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

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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
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
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
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
Census of Agriculture - 2002 County Census

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

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Corn Area, 10^6 ac</th>
<th>Unit Load, lbs/ac</th>
<th>Total Load, 10^6 lbs</th>
<th>Outflow, 10^6 lbs</th>
<th>Removal (Assim), %</th>
<th>Corn Area Increase, %</th>
<th>Outflow Change, %</th>
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<tbody>
<tr>
<td>Base</td>
<td>23.6</td>
<td>15.6</td>
<td>1,897</td>
<td>1,434</td>
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<td>2010</td>
<td>33.4</td>
<td>16.4</td>
<td>1,994</td>
<td>1,513</td>
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<td>2015</td>
<td>35.6</td>
<td>16.3</td>
<td>1,976</td>
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## Scenario Results

### Phosphorous Load

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<th>Scenario</th>
<th>Corn Area, 10^6 ac</th>
<th>Unit Load, lbs/ac</th>
<th>Total Load, 10^6 lbs</th>
<th>Outflow, 10^6 lbs</th>
<th>Removal (Assim), %</th>
<th>Corn Area Increase, %</th>
<th>Outflow Change, %</th>
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## Scenario Results

### Sediment and Flow

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Corn Area, $10^6$ ac</th>
<th>Sediment, $10^6$ tons</th>
<th>Flow, cfs</th>
<th>Sediment Change, %</th>
<th>Flow Change, %</th>
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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

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