Modeling ... What’s the Use?

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Lake Leaders 2014
What’s a model

One definition:

A mathematical description to help visualize something

Model airplane

Very large computer
Example– General Circulation Model

http://celebrating200years.noaa.gov/breakthroughs/climate_model/AtmosphericModelSchematic.png
What’s a model

One definition: A mathematical description to help visualize something

Can this help us “visualize” how past actions have led to a current condition
or help us “visualize” how future actions could alter the current condition
Today…. 1) Watersheds and 2) Lakes & 3) Streams

- Functioning – big picture arm waving – & the development of “Conceptual” Models
- Modeling Approaches –
  - Fundamentals
  - Examples (simple & not so simple)
  - Compare & contrast

Goal- Understand if these might be useful & what is an appropriate model

(and most important… not make a potentially confusing topic more confusing…)
Part 1 – Watersheds

Define - that area where the water drains to the outlet point of interest
all of the land surface belongs to a “watershed”
Our Watershed Interest This Morning
--- Water, Sediment & Nutrients (could be others)
Precipitation = ___ inches/yr
Evapotranspiration = ___ inches/yr
Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr
Precipitation = 32 inches/yr
Evapotranspiration = 22 inches/yr

Watershed "Runoff" = ___ inches/yr
Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr

Watershed “Runoff” = 10 inches/yr
Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr

Watershed “Runoff” = 10 inches/yr

10 inches /year on 1 square mile…
= 23,000,000 cubic feet /year!
Precipitation = 32 inches/yr

Evapotranspiration = 22 inches/yr

Watershed “Runoff” = 10 inches/yr

10 inches /year on 1 square mile...
= 23,000,000 cubic feet /year!
= 0.7 cubic foot every second!
Let’s Model That for a lake at the outlet!

- We just did

- Water Budget
Let’s Model That!

• We just did

Water Entering the Lake Each Year = (10 in/year)*(Watershed Area)
Rule #1

“All models are wrong but some are useful”

George Box
• Useful?
  – Residence time =
    = \frac{\text{Amount of Water in Lake}}{\text{Rate Which Water Leaves Lake}}
• Useful?
  – Say 10,000 acre lake, mean depth of 40 feet with a 150,000 acre watershed
  – Residence time estimate =
    \[
    \frac{(10,000 \text{ acre})(40 \text{ feet mean depth})}{(150,000 \text{ acre})(0.83 \text{ ft/yr})} = 3.2 \text{ years}
    \]
Limitations

• Year-to-Year Variations?
• Different parts of the watershed have different response
  – Impervious surfaces
  – Compacted soil / raindrop impact
How can we improve this model?

• Spatial Variability
• Temporal Variability

• Of course this comes at a cost... is it necessary? Is it worth it?
Modeling the Land?

Annual Volume

Very Simple

Follow Every drop

Very Complex
Modeling the Water on Land?

Very Simple

Annual Volume

Annual But Divide by Land use

Separate Annual Ground Water & Surface Runoff

Daily Time Step Spatial Lumping

Short Time Step Spatially Variable

Follow Every drop

Very Complex
Closely Related... **Nutrient Movement**

- Just talked about **water movement on land**
- Next... **Nutrients Loss from Land**
  - then **Lakes & Streams**
Let’s look at Phosphorus Movement

- **Important Implications for Lakes & Streams**
- **Oligotrophic** - “few” “foods”
- **Eutrophic** – “many” “foods”

http://www.secchidipin.org/trophic_state.htm
Where is the phosphorus?

45,000 lb plant P
50,000 lb organic matter P
250,000 lbs soil P (top 6”)

\[350,000 \text{ lb P per sq mile}\]

Phosphorus

300,000 microgram P /”liter”

40 microgram P /liter
• Water Across Land = Phosphorus in the Water
Interesting Modeling Challenge

• Pathway that the water takes is important
• The soil & vegetation it contacts is important

• Higher Land Concentration--- More P
• More Surface Runoff Water – More P
Modeling P Movement

• Let’s consider two approaches
  – 1) every year the same, some adjustment for land use
  – 2) try to track the daily runoff / some characteristics of the land
Tale of Two Pathways

10 inch/year @ 0.02 mg/l < 0.01 lb/acre/year

2 inch/year @ 1 mg/l = 0.45 lb/acre/year
(+ 9 inch/yr @ 0.02 mg/l)
### "Phosphorus Export Coefficients" (pounds/acre-year)

<table>
<thead>
<tr>
<th>Category</th>
<th>Low</th>
<th>Most Likely</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture (Mixed)</td>
<td>0.3</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Med Density Urban</td>
<td>0.3</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Pasture</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Forest</td>
<td>0.05</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Atmospheric (lake surface)</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Adapted from WiLMS, Wisconsin Lake Modeling Suite
http://dnr.wi.gov/lakes/model/
Useful?

• Estimate the long term average P transfer from a watershed to the lake
  – 90,000 acres Row Crop
    • 90,000 ac*0.8 lb/ac-year = 72,000 lbs/year
  – 30,000 acres Pasture/Grass
    • 30,000 ac*0.3 lb/ac-year = 9,000 lbs/year
  – 30,000 acres Med Den Urban
    • 30,000 ac*0.5 lb/ac-year = 15,000 lbs/year
  – TOTAL = 96,000 lbs/year
Challenges: Annual Variations in P to Lake!

- P Load (lb) to Lake (Lathrop and Panuska)
More Complicated Model
Spatial Variations
Daily Rainfall
Output by Day
Varies Year to Year

- Watershed
  - 250 km²

- SWAT Model
  - 10 subbasins
  - 119 HRUs

- Calibration
  - 2 years flow / TSS / TP
  - Matched total w/ CN
  - Adjusting USLEP, Filterw
  - Tried to fit P fractions and P Content
Modeling the Land?

Annual Export Based on Land Use

Annual Volume x Average Concentration

Daily Time Step Spatial Lumping

Avg. Annual Spatially Variable

Short Time Step Spatially Variable

Follow Every drop

Very Simple

Very Complex
Part 2 - LAKES
• Important

• But what do we want to model?
  – Water level, Algal density, Fish, Phosphorus Concentration

• Complex?
Our First Model

• Goal – predict the P concentration

Given

• The amount of P entering the lake
• The amount of water entering the lake
Water Entering

Phosphorus Entering

~Mix~

Phosphorus leaving
In water
How does this calculate concentration?

Concentration of $P = C_P = \frac{\text{Mass of Phosphorus}}{\text{Volume of Water}}$
Let’s give this a try

- 10,000 acre lake
- 150,000 acre watershed

Recall our simple watershed model...
- 96,000 lb/year P
- 125,000 acre-ft/year water
“Simple Model”

• Concentration of $P$

\[ \text{= Mass of } P / \text{Volume of Water} \]

\[ \text{= 285 } \mu g/l \]
Take a look at some data

285 ug/l

Lathrop and Panuska 1998
Not a very good model

• Why?

• What happens to P in a lake?

• Another observation on modeling
  – “Everything should be made as simple as possible, but no simpler”    A. Einstein
Historical Note– 1960s... higher “Inflow P Conc” OK if you have a longer residence time

We just calculated this (inflow concentration)
“Vollenweider Plots”

Graph showing the relationship between average inflow concentration (L/Qs) and water residence time (years) for different levels of nutrient enrichment:
- **Excessive**
- **Permissible**
- **Oligotrophic**

The graph illustrates how nutrient concentration increases over time, with different curves for excessive and permissible concentrations, compared to the oligotrophic state.
L gram P per m²-yr

EUTROPHIC

PERMISSIBLE

EXCESSIVE

PHOSPHORUS LOADING (gP/m²/yr)

MEAN DEPTH $\bar{z}$ / HYDRAULIC RESIDENCE TIME, $T_w$ (m/yr)

(mean depth/water res time) = $q_s$

Mendota (22)

Camelot/Sherwood (4)

Redstone (31)
“mean total P concentration is amount of phosphorus divided by volume of water and diminished by retention term as P apparently lost to sediments” (Nurnberg, 1984)
“mean total P concentration is amount of phosphorus divided by volume of water and diminished by retention term as P apparently lost to sediments” (Nurnberg, 1984)
• Uniform ("steady-state") Conditions
  – The P concentration doesn’t change with time
  – The amount of P in the lake is constant

  – *What goes in must be equal to what goes out*

\[
P \, \text{Into Lake} = P \, \text{Flowing Out of Lake} + P \, \text{Lost To "Settling"}
\]
Uniform ("steady-state") Conditions
The P concentration doesn’t change with time
The amount of P in the lake is constant

\[ C_P = \frac{M}{Q + vA} \]

- \( C_P \): Phosphorus Concentration in Lake
- \( M \): Mass of Phosphorus per year entering lake
- \( Q \): Amount of water Entering lake in a year
- \( vA \): Settling term ("settling velocity" * Area)
Let’s give this a try

- 10,000 acre lake
- 150,000 acre watershed

Assume
- 96,000 lb/year P
- 125,000 acre-feet water/year
- 40,500,000 m² lake surface
- 10 meter/year settling velocity
Our “Less Simple Model”

• Concentration of P
  
  = 79 ug/l  (better?)

• Useful?
Annual Phosphorus Input

Simpler Models...
--completely mixed
--steady with time

Complex Models...
--segments in lake
--vary with time
--biology!

Annual Water Input

Annual Phosphorus Settling
What about this Steady-State Assumption?

• Is that an important assumption?

• What about concentrations that vary during the growing season

• What about long-term trends or large year-to-year variations?
What about the P concentration in this lake?
Lake Response Model?

Phosphorus Concentration

Algal Concentration
• Useful?
But we can make this very complex!
Lake Model with changing daily inputs and spatial variations within the lake...
Summary Discussion

- **Watershed**
  - Water Budget
  - Phosphorus Budget

- **Lake**
  - Concentrations
  - Response

- **Simple**
  - Reduce Spatial Variations
  - Long Term Averages

- **Complex**
  - Time and Space Variations
  - Daily / Yearly Variations
Questions

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A model for the phosphorus concentration in a lake

Amount of Phosphorus = \frac{\text{Amount of Water}}{325 \text{ million gallons/yr}}

80 lb Phosphorus/yr
= 80 lb/ 325 million gallons =
80 lb Phosphorus/yr

325 million gallons/year

= 80 lb/ 3 billion lbs water =
80 lb Phosphorus/yr

325 million gallons/year

= 80 lb / 3 billion lbs water = 27 ppb
Why Model?

- Groundwater flow—where water is coming from?
- Lake concentration—what if we change the amount added?
- Watershed modeling—can watershed changes help and by how much?
- In-Lake Restoration—“experiment” with treatment, diversions etc.
Land is a concentrated nutrient source

300,000 microgram /liter

40 microgram /liter
Simple Model: Assign annual transfer rate to different land uses

Complex Model: Simulate every storm, interaction with ground, conveyance to channel, transport to lake
## Phosphorus Concentration

<table>
<thead>
<tr>
<th>Phosphorus Concentration (µg/l)</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Low (Oligotrophic)</td>
</tr>
<tr>
<td>10-20</td>
<td>Medium (Mesotrophic)</td>
</tr>
<tr>
<td>Greater than 20</td>
<td>High (Eutrophic)</td>
</tr>
</tbody>
</table>
Annual Phosphorus Input

Simpler Models...
--completely mixed
--steady with time

Complex Models...
--segments in lake
--vary with time
--biology!

Annual Water Input

Annual Phosphorus Settling
Lake Response Model?

- Phosphorus Concentration
- Algal Concentration
The graph shows the Phosphorus/Algae Response Curve. The x-axis represents Chlorophyll a (% days exceeding 10 ppb), while the y-axis represents TP (µg/L). The current condition is indicated by a marker on the curve.
Application to Portage County
Modeling the Land?

Annual Volume x Average Concentration

Very Simple

Follow Every drop

Very Complex
Modeling the Land?

Annual Export Based on Land use

Annual Volume x Average Concentration

Daily Time Step Spatial Lumping

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Follow Every drop

Very Simple

Very Complex
• Groundwater Inputs (groundwater modeling)
Groundwater Flow System
Relatively Simple Lake Model

Annual Phosphorus = P-Undeveloped + P-Developed

\[ C = \frac{W}{A_S v_S + Q} \]

“Settling Factor”

Amount of Water

Portage County Model
Used Actual Lake Data to Determine Watershed Export Coefficients
Use Lake Phosphorus to Predict Lake Chlorophyll

Portage County Model
Questions
WATERSHED DELINEATION DISCUSSION
Watershed Delineation

• Topography
• Groundwater Complications
• Tools
  – WDNR Surface Water Data Viewer
  – New WDNR Tools (soon in PRESTO)
L-THIA

Long Term Hydrologic Impact Analysis (L-THIA)

LTHIA

- Basic Spreadsheet L-THIA
- LOW-IMPACT Development (CN) spreadsheet
- L-THIA GIS 2013
- Great Lakes Watershed Management Project
- L-THIA for Burns Ditch - Trail Creek (IN)
- Root River Customized Model
- Swan Creek (Ohio) Management System

Run Google Map Interface with KML download
- L-THIA in Indiana (10 meter DEM)

Click on a state or a circle
Click the search button and click on the watershed you are in to your area. Your location is sent to the database and the closest point is calculated. Import the THIA model on it

Green indicates latitude, longitude. Enter the number below, up to 87.000000 and 42.000000

The 16 N coordinates in X should be within 0.00000 and Y within 0.00000
WDNR SWDV (Surface Water Data Viewer)
Groundwater Flow System