Water Quality Modeling Efforts to Assess the Impacts of Ethanol Corn Production in the Upper Mississippi River Basin

Paul R. Hummel[1], Anthony S. Donigian, Jr.[1], David Wells[2], Roberta Parry[2], and R. Srinivasin[3]

[1]AQUA TERRA Consultants

[2]U.S. EPA Headquarters

[3]Texas A & M University

2009 5th Interrnational SWAT Conference August 5-7, 2009
Boulder, CO

Introduction – Why?

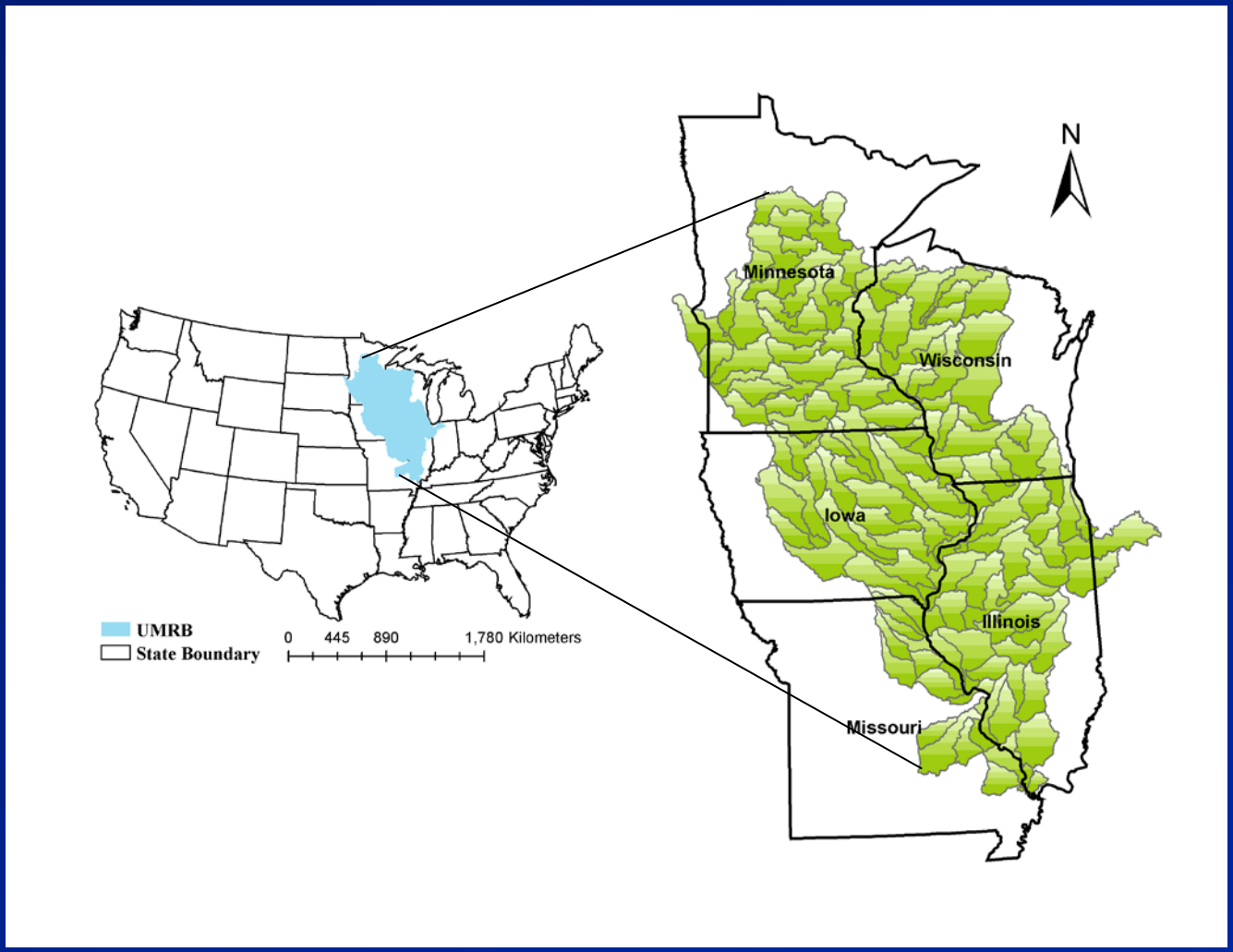
- **Renewable Fuel Program established by Energy Independence and Security Act (EISA) mandates the use of 36 BG of renewable fuel by 2022**
  - ***Includes 15 BG of ethanol from corn kernels by 2015***
- **Of potential biofuel crops, corn has highest rates of application of fertilizer and pesticides**
  - ***Concerns over increased loadings of nutrients and sediments in surface waters***

Introduction – Where?

Upper Mississippi River Basin (UMRB)

- **High corn production**
- **Numerous corn ethanol plants**
- **High potential to impact surface water**
- **May be able to relate analysis to Gulf Hypoxia issues**
- **Prior modeling of UMRB by USDA available to use as starting point**

Introduction – Where?



121.5 million acres; 131 HUC-8s; 14 HUC-4s

AQUA TERRA CONSULTANTS

Introduction – How?

- **Modeling**
  - *Establish baseline conditions*
  - *Develop future scenarios*
  - *Assess changes to water quality across scenarios*
- **What model?**
  - *Soil and Water Analysis Tool (SWAT)*

SWAT Model

- **Physically based**
- **Uses readily available inputs**
- **Comprehensive representation of watershed processes**
- **Can evaluate the relative impact of changes in management practices, land use changes, climate, and vegetation on water quality**

SWAT Model

- **Simulates crop and plant communities**
- **Provides crop yield and plant biomass**
- **Widespread use**
- **Prior applications of SWAT by USDA for hydrology and nutrient simulation in the UMRB completed and available as a starting foundation**
- **Should model the expected nutrient loads from increased corn production well**

SWAT Inputs

- **HUC boundaries**
  - *8-digit HUCs*
- **Elevation Data**
- **Land Use**
  - *NLCD 2001*
  - *CDL 2000-2006*
- **Soil data**
  - *STATSGO*
- **Agricultural Practices**
  - *Tile drain potential*
  - *Tillage*
  - *Fertilizer/Manure*
- **Meteorological data**
  - *NCDC data 1960-2001*
  - *PRISM maps*
- **USGS Monitoring data**

Elevation Data

- **Source of:**
  - ***Channel Length***
  - ***Channel Slope***
  - ***Overland Slope***
- **30 meter (1:24K) and 90 meter (1:100K) DEM available**
- **Compared 30 vs. 90 meter DEM**
  - ***Significantly higher processing for 30 m DEM***
  - ***Difference in Overland Slope not significant***
  - ***Test runs showed no significant difference in monthly & annual stream flow predictions***
- **90 meter DEM selected to use in modeling**

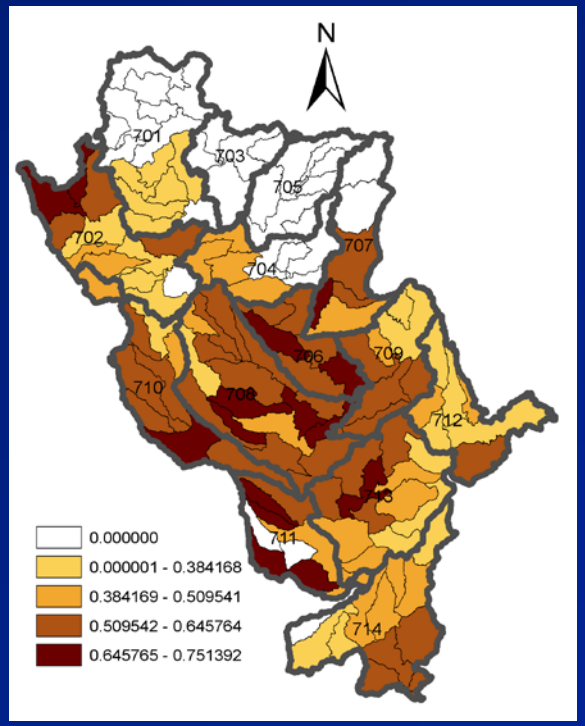
AQUA TERRA CONSULTANTS

Land Use Data

- **Final land use data was a combination of:**
  - *2001 National Land Cover Data (NLCD 2001)*
  - *Cropland Data Layer (CDL, 2004-2006)*
- **NLCD classification defines non-ag land use types**
  - *Limited on specific cropland classes (row and hay crops)*
- **CDL focuses on cultivated land use**
  - *Classifies corn/soybean/rice/cotton agricultural regions in many of the Midwestern states and Mississippi delta*
    - *Uses remote-sensing imagery and on-the-ground monitoring programs*
    - *Crop rotation data - essential for nutrient management estimation and water quality modeling in Ag areas*

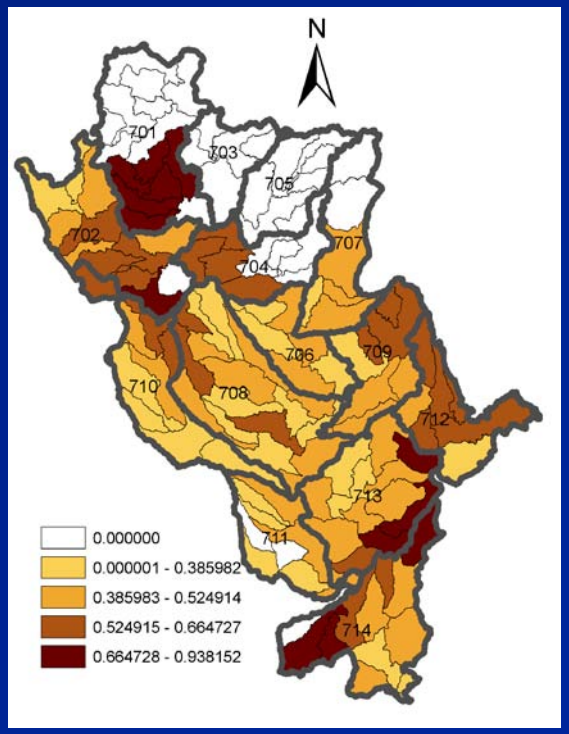
Management Practices

Conservation Technology Information Center



Conservation Tillage

- **No-tillage**
- **Ridge-tillage**
- **Mulch-tillage**



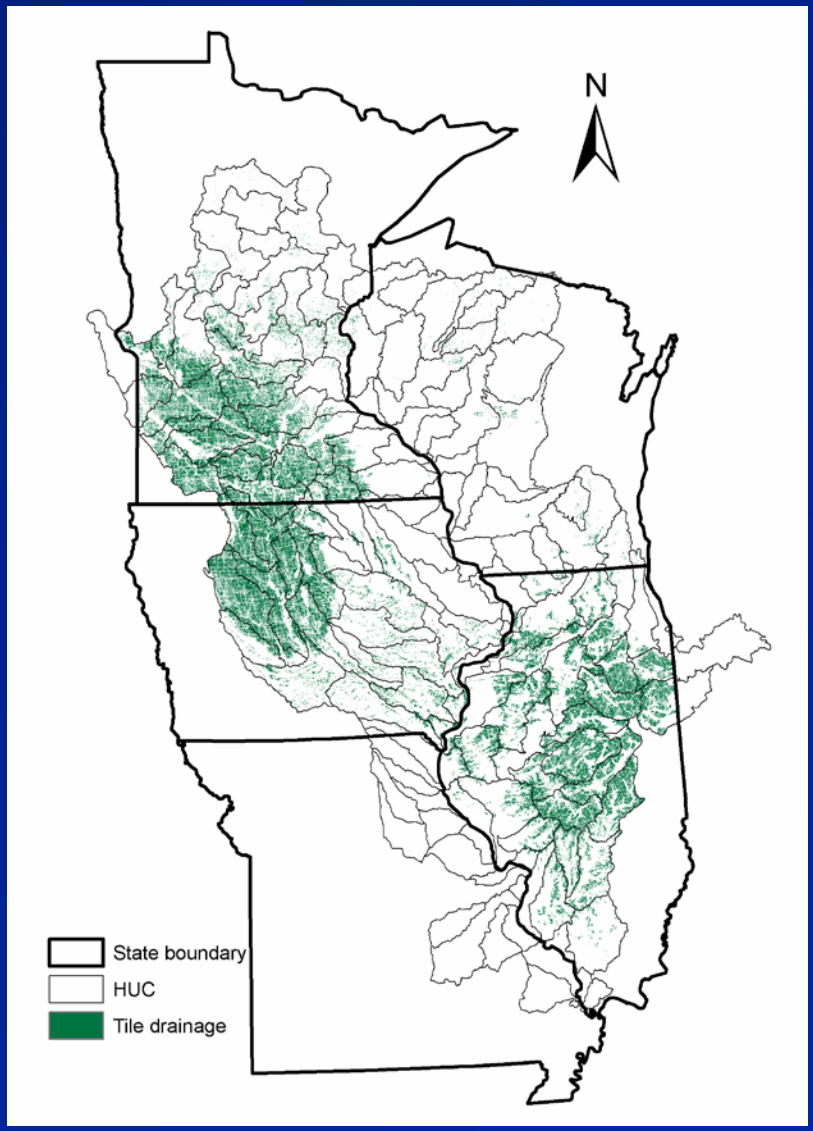
Non-Conservation Tillage

- **Reduced-tillage**
- **Intensive-tillage**

AQUA TERRA CONSULTANTS

Tile Drainage

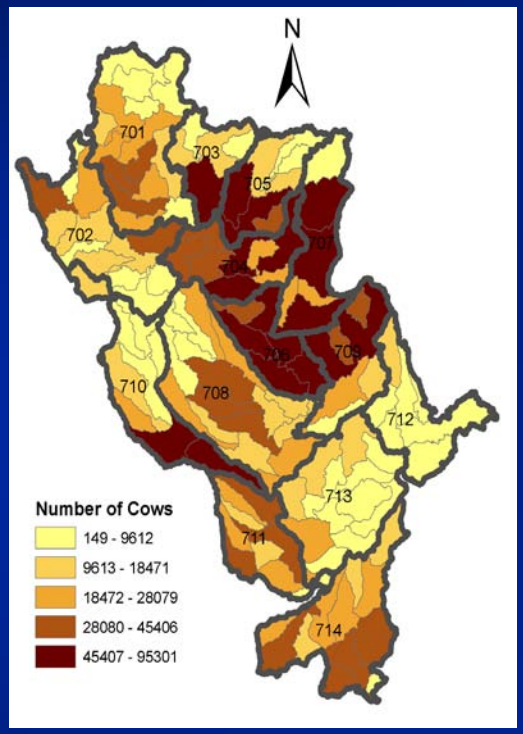
- No recorded data, only research reports
- STATSGO data analyzed to identify poorly drained soils
- Areas with critical amount of poorly drained soils and low slope identified as tile candidates



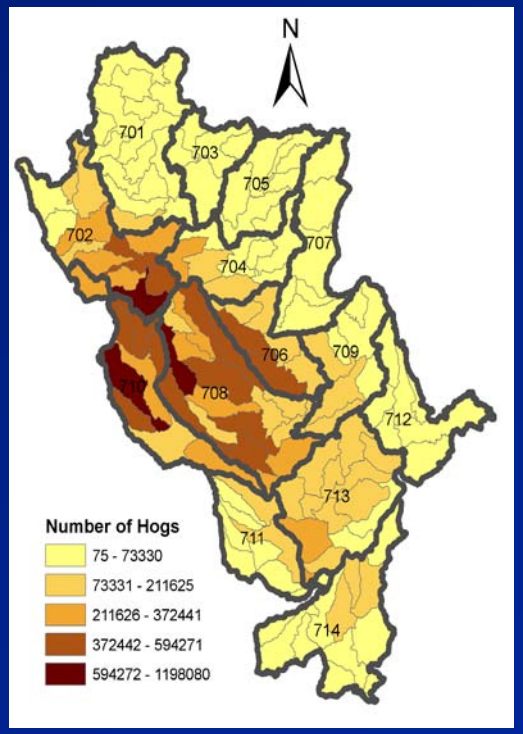
AQUA TERRA CONSULTANTS

Fertilizer and Manure

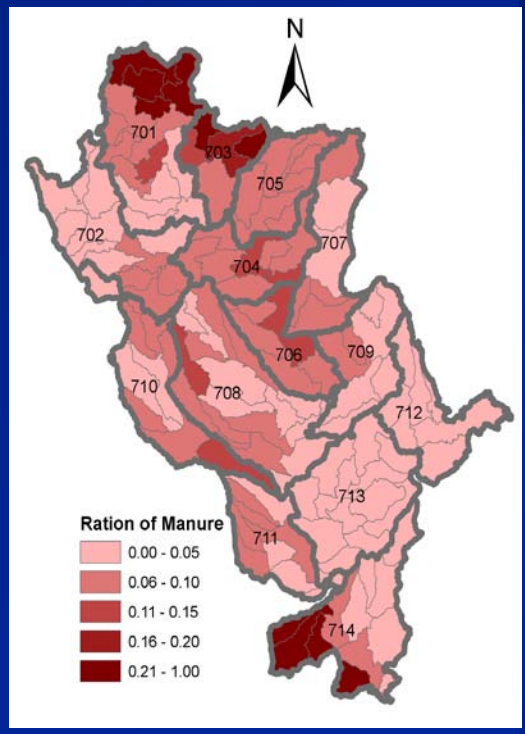
Cows



Hogs



Manure



Census of Agriculture - 2002 County Census

- **Estimate number of animals for each HUC-8**
- **Hogs and Cattle considered predominate source**
- **ASABE manure production rates**

AQUA TERRA CONSULTANTS

Fertilizer and Manure

- **Developed Fertilizer Rules**
  - ***Fertilizer is only applied to Ag lands***
  - ***Applied to Hay, Corn, Row Crops***
    - **Not legume crops such as alfalfa or soybeans**
    - **Need to account for corn-soybean rotations**
    - **Chemical fertilizer only applied to supplement manure applications**

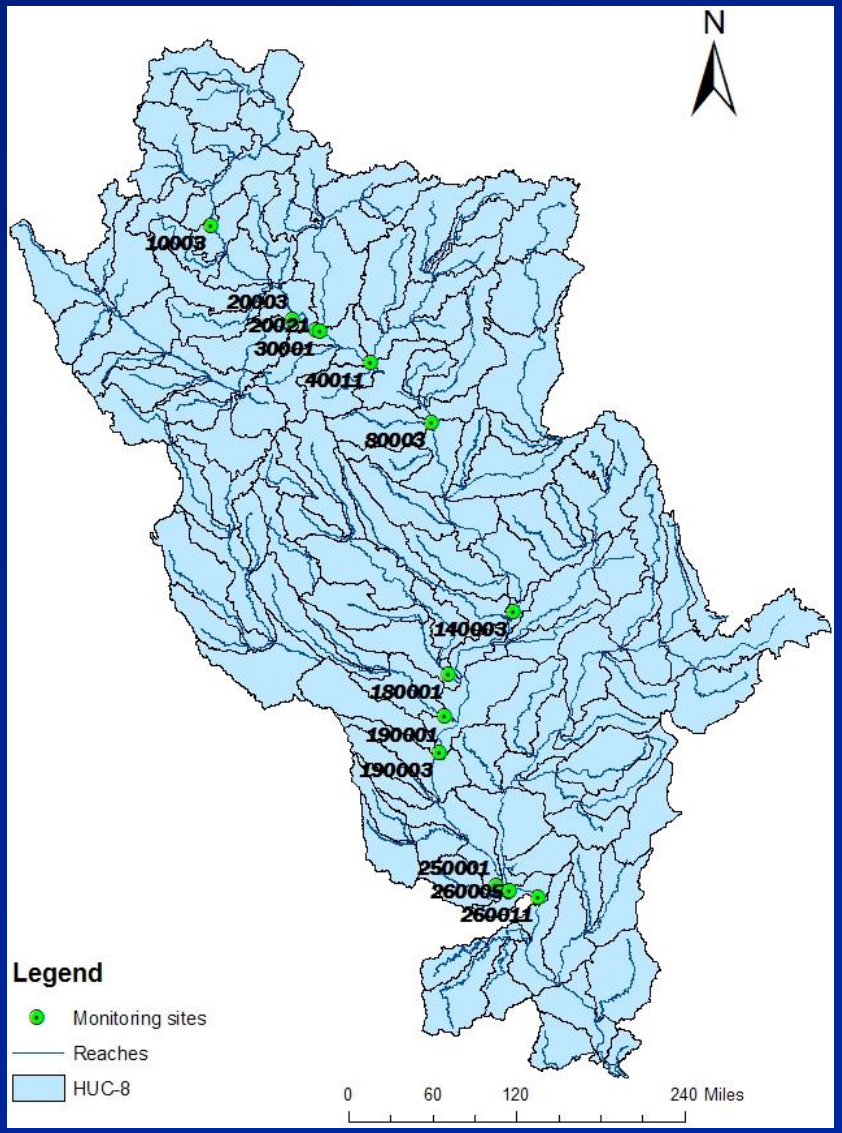
- **SWAT set up to supplement manure application with chemical fertilizer as needed**
  - ***Based on nitrogen or phosphorus stress levels in plants***

Meteorological Data

- **National Climatic Data Center (NCDC)**
  - ***Long-term historical data (1960 - 2001)***
  - ***Daily precipitation and min/max temperature***
- **Parameter–Elevation Regressions on Independent Slopes Model (PRISM) maps (Oregon State, 2008)**
  - ***Long-term monthly and annual precipitation and temperature***
  - ***Compiled in ~4km grids nationally***
- **Data aggregated to create unique weather station for each of 131 sub-basins (Di Luzio method, 2008)**

Observed Data

- **13 USGS stations**
- **Stream flow and water quality data ranged from 6 years to 37 years in length**



AQUA TERRA CONSULTANTS

Scenario Development

Corn Yield Assumptions

- **National average corn yield 150 bu/acre**
- **UMRB area-weighted average yield 140.7 bu/ac**
- **1.23% annual yield increase based on USDA projections (USDA, 2008), to account for assumed advances in crop science**
- **Resulted in future yield averages:**
  - **2010 – 149.6 bu/ac**
  - **2015 – 159.0 bu/ac**
  - **2020 – 169.0 bu/ac**
  - **2022 – 173.2 bu/ac**

Scenario Development

Biofuel Assumptions

- **National Corn Ethanol Production Goals:**
  - **2010 12 BG**
  - **2015-2022 15 BG annually**
- **UMRB estimated at 42.3% national production**
  - **GIS overlay of current biofuel plants and UMRB**
- **UMRB Estimated Ethanol Production**
  - **2010 5.1 BG**
  - **2015-2022 6.3 BG annually**

Scenario Results
Nitrogen Load

Scenario	Corn Area, 10^6 ac	Unit Load, lbs/ac	Total Load, 10^6 lbs	Outflow, 10^6 lbs	Removal (Assim), %	Corn Area Increase, %	Outflow Change, %
Base	23.6	15.6	1,897	1,434	24.4		
2010	33.4	16.4	1,994	1,513	24.1	41	5.53
2015	35.6	16.3	1,976	1,500	24.1	50	4.66
2020	34.7	16.0	1,939	1,470	24.2	47	2.51
2022	34.4	15.9	1,926	1,460	24.2	45	1.82

Scenario Results
Phosphorous Load

Scenario	Corn Area, 10^6 ac	Unit Load, lbs/ac	Total Load, 10^6 lbs	Outflow, 10^6 lbs	Removal (Assim), %	Corn Area Increase, %	Outflow Change, %
Base	23.6	1.45	177	132	25.0		
2010	33.4	1.49	181	136	24.6	41	2.79
2015	35.6	1.47	179	135	24.6	50	1.74
2020	34.7	1.46	178	135	24.7	47	0.98
2022	34.4	1.46	177	133	24.7	45	0.76

Scenario Results
Sediment and Flow

Scenario	Corn Area, 10^6 ac	Sediment, 10^6 tons	Flow, cfs	Sediment Change, %	Flow Change, %
Baseline	23.6	6.34	122084		
2010	33.4	6.37	122257	0.54	0.14
2015	35.6	6.36	122013	0.25	-0.06
2020	34.7	6.35	121819	0.16	-0.22
2022	34.4	6.35	121759	0.14	-0.27

Next Steps

- **Alternative future scenarios**
  - ***Revised ethanol goals***
  - ***Cellulosic (corn stover)***
- **Sensitivity Analysis of SWAT model for UMRB**
- **Case Study of the Raccoon River, IA watershed**
  - ***Characterize the impacts at the local level***
  - ***Contains the following:***
    - **Ethanol plant**
    - **High corn production**
    - **Listed stream segment for nutrients (nitrogen)**
    - **Drinking water intake**
- **Comparison to other models**
  - **SPARROW**
  - **FASOM (Forest & Ag Sector Optimization Model)**

Acknowledgment

This work was funded by the U.S. Environmental Protection Agency under contract # EP-C-06-029. The views expressed in this paper are those of the authors and do not necessarily represent those of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.