Monitoring and Modeling of Nutrient & Sediment Loads for Varying Climate & Landscapes

Laura Keefer, Momcilo Markus and Elias Getahun
Illinois State Water Survey
Champaign, IL
Overview

- **ISWS Watershed Data Collection Activities** – Laura Keefer
  - What, where and how data is collected
  - Not all watersheds are the same
    - Examples from Illinois River & Kaskaskia River Basins
  - Monitoring for long-term sediment trends
  - Data applied for better modeling...

- **Watershed Management Tool (WMT)** – Elias Getahun

- **Statistical Modeling** – Momcilo Markus
  - Development of short- and long-term nutrient predictions
  - How and why to calculate nutrient and sediment loadings
ISWS Monitoring Stations
-since 1980s

- Investigative:
  - Streamgaging
  - Sediment
  - Nutrient
- ISWS Sediment Network
  - 15 stations (1981-today)
Current ISWS Stations

- Solar Panel
- Cell Modem
- Automatic Water Sampler
- Data logger (brains)
- Radar – touchless water level readings
Kaskaskia – nitrogen & sediment sampling

- Weekly samples
- High frequency during flow events
## Nutrient & Sediment Summary Statistics

<table>
<thead>
<tr>
<th></th>
<th>NO₃-N</th>
<th>NH₄-N</th>
<th>TKN</th>
<th>t-P</th>
<th>t-P-dissolved</th>
<th>oPO₄-P</th>
<th>SSC</th>
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<tbody>
<tr>
<td><strong>Court Creek - ILL</strong></td>
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<td>747</td>
<td>747</td>
<td>747</td>
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<td>2.5</td>
<td>0.8</td>
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<td>1.4</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
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<td>Min</td>
<td>&lt; 0.04</td>
<td>&lt; 0.03</td>
<td>0.23</td>
<td>0.03</td>
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<td>&lt; 0.003</td>
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<td>1.7</td>
<td>18.7</td>
<td>6.6</td>
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<td>0.1</td>
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<td>389</td>
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<td>0.2</td>
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<td>Median</td>
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<td>Maximum</td>
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<td>21.3</td>
<td>6.2</td>
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<td>1.2</td>
<td>0.6</td>
<td>0.2</td>
<td>589</td>
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</table>
Kaskaskia – N loads

Monthly Nitrate-N Yield per Acre
Water Year 2015

- Lost Creek (402) EAST
- North Fork Kaskaskia River (403)
- Hurricane Creek (404) WEST
- East Fork Shoal Creek (405)

YIELD, pounds per acre

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

MONTH
Benchmark Sediment Monitoring Program

Develop comprehensive, long-term database of suspended sediment transport to provide a means for investigating and quantifying long-term trends that may be occurring in Illinois watersheds.

Has 35+ years of suspended sediment data.

- Identify watersheds with high erosion rates
- Evaluate effectiveness of erosion control programs
- Identify areas of potential degradation of surface water supplies
- Estimate sediment loads in nearby unmeasured streams

- Determine long-term trends in sediment transport
Long-term trends in Sediment Loading

**Spoon River @ London Mills**

\[ y = 2.4698x - 4063.1 \]
\[ R^2 = 0.0037 \]

**Kaskaskia River @ Vandalia**

\[ y = 10.934x - 19984 \]
\[ R^2 = 0.0197 \]
Watershed Management Tool
for Improving Water Quality in Streams and Rivers

➢ 75% of nutrient fluxes to the Gulf of Mexico originates from only 9 midwestern states including Illinois (Alexander et al, 2008), mainly from agricultural sources

➢ Nutrient Loss Reduction Strategies

➢ Agricultural watershed management tools can be used to identify critical source areas of nutrient loss and BMP selection and placement

➢ ISWS developed WMT to:
  ➢ evaluate water quality impacts of user-specified BMP scenarios and unit costs
  ➢ provide comparison of selected BMP implementations between
    ➢ user specified and
    ➢ optimal scenario
FRAMEWORK OF THE WATERSHED MANAGEMENT TOOL

**MODEL INPUTS**
- Topography (DEM), land uses, soils, management operations (e.g., crop rotations, tillage fertilization), climate data including precipitation, temperature, etc...

**BMP INPUTS**
- Information specific to BMPs (e.g., fertilizer rate and timing)
- Unit cost of BMP implementation

**SWAT**
- Simulates hydrologic and **water quality** processes, plant growth, impacts of management practices

**COST FUNCTION**
- Computes cost of BMP implementation

**OPTIMAL BMP SCENARIOS**
- Optimal BMP placements and tradeoffs b/n WQ reduction and cost

**WMT OUTPUTS**
- Percentage of sediment & nutrient reductions
- Optimal BMP placement based on user-specified costs of implementation
Statistical methods used in nutrient and sediment load calculation, trend analysis and prediction
State Contributions to Nitrogen and Phosphorus loads delivered by the Mississippi River to the Gulf of Mexico

<table>
<thead>
<tr>
<th>State</th>
<th>Total Nitrogen</th>
<th>Total Phosphorus</th>
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<tbody>
<tr>
<td></td>
<td>Percent of Total Flux</td>
<td>Cumulative Percent of Total Flux</td>
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<tr>
<td>Illinois</td>
<td>16.8</td>
<td>16.8</td>
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<td>Iowa</td>
<td>11.3</td>
<td>28.1</td>
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<td>Indiana</td>
<td>10.1</td>
<td>38.2</td>
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<tr>
<td>Missouri</td>
<td>9.6</td>
<td>47.8</td>
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<tr>
<td>Arkansas</td>
<td>6.9</td>
<td>54.7</td>
</tr>
</tbody>
</table>

Nitrogen

Phosphorus

Percent Share

- < 1
- 1 to 5
- 5 to 10
- 10 to 17
Excessive Nutrient Loadings

• The hypoxic (low oxygen) zone in the Gulf of Mexico is a result of excessive nutrient loadings (primarily N and P) from the Mississippi River.


Why do we calculate nutrient loadings?

• To detect watersheds with highest and lowest contributions.
• To determine if the management practices are efficient.
• To predict future trends (short-term, annual, and long-term)
• To design nutrient reduction strategies.
How do we calculate nutrient loadings?

\[ L = c \times Q \]

- **Nutrient loading (Tons)**
- **River discharge (m³/s)**
- **Nutrient concentration (mg/L)**
How do we calculate nutrient loadings?

**Regression-Based Estimator**

\[
\ln(C) = \beta_0 + \beta_1 \ln\left(\frac{Q}{\tilde{Q}}\right) + \beta_2 \left[\ln\left(\frac{Q}{\tilde{Q}}\right)\right]^2 + \beta_3 (T - \tilde{T}) + \beta_4 (T - \tilde{T})^2 + \beta_5 \sin(2\pi T) + \beta_6 \cos(2\pi T) + \varepsilon
\]

**Rating Curve Estimator:**

\[
L_{RC} = \sum_{j=1}^{N} C_j Q_j \Delta t
\]

**MVUE:**

\[
L_{MVUE} = L_{RC} g_m \left[ \frac{m+1}{2m} (1-v)s^2 \right]
\]

**Smearing Estimator:**

\[
L_{SM} = L_{RC} \frac{1}{M} \sum_{i=1}^{M} \exp[e(i)]
\]
Nitrate yields in the Illinois River Basin 1975-2012

La Moine River at Ripley

Kankakee River at Wilmington

Illinois River at Marseilles

Sangamon River at Oakford

Illinois River at Valley City

Annual Nitrate Load (kg/yr/km²)
- Regression correction
- EGRET flow-dependent
- Regression correction linear trend
- Discharge (m³/day/km²)
TP yields in the Illinois River Basin 1975-2012

- Illinois River at Marseilles
- La Moine River at Ripley
- Kankakee River at Wilmington
- Sangamon River at Oakford
- Illinois River at Valley City

Annual TP Load (kg/yr/km²)
- Regression correction
- EGRET flow-dependent
- Regression correction linear trend
- Discharge (m³/day/km²)
# Trend Analysis

<table>
<thead>
<tr>
<th>Confidence Level (%)</th>
<th>Decreasing Trends</th>
<th>Increasing Trends</th>
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</thead>
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<tr>
<td></td>
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<td>95</td>
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<tr>
<td>Discharge</td>
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<td>NO₂+NO₃ Conc.</td>
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<td>NO₂+NO₃ Load</td>
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<td>DP Concentration</td>
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# Trend Analysis (continued)

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<tr>
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<td>DP Concentration</td>
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<td>TP Load</td>
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**Nutrient Reduction Goals**

- To reduce the size of the hypoxic zone in the Gulf of Mexico, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force set a nutrient reduction goal of 45% for nitrogen and phosphorus by 2050 to reduce the size of the hypoxic zone from 8000 to 5000 square miles (MRGMWNTF, 2008).

http://water.epa.gov/type/watersheds/named/msbasin/actionplan.cfm
Nutrient Loadings: Contributing factors

- A wet year in terms of nutrient loading is defined by large storm events.
- More precipitation, on average, in a given year doesn’t necessarily lead to an increase in pollution.
- The increase is tied to heavy precipitation.
Evaluating the Impact of Legacy P and Agricultural Conservation Practices on Nutrient Loads from the Maumee River Watershed
Rebecca Logsdon Muenich,* Margaret Kalcic,† and Donald Scavia
Graham Sustainability Institute, University of Michigan, 625 East Liberty Street, Suite 300, Ann Arbor, Michigan 48104, United States

Total Phosphorus (tonnes)

after cessation of phosphorus fertilizer applications under: *wet climate* and *average climate*

Lake Erie Phosphorus Load Target

0  Years After P Fertilizer Cessation  80
Probabilistic assessment and validation of nutrient reduction goals
Goals:

• To design a new probabilistic framework for setting the nutrient reduction goals, which would also show the uncertainty distribution based on past observed climates.

• To evaluate the potential effects of climate variability on achieving the nutrient reduction goals.

• To design a tool to verify if the goals have been achieved.
Summary

• Importance of modeling
  • Watershed models/Statistical models

• Monitoring, monitoring, monitoring
  • Frequency/Spatial distribution