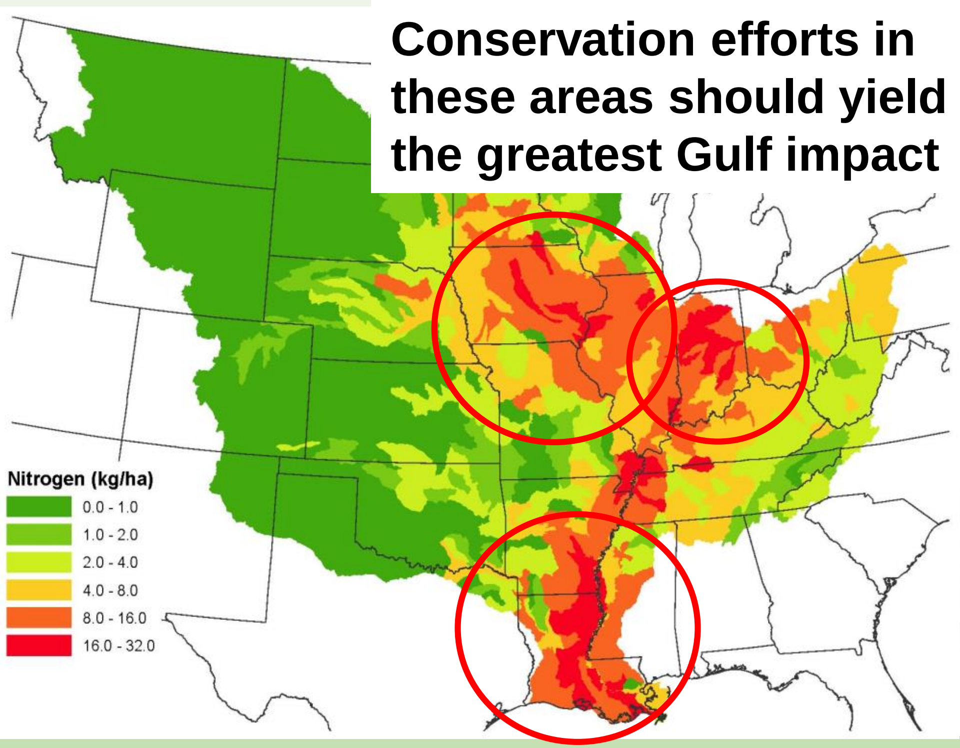
N and P – Yield to Local Waters



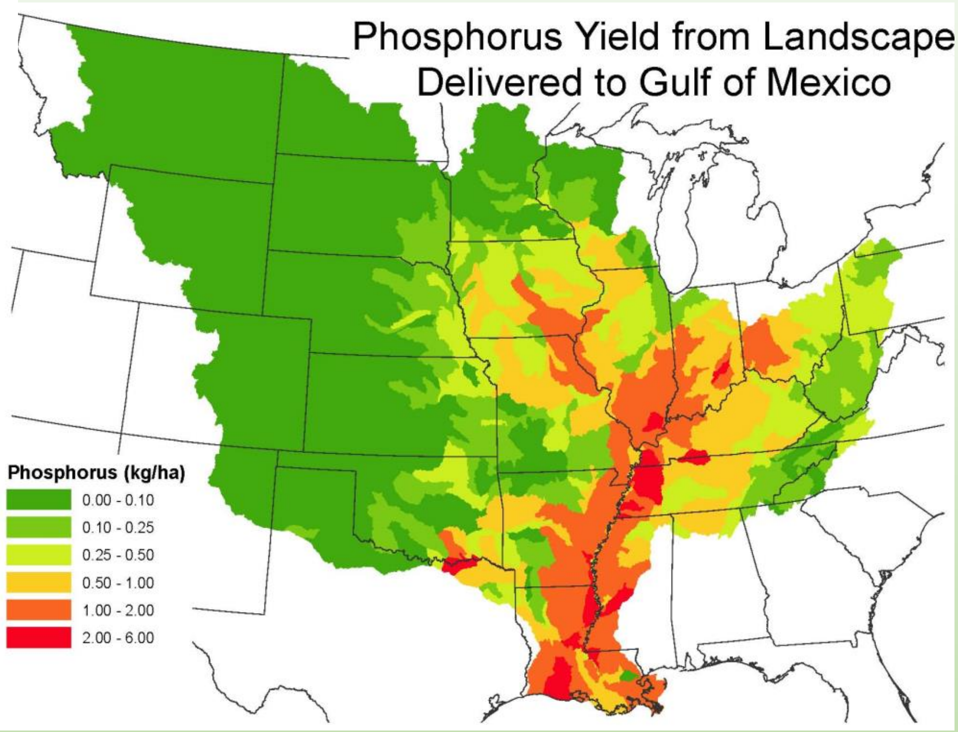


- **Nutrient losses to local waters strongly correlated (67% variability explained) with the fraction of cultivated land use, density of tile drains, and precipitation**
- **The highest nutrient loads on a per acre basis occur in the upper and lower portions of the MRB**

N and P – Delivered to the Gulf of Mexico



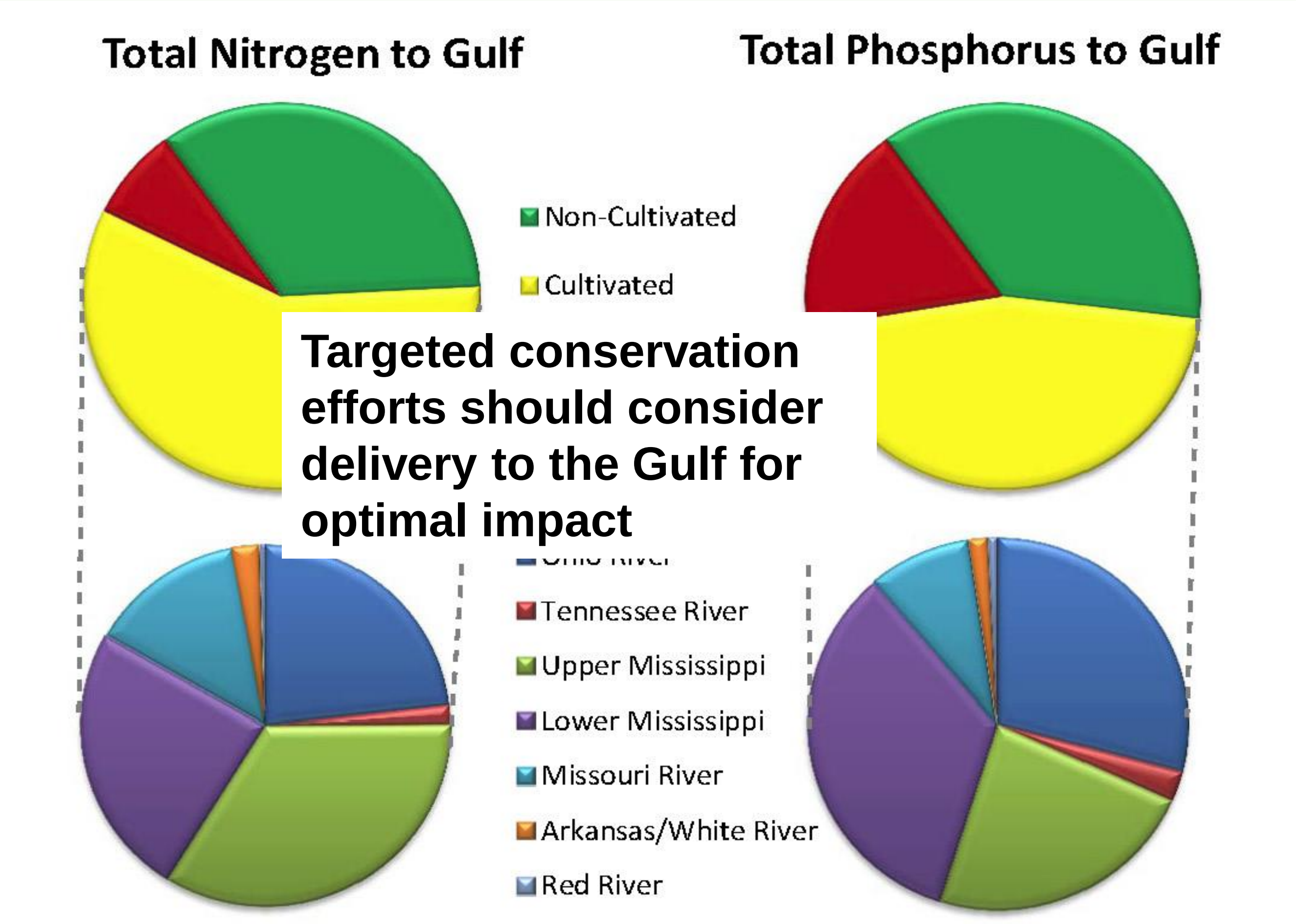
Conservation efforts in these areas should yield the greatest Gulf impact



Phosphorus Yield from Landscape Delivered to Gulf of Mexico

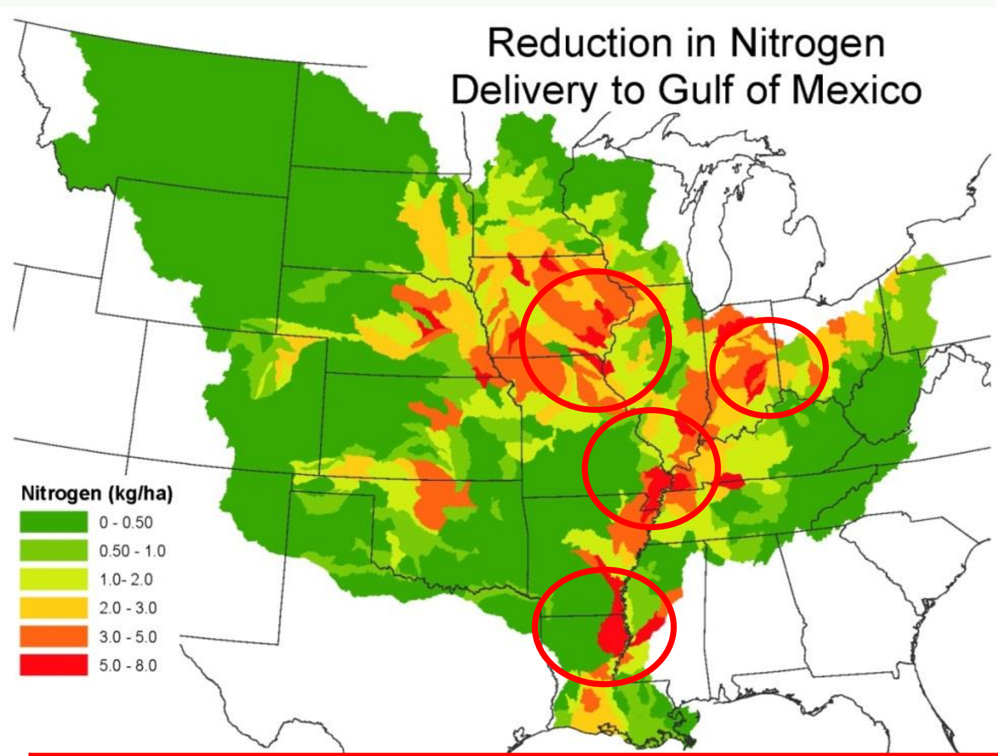
- ❖ **Includes local and in-stream nutrient delivery**
- ❖ **58% of N and 54% of P entering streams from all sources predicted to reach the Gulf (the remainder are sequestered or lost in lakes, reservoirs, rivers, and streams)**
- ❖ **Delivery along the main stem of the Mississippi is relatively high with 87% of N and 90% of P at the confluence of the Missouri and Mississippi Rivers reaching the Gulf**

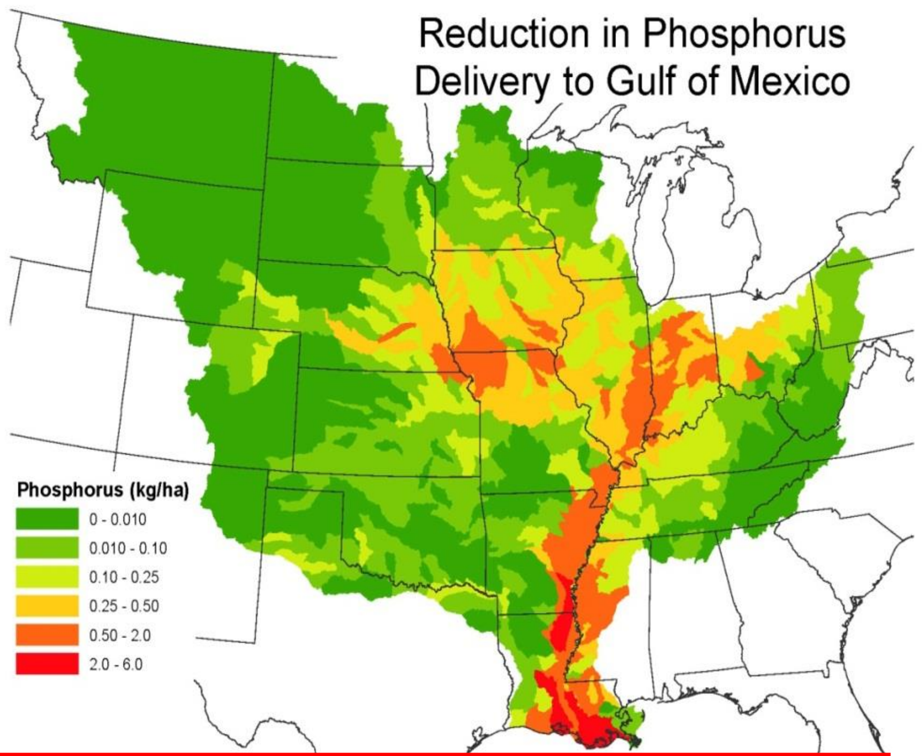
Gulf of Mexico Load Allocation



Targeted conservation efforts should consider delivery to the Gulf for optimal impact

- **N and P load from cultivated agriculture to local waters and to the Gulf is similar**
- **If delivery to the Gulf is considered, the worst 10% of the HUC8s contribute 36% of the entire cultivated N load to the Gulf**



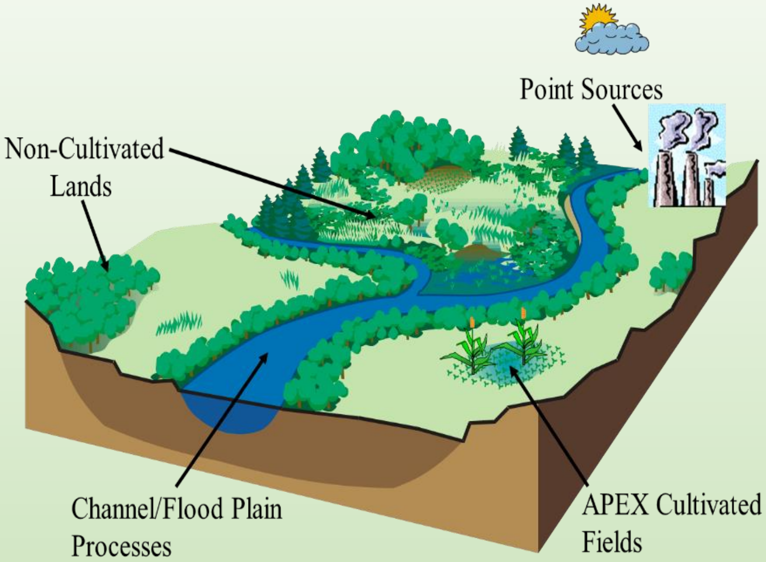


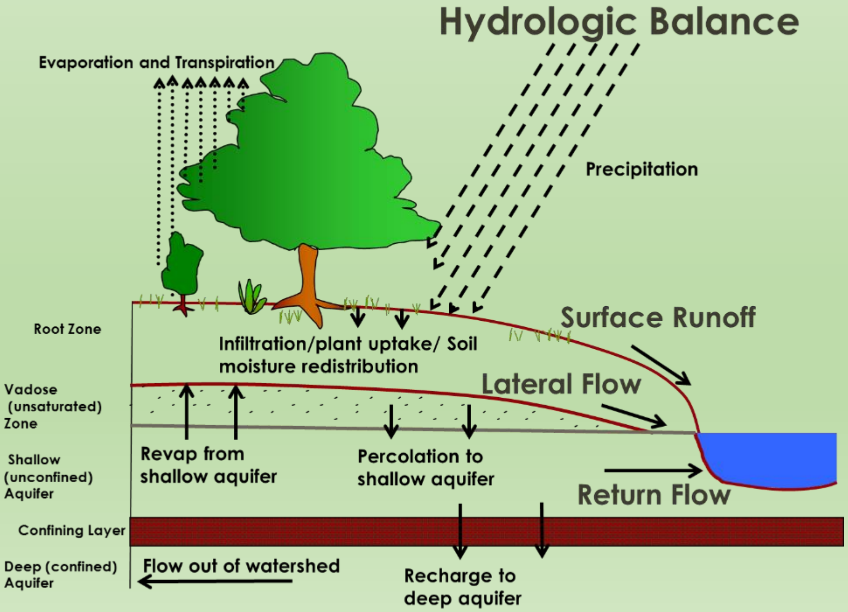
Areas with relatively high nutrient delivery (>80%) and extensive agricultural production such as the lower Missouri, upper and lower Mississippi, and Ohio show the most benefit from the establishment of conservation practices

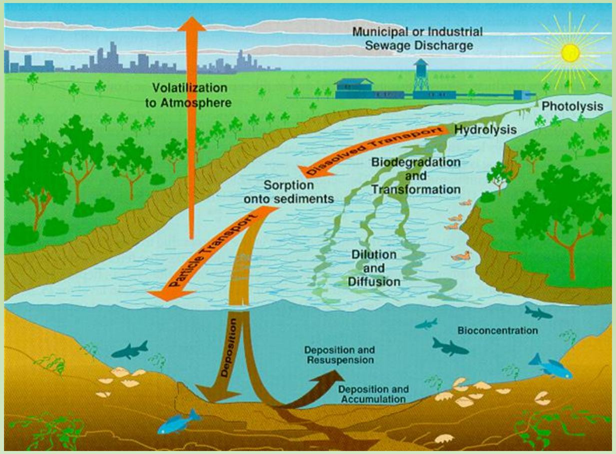
No Conservation Practices	***1,640***	***165***
Current Conservation Condition	**1,350**	**132**
Reduction due to Conservation	**18%**	**20%**
Load From Only Cultivated Agriculture Delivered to the Gulf		
No Conservation Practices	**1,110**	**115**
Current Conservation Condition	**796**	**63**
Reduction Due to Conservation	**28%**	**45%**

SWAT 2012-2013 Development Status

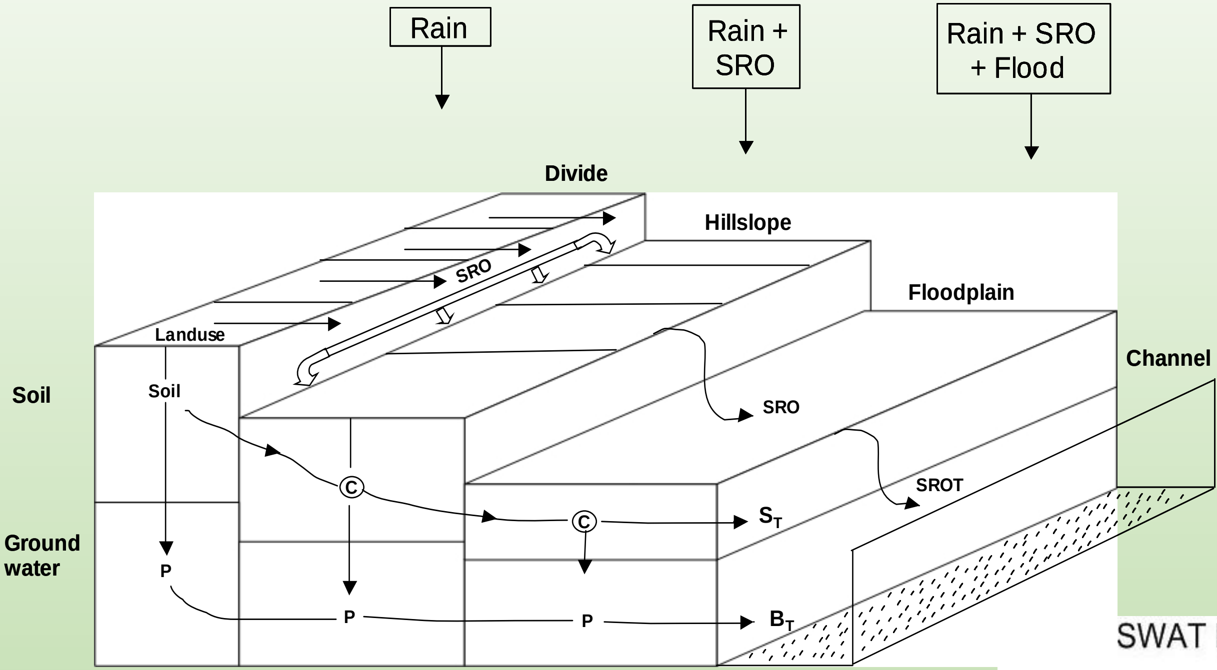
- Landscape Processes
- Conservation Practices, Urban BMPs
- Defining Phosphorus Pools
- Channel Morphology and Sediment Routing
- Real Time Irrigation Scheduling
- Database Read/Writes
- Code Parallelization
- Management Scheduling
- Tile Drainage







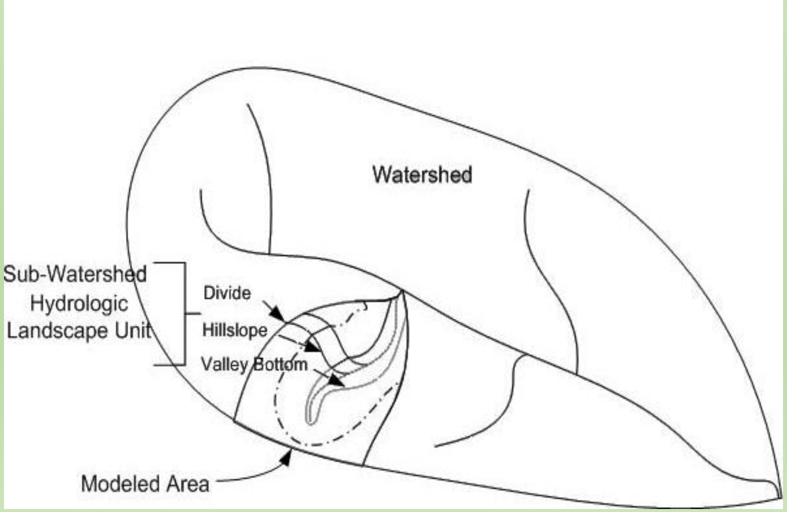
SWAT Landscape Modeling Approach



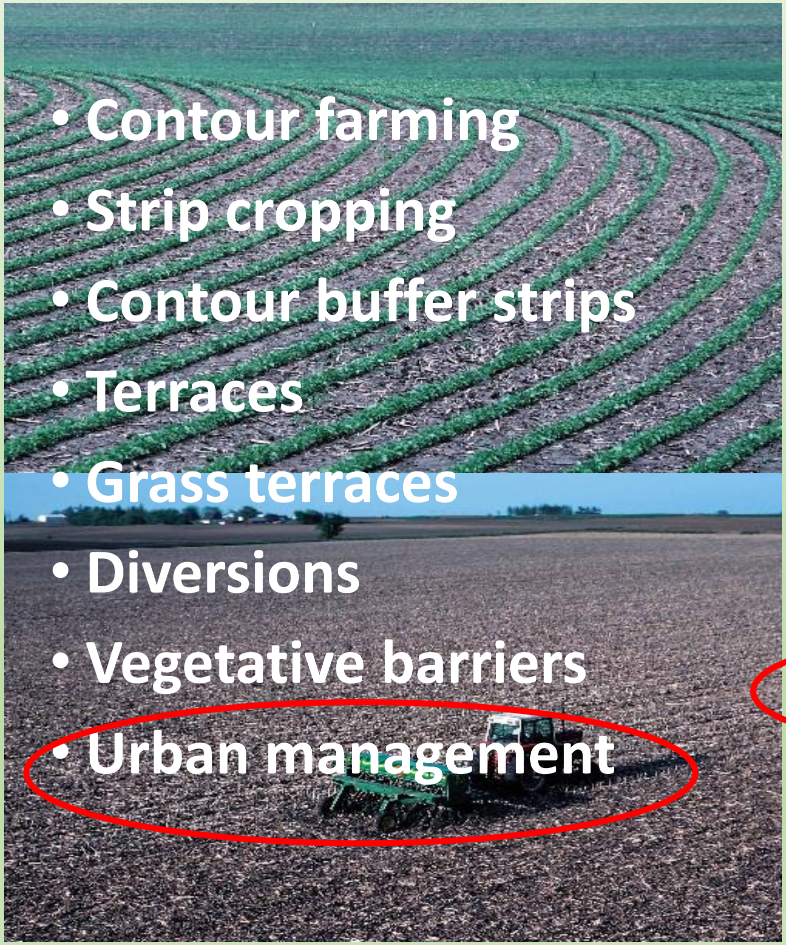
B_T= Groundwater Total
SRO = Surface Runoff Total
S_T = Lateral Soil Flow Total

- ➢ **Landscape Positions (Flood Plain, Hillslopes, Divide)**
- ➢ **Riparian Zones**

SWAT Modeling Strategy



Expansion of Structural Management Practices Addressed by SWAT

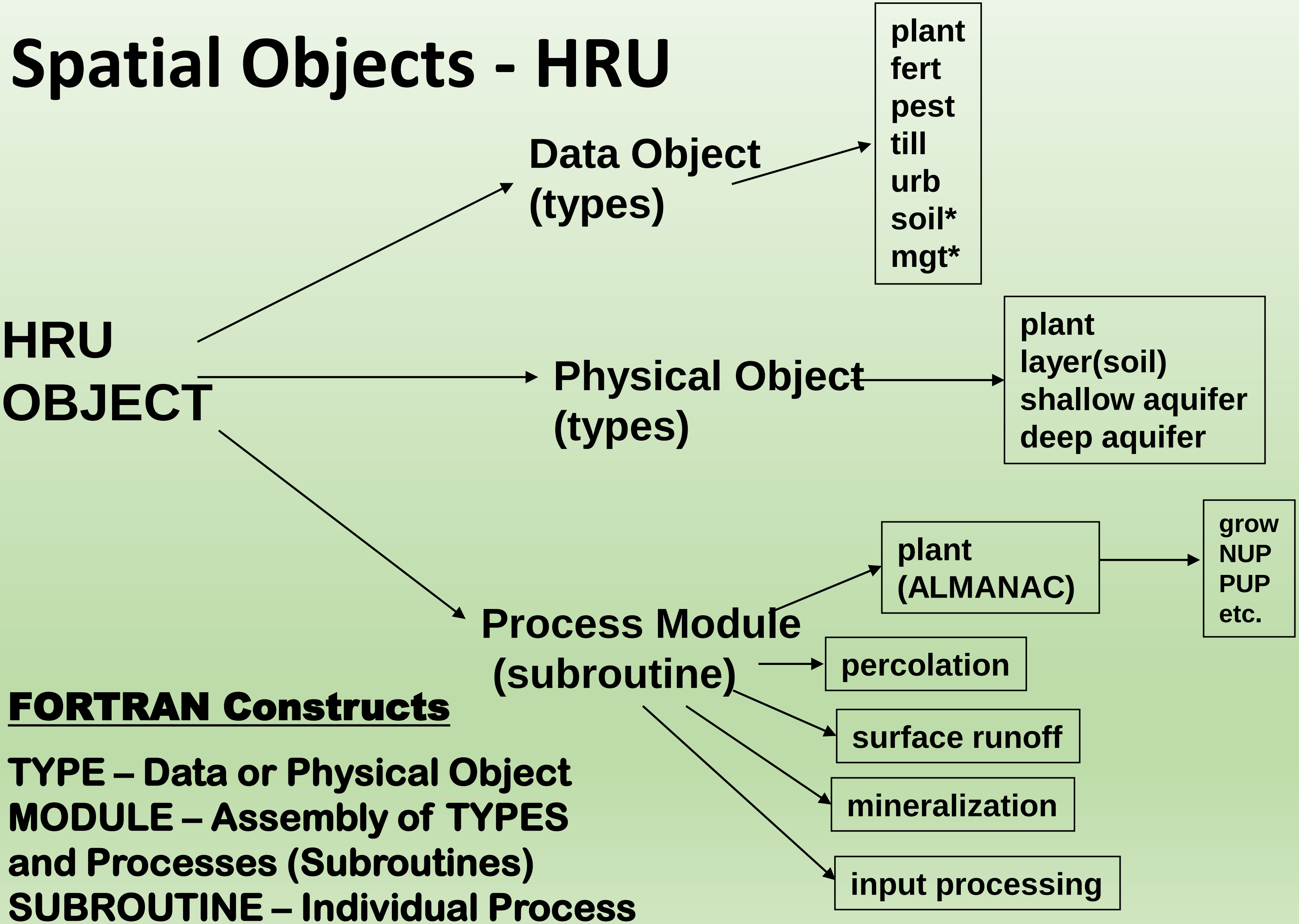


- Contour farming
- Strip cropping
- Contour buffer strips
- Terraces
- Grass terraces
- Diversions
- Vegetative barriers
- Urban management

- Field borders
- Grade stabilization structures
- Grass waterways
- Hedgerows
- Cross wind practices
- Windbreak/shelterbelt
- Herbaceous wind barrier
- Tile drains

SWAT Model FORTRAN Re-Coding

Spatial Objects - HRU



HRU OBJECT

Data Object (types)

plant
fert
pest
till
urb
soil*
mgt*

Physical Object (types)

plant
layer(soil)
shallow aquifer
deep aquifer

Process Module (subroutine)

plant (ALMANAC)

grow
NUP
PUP
etc.

percolation

surface runoff

mineralization

input processing

FORTRAN Constructs

TYPE – Data or Physical Object
MODULE – Assembly of TYPES and Processes (Subroutines)
SUBROUTINE – Individual Process

Estimating Nitrate-N Removal by Wetlands Placed using LiDAR Topographic Data: A Watershed-Scale Modeling Exercise

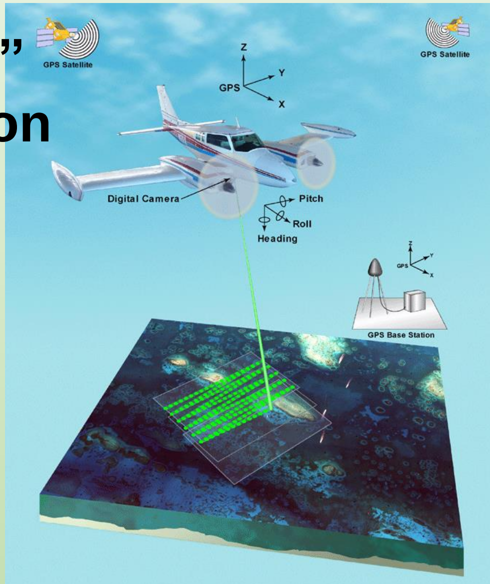
Objectives

- To demonstrate that sites for nutrient removal wetlands can be identified using LiDAR topographic data
- Illustrate factors impacting N removal performance of wetlands through AnnAGNPS modeling

Tomer, M.D. et al. 2013. Estimating nitrate load reductions from placing constructed wetlands in a HUC-12 watershed using LiDAR data. J. Ecol. Eng. In Press.

Aerial "LiDAR" data acquisition

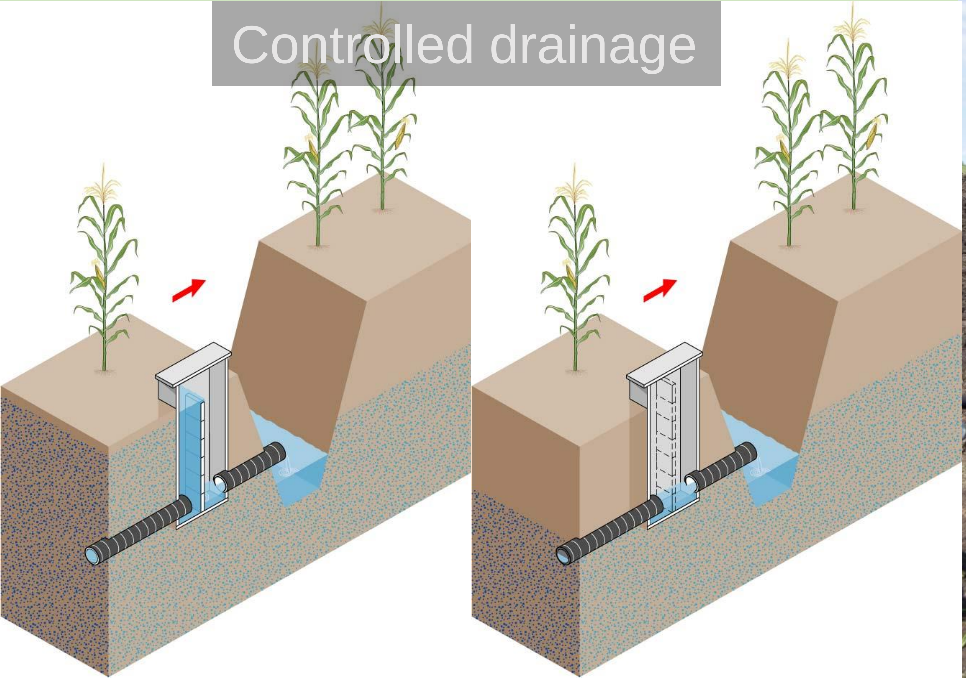
Light
Detection
And
Ranging



Practices for Managing Tile Drainage Water Quality

Two-stage drainage ditch

Nutrient interception wetlands



Controlled drainage

Wood chip “bioreactors”

Rationale

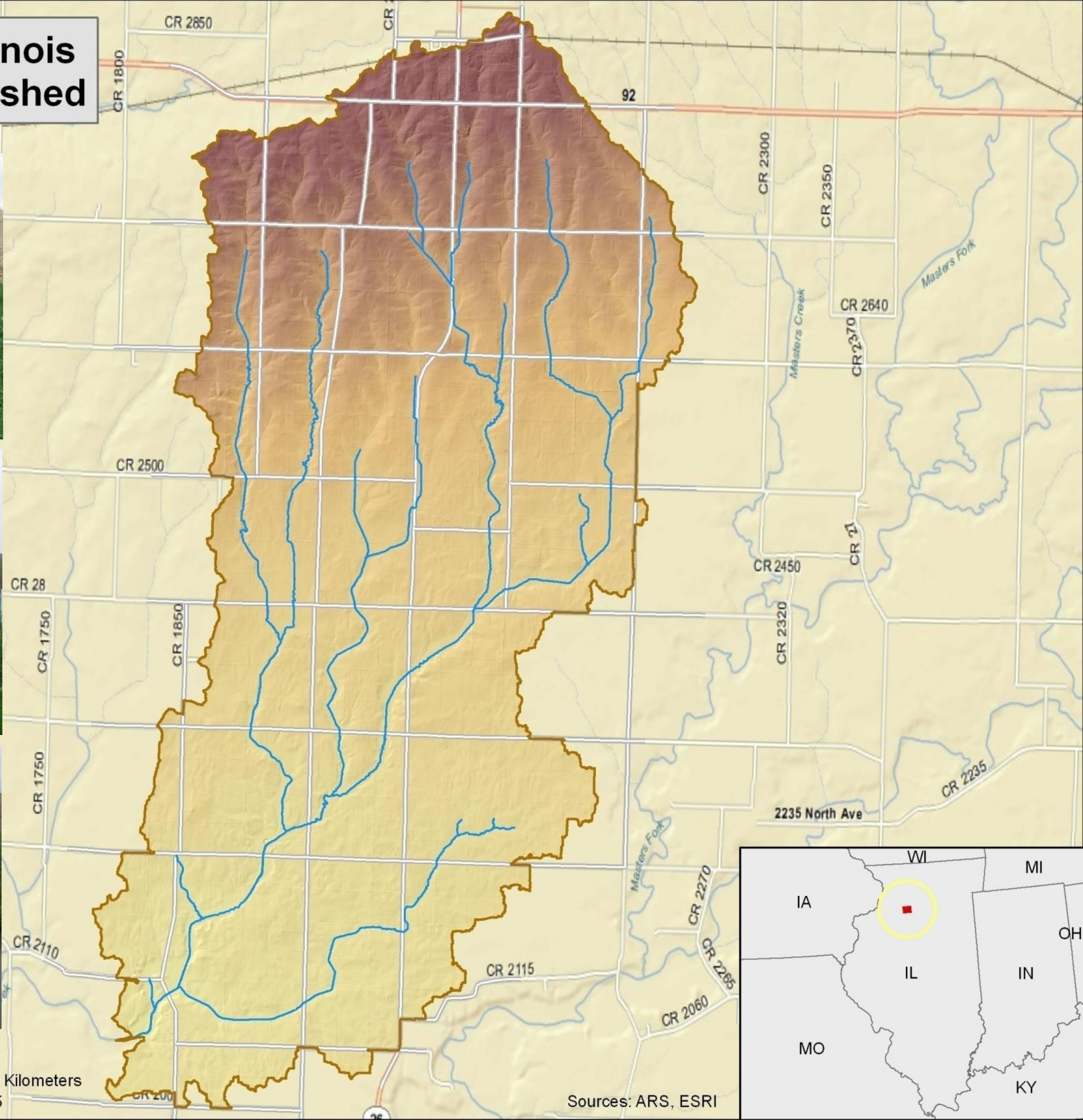
- Nutrient losses from tile drained cropland (20 x 10^6 ha) in the Midwest are significant, particularly for nitrate, and are contributing to Gulf of Mexico hypoxia
- We need the ability to: 1) locate sites suitable for installation of wetlands, and 2) develop water quality management approaches for watersheds
- We need to understand: 1) how wetlands can help meet nutrient reduction goals, and 2) how to implement alternative practices to intercept nutrients where wetlands are unfeasible

Big Bureau Creek, Illinois
Lime Creek subwatershed

Upper Watershed

Middle Watershed

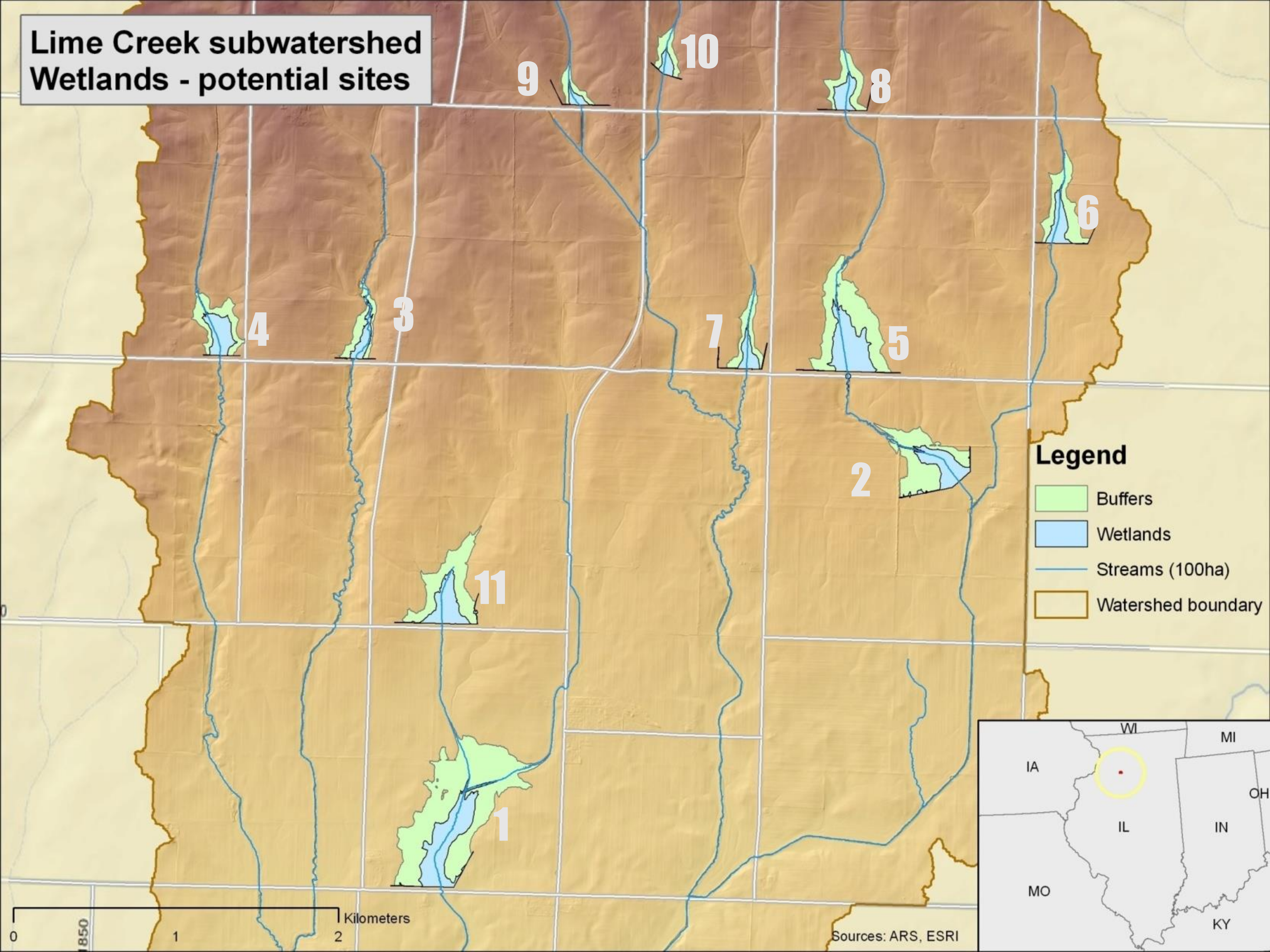
Lower Watershed



Sources: ARS, ESRI

Wetland Site Criteria

- Minimum contributing area (CA) of 100 ha
- Depth criteria of 0.9 m wetland depth, plus a 1.5 m vertical buffer where the wetland could impede drainage (from Iowa CREP program)
- Neither a wetland nor its buffer can impede drainage along roads or within farmsteads
- Conducted field review of sites meeting criteria
- Sorted sites into a preliminary ranking to favor large contributing areas (CA), wetland areas <2% of CA, and small buffer areas



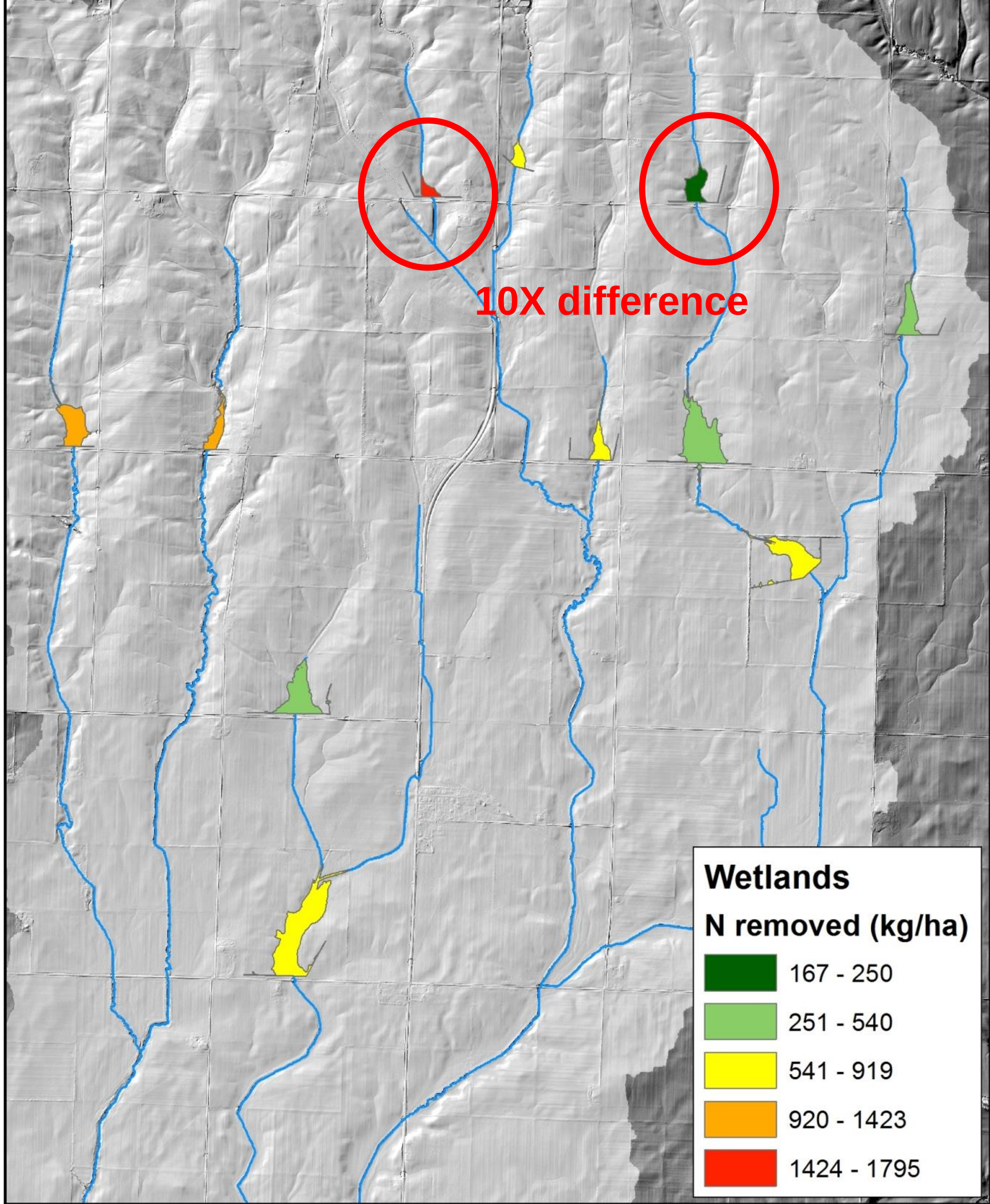
Lime Creek subwatershed Wetlands - potential sites

Sources: ARS, ESRI

AnnAGNPS Simulation: Average Annual N Removal Rates Varied 10X

Factors Impacting Performance Include:

- Hydraulic loading (contributing area to wetland area ratio)
- Nitrate concentration in tile drainage (row cropping, nutrient management practices, soil type)
- Regional and year-to-year variation in climate that impact amounts and timing of loads
- Wetland characteristics (flow routing, vegetation, organic substrates)



10X difference

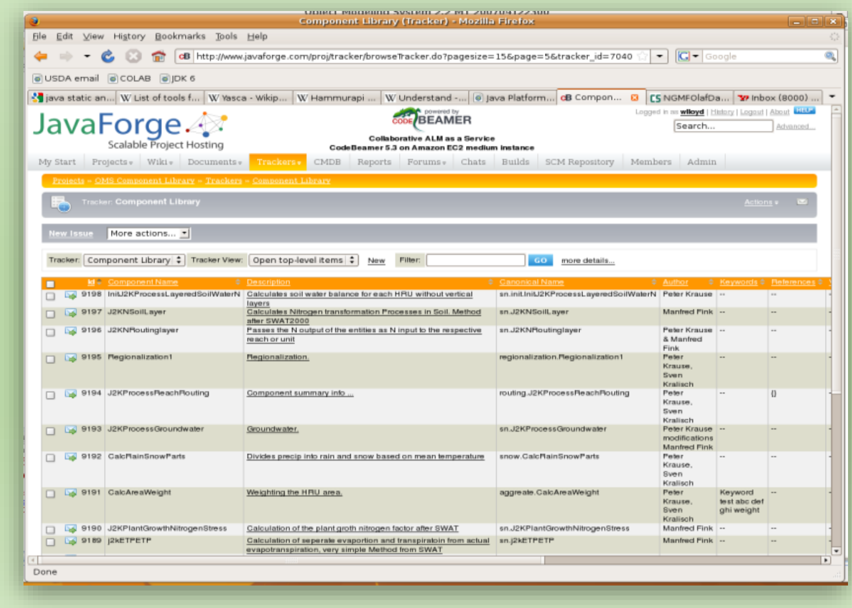
Major Study Findings

- LiDAR data helped to identify potential sites for wetlands in a 6500 ha watershed (a field review was critical to confirm site suitability)
- Wetlands could intercept drainage from 30% of the watershed and occupy only 1.3% of the contributing area (4.2% incl. buffers)
- These wetlands could reduce nitrate-N load from the watershed by 11-16%, based on model estimates
- Additional practices would be required to meet a targeted nitrate N load reduction of 45%

AgroEcosystem-Watershed (AgES-W) Model Overview

- Continuous simulation, process-oriented, small number of watershed-scale parameters (~20-30 with 10 for calibration)
- AgES-W (130+) components taken from the J2K/J2K-S model, SWAT, WEPP, RZWQM2, and PRMS models
- Developed using the Object Modeling System (OMS) Vers. 3 environmental modeling framework

- AgES-W components stored in OMS Component Repository (www.oms.javaforge.com)
  - Supports standard libraries of interoperable science and auxiliary components
  - Integration with model development environment and JavaForge facilitates distribution



http://www.javaforge.com/proj/tracker/browseTracker.do?pagesize=15&page=5&tracker_id=7040

Collaborative ALM as a Service
CodeBeamer 5.3 on Amazon EC2 medium instance

Projects » OMS Component Library » Trackers » Component Library

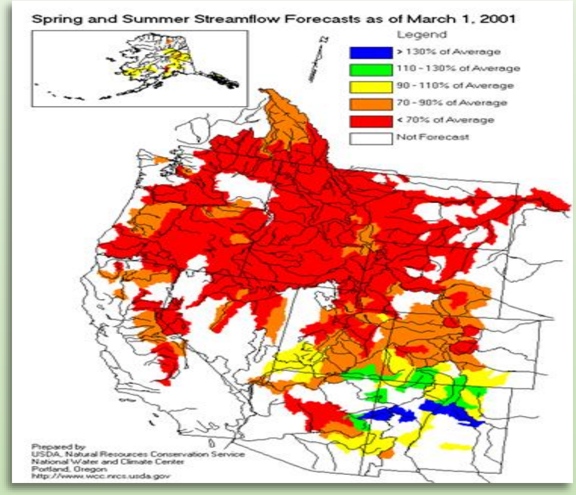
Tracker: Component Library

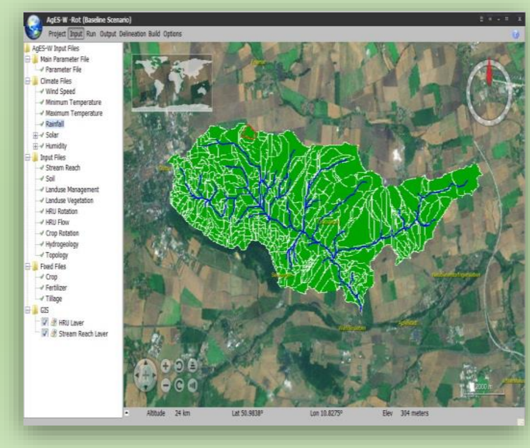
Tracker: Component Library
Tracker View: Open top-level items
Filter:

Id	Component Name	Description	Canonical Name	Author	Keywords	References
9198	InitJ2KProcessLayeredSoilWaterN	Calculates soil water balance for each HRU without vertical layers	sn.init.InitJ2KProcessLayeredSoilWaterN	Peter Krause	--	--
9197	J2KNSoilLayer	Calculates Nitrogen transformation Processes in Soil. Method after SWAT2000	sn.J2KNSoilLayer	Manfred Fink	--	--
9196	J2KNRoutinglayer	Passes the N output of the entities as N input to the respective reach or unit	sn.J2KNRoutinglayer	Peter Krause & Manfred Fink	--	--
9195	Regionalization1	Regionalization.	regionalization.Regionalization1	Peter Krause, Sven Kralisch	--	--
9194	J2KProcessReachRouting	Component summary info ...	routing.J2KProcessReachRouting	Peter Krause, Sven Kralisch	--	{}
9193	J2KProcessGroundwater	Groundwater.	sn.J2KProcessGroundwater	Peter Krause modifications Manfred Fink	--	--
9192	CalcRainSnowParts	Divides precip into rain and snow based on mean temperature	snow.CalcRainSnowParts	Peter Krause, Sven Kralisch	--	--
9191	CalcAreaWeight	Weighting the HRU area.	aggreate.CalcAreaWeight	Peter Krause, Sven Kralisch	Keyword test abc def ghi weight	--
9190	J2KPlantGrowthNitrogenStress	Calculation of the plant groth nitrogen factor after SWAT	sn.J2KPlantGrowthNitrogenStress	Manfred Fink	--	--
9189	j2kETPETP	Calculation of seperate evaportion and transpiratoin from actual evapotranspiration, very simple Method from SWAT	sn.j2kETPETP	Manfred Fink	--	--

Why Develop Another H/WQ Environmental Model?

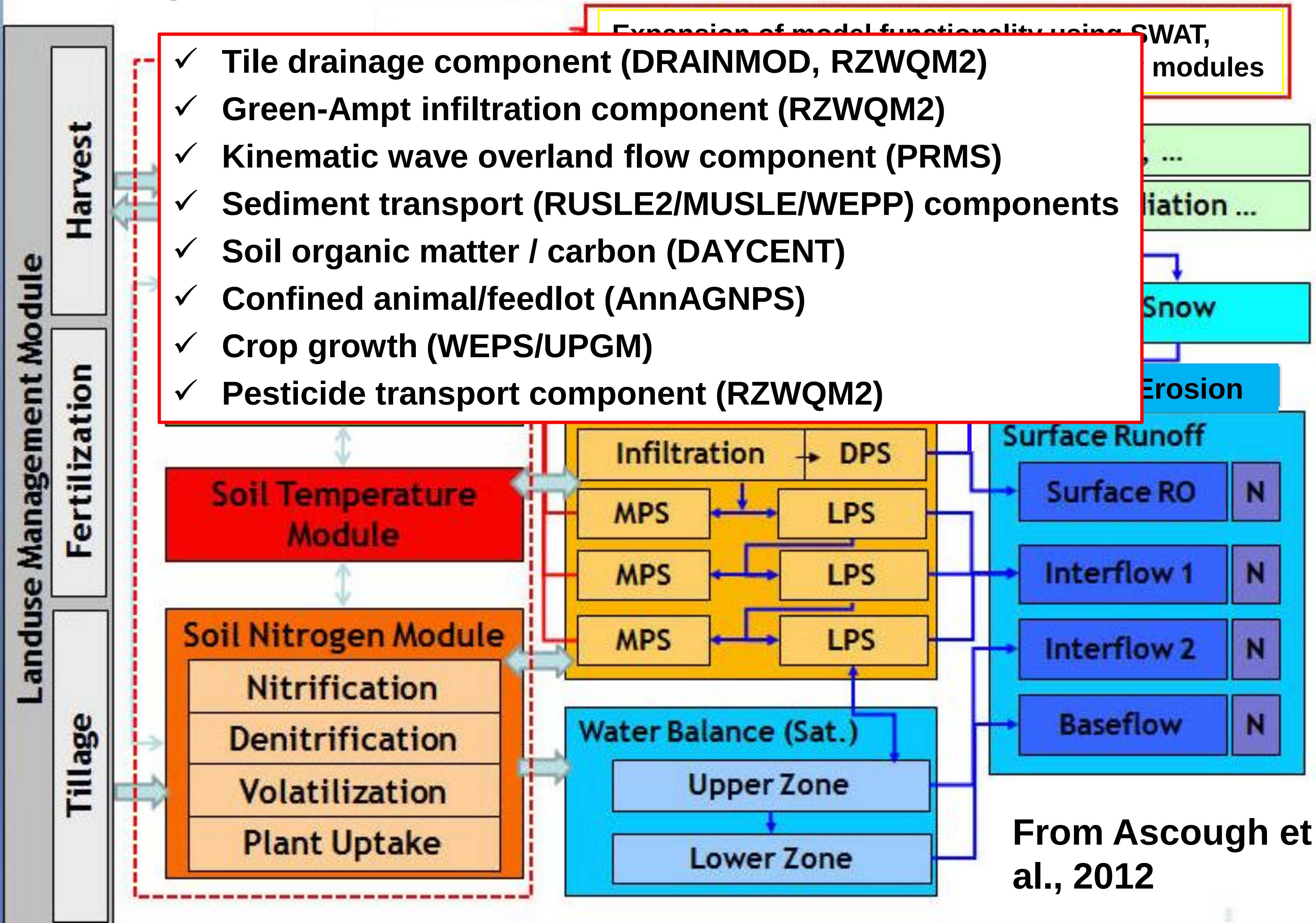
Developed to address regional **soil and water conservation** and water quality needs at multiple scales including:





- Dominant surface and subsurface hydrologic and chemical interactions between HRUs and streams/water bodies
- Micro-environment at field (HRU) scale affecting conservation practices on surface runoff, chemical, and sediment transport to streams
- Effects of soil and crop conservation management practices in space and time

AgES Watershed Model



- ✓ Tile drainage component (DRAINMOD, RZWQM2)
- ✓ Green-Ampt infiltration component (RZWQM2)
- ✓ Kinematic wave overland flow component (PRMS)
- ✓ Sediment transport (RUSLE2/MUSLE/WEPP) components
- ✓ Soil organic matter / carbon (DAYCENT)
- ✓ Confined animal/feedlot (AnnAGNPS)
- ✓ Crop growth (WEPS/UPGM)
- ✓ Pesticide transport component (RZWQM2)

From Ascough et al., 2012

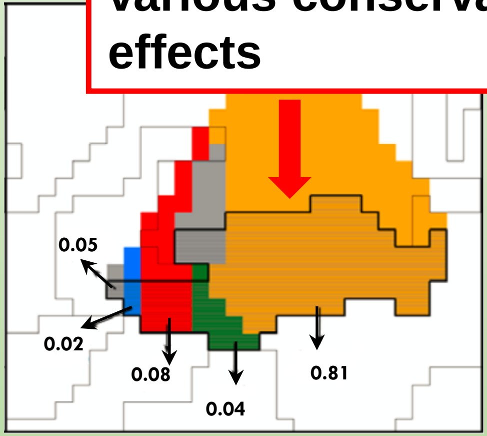
HRU Topology

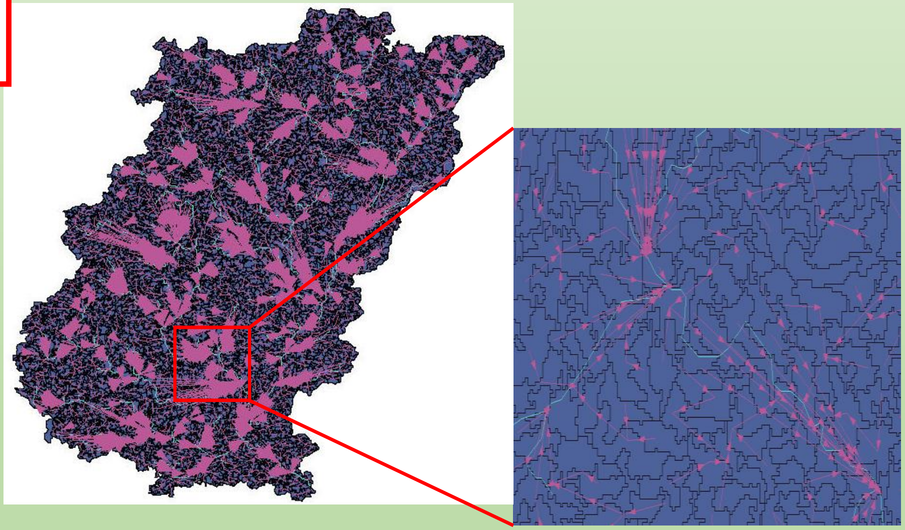
[HRU]	[HRU_1]....		[HRU_n]...		[Stream]	
From	To	Flow	To	Flow	To	Flow
121	113	0.411	140	0.387	-5	0.202
126	34	0.446	103	0.554		
[...]						

- Inputs
  - HRU delineation
  - Drainage mulation, streams
  - Routing To_HRU/Stream, Flow Partition}

Permits spatially-targeted placement of various conservation effects

AMeLie Delineation Tool - Pfennig et al. 2009.

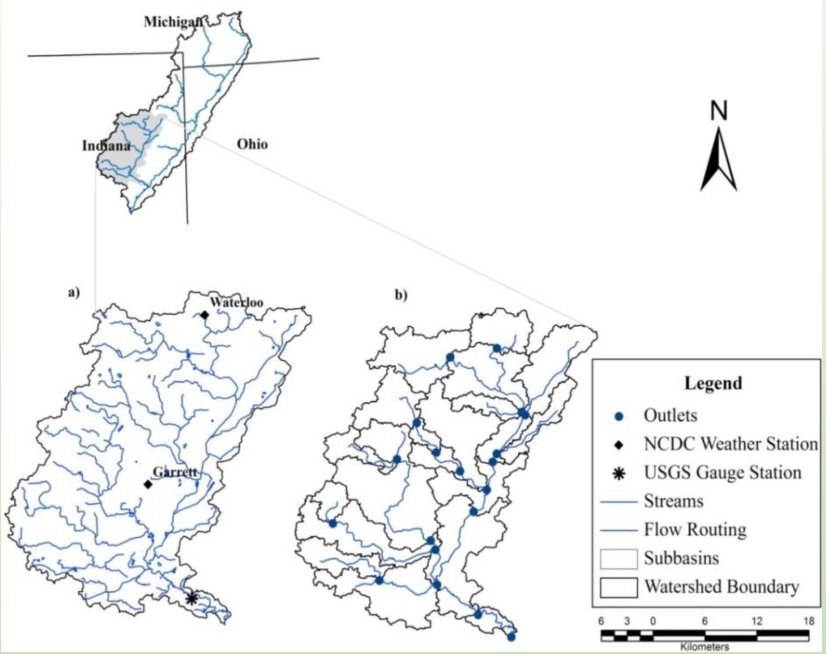


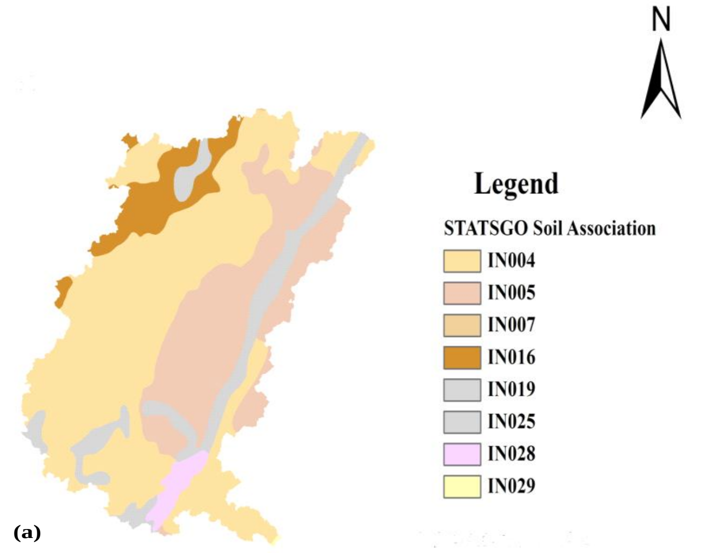


- Flow Topology Methods
  - Includes HRU → HRU and HRU → reach
  - Provides fully-distributed flow partitioning (n:1, n:m)
  - ArcGIS 10 ArcObjects and ArcInfo AML Tools

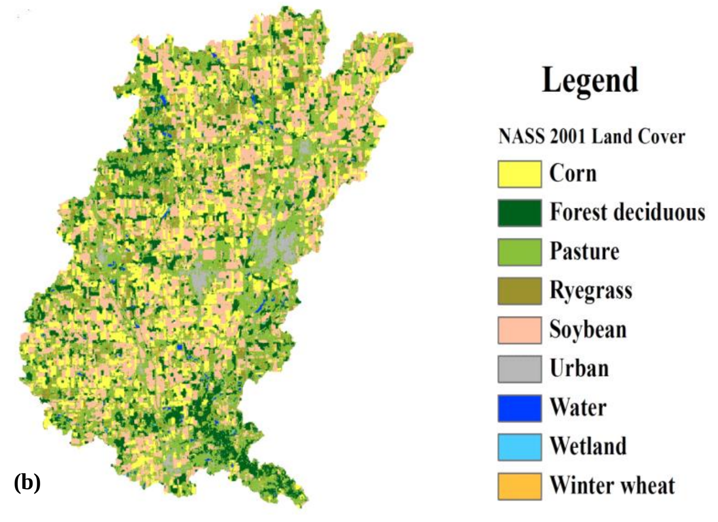
AgES-W Hydrological and Water Quality Modeling - Cedar Creek Watershed, IN USA

- **Cedar Creek Watershed (CCW), Indiana, USA**
  - **- Basin area: 707 km^2**
  - **- Avg. precip: 900 mm (35")**
  - **- 76% of watershed agricultural, 21% forest, 3% urban**
- **GIS Inputs:**
  - **- 30 m DEM (USGS)**
  - **- STATSGO and SSURGO soils (NRCS)**

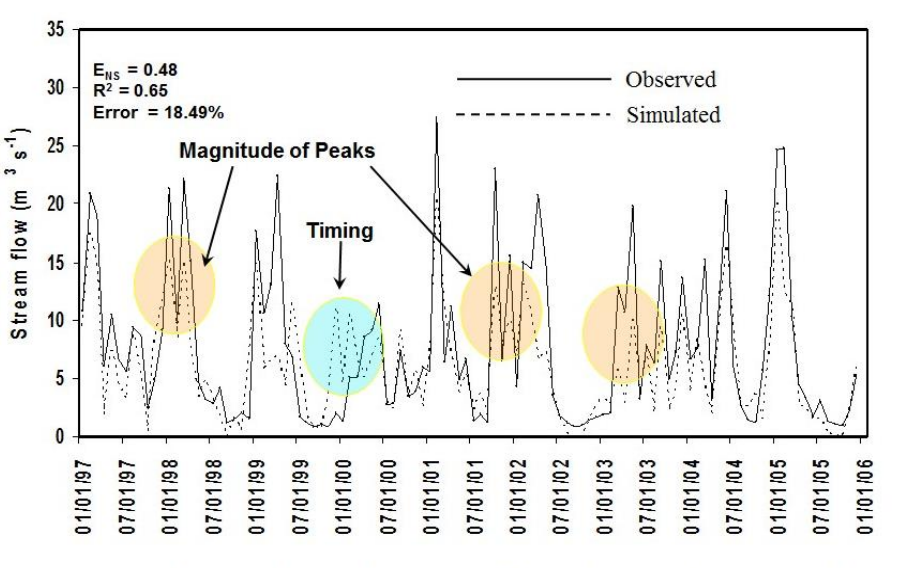




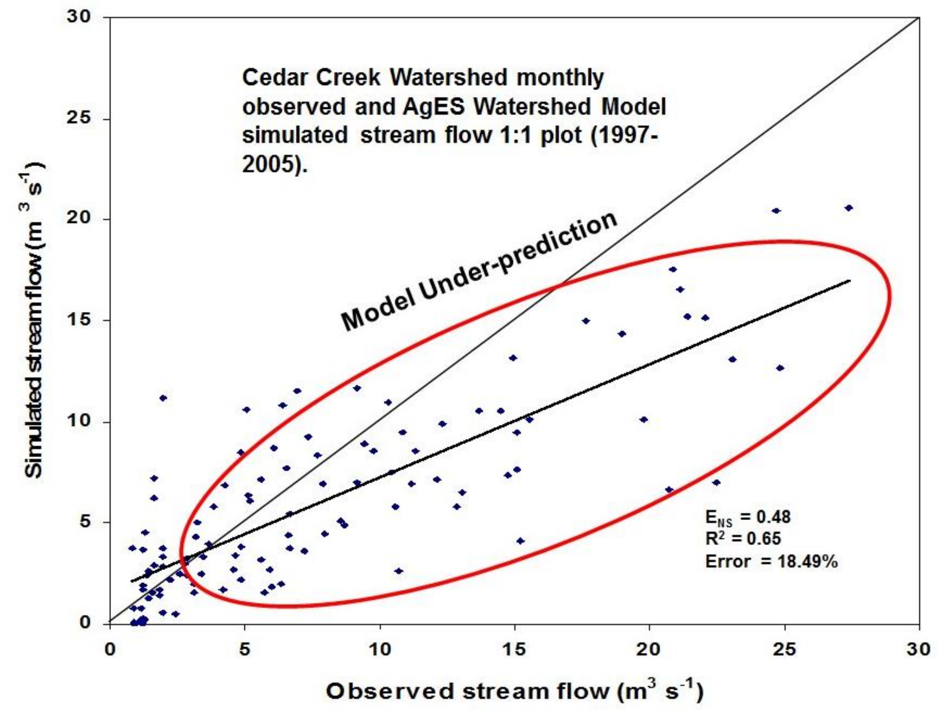
- Land use (NASS 2001)

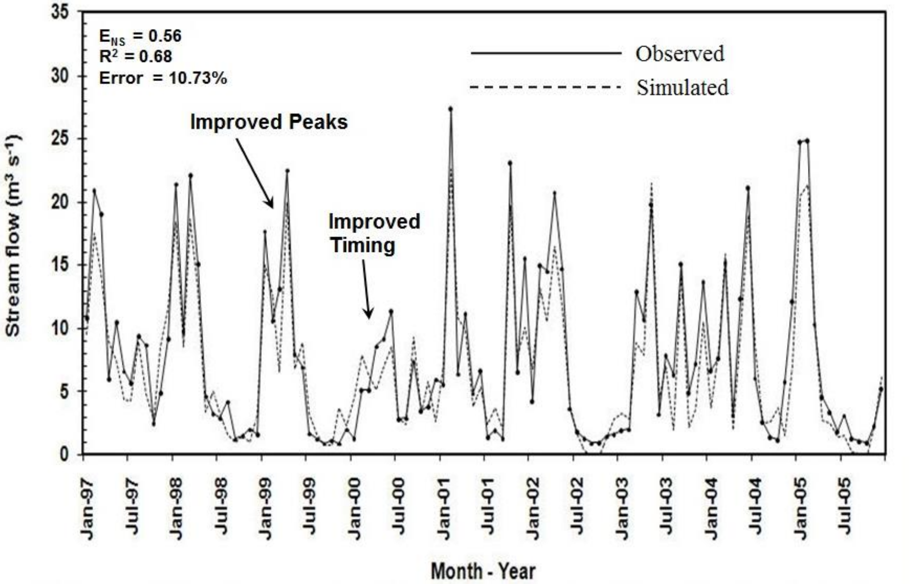


AgES-W Evaluation for Streamflow – Full CCW



Cedar Creek Watershed monthly observed and AgES Watershed Model simulated stream flow (1997-2005)





CCW monthly observed and AgES Watershed Model simulated stream flow (1997-2005) using a manually calibrated parameter set

Statistical Evaluation Coefficient	Base Parameter Set		Adjusted Parameter Set	
	Daily SFlow	Average Monthly SFow	Daily SFlow	Average Monthly SFlow
E_{NS}	0.34	0.48	0.64	0.79
PBIAS	-18.43		-8.59	

E_{NS} = Nash-Sutcliffe efficiency; PBIAS = bias or relative error (%).

Ascough et al. 2012. Development and application of a modular watershed-scale hydrologic model using the object modeling system: Runoff response evaluation. Trans. ASABE 55(1):117-135

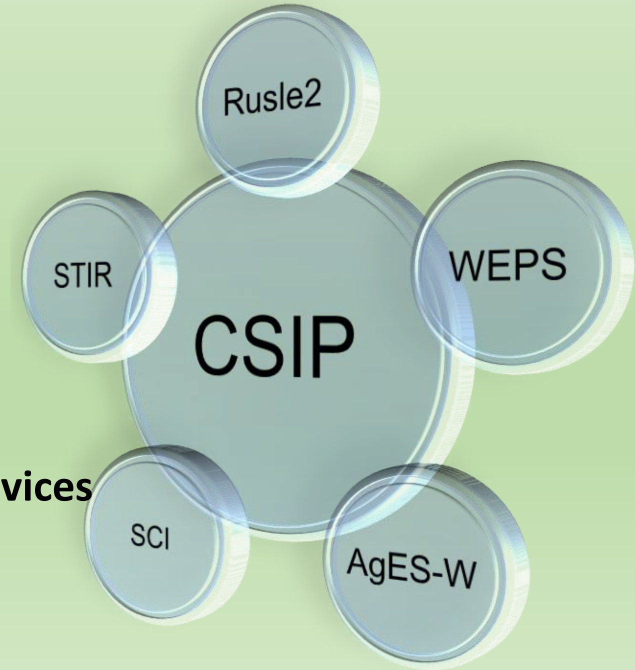
AgES-W Current Research

- Using observed data from USDA watersheds, improve model components to quantify and assess spatially targeted agricultural conservation effects on water quantity/quality

- Simulate the combined effects of projected climate change on crop production, water use, and NO_3-N transport, and assess potential cropping system adaptations at farm to sub-basin scales

Cloud Services Innovation Platform

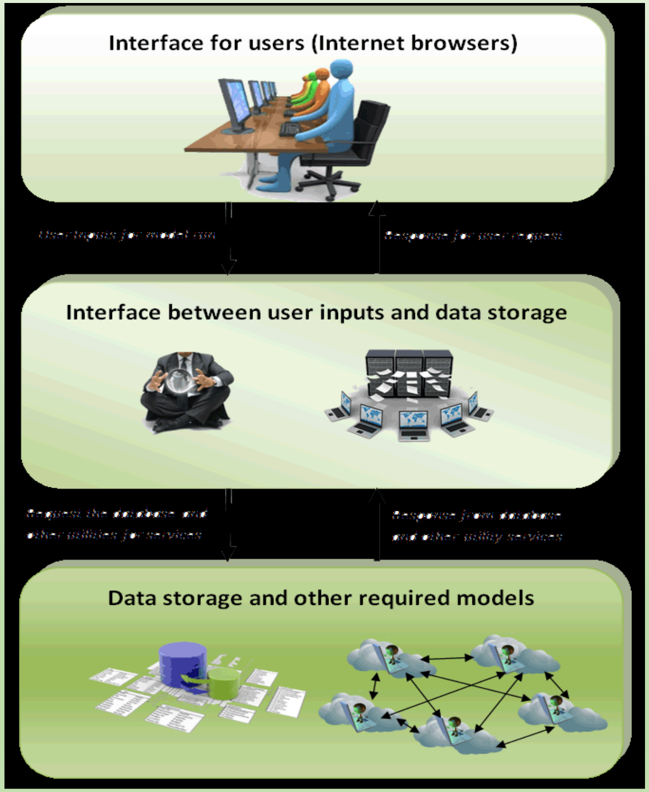
- **Model Services Architecture**
  - Support science delivery
  - Desktop models → web services
  - Scalable compute capacity:
    - AgES-W model



HAWQS (Hydrologic and Water Quality System) Status

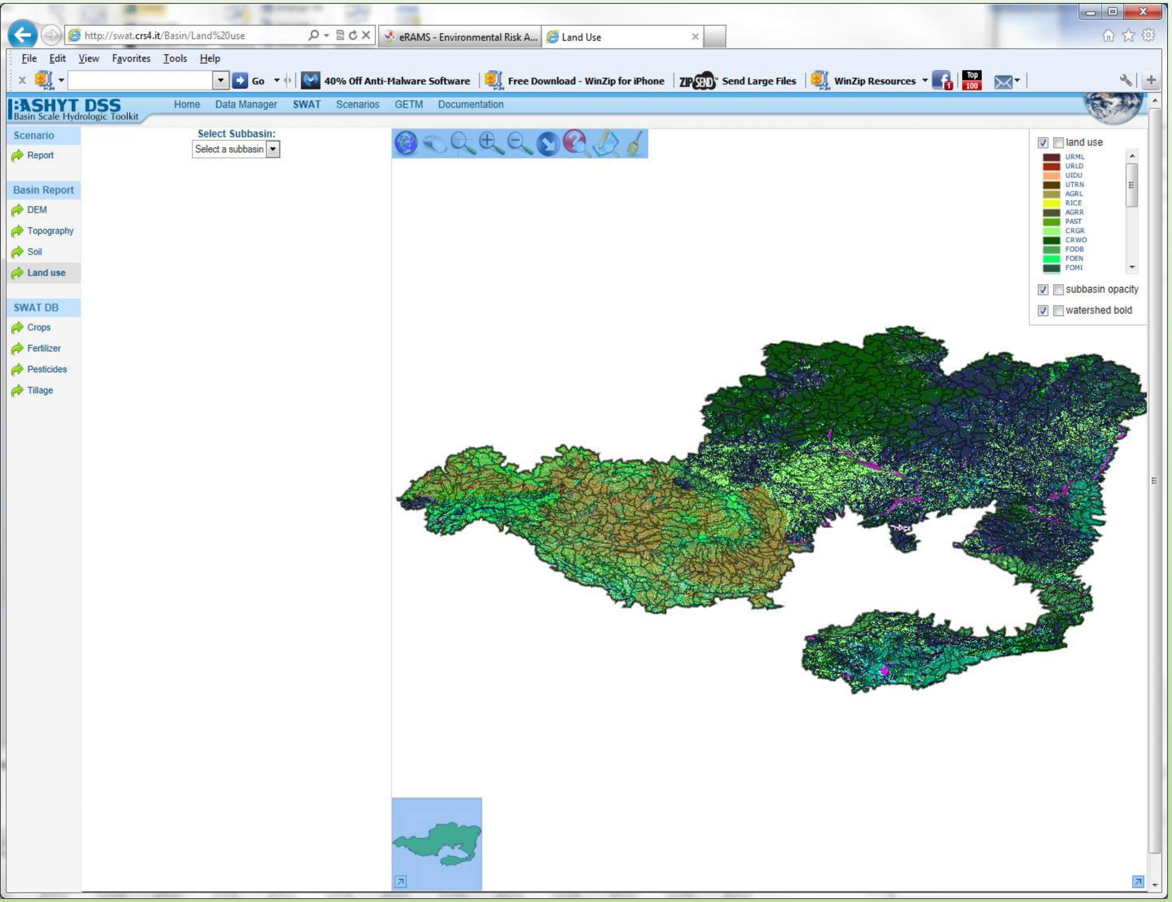
HAWQS is an advanced, state-of-the-art total water quantity and quality modeling system with databases, interfaces and models that is being developed for the U.S. Environmental Protection Agency's Office of Water to evaluate the impacts of management alternatives, pollution control scenarios, and climate change scenarios on the quantity and quality of water at a national scale.

- **Is a server/client modeling system that uses a web-based interface to access datasets for modeling at the three spatial scales for any watershed over the contiguous lower 48 states.**
- **Uses latest nationally available Federal Government databases at three spatial resolutions (NHD+, 10-digit and 8-digit watershed levels)**
- **Uses the latest SWAT model**
- **Uses National Hydrography Dataset (NHD+) stream network**



HAWQS Website: http://epahawqs.tamu.edu

BASHYT DSS
Basin Scale Hydrologic Toolkit

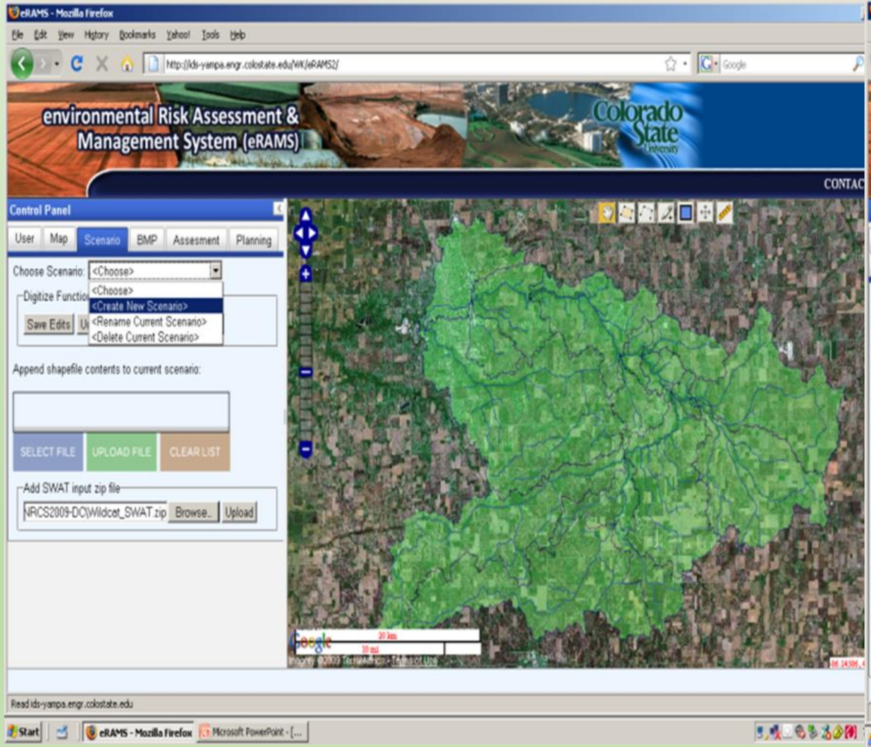


The **WEB** based **BA**sin **S**cale **HY**drological **T**ool (**BASHYT**) is a Collaborative Working Environment (CWE) on the web, that relies on the complex "physically based" **SWAT** hydrological model and web-GIS technologies to support decision makers, through a user-friendly Web interface, in the field of sustainable water resources management.

BASHYT Website: http://swat.crs4.it/

environmental Risk Assessment & Management System (eRAMS) –> Mazdak Arabi – Colorado State Univ.

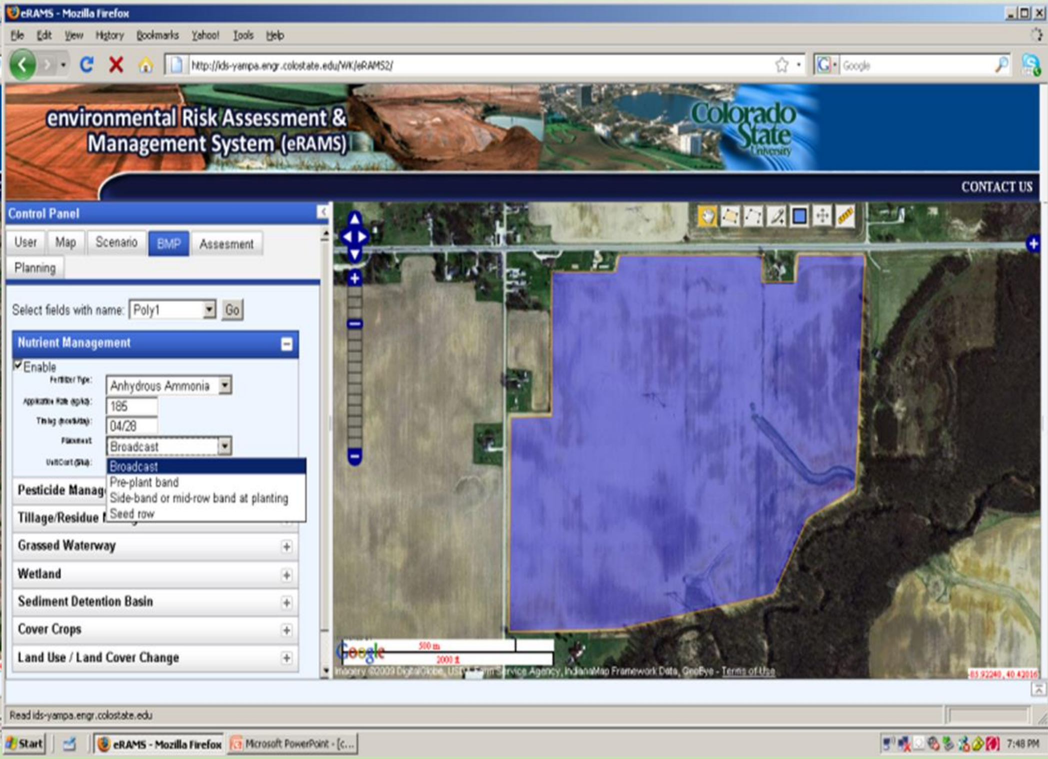
- *eRAMS* **-** a participatory web-based Geographical Information System (GIS) that facilitates:
- Collection, organization and sharing location based information
- Integration of data with complex modeling and decision support systems
- Spatial management practice inputs for SWAT and AgES-W
- Socioeconomic and environmental optimization



Choose Scenario: <Choose>

Append shapefile contents to current scenario:

Add SWAT input zip file: NRCS2009-DC\Wildcat_SWAT.zip



Select fields with name: Poly1

☑ Enable

Anhydrous Ammonia

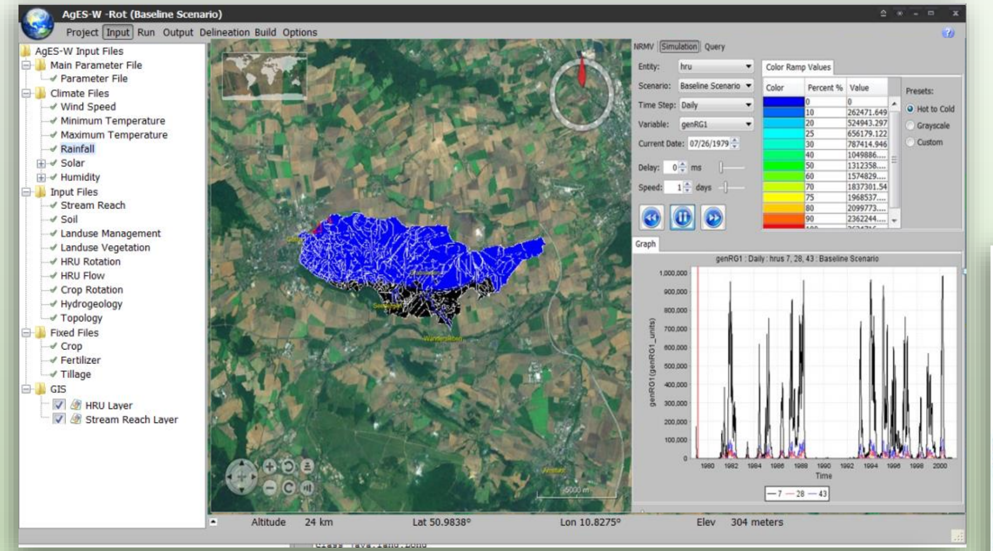
185

04/28

Broadcast

eRAMS Account Creation Site: http://www.eramsinfo.com/erams_beta/

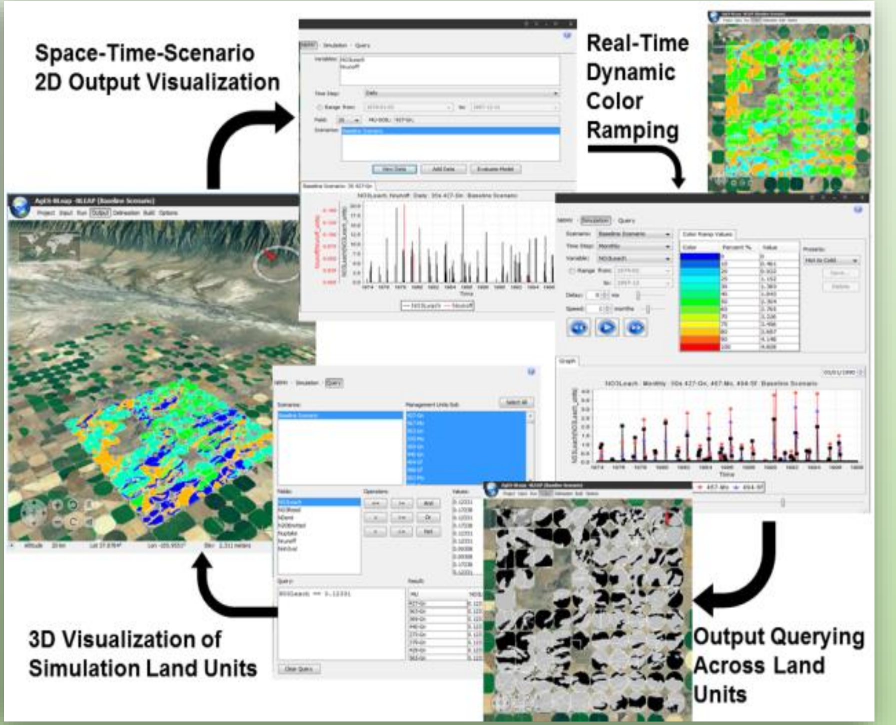
AgES-W Auxiliary Tools



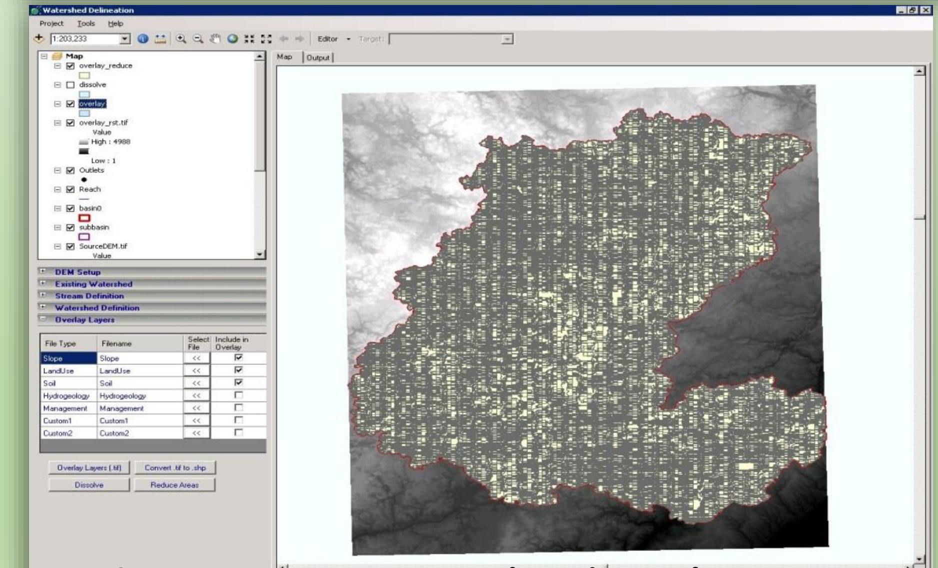
Entity: hru
Scenario: Baseline Scenario
Time Step: Daily
Variable: genRG1
Current Date: 07/26/1979
Delay: 0 ms
Speed: 1 days

Altitude 24 km Lat 50.9838° Lon 10.8275° Elev 304 meters

Geospatial Modeling Interface GUI (NASA WorldWind™)



Natural Resource Model Visualizer (NRMV) Tool



File Type	Filename	Select File	Include in Overlay
Slope	Slope	<<	☑
LandUse	LandUse	<<	☑
Soil	Soil	<<	☑
Hydrogeology	Hydrogeology	<<	☐
Management	Management	<<	☐
Custom1	Custom1	<<	☐
Custom2	Custom2	<<	☐

ArcGIS 10 Watershed Delineation Tool

AgES-W Website: http://arsagsoftware.ars.usda.gov/

Challenges in Model Application for Watershed-Scale Conservation Assessment

- **Data Availability**
  1. Locations of existing conservation practices within the watershed and characteristics
  2. Farm-level information about fertilizer/pesticide application rates, timing, and methods
  3. Locations and characteristics of structures, such as surface and subsurface drainage systems, reservoirs, diversions, and irrigation systems
  4. Long-term water quality data with a sufficient frequency and spatial coverage before and after implementation of practices
  5. Flow and water quality data from point sources, including wastewater treatment plants and septic systems
  6. Information on legacy sediments and nutrients in the channel network

- **Load Estimation**

- **Algorithms for Numerical Representation of Conservation Practices**

- **Inadequate Representation of Spatial Interactions Between HRUs and Subsequent Model Run-Time Issues**

- **Other Modeling Needs – Gully Erosion, Overland Flow Routing, In-Stream Biogeochemical Processes, etc.**

Challenges in Model Application for Watershed-Scale Conservation Assessment

- **Development of pre-calibrated, web-based tools for land management and climate scenario assessment**

- **Seamless merging of current set of tools – geodatabases, autocalibration, output analyzers, and climate and groundwater models**

Acknowledgements

Thanks to Mike White, Jeff Arnold, and Mark Tomer for sharing MS PowerPoint presentations

Featured Web Sites

HAWQS Website: http://epahawqs.tamu.edu

BASHYT Website: http://swat.crs4.it/

eRAMS Account Creation Site:
http://www.eramsinfo.com/erams_beta/

AgES-W Website:
http://arsagsoftware.ars.usda.gov/

Thank you for your Attention!