NUTRIENT RUNOFF REDUCTION VIA NUTRIENT REDUCTION WETLANDS IN AN AGRICULTURAL SETTING – A GIS MODEL

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Thanks to the ASWM

CREP Wetland from Iowa
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
Harmful Algal Blooms
Lake Erie HABs
Gulf of Mexico Hypoxic Zone
Nutrient Reductions Efforts

• State of Ohio Nutrient Task Force
  • Ohio EPA, Department of Agriculture, Dept. Natural Resources and other public / private stakeholders

• Recommendations include:
  
  • 4 Rs
    • Right source
    • Right rate
    • Right time
    • Right place

  • Structural BMPs
    • Wiers
    • End of tile and in-stream systems
    • Enhanced ditch design
Nutrient Reduction Efforts

- Water Pollution Control Loan Fund (Ohio’s SRF program)
  - Nutrient Reduction Discount of $100 million made available at 0% interest for eligible projects/equipment at POTWs financed thru the WPCLF
  - $13,300,000 in principle forgiveness for qualifying home sewage treatment system repair or replacement
- Western Lake Erie Basin Ag BMPs Linked Deposit Program
  - County SWCD and OEPA enter into MOU

Wetlands and TMDLs

• Original scope of this project was to integrate wetland condition assessment into the TMDL process that is currently focused on streams

• Create a report card of wetlands within a study watershed

• http://www.epa.state.oh.us/Portals/35/401/N134_Final_Report.pdf
Wetlands and TMDLs

- TMDL required for impaired water bodies - 303(d) list

- TMDL report includes recommended actions to achieve compliance with WQS

- Team decided to examine whether inclusion of wetland restoration could be a tool to achieve water quality standards in nutrient impaired agricultural watersheds

- TMDL was being developed for the middle Scioto River watershed – focus on HUC 12 exhibiting nutrient impairments
Ohio EPA 12 Step TMDL Process

Overview of the TMDL Project Process

Numbers on chart correspond to detailed task lists contained in Appendix B

1. Design Watershed Survey
   - Examine internal information
   - Examine external information
   - Complete study plan design

2. Collect Water Quality Data
   - Collect and compile ambient data (internal) for waterbody assessment
   - Evaluate Ambient data (external)

3. Assess Waterbodies
   - Determine impairments by designated use
   - Determine causes and sources of impairments or threats
   - Complete TMDL support documents

4. Identify Target Conditions
   - Examine rapidly available data
   - Gather additional data as needed
   - Analyze data
   - Define goals
   - Select causes of concern
   - Identify and isolate sources of causes
   - Determine geographic scope
   - Identify stakeholder involvement

5. Develop Restoration Targets
   - Decide on calculation method
   - Determine existing load
   - Determine desired load
   - Identify needed reduction
   - Generate example restoration scenarios
   - Decide how Ohio EPA authority will be used

6. Select Restoration Scenario
   - Discuss scenarios with stakeholders; generate other options
   - Develop decision criteria
   - Screen scenarios to select best option
   - Verify that scenario achieves reduction
   - Finalize allocations

7. Prepare Implementation Plan
   - Describe actions
   - Develop schedule
   - Identify legal authorities
   - Develop list of reasonable assurances
   - Estimate time to attain WQSP
   - Develop monitoring plan
   - Establish measurable milestones
   - Decide closure/reopen process

8. Submit TMDL Report
   - Prepare TMDL report
   - Certify EPA legal and management review
   - Public notice, meeting(s), respond to comments
   - Receive report as needed
   - Ohio EPA management review and signoff
   - Submit report to U.S. EPA

9. Implement TMDL (outside CEPA)
   - Identify implementing parties
   - Verify implementing parties willingness to proceed
   - Validate control actions implemented
   - Validate water quality status or re-open TMDL

10. Implement TMDL (inside CEPA)
    - Adjust work plans
    - Do the work
    - Incorporate implementation plans into other agency priorities

11. Annul Validation Activities
    - Validate wastewater reduction
    - Validate control actions
    - Evaluate effectiveness of technical decisions made on project

12. Have WQSP Been Achieved?
    - Continue monitoring
    - Reassess implementation
    - Validate water quality status or re-open TMDL
    - Adjust work plans
    - Do the work
    - Incorporate implementation plans into other agency priorities

Continuous assessment of process

Quality Improvement Process
Wetlands and TMDLs

- Discussed approach with Ohio EPA staff and external stakeholders

- TMDL will obtain high quality data, but lengthy process

- Transitioned to a more flexible model that could be developed for any watershed independent of the TMDL process
Wetlands and Nutrients

- Conducted a literature search of previous wetland nutrient removal studies

- No shortage of studies, but no consistency in the literature
  - Inconsistent descriptions of wetland restoration site
  - Inconsistent descriptions of contributing watershed and land use
  - Inconsistent monitoring protocols
  - Inconsistent methods of data collect and reporting results

- Not a criticism of previous studies – just difficult to compare them side-by-side
Wetlands and Nutrients

• Direct restoration of wetlands was not being promoted as means to control nutrients
  • Misperceptions about acreage required
  • Cultural biases
  • Concerns regarding regulation and farming activities
• Most wetland projects predicated on ecological condition or other functions such as wildlife (hunting)
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 be limited by preparation of TMDL

• Cost-effective but high degree of confidence in results
Models Explored

- Generalized Watershed Loading Function Model
- Agricultural Non-Point Source Pollution Model (ANN-AGNPS)
- Soil Water Assessment Tool (SWAT)
  - Above models very data intensive, require validation and calibration
- Open N-SPECT
  - (Non-Point Source and Erosion Control Tool)
  - Calibrated for coastal areas with different ET regimes
Using wetlands for water quality improvement in agricultural watersheds; the importance of a watershed scale approach

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Department of Botany, Iowa State University, Ames, IA 50011, USA

Abstract Agricultural applications of fertilizers and pesticides have increased dramatically since the mid-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 wetland 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 siting 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...
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 tiles areas

- Most wetland restoration projects are not strategically placed to intercept nutrient loading hot spots
“Nutrient Reduction Wetland” (NRW)

• Term does not appear in the Iowa method

• Term we adopted for this report

• Felt it was necessary to differentiate from wetlands restored to enhance other functions such as ecological condition
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
  • 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
- Annual discharge
- Nutrient concentrations based on land use
- Flow Weighted Average (FWA) concentration
- Wetland and watershed area (ha)
- Hydraulic loading
- Nutrient removal efficiencies used in model
  - $\text{NO}_3$-N – Crumpton equation from Iowa
  - P removal efficiency rate (CWP, 2008)
Phosphorus Removal

• P is removed through:
  • Binding to sedimentation
  • Biological uptake

• Reported removal rates for P vary in the literature

• We used data from the CWP (Cappiella, 2008)

• Wetlands can actually be sources of P
### 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>
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</thead>
<tbody>
<tr>
<td>Total Suspended Solids</td>
<td>45</td>
<td>70</td>
<td>85</td>
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<tr>
<td>Total Phosphorus</td>
<td>15</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td>Soluble Phosphorus</td>
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<tr>
<td>Total Nitrogen</td>
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<tr>
<td>Organic Carbon</td>
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<td>45</td>
</tr>
<tr>
<td>Total Zinc</td>
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<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>
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<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 25<sup>th</sup> and 75<sup>th</sup> quartiles.
NO$_3$-N Removal

- Nitrate is removed thru microbial mediated denitrification
- Need residency time in the wetland
NO$_3$-N Removal

• Iowa State University Equation:

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

  • where

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

  • 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)
Identify Nutrient Loading Hot Spots

1. Define study watershed
2. Determine land use in target watershed
3. Identify potential NRW locations based on siting criteria
3. Calculate nutrient concentrations based on land use
4. Calculate discharge
5. Calculate the flow weighted average
5. Select best NRWs based on nutrient loading “hotspots” and wetland/watershed ratios

NRW location flexible based on constraints
GIS Model

- Land cover grid (NLCD 2006)
- Convert land classification into nutrient concentration grid
- Nutrient concentration grid (g/m³)
- Mass of nutrient per cell (g)
- Nutrient mass per area (g/m²) X area per cell (m²)
- Nutrient mass per area (g/m²)
- Nutrient concentration (g/m³) X water yield (m)
- Flow accumulation of cells
- Accumulative nutrient mass (g)
- Accumulative nutrient mass (g)/watershed area (m)
- Accumulative nutrient mass per area
Watershed Selection

- Working on TMDL for Middle Scioto River basin at the time the project was initiated

- HUC 12 watersheds identified as impaired for nutrients
  - Treacle Creek – West Columbus/Franklin and Union counties (Ohio River basin)
  - Indian Run – northwest of Columbus/Champaign and Union counties (Ohio River basin)
  - Upper Riley Creek – NW Ohio Hancock County (Lake Erie basin)
Watershed Selection
Watershed Selection
## Land Cover

Land cover for the respective watersheds extracted from the 2006 NLDC (Fry, 2011)

<table>
<thead>
<tr>
<th>Land Cover Category</th>
<th>Upper Riley Creek</th>
<th>Indian Run (Headwaters)</th>
<th>Treacle Creek (Headwaters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ha)</td>
<td>% of Total Land Cover</td>
<td>Area (ha)</td>
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<tr>
<td>Open Water</td>
<td>2.39</td>
<td>0.66</td>
<td>18.92</td>
</tr>
<tr>
<td>Developed, Open Space</td>
<td>227.36</td>
<td>6.289</td>
<td>940.94</td>
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<td>Developed, Low Intensity</td>
<td>30.89</td>
<td>0.854</td>
<td>994.22</td>
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<td>Developed, Medium Intensity</td>
<td>17.01</td>
<td>0.470</td>
<td>370.42</td>
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<tr>
<td>Developed, High Intensity</td>
<td>0.0</td>
<td>0.0</td>
<td>85.27</td>
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<tr>
<td>Barren Land (Rock/Sand/Clay)</td>
<td>1.92</td>
<td>0.053</td>
<td>3.68</td>
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<tr>
<td>Deciduous Forest</td>
<td>372.58</td>
<td>10.307</td>
<td>173.63</td>
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<tr>
<td>Evergreen Forest</td>
<td>1.39</td>
<td>0.039</td>
<td>3.42</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>56.96</td>
<td>1.576</td>
<td>39.79</td>
</tr>
<tr>
<td>Hay/Pasture</td>
<td>33.06</td>
<td>0.915</td>
<td>245.91</td>
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<tr>
<td>Cultivated Crops</td>
<td>2870.90</td>
<td>79.418</td>
<td>1564.41</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetlands</td>
<td>0.48</td>
<td>0.013</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>3614.94</td>
<td>100.00</td>
<td>4440.61</td>
</tr>
</tbody>
</table>
Calculate Nutrient Concentrations

- Nutrient concentrations for TP and NO$_3$ 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 source
# Nutrient Concentrations – Indian Run

(kg/ha/yr\(^1\))

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Landuse</th>
<th>NO(_3)</th>
<th>TP</th>
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</thead>
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<tr>
<td>Indian Run</td>
<td>Open Water</td>
<td>0.00</td>
<td>0.00</td>
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<td>Developed, Open Space</td>
<td>0.80</td>
<td>0.10</td>
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<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>0.30</td>
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<tr>
<td></td>
<td>Developed, High Intensity</td>
<td>0.25</td>
<td>0.49</td>
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<td></td>
<td>Barren Land (Rock/Sand/Clay)</td>
<td>0.25</td>
<td>0.08</td>
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<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>0.40</td>
</tr>
<tr>
<td></td>
<td>Cultivated Crops</td>
<td>7.94</td>
<td>0.40</td>
</tr>
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</table>
## Nutrient Concentrations – Treacle Creek
*(kg/ha/yr)*

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Landuse</th>
<th>NO&lt;sub&gt;3&lt;/sub&gt;</th>
<th>TP</th>
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<tbody>
<tr>
<td>Treacle Creek</td>
<td>Developed, Open Space</td>
<td>0.80</td>
<td>0.10</td>
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<tr>
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<td>1.72</td>
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<td>Barren Land (Rock/Sand/Clay)</td>
<td>0.25</td>
<td>0.08</td>
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<tr>
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<td>Deciduous Forest</td>
<td>0.53</td>
<td>0.15</td>
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<td></td>
<td>Evergreen Forest</td>
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<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Grassland/Herbaceous</td>
<td>0.80</td>
<td>0.15</td>
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<tr>
<td></td>
<td>Pasture/Hay</td>
<td>1.90</td>
<td>0.40</td>
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<td></td>
<td>Cultivated Crops</td>
<td>7.94</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Emergent Herbaceous Wetlands</td>
<td>0.34</td>
<td>0.20</td>
</tr>
</tbody>
</table>
## 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>
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<td>Developed, Open Space</td>
<td>0.80</td>
<td>0.1</td>
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<td>Developed, Low Intensity</td>
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<td>Barren Land (Rock/Sand/Clay)</td>
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<td>0.08</td>
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<td></td>
<td>Deciduous Forest</td>
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<td>0.15</td>
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<td></td>
<td>Evergreen Forest</td>
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<td>0.15</td>
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<td>Emergent Herbaceous Wetlands</td>
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<td>0.2</td>
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</table>
Calculate Annual Discharge
Accumulative Nutrient Mass

85490 kg NO3 yr⁻¹

83999 kg NO3 yr⁻¹
Portion of the Excel Spreadsheet
NRW Siting Criteria

• NRW located in small drainages in agricultural land use as determined by aerial imagery

• Assumption that agricultural land use upstream of NRW is tile drained ag land

• Hydric soils or hydric soil inclusions
NRW Siting Criteria

- Contributing upstream drainage is between 500 to 2,000 acres of tile drained ag land
  - < 500 acres to 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 should compose between 0.6 to 2.2% of the contributing drainage area
  - 0.5 % to 2.0% for Iowa
NRW Siting Criteria

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

- OEPA does not endorse damming of streams or activities that will result in violations of state WQS

- Avoid constraints
  - Roads
  - Homes and structures
  - Utilities
  - Tile mains or laterals
Construction Related Details

• Install forebays for phosphorus removal

• Allow to revegetate naturally or plant
  • Common plant species include cattails, bulrush, sedges, arrowhead

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

• Berm across drainage
Example of a Forebay (CWP, 2008)
Example of a Berm
Buffers

• For the CREP - easement boundaries are negotiated with landowners to accommodate farming operations and address technical requirements

• Buffers are typically seeded consisting of grasses and forbs

• Wildlife benefit from the high quality buffer
Siting NRWs

- Varied the size of the NRWs for the study
- 0.5 %, 1.0 %, 1.5%, 2.0%, 2.5% of the DA
Riley Creek – Study HUC 10
Riley Creek- Study HUC 12 in Red
Riley Run – High Res Aerial Imagery
Upper Riley Creek – Potential NRW locations
Upper Riley Creek – NRW No 7
Contributing DA

- Wetland area = 19.8 acres
- Watershed area = 820 acres
- Wetland to Watershed = ~2.4%
Riley Creek – Location of NRW 7
Iowa CREP Wetlands
Results for Upper Riley Creek
Upper Riley Creek – TP Removal

<table>
<thead>
<tr>
<th>Riley Creek Nutrient Reduction Wetland (NRW)</th>
<th>Upstream Total P load pre-NRW (kg/year)</th>
<th>Total P load removal by NRW (kg/year) at 50% efficiency</th>
<th>Total P load remaining after NRW wetland, at 50% efficiency</th>
<th>Total P load removal by NRW (kg/year) at 75% efficiency</th>
<th>Total P load remaining after NRW wetland, at 75% efficiency</th>
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<td>1</td>
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<td>80.73</td>
<td>80.73</td>
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# Upper Riley Creek – NO$_3$- N Removal

<table>
<thead>
<tr>
<th>Riley Creek Nutrient Reduction Wetland (NRW)</th>
<th>Nutrient Reduction Wetland area (ha)</th>
<th>Watershed area draining to NRW (ha)</th>
<th>NRW area, as % of upstream watershed</th>
<th>NO$_3$ removed by wetland (kg/year) {column O}</th>
<th>NO$_3$ removal efficiency (%)</th>
<th>Hydraulic Loading Rate (meters/year)</th>
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Upper Riley Creek – NRW 7

- Sediment P Removed
  - Loading – 375.2 kg/yr$^1$
  - 50% efficiency - 187.6 kg/yr$^1$
  - 75% efficiency – 281.4 kg/yr$^1$

- NO$_3$ – N
  - Loading – 7,165.51 kg/yr$^1$
  - Removed - 3,172 kg/yr$^1$
  - 44% Removal Efficiency
% TP Removal

- Wetland area vs. total watershed area and corresponding phosphorous reduction for the most efficient set of wetlands for each watershed
Nitrate Reduction Efficiency as a function of wetland:watershed ratio
Percent nitrate-N removal efficiency as a function of HLR
• Wetland area vs. total watershed area and corresponding nitrate reduction for most efficient set of wetlands for each watershed
More Iowa CREP Wetlands
Ramifications

- Major sources of nutrients to western Lake Erie Basin
  - Detroit River from Michigan
  - NW Ohio tributaries Maumee River, Portage River, Sandusky River

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

- Reduction on NO$_3$-N loading may reduce severity of HAB outbreak

- Nutrient reductions wetlands located in NW Ohio can help achieve this goal
Western Lake Erie Basin

A comparison of phosphorus concentrations among Lake Erie tributaries

- **Detroit River**
  - Flow WT. P conc., mg/L
  - TP = 0.013 – 0.019
  - DRP = 0.006
  - 2004-5

- **River Raisin (01-07)**
  - Flow WT. P conc., mg/L
  - TP = 0.198
  - DRP = 0.043
  - 2001-07

- **Maumee River**
  - Flow WT. P conc., mg/L
  - TP = 0.381
  - DRP = 0.093
  - 2001-08

- **Sandusky River**
  - Flow WT. P conc., mg/L
  - TP = 0.395
  - DRP = 0.089
  - 2001-08

- **Cuyahoga River**
  - Flow WT. P conc., mg/L
  - TP = 0.293
  - DRP = 0.043

- **Grand River (OH)**
  - Flow WT. P conc., mg/L
  - TP = 0.129
  - DRP = 0.015
  - 2001-06

Rivers monitored by the Heidelberg NCWQR
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
  Can easily manipulate the location/size of NRWs
Conclusions

- Relatively small acreages (< 3% of watershed) of strategically sited wetlands restoration can significantly reduce nutrient loadings

- Targeted wetland function is nutrient reduction, not ecological condition, but other functions are still present

- NRWs have the potential to reduce nitrogen loadings by 25-40%

- Literature search indicated up to 50%+ P removal is possible

- NRWs are more appropriately considered a type of BMP

- NRWs are only one of many tools in the tool box
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

http://www.epa.state.oh.us/Portals/35/wetlands/STSGISpaperPI Crev_FINAL_20160115.pdf
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