An Integrated Modeling Approach for Assessment of Water Quality Conditions in the Upper Mississippi River Basin

Presentation Overview

- CEAP National Assessment -
  - Integrated Modeling Approach
  - HUMUS/ SWAT/ APEX Modeling Approach
  - Databases Used

- Upper Mississippi River Basin
  - Calibration and Validation Process & Results

- Benefits of Conservation Practice Scenarios Simulated in the River Basin
  - Off-site water quality impacts

- Future Direction
Conservation Effects Assessment Project (CEAP) - National Assessment

SWAT/ APEX Modeling Approach

CEAP - National Assessment : Goal

• To measure the environment benefits of conservation programs currently implemented on cropland at the national level (on-site and off-site benefits) and

• prospects for attaining additional environmental benefits with further conservation treatment needs to meet the nation’s natural resources needs
Schematic for Construction of CEAP - Sampling and Modeling Approach

Farm survey and NRI data at CEAP sample points → Field-level modeling (APEX) - BMPs → CEAP Current conditions, onsite estimates

Field-level modeling (APEX) - BMPs → Watershed modeling (HUMUS/SWAT) → CEAP Current conditions, in-stream water quality estimates

APEX: Agricultural Policy Environ. Extender
SWAT: Soil and Water Assessment Tool
CEAP Watershed System

Non-Cultivated Lands (SWAT)

Channel/Flood Plain Processes (SWAT)

Muni/Industrial Point Sources - (SWAT)

Cultivated Land/CRP and BMPs (APEX)
APEX-SWAT model integration for CEAP national assessment

Flow, TSS and nutrient loadings from Point Sources

Flow, sediment, nutrient and pesticide loadings from Non-Cultivated Land

Flow, sediment, nutrient and pesticide loadings from Cultivated Cropland & CRP with BMPs

Routing through reach, ponds, reservoirs to 8-digit watershed outlet

Continue routing and adding 8-digit watershed flows through main routing reaches along the river

Outputs: Simulated flow, sediment, nutrient and pesticide loadings for analysis
CEAP: HUMUS/ SWAT/ APEX Modeling Approach

**INPUT DATA FOR HUMUS**

- Landuse (Non-Cultivated) 2001 NLCD
- Soils (STATSGO)
- Management Data - Pasture, Hay, Urban, Forest & Orchards
- Topographic Data – 3 arc DEM
- Point Sources (Municipal & industrial) -1997 Adj for 2000 Pop
- Weather (PCP & TMP) PRISM 1960 - Current
- Atmos. N Deposition 1994 - 2006

**SWAT**

Field level: Runoff & sediment, N & P, Pest loads from Cultivated cropland and CRP

**APEX**

- Calibration at each 8-digit using USGS average annual runoff. Additional calibration of flow at selected USGS monitoring stations
- Validation using USGS stream flow, sediment, nutrient and pesticide loads at major locations along the river

**INTEGRATION**

- Calibration at each 8-digit using USGS average annual runoff. Additional calibration of flow at selected USGS monitoring stations
- Validation using USGS stream flow, sediment, nutrient and pesticide loads at major locations along the river

**CALIBRATION**

- Farmers Survey - Conservation Practices (BMPs) - Farming activities

**VALIDATION**

**SCENARIOS**

- 1. Current Condition Scenario: HUMUS/SWAT simulation using APEX output for current conservation practices from CEAP farmers survey
- 2. No Practice Scenario: HUMUS/SWAT simulation using APEX output without conservation practices

**OUTPUTS**

- 1. Reductions in sediment, nutrient and pesticide loads at 4-digit watersheds
- 2. Reductions in loads and conc.; No of days nutrient conc. exceeding human/ecological standard

Cultivated Land and CRP - 2003 NRI Data - Farmers Survey
Databases Used for CEAP/ HUMUS/ SWAT

**Land use**: 2001 USGS-National Land Cover Data (NLCD) at 30-m res; 2003 National Resources Inventory (NRI) land use and 2003 Ag-Census data

**Soils**: STATSGO database

**Management**: Management operations from planting, fertilizer, irrigation and harvesting; Heat units based operation scheduling

- Pasture and hay land: CAFO-manure application
- Pasture - Grazing and manure/excretion application
- Range Grass and Range Shrub
- Urban land - simulation of impervious area (parking lots) and pervious area (lawns)
- Forest (Mixed, Deciduous and Evergreen)
- Horticultural/Orchards
- Forested and non-forested wetlands
Databases Used for CEAP/ HUMUS

• *Weather* : Daily precipitation and temperature data developed for 8-digit watersheds using National Climatic Data Center point measurements and monthly Parameter-elevation Regressions on Independent Slopes Model (PRISM) grids.

• *Point Source Data* : Effluent discharge from municipal and industrial treatment plants; USGS point source database adjusted for 2000 pop. conditions

• *Atmospheric Nitrogen Deposition* : Loads and concentrations developed for 8-digit watersheds using National Atmospheric Deposition Program/ National Trends Network database - yearly deposition grids.
Upper Mississippi River Basin

14 4-digit watersheds & 131 8-digit watersheds (111 above Grafton)

DA – 491,699 Sq.km.
Cropland and CRP – 52%
Non-cultivated Land – 48%
APEX-SWAT CALIBRATION PROCESS

APEX

Field level calibration at several locations

8-digit level calibration using USGS total runoff

SWAT

Calibration of average annual base flow, surface runoff and total runoff at 8-digit level


Several Model Iterations

• Automated procedure for calibration (9 Parameters)
• Runoff, surface runoff and sub-surface runoff
• Threshold % difference between predictions and observations

Surface runoff 10 %  Sub-surface runoff 10 %  Runoff 20 %
APEX-SWAT CALIBRATION PROCESS

APEX

Field level calibration at several locations
Field to 8-digit watershed using delivery ratio

SWAT

Grab samples used from USGS and NASQAN at key locations along the river
- Sediment related parameters for land use related loadings
- Delivery ratio from field to 8-digit watershed
- In-stream sediment routing parameters

Several Model Iterations
APEX-SWAT CALIBRATION PROCESS

APEX
- Field level calibration at several locations
- Field to 8-digit watershed nutrient adjustment factors

SWAT
- Grab samples data from USGS and NASQAN at key locations along the river
- Comparison with SPARROW Source wise Loadings (Point, cropland and non-cropland)
  - Nutrient related parameters for land use loadings
  - Delivery ratio from field to 8-digit watershed
  - In-stream nutrient routing parameters

Several Model Iterations

NUTRIENTS
Calibration of Average Annual Runoff

- USGS Developed Spatial Maps of Total Annual Runoff
- Calibrated both SWAT and APEX models
- Regression of Measured and Predicted Water Yield for Each 8-digit Basin (APEX $R^2 = 0.82$   SWAT $R^2 = 0.92$ )
Calibration of Average Annual Runoff

Spatial flow calibration for surface runoff, base flow and total runoff

- Accurate base flow prediction - for WQ and ecological thresholds
- Percent Difference after calibration for SWAT

Surface runoff  Baseflow  Runoff
Monthly stream flow calibration and validation at Grafton, IL

Monthly flow for Upper Mississippi-Grafton/Alton, IL

b) Monthly flow

Flow (mm)

- Observed
- Predicted
Observed and Predicted Concentrations of Sediment, Total Nitrogen, Total Phosphorus and Atrazine at Grafton, IL

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Predicted (with practices)</th>
<th>Observed</th>
<th>No. of data points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment mean concentration (mg/L)</td>
<td>189.0</td>
<td>185.5</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>69.7</td>
<td>206.9</td>
<td></td>
</tr>
<tr>
<td>Standard deviation (mg/L)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TN mean concentration (mg/L)</td>
<td>4.31</td>
<td>4.08</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>1.52</td>
<td>1.51</td>
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</tr>
<tr>
<td>Standard deviation (mg/L)</td>
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<td></td>
<td></td>
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<tr>
<td>TP mean concentration (mg/L)</td>
<td>0.35</td>
<td>0.26</td>
<td>200</td>
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<td>0.11</td>
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<tr>
<td>Standard deviation (mg/L)</td>
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<td>Atrazine mean concentration (ppb)</td>
<td>0.80</td>
<td>0.90</td>
<td>71</td>
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<tr>
<td></td>
<td>1.5</td>
<td>1.3</td>
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</tr>
<tr>
<td>Standard deviation (ppb)</td>
<td></td>
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</tbody>
</table>
Practices Simulated Within APEX

a) Structural Practices Simulated

In-field Practices for erosion control
• Contour Farming
• Strip Cropping
• Contour Buffer Strips
• Terraces
• Grass Terraces
• Tile Drain
• Grade Stabilization Structures
• Grassed Waterways
• Diversion

Edge of field Practices for buffering
• Vegetative Barrier
• Filter Strips
• Riparian Forest Buffers
• Riparian Herb. Cover
• Field Borders

Wind Erosion Control Practices
• Windbreak / Shelterbelt
• Herbaceous Wind Barrier
• Hedgerow planting
• Cross Wind Practices
b) Annual Practices Simulated Within APEX

- Residue management practices and Reduced Tillage management practices
- Nutrient management practices – (Fertilizers, Manure)
- Pesticide management practices
- Irrigation management practices
- Cover crops

c) Long-term conservation cover

- Conservation Reserve Program - Grass or trees grown on cropland
Conservation Practice Scenarios

- *Current Condition Scenario*: HUMUS/ SWAT simulation using APEX output for current conservation practices from CEAP survey

- *No Practice Scenario*: HUMUS/ SWAT simulation using APEX output without conservation practices

- *No Cultivated Cropland Contribution*: HUMUS/ SWAT simulation using APEX flow: No loading contribution from cropland/ CRP
  - Includes source loadings from non-cultivated land and point sources
Conservation Practice Scenarios

- **Additional Treatment Scenarios:**
  - HUMUS/SWAT simulation using APEX output with various combinations of conservation practice options and acres of treatment needed
  - Treatment of Critically Under Treated Acres
  - Treatment of All Under Treated Acres
  - Enhanced Nutrient Management Treatment of Vulnerable Acres
  - Enhanced Nutrient Management Treatment of All Vulnerable Acres
Offsite Water Quality Benefits

Off-site water quality benefits:

a) Comparing no practice scenario and current conditions and
b) Current conditions and Treatment Scenarios

Reductions in source loads or instream loads
1. Edge-of-Field from cultivated cropland and CRP
2. Delivery to the watershed outlet (8-digit) from cultivated cropland and CRP
3. Delivery to the watershed outlet from all sources including non-cultivated land and point sources
Offsite Water Quality Benefits

- 4. Instream loads – All sources aggregated and routed through rivers and reservoirs
- 5. Reductions in concentrations at key river locations: number of days concentrations of nutrients/pesticides exceeding human health and ecological thresholds

Results for the UMRB

- At the outlet of each 4-digit watersheds
- At 5 locations on the main stem of the UMRB (Grafton, IL)
- Water quality conditions of the UM river at current conservation effort and additional conservation treatment needed scenarios
Instream Sediment Load and Reductions

- Treatment of Critically Under Treated Acres: 7%
- Treatment of All Under Treated Acres: 15%
- Enhanced NM Treatment of All Vulner. Acres: 18%
- Enhanced NM Treatment of All Acres: 23%

Current Conservation Conditions: 31%
Instream Nitrogen Load and Reductions

Current Conservation Conditions 28%
Treatment of Critically Under Treated Acres 8%
Treatment of All Under Treated Acres 21%
Enhanced NM Treatment of All Vulner. Acres 34%
Enhanced NM Treatment of All Acres 50%
Instream Phosphorus Load and Reductions

Current Conservation Conditions: 21%
- Treatment of Critically Under Treated Acres: 6%
- Treatment of All Under Treated Acres: 19%
- Enhanced NM Treatment of All Vulner. Acres: 30%
- Enhanced NM Treatment of All Acres: 45%

Phosphorus Reduction maps for Minnesota, Wisconsin, Iowa, Missouri, and Illinois showing phosphorus load and reduction data.
Instream Atrazine Load and Reductions

Current Conservation Conditions 29%
Exceedence Probability for sediment Concentration (above 200 mg/L) at Grafton, IL

- Current conditions
- No practices
- NoCultCropContr

- Threshold

30% (108 days)
53% (193 days)
Exceedence Probability for Total Nitrogen Concentration (above 3.2 mg/L) at Grafton, IL

- Current conditions
- No practices
- NoCultCropContr

63% exceedence probability in 229 days
83% exceedence probability in 304 days

Threshold concentration: 3.2 mg/L
Exceedence Probability for Total Phosphorus Concentration (above 0.118 mg/L) at Grafton, IL

- Current conditions: 99.4% over 363 days
- No practices: 99.7% over 364 days

The graph shows the exceedence probability for phosphorus concentration over time under different conditions.
Exceedence Probability for Atrazine Concentration (above 3 ppb) at Grafton, IL

- Current conditions: 0.28% 1 day, 1.12% 4 days
- Threshold: 0.28%
- No practices: 1.12%
- NoCultCropContr: 0.28%

Map showing the exceedence probability for atrazine concentration at Grafton, IL, with a legend indicating current conditions and threshold levels.
Application of the Modeling Framework

- National Scale Modeling Framework - intensively data driven system

“Quantitative information” for policy makers and planners

- To assess the impacts of existing conservation practices on water quality
- To assess future conservation treatment needs and develop new programs
Future Direction

- Continuous Improvement of Model Routines and Databases
- Calibration & Validation with additional gages & data
- River Basin Analysis - Mississippi Basin and Other Basins

Future Scenarios -
Evaluate and Identify Natural Resource Problems & Find Solutions

- Bio-Fuel Production
- Climate Change Scenarios
- Carbon Credit Analysis
- Source Contribution and Targeting on Priority Areas
Publications

• CEAP - UMRB Report, USDA-NRCS, 2009
• Di Luzio et al., 2008
• Kannan et al., J. Hydrology, 2008
• Santhi et al., JAWRA, 2008
• Santhi et al., ASABE, 2005
• Wang et al., ASABE, 2006

Thank You