Nutrient Runoff Reduction via Nutrient Reduction Wetlands in an Agricultural Setting – a GIS Model

• OWEA
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Iowa Conservation Reserve Enhancement Program (CREP) Wetland
Problem Statement – Excess Nutrients

Nutrients in small amounts are essential, but excess nutrients lead to water quality and human health related issues:

– Shifts toward pollution tolerant aquatic species
– HAB outbreaks
– Drinking water advisories due to elevated nitrates
– Gulf of Mexico hypoxia
– P causes the HABs, NO₃-N makes them more severe
Project Goals

• Identify a model that is accessible to a wide array of stakeholders

• Use readily available data sets/software

• Recognize that some technical expertise will be required

• Not limited to the preparation of TMDL

• Cost-effective but high degree of confidence in results
Iowa State University
GIS Mass Balance Model

Using wetlands for water quality improvement in agricultural watersheds; the importance of a watershed scale approach

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Abstract Agricultural applications of fertilizers and pesticides have increased dramatically since the middle 1960s, and agrochemical contamination of surface and groundwater has become a serious environmental concern. Since the mid-1960s, a variety of state and federal programs have been used to promote wetland restoration, and these continuing efforts provide a unique opportunity for water quality improvement in agricultural watersheds. However, wetland restorations have been motivated primarily by concern over waterfowl habitat loss, and model simulations suggest that commonly used site selection criteria for wetland restorations may be inadequate for water quality purposes. This does not lessen the promise of wetlands for water quality improvement in agricultural watersheds, but rather emphasizes the need for watershed scale approaches to wetland string and design. Water quality is best viewed from a watershed perspective, and watershed scale endpoints should be explicitly considered in site selection for wetland restoration.

Keywords Nitrate, water quality, wetland restoration

Introduction
Agricultural applications of fertilizers and pesticides have increased dramatically since the mid-1960s, and agrochemical contamination of surface and groundwater has become a pressing environmental problem. Nitrogen (N) and pesticides are of foremost concern because of their potential impacts on both public health and ecosystem function, and because of the widespread use of N and pesticides in modern agriculture. The total amount of N applied in fertilizers far exceeds that of any other nutrient, and annual application of fertilizer-N in the U.S. has grown from a negligible amount prior to World War II to over ten million metric tons of N per year (Terry and Kirby, 1997). As much as 50% of the fertilizer-N applied to cultivated crops may be lost in agricultural drainage water, primarily in the form of nitrate (Neely and Baker, 1989). The environmental impacts of agriculture

- Dr. William Crumpton
- Focus on NO₃-N
- Funded thru Iowa CREP
- Simple mass-balance model
- Watershed scale
- Several years of field verified monitoring data
Iowa State University
GIS Mass Balance Model

• Proper fertilizer management is important but insufficient to fix problem due to sheer volume being applied

• NO$_3$-N and P bypass riparian zones in heavily tiled areas

• Most wetland restoration projects are not strategically placed to intercept nutrient loading hot spots
GIS Model Development

Software Requirements

– ArcGIS 10.0

– ArcHydro tools

– Microsoft Excel 2010
GIS Model Development

Datasets

• Lidar data from Ohio Statewide Imagery Program (OSIP)

• National Land Cover Dataset (NLCD 2006)

• StreamStats for Ohio

• USGS long term gage data from nearby watersheds

• Nutrient concentrations from literature (Lin, 2004)
  – Supplement with Ohio EPA data
Key Model Parameters

• Land use

• Nutrient concentrations based on land use

• Discharge

• Flow Weighted Average (FWA) concentration

• Wetland area and watershed area (ha)

• Hydraulic loading rate

• Nutrient removal efficiencies used in model
  – NO$_3$-N – Crumpton equation from Iowa
  – P removal efficiency rate (CWP, 2008)
# Center for Watershed Protection, 2008

## Table 1: Range of Reported Removal Rates for Constructed Wetlands

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Low End</th>
<th>Median</th>
<th>High End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>45</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>15</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td>Soluble Phosphorus</td>
<td>5</td>
<td>25</td>
<td>55</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>0</td>
<td>25</td>
<td>55</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>0</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>Total Zinc</td>
<td>30</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>Total Copper</td>
<td>20</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Bacteria</td>
<td>40</td>
<td>60</td>
<td>85</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>50</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Chloride</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trash/Debris</td>
<td>75</td>
<td>90</td>
<td>95</td>
</tr>
</tbody>
</table>

See Appendix D for data sources and assumptions used to derive these removal rates. Low End and High End are the 25th and 75th quartiles.
NO$_3$-N Removal

Iowa State University Equation:

- $10.3 \times \text{(Hydraulic Loading Rate)}^{0.67} \times \text{(Flow Weighted Average)}$

where

- $\text{HLR} =$ annual discharge /wetland area (m/yr$^1$)
- (How much water is entering the wetland)

- $\text{FWA} =$ the total load to the wetland for the time period divided by the total discharge to the wetland for the time period (eg. g/m$^3$)
- (Divide the load (mass) by the volume of water going to the wetland)
Model Steps

1. Define target watershed
2. Determine land cover in target watershed (NLCD, 2006)
3. Convert land cover classification into a nutrient concentration grid (g/m$^3$)
4. Calculate discharge at a given point(s)
5. Calculate the HLR and FWA
6. Identify nutrient loading “hotspots”
7. Identify potential NRW locations based on siting criteria
GIS Model

1. **nld3mrs**
   - Converts land classification to nutrient concentration grid

2. **Lookup (2)**
   - Nitrates concentration grid (g/m²)

3. **Flow Accumulation (2)**
   - Creates raster of accumulated flow into each cell. A weigh factor (nitrate concentration) is applied.

4. **wghfac_rev**
   - Water flow direction grid

5. **fdr (2)**
   - Raster of accumulated cell flow weighted by nitrate concentration into each cell - accumulated nutrient

6. **wghfac (2)**
   - Raster of accumulated cell flow weighted by nitrate concentration into each cell - accumulated nutrient

7. **(2) Raster Calculator**
   - Accumulative nutrient mass (g) per area

8. **wghfacYd**
   - Accumulative nutrient mass (kg) per area

9. **Raster Calculator (4)**
   - Annual watershed yield/number of cells in watershed

10. **mgtokg_rev**
Step 1: Watershed Selection
Riley Creek – Study HUC 12
Step 2: Identify Land Use
Step 3: Calculate Nutrient Concentrations

- Nutrient concentrations for TP and NO$_3$-N derived from published values (Lin, 2004)

- In the absence of specific regional data or sampling – use published values

- Benefit of the model – allows flexibility in use of data sources
## Nutrient Concentrations - Upper Riley Creek

(kg/ha/yr$^1$)

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Landuse</th>
<th>NO$_3$</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Riley Creek</td>
<td>Developed, Open Space</td>
<td>0.80</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Developed, Low Intensity</td>
<td>1.72</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Developed, Medium Intensity</td>
<td>1.72</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Barren Land (Rock/Sand/Clay)</td>
<td>0.25</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Deciduous Forest</td>
<td>0.53</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Evergreen Forest</td>
<td>0.53</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Grassland/Herbaceous</td>
<td>0.80</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Pasture/Hay</td>
<td>1.90</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Cultivated Crops</td>
<td>7.94</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Emergent Herbaceous Wetlands</td>
<td>0.34</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Step 4: Calculate Annual Discharge
Step 5: Accumulative Nutrient Mass
Step 6: NRW Siting Criteria

• Contributing upstream drainage is between 500 to 2,000 acres of tile drained ag land
  – < 500 acres too small to make an impact
  – > 2,000 acres result in large wetlands
    • Require more area than landowner is willing to concede
      – 2.2% of 2,000 acres = 44 acres
    • More costly to construct

• NRW area generally compose between 0.6 to 2.2% of the contributing drainage area
  – 0.5 % to 2.0% for Iowa
Step 6: NRW Siting Criteria

• Hydric soils or hydric inclusions

• Drainage must exhibit limited potential to attain CWA goals of WWH or better

• Ohio EPA does not endorse damming of streams or activities that will result in violations of state WQS

• Avoid anthropogenic constraints
  – Roads
  – Homes and structures
  – Utilities
  – Tile mains or laterals
Construction Related Details

• Install forebays for phosphorus removal

• Plant wetland vegetation or allow wetland to revegetate naturally
  – Common plant species include cattails, bulrush, sedges, arrowhead

• Max depth 0.9 meters (Tomer et al, 2013)

• Berm across drainageway
Example of a Berm
Model Different Sized NRWs

- 0.5 %, 1.0 %, 1.5%, 2.0%, 2.5% of the DA

- NRWs located in the maximum number of areas that fit criteria, goal to have only one NRW/stream

- Remove NRWs one-by-one then rerun the model to determine impact of each individual NRW
Step 6: Upper Riley Creek
Potential NRW Locations
Step 6: Upper Riley Creek
NRW No 7 Contributing DA

Wetland area = 19.8 acres
Watershed area = 820 acres
Wetland to Watershed = ~2.4%
Upper Riley Creek Results

• N\textsubscript{03}-N Removal
  – 33.37% - 44.28%
  – 1,396.4 kg/yr - 3,172.58 kg/yr

• TP Removal
  – 50%
    • 81.32 kg/yr - 603.86 kg/yr
  – 75%
    • 121.98 kg/yr - 905.78 kg/yr
Upper Riley Creek – NRW 7

• Sediment P Removed
  – Loading – 375.2 kg/yr¹
  – 50% efficiency - 187.6 kg/yr¹
  – 75% efficiency – 281.4 kg/yr¹

• NO₃ – N
  – Loading – 7,165.51 kg/yr¹
  – Removed - 3,172 kg/yr¹
  – 44% removal efficiency
NRW 7

Wetland area vs. total watershed area and corresponding nutrient reduction for the most efficient set of wetlands for each watershed
Iowa CREP Wetlands
Nitrate Reduction Efficiency as a Function of Wetland:Watershed Ratio
Percent Nitrate-N Removal Efficiency as a Function of HLR
GIS Model Advantages

• Simple model using readily available software and datasets

• Model is highly flexible
  – Scalable to the whichever size watershed you want to study
  – Can use published values or more detailed data if available (nutrient, application rates, hydrology...)
  – Can easily manipulate the location/size of NRWs
Conclusions

• Need to reduce P loadings to Lake Erie by 40% to have a significant positive impact on HABs.

• Relatively small acreages (< 3% of watershed) of strategically sited NRWs can reduce nitrogen loadings by 25-40%.

• Literature search indicated up to 50%+ P removal is possible.
NRWs

• Term NRW adopted strictly for this report

• NRWs are more appropriately considered a type of BMP

• Differentiate NRWs from wetlands restored for functions such as ecological condition

• NRWs are *only one of many* tools in the tool box
What is the most effective scale to address water quality? How do we avoid tradeoffs among pollutants? How does it depend on the ecoregion? How do we convince landowners to look at their individual fields in a larger environmental context?
Potential Future Actions

• Additional research on wetland construction/design details
  – (hydrology, pulses, plants, wetland shape, length/width ratio)

• Modeling effort for NW Ohio watersheds to determine acreage to achieve loading reduction goals for Lake Erie

• Outreach effort to county SWCD and NRCS offices

• Identify funding for demonstration projects
Link to the Report

www.epa.state.oh.us/Portals/35/wetlands/STSGISpaperPICrev_FINAL_20160115.pdf
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