Session B3
Wednesday, 24 June:

BMPs
“Best Management Practices”
WMPs
“Worst Management Practices”

• Really not a good idea...
• Funding for WMP projects is almost impossible
Other MPs

• Minnesota (humble)
  • Not Too Bad Management Practices
  • Could Be Worse Management Practices
  • OK Management Practices
  • Better Than I Thought Management Practices

• Texas (bold)
  • Best Management Practices
Session B3 speakers:

1) Jim Almendinger  
   Science Museum of Minnesota

2) Nicola Fohrer  
   Christian Albrechts University

3) Olga Vigiak  
   European Commission - Joint Research Center

4) Raghavan Srinivasan (Srini)  
   Texas A&M University
Phosphorus Load Reductions due to Agricultural “Best” (Not Too Bad) Management Practices and Spatial Scaling of Phosphorus Export Coefficients

James E. Almendinger
St. Croix Watershed Research Station, Science Museum of Minnesota

Jason Ulrich
Dept. of Bioproducts and Biosystems Engineering, University of Minnesota

Funding and data provided by:

Data provided by:
Issue of Concern:

- Excess P loads from the watershed cause eutrophication = excessive algal growth in lakes and rivers.
Purpose:

• To use SWAT to estimate the reduction in *phosphorus loads* in our study watershed by applying best management practices (BMPs)
  • Load = kg/yr
  • BMPs = Filter strips, grassed waterways, no-till, etc.

• To quantify how *phosphorus yields* for agricultural land change with spatial scale
  • Yield = kg/ha/yr
  • Net TP yield at different spatial scales = “Total Phosphorus Export Coefficient” (TPEC)
  • Scales: from local (~0.5 km²) up to basin (1000s of km²)
Many lakes and rivers impaired by excess phosphorus

Goal is to reduce P loads by 20%

SWAT2009 model complete for Sunrise

SWAT2012 nearly completed for St. Croix
Sunrise River Watershed

- Land use
  - Agricultural in the north
  - Many lakes and large wetlands in the south
  - Urban areas around some lakes.

- Impaired waters
  - 4 River reaches
  - 10 Lakes

- Monitoring stations : 3
Building the SWAT model: 142 subbasins

The fundamental spatial framework of SWAT:
-- Channel network ("reaches" in SWAT)
-- Subbasin polygons
-- Topographic and hydrographic statistics (slope, reach lengths, etc.)
-- Subbasin polygons key in clipping soils and land use
Building the SWAT model: 1,643 HRUs

Land-Cover X Soil-Type X Slope Class Combos in each subbasin = 1,643 HRUs

-- E.g.: Corn/Soil-A/Slope1, Corn/Soil-B/Slope2, Beans/Soil-A/Slope2, Beans/Soil-B/Slope1, etc.
Model calibration: Flow

Sunrise River at Sunrise

Discharge (m$^3$ s$^{-1}$)

E$_{NS}$ = 0.88

Water Year 1999

Discharge (m$^3$ s$^{-1}$)

2006  E$_{NS}$ = 0.60

2007  E$_{NS}$ = 0.36

2008  E$_{NS}$ = 0.75

E$_{NS}$ = 0.88

MDNR  SWAT

USGS  SWAT
Model calibration: Phosphorus

Sunrise at Sunrise

Total Phosphorus (kg)

- Estimated
- SWAT

North Branch at Hwy 95

Total Phosphorus (kg)

- Estimated
- SWAT

Sunrise at Hwy 14

Total Phosphorus (kg)

- Estimated
- SWAT

100%
33%
23%
(43%)
Subbasin-wide phosphorus yields

Phosphorus yields to channel are highest where:

-- Soils are less sandy
-- Slopes are steeper
-- Land use = agriculture or urban
-- Less runoff captured by ponds and wetlands
SWAT schematic view -- HRU / subbasin / reservoir:

Upland/Field Scale
(HRU output)

Subbasin scale
(Subbasin output)

Watershed Scale
(after all Reaches & Reservoirs)

-- J.E. Almendinger, St. Croix Watershed Research Station, 2011 --
Loads at different spatial scales

EXPLANATION

- **Groundwater**
- **Surface Water**

Loss to settling in Ponds and Wetlands (off-channel depressions)
Loss to settling in Reservoirs (on-channel depressions)

To evaluate BMPs, use this scale (HRU output, with Ponds removed)
To evaluate downstream impacts, use this scale (watershed output)
TP Load Reductions from Agricultural BMPs in the Sunrise
Agricultural Areas and TP Loads in the Sunrise

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (%)</th>
<th>TP Load (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>21%</td>
<td>55%</td>
</tr>
<tr>
<td>CS rotation</td>
<td>11%</td>
<td>44%</td>
</tr>
<tr>
<td>CA rotation</td>
<td>2%</td>
<td>7%</td>
</tr>
<tr>
<td>Hay, Pasture</td>
<td>8%</td>
<td>4%</td>
</tr>
<tr>
<td>Developed</td>
<td>16%</td>
<td>27%</td>
</tr>
<tr>
<td>Other</td>
<td>63%</td>
<td>17%</td>
</tr>
</tbody>
</table>

**NOTES:** TP, total phosphorus; CS, grain corn-soybean rotation; CA, silage corn-alfalfa rotation.
Agricultural BMPs in SWAT

-- No-Till agriculture
-- Filter strips
-- Grassed waterways
-- Reduction of soil phosphorus
Agricultural BMPs: What works?
-- a little of everything

EXPLANATION

- Other
- Developed
- Agriculture

Upland Phosphorus Load (metT/yr)

- Baseline
- No-Till
- Veg Filter Strips
- Grassed Waterways
- Soil P 20 ppm

HRU output
Watershed output

0%
-3.9%
-11.1%
-17.6%
-19.7%
How phosphorus yield changes with scale

Why should I care?

Because phosphorus yields for selected land uses -- “Total Phosphorus Export Coefficients” (TPECs) – are used to estimate loads of phosphorus to streams and lakes.

Scale effects need to be quantified!
Simple P Loads = TPEC * Land-Use Area

St. Croix River Basin (20,000 km²)

Urban: 140 km²
Water: 1,800 km²
Agriculture: 3,200 km²
Grassland: 3,400 km²
Forest: 11,300 km²

Explaination
NLCD 1992 Land Cover
- Cropland
- Forest
- Grassland
- Urban, low density
- Urban, med-high density
- Water
- Wetland

0 25 50 75 100 Kilometers
Simple P Loads = Land-Use Area * TPEC

- These TPEC values are surely not constant everywhere in the basin.
- How do they change with scale?
- From local scales (< 1 km$^2$) to regional scales (1000s km$^2$)

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (km$^2$)</th>
<th>TPEC (kg/ha/yr)</th>
<th>Load (t/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>3,200</td>
<td>0.63</td>
<td>= 202</td>
</tr>
<tr>
<td>Grassland</td>
<td>3,400</td>
<td>0.22</td>
<td>= 75</td>
</tr>
<tr>
<td>Forest</td>
<td>11,300</td>
<td>0.10</td>
<td>= 113</td>
</tr>
<tr>
<td>Urban</td>
<td>140</td>
<td>0.63</td>
<td>= 9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>398</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(converting km$^2$ to ha, and kg to tons)
Why export coefficients change with scale
Because some P is trapped (lost) during transport

Start with gross P yield (e.g. 5 kg/ha/yr)

1a. In-field loss (slope change, residue): 25%?
1b. Overland flow loss: 20%?
2a. Lowland loss: 20%?
2b. Subbasin channel loss: 5%?
3. Watershed loss (lakes and floodplains): 10%?

End with apparent P yield, or “export coefficient” (e.g. 1 kg/ha/yr)

SWAT can help quantify “scale appropriate” export coefficients:
1 = HRU output
2 = Subbasin output
3 = Watershed output
SWAT schematic view -- HRU / subbasin / reservoir:

- **Upland/Field Scale** (HRU output)
  - Tributary
  - Infiltration

- **Pond & Wetland**
  - Infiltration
  - Seepage

- **Subbasin scale** (Subbasin output)
  - Reach
  - Infiltration

- **Watershed Scale** (after all Reaches & Reservoirs)
  - Reservoir
  - Seepage

-- J.E. Almendinger, St. Croix Watershed Research Station, 2011 --
Apparent yields (TPECs) at different spatial scales

Which of these values should be used as a TPEC depends on the scale of application.

Sunrise SWAT data -- internally consistent

1.941*A^{-0.117}

Error Bars +/- 1 SD

Estimated for St. Croix basin
Agricultural BMPs could reduce TP loads by:
- 4% from No-Till
- 11% from filter strips
- 18% from grassed waterways
- 20% for reducing soil phosphorus (P)

Total Phosphorus Export Coefficients (TPECs) for cropland depend on spatial scale:
- Negative power relationship: $TPEC = a \times \text{Area}^{-b}$
- Upland field scale (0.6 km²): 2.12 kg/ha/yr
- Subbasin scale (7 km²): 1.39 kg/ha/yr
- Watershed scale (991 km²): 0.85 kg/ha/yr
- River basin scale (20,000 km²): 0.63 kg/ha/yr
Questions?

I envy this kid... He really, really knows the right answer!

When was the last time that you really, really knew the right answer?
(Misc. further slides / extras)
Agricultural BMPs: What is a SWAT filter strip?

A strip along the bottom of an HRU – not necessarily along a stream.

Some portion reaches the filter strip as sheet flow, with effective treatment.

25-75% blows through filter strip as concentrated flow, essentially untreated.

Width of strip determined as % of HRU area.
Agricultural BMPs: What is a SWAT grassed waterway?

A strip down the middle of an HRU (I think)

Grassed waterway length set to square root of HRU area (by default). Should act as filter strip from both sides, plus slowing longitudinal flow, plus armoring channel from gullyng.
Apparent yields (TPECs) at different spatial scales

Which of these values should be used as a TPEC depends on the scale of application.

Sunrise SWAT data -- internally consistent

Estimated for St. Croix basin
What about South Center Lake? (one of our Sentinels)
• South Center Lake phosphorus loads
  • How much is coming in (input load)?
  • How much is being trapped?

(1) Input Load (kg/yr)
  a. By land use TPEC \((Total\ P\ Export\ Coefficient)\)

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (km²)</th>
<th>St. Croix Basin-Scale</th>
<th>TP Load (kg/ha/yr)</th>
<th>TP Load (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>3.64</td>
<td>8%</td>
<td>0.63</td>
<td>229</td>
</tr>
<tr>
<td>Agriculture</td>
<td>11.76</td>
<td>27%</td>
<td>0.63</td>
<td>739</td>
</tr>
<tr>
<td>Grassland</td>
<td>6.97</td>
<td>16%</td>
<td>0.22</td>
<td>154</td>
</tr>
<tr>
<td>Forest</td>
<td>8.91</td>
<td>20%</td>
<td>0.10</td>
<td>88</td>
</tr>
<tr>
<td>Shrubland</td>
<td>0.03</td>
<td>0%</td>
<td>0.10</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>12.18</td>
<td>28%</td>
<td>0.01</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>43.49</td>
<td>100%</td>
<td></td>
<td>1,218</td>
</tr>
</tbody>
</table>

b. By SWAT:
  -- For 2000s: 1,875 kg/yr

(2) Trapped in lake (kg/yr)
  a. By SWAT:
  -- For 2000s: 1,795 kg/yr (96% -- too high?)
  b. By lake-sediment analysis (Mark’s work):
  -- For 2000s: 3,023 kg/yr (too high)
Watershed-wide export coefficient will be average of all subbasins.