Phosphorus Risk Assessment Using the Variable Source Loading Function Model

Zachary Easton¹, Elliot Schneiderman², M. Todd Walter¹, and Tammo Steenhuis¹

¹Dept. Biological and Environmental Engineering, Cornell University, Ithaca, NY
²New York City Dept. Environmental Protection, Kingston, NY
*zme2@cornell.edu
We know that in many areas with steep slopes and shallow soils hydrology is, to a great extent, driven by topology.... Variable Source Areas (VSA)

Near stream areas, areas with shallow, slowly permeable soil or a large contributing areas produce the majority of runoff.
Why is P Modeling Difficult in VSA Watersheds

• Spatially and temporally heterogeneous
  - Watershed properties (soil, landuse, topology, STP, management) can display great variability
    • Thus another level of complexity is added to predicting P loss

• How can we as scientists, planners, and watershed managers identify areas of the landscape prone to high runoff and thus potentially high P losses?
Many Current Water Quality Models Cannot Capture this Complexity, e.g.,

- General Watershed Loading Function (GWLF)
- Soil Water Assessment Tool (SWAT)
- Agricultural Nonpoint Source Pollution Model (AGNPS)
• First we must delineate topographic source areas and predict where runoff source areas are.

• Only distributed models can do this.

• Now we can visualize and begin to manage critical source areas.

• Only distributed models can do this.
P Sources

Impervious surfaces

Plant tissue

Manured Areas

Disturbed un-vegetated sites

Fertilized areas
Modeling P Loss

- Since different P sources contribute P differently, model processes separately
  - Fertilizer/manure
  - Impervious areas
  - Baseflow
  - Soils
- Hydrologic input were taken from VSLF and used in the P model
Fertilizer/manure P

- Fertilizer/manure P declines with successive runoff (R) events following application:

\[ \frac{dD_{F,t}}{dR} = k_F \left[ M_{F,t} - D_{F,t} \right]^2 \]

- \( D_{F,t} \) is the cumulative P loss,
- \( k_F \) is the reaction constant,
- \( M_{F,t} \) is the amount of P left at time \( t \)
Impervious Surfaces

- $P$ accumulates on impervious surfaces
  - Modeled with an exponential relationship

- Wash off of accumulated $P$ is modeled with a first order relationship
Baseflow

- Represents integrated influence of surface and subsurface factors. An export coefficient approach was used.

\[ L_{B,t} = \mu_B B_t \]

- where \( L_{B,t} \) is baseflow P load, \( \mu_B \) is the mean expected P concentration in baseflow, and \( B_t \) is the baseflow volume.
Soil P

• P losses from soil can be approximated using soil test P values:

\[ D_{S,t} = \mu_s M_S R_t \]

where \( D_{S,t} \) is the runoff P load
• \( \mu_s \) is the soil specific coefficient determined from sampled runoff
• \( M_S \) is the soil test P
• \( R_t \) is the runoff

\[ y = 0.0612x + 0.1279 \]
\[ r^2 = 0.74 \]
Agricultural

Discharge (cm/d)

SRP Load (kg/d)

1/1  2/21  4/13  6/3  7/24  9/13  11/3  12/24
Developed
How Does Temp Affect P Availability?

Suburban Watershed

- Forested Watershed (Catskills, NY)

Scott et al. 2001 *Biogeochemistry*
Possible Link to DOC

Phosphate (mg/L)

DOC (mg/L)

$R^2 = 0.3$
Linking Biogeochemical Systems

Van’t Hoff (1898)

\[ C = Q_{10} \left( \frac{T - T_o}{10} \right) \]

DOC

Chile Study

Valdivia, Walter, Hedin. 2006. <in preparation>

Observed DOC Simulated DOC

\[ y = 100x - 0.03 \]

\[ R^2 = 0.81 \]
How Does Temp Affect P Availability?
Improved Corroboration

Discharge (cm/d)

SRP Load (kg/d)

Hively et al. 2005. HESS
Streamflow (mm d\(^{-1}\))

- Measured: 18.3
- Modeled: 23.7

DP Load (kg d\(^{-1}\))

- Measured: 3.2
- Modeled: 3.1

\(r^2 = 0.77\)

\(E = 0.75\)
Where are the High Risk Areas?

High Runoff
Low Runoff
High P
Low P

P Loss (kg/ha)
Sept 20 2000

Weti LU Dissolved P
25-Jan-1999

0 - 0.007
0.007 - 0.019
0.019 - 0.053
0.053 - 0.110
0.110 - 0.325

Low Runoff High P
High Runoff Low P
<table>
<thead>
<tr>
<th>P Loss (kg/ha)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.0246</td>
<td>Green</td>
</tr>
<tr>
<td>0.0246 - 0.0391</td>
<td>Yellow</td>
</tr>
<tr>
<td>0.0391 - 0.0569</td>
<td>Orange</td>
</tr>
<tr>
<td>0.0569 - 0.1414</td>
<td>Red</td>
</tr>
<tr>
<td>0.1414 - 0.4941</td>
<td>Black</td>
</tr>
</tbody>
</table>
VSAs Discussed

- Spatial and temporal components to P loss
- Areas with high runoff losses can be P source areas, but not all of them!
  - Interaction between runoff source areas
  - and P source areas
• Landscape P loss originates from definable areas of the watershed... VSAs
• Landscapes contribute differing P loads at different times.... temp dependency
  - Winter vs. summer
  - Soils vs. fertilized/manured vs. baseflow
• To reduce P loads in surface waters we need to consider all these factors