Integrative approach for forecasting water quality and quantity within the framework of climate and land-use change in Kansas

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Outline

1. Background
2. Interdisciplinary Methodology and Concept Diagram
3. Results from EUTROMOD Modeling Study – Evaluation of empirical model for water quality prediction in Kansas
4. Propose Modeling Study – Examine detailed impacts of land-use change and climate change on water quality in Kansas watersheds
Limnologists have detected strong relationships between nutrients and agricultural land use in both Kansas and Missouri.

Sources: Jones et al. (2008); Carney (2009)
Empirical studies also show that crop type can have a distinct effect on nutrient and sediment yields.

From Turner and Rabalais, 2003 “Linking Landscape and Water Quality in the Mississippi Basin for 200 years”
Increased acreage of biofuel feedstocks (i.e. corn, sorghum, soybeans) may further complicate current Kansas water issues, such as diminishing water availability and quality.

**PREDICTION:** Extensive land-use change in Kansas will most likely occur due to economic and policy incentives to grow feedstocks for biofuel production – such as corn for ethanol.

**HYPOTHESIS:** If farmers intensify biofuel feedstock production, or bring conserved land back into production, then water use will increase and water quality degradation is likely to occur.

From 2009 Kansas Energy Report
Objective: Establish methodology to analyze the impacts of land-use change on water quality in Kansas reservoirs

Modified from:
http://wisconsinrivers.org/documents/general/POPSlinks/POPS_Sorge.pdf
Interdisciplinary methodology and conceptual connections between climate and farmers’ land-use choices pertaining to water quality.

- **Climate Projections:** IPCC-NA or NARCCAP
- **Process-based modeling:** Soil and Water Assessment Tool
- **Empirical modeling:** Phosphorus-loading and regional Chlorophyll response equations

**Climate Change**
- Weather and Climate Change
- Economic Forces
  - Fuel Prices
  - Food Prices
- Governmental Policy
  - Subsidies
- Farmer’s Land Use Choice
- Land Management Practices and Water Use

**Precipitation Patterns and Soil Erosivity**
- Changes in Non-Point Source Runoff and Erosion

**Water Quality Issues**
- Nutrient Loading
- Algal Blooms
- Recreation Impairment and Fish Kills
- Increased Sedimentation

Determined by surveys and interviews with farmers, as well as field-scale land use maps; water use determined by USGS well surveys and legal documents.
Empirical Water Quality Modeling with EUTROMOD

- Model Inputs:
  - Land-use type
  - Runoff Coefficient
  - Parameters for Universal Soil Loss Equation
  - Dissolved nutrient load and sediment-attached nutrient load per hectare
  - Lake characteristics
  - Mean Annual Precipitation

EUTROMOD Model developed by Reckhow *et al.*
Assumptions

• Single value of cropping factor in USLE was used for each land-use category
  – Row Crop: Assumes continuous corn or corn/soybean rotation with conventional tillage (0.42)

• Same dissolved nutrient concentrations were applied to all watersheds (values dependent on land-use)
  – Ex. Row crop
    • 2.9 mg N/L and 0.26 mg P/L
# Lake Characteristics

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>Maximum</th>
<th>Median</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Watershed Area (acres)</td>
<td>10170</td>
<td>3649</td>
<td>885</td>
</tr>
<tr>
<td>Lake Area (acres)</td>
<td>540</td>
<td>116</td>
<td>33</td>
</tr>
<tr>
<td>Watershed/Lake Ratio</td>
<td>65</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>Volume (Ac-Ft)</td>
<td>7684</td>
<td>1267</td>
<td>108</td>
</tr>
<tr>
<td>Mean Depth (m)</td>
<td>4.70</td>
<td>3.20</td>
<td>0.50</td>
</tr>
<tr>
<td>Years Retention Time</td>
<td>4.08</td>
<td>0.78</td>
<td>&lt; 0.10</td>
</tr>
<tr>
<td>TP - Observed Means (μg/L)</td>
<td>784.9</td>
<td>32.05</td>
<td>10</td>
</tr>
<tr>
<td>TN - Observed Means (μg/L)</td>
<td>7400</td>
<td>860.5</td>
<td>342</td>
</tr>
<tr>
<td>Chlorophyll - Observed Means (μg/L)</td>
<td>496.50</td>
<td>11.44</td>
<td>4.48</td>
</tr>
<tr>
<td>Agriculture - Row Crop</td>
<td>92.84%</td>
<td>19.75%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Pasture</td>
<td>98.43%</td>
<td>62.39%</td>
<td>2.45%</td>
</tr>
<tr>
<td>Urban</td>
<td>29.10%</td>
<td>0.08%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Feedlot</td>
<td>1.58%</td>
<td>0.02%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Natural</td>
<td>57.46%</td>
<td>6.16%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Predicted total nitrogen concentrations from EUTROMOD were used without modification

\[ TN_{in-lake} = \frac{TN_{input}}{1 + (0.459 \times HRT^{0.253} \times z^{0.218} \times TN_{input}^{0.955} \times 10^{0.0058})} \]
Predicted total nitrogen concentrations using Bachmann (1980) empirical model

Bachmann total nitrogen model:

\[ TN = \frac{L_N}{z(\alpha + \rho)} \]

Nitrogen attenuation for artificial lakes based on areal loading:

\[ \ln \alpha = -6.430 + 0.7091 \ln L_N \]

\( L_N \) = areal load /year
\( z \) = mean depth (m)
\( \alpha \) = N attenuation coefficient
\( \rho \) = flushing rate, yr\(^{-1} \)
Total phosphorus predicted with EUTROMOD before adjusting with the Canfield-Bachmann P-loading model

\[ TP_{in-lake} = \frac{TP_{input}}{1 + (10.767 \times HRT^{0.395} \times z^{0.009} \times TP_{input}^{0.821} \times 10^{0.024})} \]
Total phosphorus predictions were improved by using the Canfield-Bachmann (1980) phosphorus loading model for artificial lakes.

Canfield-Bachmann Phosphorus Loading Model:

\[ TP = \frac{0.8L_p}{z(0.0569(L_p/z)^{0.639} + \rho)} \]

- \( L_p = \) areal load/year
- \( z = \) mean depth, m
- \( 0.0569 \left( \frac{L}{z} \right)^{0.639} = \sigma \) or the P-sedimentation coefficient
- \( \rho = \) flushing rate, yr\(^{-1}\)
Chlorophyll $\alpha$ predicted in EUTROMOD, using EUTROMOD-predicted phosphorus

$$Chl\,\alpha = 10^{1.985} + 0.51 \times \log \left( \frac{TP}{10^{0.024}} \right) - 0.352 \times \log(z) + 0.234 \times \log(HRT) \times 10^{0.025}$$

\[
\log(y) = 0.19 \times \log(x) + 10.54 \\
\text{r}^2 = 0.48
\]
The best predictive model for chlorophyll $a$ was an empirically-derived equation developed by Jones et al. (2008), which relates total phosphorus (TP) to chlorophyll $a$ concentrations

$$Chl\_a_{log} = -0.59 + (1.09 \times TP_{log})$$
Lessons Learned

• EUTROMOD, and other watershed models, should be modified to represent regional differences
  – Our study suggests that by mining regional empirical models already in the literature, one can improve water quality modeling results for lakes and reservoirs
Next Step: Incorporating Process-based modeling and empirical modeling

• EUTROMOD does not adequately incorporate detailed climatic and land-use parameters and predicts long-term nutrient concentrations
• Necessary to move to process-based approach, such as SWAT, to incorporate temporal effects of climate and land-use change
• SWAT output can be combined with empirical models to predict in-lake nutrient concentrations and water quality

- SWAT Watershed Model
- Empirical Phosphorus Loading Model
- Regional Empirical Chlorophyll a Model

Calibrate with Monitoring Data
Future Modeling Study in SWAT

1. Model historical land-use and water quality for six Kansas reservoirs – calibrate and compare model outcomes with empirical data
   - El Dorado Lake
   - Clinton Lake
   - Pomona Lake
   - Perry Lake*
   - Cedar Bluff Lake*
   - Kanopolis Lake*

* Analysis of watershed land-use demonstrates an increase in corn acreage from 2006 to 2009

Watershed delineations from KARS
Example of Land-use Analysis

2006 – 2009 Land Use Data from USDA Data Gateway
2. Incorporate forecast of land-use change (as predicted from economic model in BACC: FLUD project)

3. Incorporate climate change model (details to be determined)

4. Analyze the impacts of forecasted land-use change and climate change on water quality in study watersheds
Acknowledgements

- Belinda Sturm and Val Smith for guidance
- Financial support for this research came in part from the NSF EPSCoR Project “Biofuels and Climate Change: Farmers’ Land-Use Decisions” and the NSF GK-12 Teaching Fellowship
- I would like to express my gratitude to Dr. Kenneth Reckhow and Dr. Cully Hession for providing the 1996 EUTROMOD model and the user manual to begin this research.
- Ed Carney and others at KDHE for collecting and providing hydrologic and water quality data, and land-use maps
Supplemental Slides
Climate Model

• What models and scenarios are being explored?
  – IPCC climate forecasts for North America can be used to obtain a general estimate of range of water quality variability to be expected
  – NARCCAP – downscaled models which represent added component of irrigation are still being developed
    • Use A2 SRES scenario
Land-use Decisions and Change

• Land-use Maps: USDA Crop Data Layer data from 2006- current and refining by eliminating per pixel noise (generalization) and then build on by adding irrigation status, back-filling 2001-2004 LULC data

• Surveys and Interviews for social data collection
  – 3 rounds of surveys 10,000 sent out
  – 3 rounds of interviews 256 each wave
<table>
<thead>
<tr>
<th>Model</th>
<th>Slope</th>
<th>CI Slope</th>
<th>$r^2$</th>
<th>RMSE</th>
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</thead>
<tbody>
<tr>
<td>EUTROMOD TN</td>
<td>0.57</td>
<td>0.45-0.68</td>
<td>0.81</td>
<td>820</td>
</tr>
<tr>
<td>Bachmann TN</td>
<td>0.89</td>
<td>0.70 – 1.08</td>
<td>0.78</td>
<td>1556</td>
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<tr>
<td>EUTROMOD TP</td>
<td>0.48</td>
<td>0.36-0.59</td>
<td>0.72</td>
<td>91</td>
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<tr>
<td>Canfield-Bachmann TP</td>
<td>0.69</td>
<td>0.52-0.86</td>
<td>0.72</td>
<td>119</td>
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<tr>
<td>EUTROMOD Chl $a$ (EUTROMOD TP input)</td>
<td>0.19</td>
<td>0.11-0.27</td>
<td>0.48</td>
<td>96</td>
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<tr>
<td>Dodds et al Chl $a$ (EUTROMOD TP input)</td>
<td>0.38</td>
<td>0.28-0.48</td>
<td>0.70</td>
<td>76</td>
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<td>Dodds et al Chl $a$ (Canfield-Bachmann TP input)</td>
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<td>0.39-0.69</td>
<td>0.67</td>
<td>61</td>
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<td>Jones et al Chl $a$ (EUTROMOD TP input)</td>
<td>0.43</td>
<td>0.32-0.55</td>
<td>0.70</td>
<td>67</td>
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<td>Jones et al Chl $a$ (Canfield-Bachmann TP input)</td>
<td>0.61</td>
<td>0.44-0.79</td>
<td>0.67</td>
<td>55</td>
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