Nutrients in Illinois Waters (& Sources)

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Acknowledgements

• Greg McIsaac
• Lowell Gentry
• Laurie Drinkwater
• Corey Mitchell
• Linda Jacobson
What I will cover

• N and P sources, balances, and riverine exports in the Mississippi River Basin (MRB), focusing on Illinois
  - what is going to the Gulf

• importance of modified hydrology (tile drainage)

• timing of flow and nutrients

• response of streams & rivers to nutrients (local effects)
Recent County Level Analysis

- all counties in MRB (1768)
- 1997 to 2006 annual data on fertilizer, crops, animals, people, deposition
- predictive model from watersheds applied to all MRB counties
- for both N and P
Components of Nitrogen Mass Balances

• net nitrogen inputs (NNI)
  = inputs - outputs
  inputs (deposition, fertilizer, fixation)
  outputs (grain harvest - human + animal consumption)

• NNI is N available for leaching, denitrification, adding to soil N pools

• data from agricultural statistics (crops and animals), fertilizer industry, assumptions about N in various components
Annual N Fertilizer Applications

Fertilizer (kg N ha⁻¹)

- 0.0 - 11.2
- 11.3 - 27.2
- 27.3 - 45.4
- 45.5 - 65.9
- 66.0 - 107.1
Tile drainage is concentrated in the corn belt.
Net N Inputs (NNI)

Some counties negative, N from soil mineralization
Watershed Data

- 153 from across basin
- January to June nitrate-N concentrations and flow
  - typically about 40 concentrations for a given location
- median watershed size was 1982 km²
  - 79 to 50,360 km²
- nonlinear model has flow* fertilizer (76%), human consumption (7%), and fraction of county tile drained (17%)
Modeled January to June Nitrate Export

Predicted N Yield (kg N/ha)

- 0.00 - 3.00
- 3.01 - 7.50
- 7.51 - 10.00
- 10.01 - 15.00
- 15.01 - 25.00
P Yields in MRB from our analysis (A) and SPARROW (B)
Sources of Nutrients in Illinois

- agriculture
  - surface runoff
  - tile drainage
  - many watersheds > 90% row cropped
  - animal agriculture less important

- sewage effluent
  - Illinois has ~ 12.9 million people
  - dominates upper Illinois River
  - generally, no N or P removal technology used
Illinois N budget

Net Nitrogen Inputs

Fertilizer
Legume N
NOy deposition
Grain harvest
Manure
Human consumption

Nitrogen (kg N ha⁻¹)

0 10 20 30 40 50 60 70 80 90 100

Linking N balances to N Export

- hydrology overwhelming factor
  - tile drainage, channelization
- can look at watershed N export as a fraction of net N inputs
  - most studies have found this to be about 25%
  - however in MRB we know it is larger in critical areas
  - can be > 100% in Illinois tile drained watersheds
Drainage by tiles and ditches
Tile nitrate concentrations

ADM NH₃ UAN

ADM UAN

NO₃⁻-N (mg N L⁻¹)

corn soybean corn

Embarras River

Nitrate Export (kg N ha\(^{-1}\) yr\(^{-1}\))

Water Year

- 1991
- 1992
- 1993
- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
Components of Phosphorus Mass Balances

• net P inputs
  = inputs – outputs
  inputs (fertilizer)
  outputs (grain harvest - human and animal consumption)

• net indicates additions or removals from soil

• little P (relative to N) is lost to streams, but it biologically important

• surface runoff and tile leaching
Illinois P budget
P from fields to rivers - tiles

From Gentry et al. (2007)
From Gentry et al. (2007)
Particulate P from fields to rivers

From Gentry et al. (2007)
Sewage Effluent - 12.9 million people

16% of total N load statewide
21% for Illinois River, 14% for others

47% of total P load statewide
70% for Illinois River, 33% for others

From David and Gentry (2000)
N and P Fluxes for State, 1980 to 1997

**N or P Flux (kg ha\(^{-1}\) yr\(^{-1}\))**

- Rock
- Illinois
- Embarras
- Kaskaskia
- Little Wabash
- Big Muddy
- Illinois - All
- Mississippi
- Ohio

**NO\(_3\)\(^{-}\)-N**

**Organic + NH\(_4\)\(^{+}\)-N**

**Dissolved P**

**Particulate P**
Nutrient Export Patterns
Importance of a Few Storm Events

The graph shows the cumulative percentage of nutrient export (NO$_3$-N, DRP, Total P) over the water year from October 2002 to October 2003. The top graph plots nutrient export against time, while the bottom graph shows discharge and precipitation rates.
N and P Inputs and River Export - Conclusions

• N balances don’t relate well to nitrate loss across the entire MRB, or Illinois

• watersheds (counties) with high fertilizer inputs have high crop fractions (and corn acres) and tile drainage
  - all lead to riverine nitrate export
  - row crops (corn & soybean) on tile drained land much more important than manure, deposition, or sewage effluent

• P from both surface runoff and tiles
  - sewage effluent also important

• high winter/spring flow and nutrient losses are a challenge

• fall fertilizer N?
Will reducing nutrient loads (even by 45%) to the Gulf improve local water quality?

- not always clear in streams draining agricultural areas, and those with sewage effluent
- states such as Illinois, Iowa, Indiana, have few high quality streams
- difficult to find relationships between nutrients and biotic integrity
  - nearly all P concentrations above critical level
  - N relationships typically not found or very weak
Operational Model

Light & Nutrients → Chlorophyll & \( \text{O}_2 \) respiration → Low Nighttime DO → Biotic impairment

• How strong is this relationship in Illinois streams?

• How might we modify the model to fit various categories of Illinois streams?
Extensive Sampling in 2004 and 2005
Nutrient Concentrations - seldom limiting

From Royer et al. (2008)

Table 1. Distribution of water chemistry values from the 2004 state-wide surveys.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>25th Percentile</th>
<th>Median</th>
<th>75th Percentile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Q† survey (May–July, n = 138)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRP‡ (mg L⁻¹)</td>
<td>&lt;0.005</td>
<td>0.038</td>
<td>0.069</td>
<td>0.156</td>
<td>1.9</td>
</tr>
<tr>
<td>Total P (mg L⁻¹)</td>
<td>0.013</td>
<td>0.123</td>
<td>0.185</td>
<td>0.326</td>
<td>2.0</td>
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<tr>
<td>NH₄–N (mg L⁻¹)</td>
<td>0.008</td>
<td>0.040</td>
<td>0.058</td>
<td>0.089</td>
<td>0.387</td>
</tr>
<tr>
<td>NO₃–N (mg L⁻¹)</td>
<td>0.100</td>
<td>1.0</td>
<td>4.3</td>
<td>10.2</td>
<td>20.2</td>
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<tr>
<td>Total N (mg L⁻¹)</td>
<td>0.37</td>
<td>2.2</td>
<td>5.6</td>
<td>11.0</td>
<td>20.9</td>
</tr>
<tr>
<td>Silica (mg L⁻¹)</td>
<td>1.5</td>
<td>6.7</td>
<td>9.6</td>
<td>11.8</td>
<td>16.6</td>
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<tr>
<td>pH</td>
<td>7.0</td>
<td>7.7</td>
<td>7.9</td>
<td>8.1</td>
<td>8.7</td>
</tr>
<tr>
<td>Specific conductivity (µS cm⁻¹ @ 25°C)</td>
<td>106</td>
<td>586</td>
<td>658</td>
<td>751</td>
<td>2240</td>
</tr>
<tr>
<td>Turbidity (NTU§)</td>
<td>&lt;1</td>
<td>21</td>
<td>36</td>
<td>61</td>
<td>614</td>
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<tr>
<td>Low-Q survey (Sept., n = 109)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>DRP (mg L⁻¹)</td>
<td>0.001</td>
<td>0.029</td>
<td>0.081</td>
<td>0.345</td>
<td>2.8</td>
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<tr>
<td>Total P (mg L⁻¹)</td>
<td>0.007</td>
<td>0.112</td>
<td>0.168</td>
<td>0.456</td>
<td>2.8</td>
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<tr>
<td>NH₄–N (mg L⁻¹)</td>
<td>0.002</td>
<td>0.011</td>
<td>0.022</td>
<td>0.042</td>
<td>0.696</td>
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<tr>
<td>NO₃–N (mg L⁻¹)</td>
<td>&lt;0.05</td>
<td>0.18</td>
<td>1.5</td>
<td>3.9</td>
<td>18.0</td>
</tr>
<tr>
<td>Total N (mg L⁻¹)</td>
<td>0.21</td>
<td>1.0</td>
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<td>Specific conductivity (µS cm⁻¹ @ 25°C)</td>
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<td>556</td>
<td>664</td>
<td>814</td>
<td>3246</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>&lt;1</td>
<td>10</td>
<td>18</td>
<td>29</td>
<td>159</td>
</tr>
</tbody>
</table>
From Royer et al. (2008)
Macroinvertebrate Results

- four major groups based on taxa dissimilarity
- habitat quality and nutrients responsible for separation
- streams with high quality habitats had low concentrations of nutrients
- biological integrity (forested > agricultural > urban)
- physical habitat degradation confounded with nutrients

From Heatherly et al. (2007)
Dissolved oxygen in Illinois streams

Fig. 6. Dissolved O$_2$ patterns during (upper) late May and (lower) early November 2004 in two open-canopy and two shaded agricultural streams. Daily solar radiation values were measured at Site BLS (open canopy) and do not reflect available light at the water surface for the shaded sites.

From Morgan et al. (2006)
Black Slough (small headwater stream)
Grouping streams for water quality

Sestonic chl-a (mg m$^{-3}$)

Benthic chl-a (mg m$^{-2}$)

Watershed Area (km$^2$)

DO Super-saturation (hrs d$^{-1}$)
Nutrient Criteria with Complex Relationships

• correlations/regressions unlikely to work
  - much of the data are not normally distributed

• nutrient, chl-\(a\), dissolved oxygen, and biotic integrity linked but not straightforward
  - is increased chl-\(a\) enough?

• can’t study every site

• how to get overall relationships?
Modifications to Original Model

Light & Nutrients → Chlorophyll & O₂ respiration → Low Nighttime DO → Biotic impairment

Light & Substrate appear more important than nutrients
(Nutrients generally not limiting)

Diel range in DO more consistently affected than the DO minima

Physical habitat appears to play a much larger role than nutrients
Small to medium streams
Modified Model for Illinois (1)

Small to medium streams
(in which nutrients are \textit{almost} never limiting)

Light & Substrate

Chlorophyll & O$_2$ respiration

High minimum DO

Biotic impairment

Habitat

Periphyton & Macroalgae
Medium streams
Modified Model for Illinois (2)

Medium streams
(in which nutrients are never limiting)

Limited by light, substrate, and/or time

Chlorophyll & \( \text{O}_2 \) respiration

Small Diel DO Range

Biotic impairment

Limited Sestonic, Periphyton or Macroalgae

Habitat
Medium to large rivers
Modified Model for Illinois (3)

Medium to large rivers
(in which nutrients are never limiting)

Light & Time → Sestonic algae
Chlorophyll & O₂ respiration → Moderate to large Diel DO Range → Physical controls on DO

Habitat → Biotic impairment
Nutrients and Biotic Integrity

Habitat Quality

Nearly all sites in IL

Biotic Integrity

Nutrients

excellent → Habitat Quality → poor

low ← Nutrients → high
Conclusions - Illinois Local Water Quality

- complex relationships at each step
  - many factors confounded
- nutrients almost never limiting algal biomass
- cluster analysis supports conceptual models
  - large river (sestonic, lower min DO, large diel range)
  - small streams with clear water (periphyton, high min DO)
  - many intermediate streams (little productivity, limited DO diel range)
- physical habitat (including sediment) major limit to biotic integrity throughout the state
  - improve habitat (reduce sediments), nutrients likely become more of a problem
  - relationships difficult to establish because Illinois lacks a wide range of conditions
Thank you