Changes in Hydrology and Phosphorus Loading to the Great Lakes Caused by Future Climate Change

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Slow the Flow, Coastal Climate Resilience Workshop
Lansing, Michigan: October, 2018
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Eutrophication Issues in the Great Lakes

Driven by excess nutrient inputs (primarily phosphorus)

Lake Erie

Pelee Island, Lake Erie

Cladophora on Beaches
How will climate change affect P loading??

Simulated impacts of climate change on phosphorus loading to Lake Michigan

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Predicting the Effects of Climate Change

IPCC Projections

Many climate models with a range of projections, especially for precipitation.
Projected Changes in Climate for Lake Michigan Basin
Average of 8 different models for 3 future emission scenarios

Air Temperature
Notaro et al. 2011


Precipitation
Notaro et al. 2011

Δ Air Temperature (C)
Δ Precipitation (mm/yr)
Mass Balance Modeling

\[ \text{Target} = \text{Flux out} = \text{Flux in} + (\alpha_s \times \text{Sources} \times \theta_D \times \text{Delivery}) - \theta_I \times \text{Instream Decay} \]
Can this simply be incorporated into Calibrated SPARROW Model??

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient units</th>
<th>Parameter values</th>
<th>Parameter Values 2</th>
<th>Standard error</th>
<th>P value</th>
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</thead>
<tbody>
<tr>
<td>Sources</td>
<td></td>
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</tr>
<tr>
<td>Atmosphere (Total)</td>
<td>fraction</td>
<td>0.513</td>
<td>0.650</td>
<td>0.040</td>
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<tr>
<td>Point Sources (Total)</td>
<td>fraction</td>
<td>0.789</td>
<td>0.755</td>
<td>0.113</td>
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<tr>
<td>Manure (confined)</td>
<td>fraction</td>
<td>0.291</td>
<td>0.363</td>
<td>0.055</td>
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<tr>
<td>Fertilizers (farm)</td>
<td>fraction</td>
<td>0.131</td>
<td>0.142</td>
<td>0.038</td>
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<tr>
<td>Additional agricultural sources</td>
<td>kg/km²/yr</td>
<td>62.506</td>
<td>21.780</td>
<td>2.967</td>
<td>0.018</td>
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<tr>
<td>Land-to-Water Delivery</td>
<td></td>
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<tr>
<td>Drainage Density (log)</td>
<td>km/km²</td>
<td>0.134</td>
<td>0.176</td>
<td>0.057</td>
<td>0.018</td>
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<tr>
<td>Precipitation</td>
<td>mm/yr</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>Air Temperature</td>
<td>°C</td>
<td>-0.041</td>
<td>0.048</td>
<td>0.020</td>
<td>0.035</td>
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<tr>
<td>Tiles (percentage of area)</td>
<td>%</td>
<td>1.133</td>
<td>1.175</td>
<td>0.127</td>
<td>0.000</td>
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<tr>
<td>Clay (percentage of soil)</td>
<td>%</td>
<td>0.014</td>
<td>0.009</td>
<td>0.004</td>
<td>0.001</td>
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<tr>
<td>Stream and Reservoir Decay</td>
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<tr>
<td>Stream Decay (CMS &lt; 1.1)</td>
<td>m/yr</td>
<td>0.424</td>
<td>0.508</td>
<td>0.100</td>
<td>0.000</td>
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<tr>
<td>Stream Decay (1.1 &lt; CMS &lt; 2.0)</td>
<td>m/yr</td>
<td>0.233</td>
<td>0.322</td>
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<td>Reservoir Decay</td>
<td>m/yr</td>
<td>6.710</td>
<td>8.011</td>
<td>1.453</td>
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<td>RMSE</td>
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<td>0.405</td>
<td>0.418</td>
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<td>Adj R2</td>
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<td>0.953</td>
<td>0.950</td>
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<td>Yld R2</td>
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<td>0.851</td>
<td>0.841</td>
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<tr>
<td>N</td>
<td></td>
<td>708</td>
<td>708</td>
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</tbody>
</table>
Forecasting Future Nutrient Loading with Changing Climate - HydroSPARROW
Predicting Changes in Streamflow

Current PPT and Air T from downscaled GCMs

Christiansen, et al. - USGS

D. Lorenz, UW-Madison, Center for Climate Research

Current Flows
HydroSPARROW run for 24 Scenarios:
8 General Circulation Models (GCMs):
GCM3, GFDL, MIUB, MPI, MRI, CNRM, CSIRO, GISS
3 carbon emission scenarios:
B1 – Low emission; A1B - Most likely; and A2 – High emission estimate
HydroSPARROW run for 24 Scenarios: 8 General Circulation Models (GCMs):
GCM3, GFDL, MIUB, MPI, MRI, CNRM, CSIRO, GISS
3 carbon emission scenarios:
B1 – Low emission; A1B - Most likely; and A2 – High emission estimate

Figure 3. Simulated air temperature, precipitation, streamflow, and phosphorus loading for the present (1981-2000), mid-century (2046-2065) and late-21st century (2081-2100) for the entire Lake Michigan Basin.

Christiansen et al. 2014
Air Temperature
*Notaro et al. 2011*

Precipitation
*Notaro et al. 2011*

Streamflow
*Christiansen et al. 2014*

Average of 8 different models for 3 future emission scenarios
Predicted Streamflows

SPARROW

Projected P Loading

PRMS (Christiansen and others)

Decay-corrected Total P Concentrations (because of only changes in the average travel time)

** (But concentrations could change because of more intense storms with more erosion, especially in agricultural areas)
HydroSPARROW run for 24 Scenarios:
8 General Circulation Models (GCMs):
  GCM3, GFDL, MIUB, MPI, MRI, CNRM, CSIRO, GISS
3 carbon emission scenarios:
  B1 – Low emission; A1B - Most likely; and A2 – High emission estimate
HydroSPARROW run for 24 Scenarios:
8 General Circulation Models (GCMs):
GCM3, GFDL, MIUB, MPI, MRI, CNRM, CSIRO, GISS
3 carbon emission scenarios:
B1 – Low emission; A1B - Most likely; and A2 – High emission estimate

Figure 3. Simulated air temperature, precipitation, streamflow, and phosphorus loading for the present (1981-2000), mid-century (2046-2065) and late-21st century (2081-2100) for the entire Lake Michigan Basin.
Projected Changes in P Loading for the Lake Michigan Basin
(average of 8 models with 2 emission scenarios)


P Load (kg)

Δ P Load (%)

- 0.0 - 1,900
- 1,900 - 5,450
- 5,450 - 12,000
- 12,000 - 26,000
- 26,000 - 79,000
- 79,000 - 100,000
- 100,000 - 790,000

- 0.50 - 0.75 (Future Less)
- 0.75 - 0.90
- 0.90 - 0.99
- 0.99 - 1.01
- 1.001 - 1.10
- 1.101 - 1.25
- 1.251 - 2.0 (Future More)
Average Projected Changes by 2046-2065

Average of 8 models and 3 carbon emission scenarios
Drier Conditions
Projected Changes by 2046-2065

GCM – MIUB
Scenario – B1

Δ Air Temperature
Δ Precipitation
Δ Streamflow
Δ Phosphorus Loading
Wetter Conditions
Projected Changes by 2046-2065

GCM – GISS
Scenario – A2
Conclusions

1. Projected climate change in the Midwest is quite variable
   A. Air temperatures should increase 1.5 to 3.5°C by mid century depending on the model and scenario.
   B. Precipitation could change by -5% to +15%

2. Projected streamflow could change (-20% to +15%) but will increase less than precipitation due to increased evaporation.
Conclusions

3. Projected climate change may increase or decrease P loading to Lake Michigan depending on how precipitation and streamflow changes:
   A. P loading should change a little more than the streamflow changes due to changes in decay
   B. Average projected P loading from 8 models and 3 scenarios is a 3% decrease (but range from -29% to +16%) by 2050.
   C. Precipitation has to increase more than ~8% for P loading to increase.

4. Projected land use changes may increase P loading to the Great Lakes (~4 – 10%) by 2040.
   (LaBeau, Robertson, Mayer, Pijanowski, and Saad, 2014)
Changes in Hydrology and Phosphorus Loading to the Great Lakes Caused by Future Climate Change

Questions ?????

Reference:
Robertson et al., 2016, JGLR (42) 536-548.