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

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

Bill Schumacher, Tom Harcarik, Eric Saas

Abstract

Excessive nutrients are a serious problem in Ohio. Restored wetlands in agricultural settings and Nutrient Reduction Wetlands (NRW) that intercept tile flow hold promise as a Best Management Practice (BMP) that can assist in alleviating this problem. A relatively simple GIS mass balance model was used in order to project the effect on nutrient loadings from NRWs in several small watersheds in northwest and central Ohio. It is a relatively simple model which can be used to determine how NRWs could be placed within watersheds and to estimate how much nitrate (NO_3) and Phosphorus (P) could be removed from the annual discharge by the NRWs. Key inputs include land use data, annual stream flow, nutrient concentrations associated with different land uses, and LIDAR data. Aspects of the GIS tool are discussed, as well as the results of running it in the above mentioned watersheds. Nitrate and Phosphorus loads were reduced by over 40 percent and 45 percent respectively, with about 1.75 percent of the watershed used for NRWs in one watershed. The GIS model is dynamic; it can be made more precise with localized knowledge and can be used to explore how nutrient loads would change with different land use scenarios. However, it is noted that several aspects of a supportive framework need to be in place before widespread implementation of NRWs can take place. These include items such as a comprehensive nutrient strategy that is accepted by major stakeholders within the state, sources of funding that can be used to help assist interested landowners, and an acceptance of NRWs as compatible with an agricultural landscape and other uses by landowners.

Introduction

Nutrient enrichment is a commonly cited cause of impairments of water bodies (Ohio EPA, 2012). The macronutrients, nitrogen (N) and phosphorous (P), adversely affect freshwater, oceanic and wetland ecosystems due to downhill flow to low-lying areas of the landscape. The use of fertilizers has increased dramatically since the mid-1960s (Crumpton, 2001). Nutrient discharges from the agricultural Midwest have been implicated in numerous water quality issues (Kovacic, 2000). The Gulf of Mexico is experiencing severe hypoxia, or low oxygen conditions, which is caused, in part, by excess loadings of nitrogen and phosphorus. These excess nutrients promote algae growth which, upon their death and decomposition, consumes oxygen (Bianchi, 2010; U.S. EPA, 2007). In addition, many inland lakes in Ohio have experienced harmful algal blooms (HABs) in recent years, some severe enough to cause state agencies to recommend against human contact with the affected water body. Excess phosphorus loading has been implicated as a cause of these HABs (Anderson et al., 2002; Jones, 2012; Reutter, 2011). Ohio, especially western Ohio, exports very high levels of nitrate to the Gulf of Mexico and Lake Erie. A high amount of P is also exported to Lake Erie and other lakes in Ohio, as well as to the Gulf of Mexico. The high amount of nitrate, and, to a lesser extent P, contributes to the Upper Midwest region's input to the Gulf of Mexico hypoxia crisis. The high amount of P contributes, along with high N (nitrate), to stressed aquatic ecosystems in Ohio. High nutrient levels are largely responsible for large algal mats that can produce toxins and low oxygen levels that deteriorate water quality and adversely impact aquatic organisms.

Ohio EPA's Nutrient Strategy also calls for numerous nutrient management and mitigation strategies including the "4Rs" of fertilizer management (right fertilizer source, right rate, right time and right place); structural hydrologic controls; filtration, such as end of tile and in-stream treatment systems; edge of field buffers and wetlands; and, enhanced agricultural ditch design and management (OEPA, 2012).

So far, wetlands as a BMP to reduce nutrient input to aquatic systems have received little attention in Ohio, even though they have shown promise to counter the adverse effects of excess nutrient loading (Crumpton, 2001, 2006, 2012; Woltemade, 2000). Although there have been numerous BMPs implemented, treatment wetlands in agricultural areas have not been widely implemented. This is perhaps due to a number of concerns including taking land out of production and small watershed areas per treatment wetland which necessitates a considerable number of wetlands to have a significant effect on the amount of nutrients removed. Also, there is likely a cultural bias against wetlands. Society, landowners and agricultural interests have spent a large amount of time and labor ridding the land of wetlands over the years and it seems counter-intuitive to add water back to the landscape (Keddy, 2012).

Restored wetlands in agricultural settings – or Nutrient Reduction Wetlands (NRWs) - have been more extensively studied in other Midwestern areas. Iowa's Conservation Reserve Enhancement Program (CREP) program has used an approach that places NRWs in headwater areas of agricultural regions, where tile flow with high N and P concentrations, is interrupted (Crumpton, 2006, 2012, May 2012). In these wetlands N (nitrate) and P concentrations are reduced, resulting in lower concentrations of nutrients flowing into waterways and eventually to lakes and oceans. A brief description of Iowa's wetland CREP program is quoted below (Iowa Department of Agriculture, 2014)

CREP is a major state/federal initiative to develop wetlands which are strategically located using advanced computer technology and designed to remove nitrate from tile-drainage water from cropland areas. Removal of nitrate from these waters helps protect drinking water supplies and reduce hypoxia in the Gulf of Mexico. The program is implemented in cooperation with the USDA Farm Service Agency (FSA) and is available in 37 Soil and Water Conservation Districts (SWCD) in the tile-drained region of North Central Iowa.

Financial incentives are provided to private landowners to develop and restore wetlands that intercept tile drainage from agricultural watersheds. Landowners receive annual land payments for up to 15 years and reimbursement for costs of wetland and buffer establishment. Easements to maintain the wetlands and buffers are required for a minimum of 30 years with permanent easements offered as well. Water quality monitoring completed by researchers at Iowa State University has confirmed that CREP wetlands remove 40-90 percent of the nitrate and 90+ percent of the herbicide in tile drainage water from upper-lying croplands. In addition to reducing nitrate loads to surface waters, the wetlands will provide wildlife habitat and increased recreational opportunities.

Stakeholders and organizations, e.g. watershed groups, need a method to determine how much nutrients can be reduced by various BMPs, including NRWs, in a watershed. For this reason, this study emulated Iowa's approach, at least in making initial estimations, using a relatively simple GIS mass balance model, in order to project the effect on nutrient loadings from NRWs in several small watersheds in northwest and central Ohio. This project's goal was to make a relatively simple model which could be used by watershed groups to determine how NRWs could be placed within watersheds and estimate how much nitrate (NO_3) and Phosphorus (P) could be removed from the annual discharge by the NRWs.

The main purpose of this paper is to discuss aspects of the GIS tool and the results of running it in several watersheds. The above discussion alludes to a much more wide ranging discussion taken from several Iowa publications. It was not the intent to replicate those discussions here. Refer to Crumpton (2006, 2012, May, 2012) for those discussions. In addition, this paper does not discuss all the details of proper construction or placement of NRWs; refer to Tomer (2013) for details.

Methods

Initial Considerations

AnnAGNPS and SWAT

In the exploration phase, the AnnAGNPS Pollutant Loading and SWAT (Soil Water Assessment Tool) models were explored as possible models. The inherent complexity of each of these options, especially the training and expertise required to use these modeling tools, makes AnnAGNPS and SWAT impractical for the purpose of generating a simple tool for watershed organizations to use.

OpenNSPECT

The model OpenNSPECT was extensively explored. Open NSPECT is an open source, GIS version of the N-SPECT watershed model, which was an earlier developed version that was implemented as an ESRI GIS extension. OpenNSPECT is a plug-in for the free, open-source GIS software package MapWindow GIS. It has been developed and is maintained by the NOAA Coastal Services Center.

Open NSPECT was run for the Upper Riley watershed for nitrogen. After setting up the model and providing the required inputs, the model generated a runoff load that was almost twice as much runoff than what is typical for the region in which the Upper Riley watershed is located. One possibility for such a high runoff number is that NSPECT was developed for coastal areas where evapotranspiration (ET) is normally much lower than in an area like Ohio, thus resulting in higher runoff. With such a large discrepancy in runoff projections, Open NSPECT was not a suitable model for use in Ohio.

GIS Mass Balance Model

Iowa State University, after researching more complex models (e.g. SWAT), has used a relatively simple mass balance model using Arc GIS to estimate nitrate loads for wetlands (Crumpton, personal communication). This approach was adapted for Ohio for both nitrate and phosphorus (P).

Site Description

This approach was used in three agricultural dominated watersheds (see Figure 1) - all 12 digit watersheds as defined by USGS. The watersheds include: Indian Run -- northwest of Columbus; the headwaters of Treacle Creek– west of Columbus; and the Upper Riley Creek watershed – in Hancock County in Northwest Ohio.

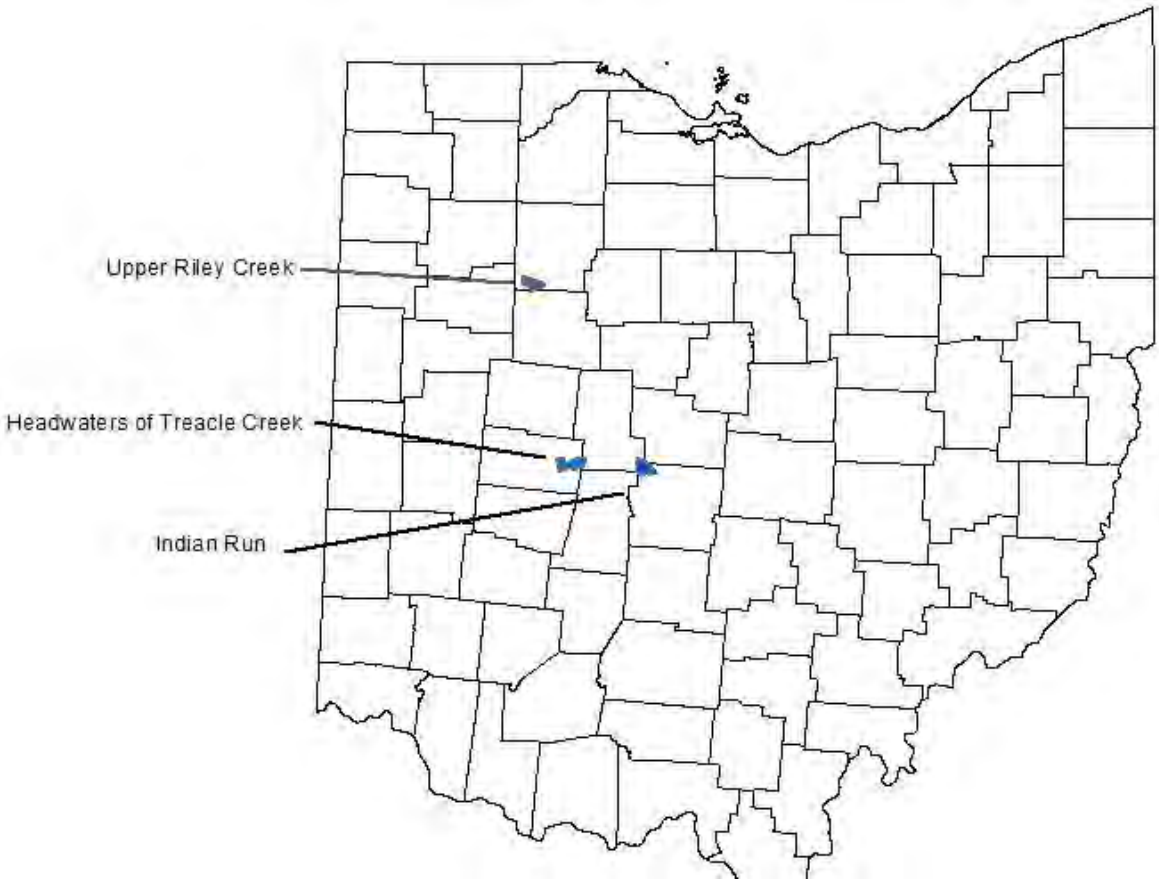

Figure 1. Watersheds included in the study

All three watersheds are in the Eastern Corn Belt Plains Ecoregion. The headwaters of Treacle Creek watershed are in a sub-region called the Darby Plains. The native vegetation was predominantly tall grass prairie located on flat to gently rolling till plains. Today, almost all of the native vegetation has been replaced by row crops, primarily corn and soybeans. Indian Run and the upper Riley Creek watersheds are similarly located on flat to gently rolling till plains. The original vegetation was deciduous forest, replaced, post European settlement, by agriculture, now primarily corn and soybeans. In the past couple of decades, the Indian Run watershed has undergone a large amount of encroachment by suburban development (Table 2).

Land Cover in Watersheds

Land cover for the respective watersheds was extracted from the 2006 National Land Cover Database (Fry, 2011) (Tables 1– 3).

Table 1: Land cover for the Upper Rile Creek watershed

Land cover category	Area (ha)	% of total land cover
Open Water	2.39	0.066
Developed, Open Space	227.36	6.289
Developed, Low Intensity	30.89	0.854
Developed, Medium Intensity	17.01	0.470
Barren Land	1.92	0.053
Deciduous Forest	372.58	10.307
Evergreen Forest	1.39	0.039
Herbaceous	56.96	1.576
Hay/Pasture	33.06	0.915
Cultivated Crops	2870.90	79.418
Emergent Herbaceous Wetlands	0.48	0.013
Total	3614.94	100.000

Table 2: Land cover for the headwaters of Indian Run – Scioto River watershed

Land cover category	Area (ha)	% of total land cover
Open Water	18.92	0.43
Developed, Open Space	940.94	21.19
Developed, Low Intensity	994.22	22.39
Developed, Medium Intensity	370.42	8.34
Developed, High Intensity	85.27	1.92
Barren Land	3.68	0.08
Deciduous Forest	173.63	3.91
Evergreen Forest	3.42	0.08
Herbaceous	39.79	0.90
Hay/Pasture	245.91	5.54
Cultivated Crops	1564.41	35.23
Total	4440.61	100.00

Table 3: Land Cover for the headwaters of Treacle Creek – Little Darby Creek watershed

Land cover category	Area (ha)	% of total land cover
Open Water	6.93	0.10
Developed, Open Space	396.70	5.84
Developed, Low Intensity	32.51	0.48
Developed, Medium Intensity	2.16	0.03
Barren Land	0.89	0.01
Deciduous Forest	434.19	6.39
Evergreen Forest	1.97	0.029
Herbaceous	44.87	0.66

Hay/Pasture	507.85	7.48
Cultivated Crops	5358.03	78.87
Emergent Herbaceous Wetland	7.27	0.11
Total	6793.33	100.00

Hydric Soils in Watersheds

Each watershed in this study had its own unique hydric soil signature, as illustrated in Figure 2. Areas were chosen that had a large percentage of hydric soils.

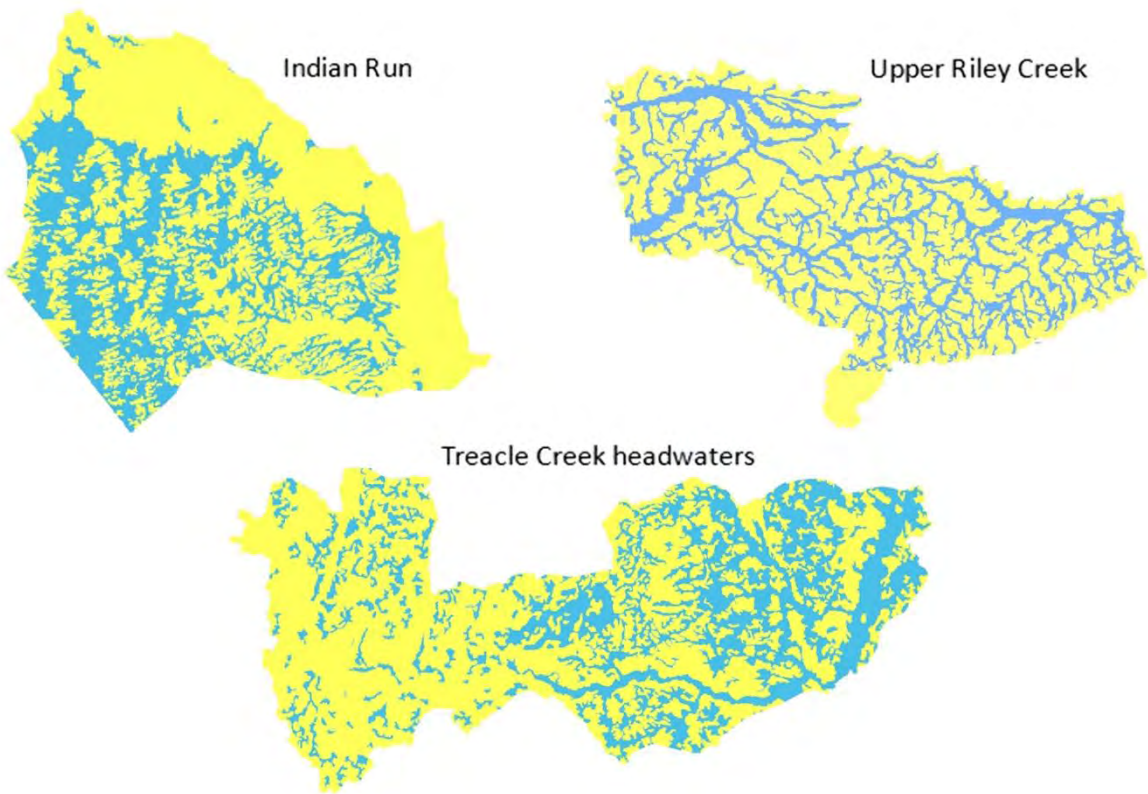

Figure 2. Pattern of hydric soils in separate watersheds. Hydric soils in blue.

Software Used

Two proprietary software programs were used for this approach – ArcGIS 10.0 and Excel 10. In the case of both of these products, there are a number of open source alternatives that may be usable.

Siting Criteria for Nutrient Reduction Wetland

Nutrient reduction wetlands were modeled on the landscape, with the aid of GIS data and aerial imagery, following, as a guideline, the wetland siting protocols of the Iowa CREP program (Iowa Department of Agriculture). The NRWs were located primarily within the headwater area of each watershed. They were digitized as polygons using the ESRI ArcGIS software, after meeting a series of criteria that governed suitable location of NRWs and the size of each NRW relative to its upstream drainage area. In this modeling exercise, NRWs were made for the purpose of illustrating the potential benefits of using NRWs to reduce in-stream nutrient concentrations on a watershed scale. The NRWs used in this exercise should not to be construed as actual site specific NRW siting or design recommendations, as those decisions in actual practice would fall under the purview of the landowners themselves.

Natural Resource Conservation Service (NRCS) has a Soil Survey Geographic database (SSURGO), which was used to ensure NRWs were located on areas of predominantly hydric soil. Aerial imagery was also used to ensure locations were on agricultural land. The assumption was made that the agricultural land upstream of these wetlands is largely tile drained, which is consistent with typical agricultural practices in the regions of Ohio subject to this study.

NRWs were digitized in the stream channel bordered by hydric soils, using siting and design features of the Iowa CREP program. NRWs that were located in the watersheds would have a berm extending across the stream channel which would form a wetland impoundment. This berm essentially extends a topographic contour line across the stream, and then the edges of the wetland trace that contour in an upstream direction so that the end result is an NRW similar to the example shown in Figure 3.

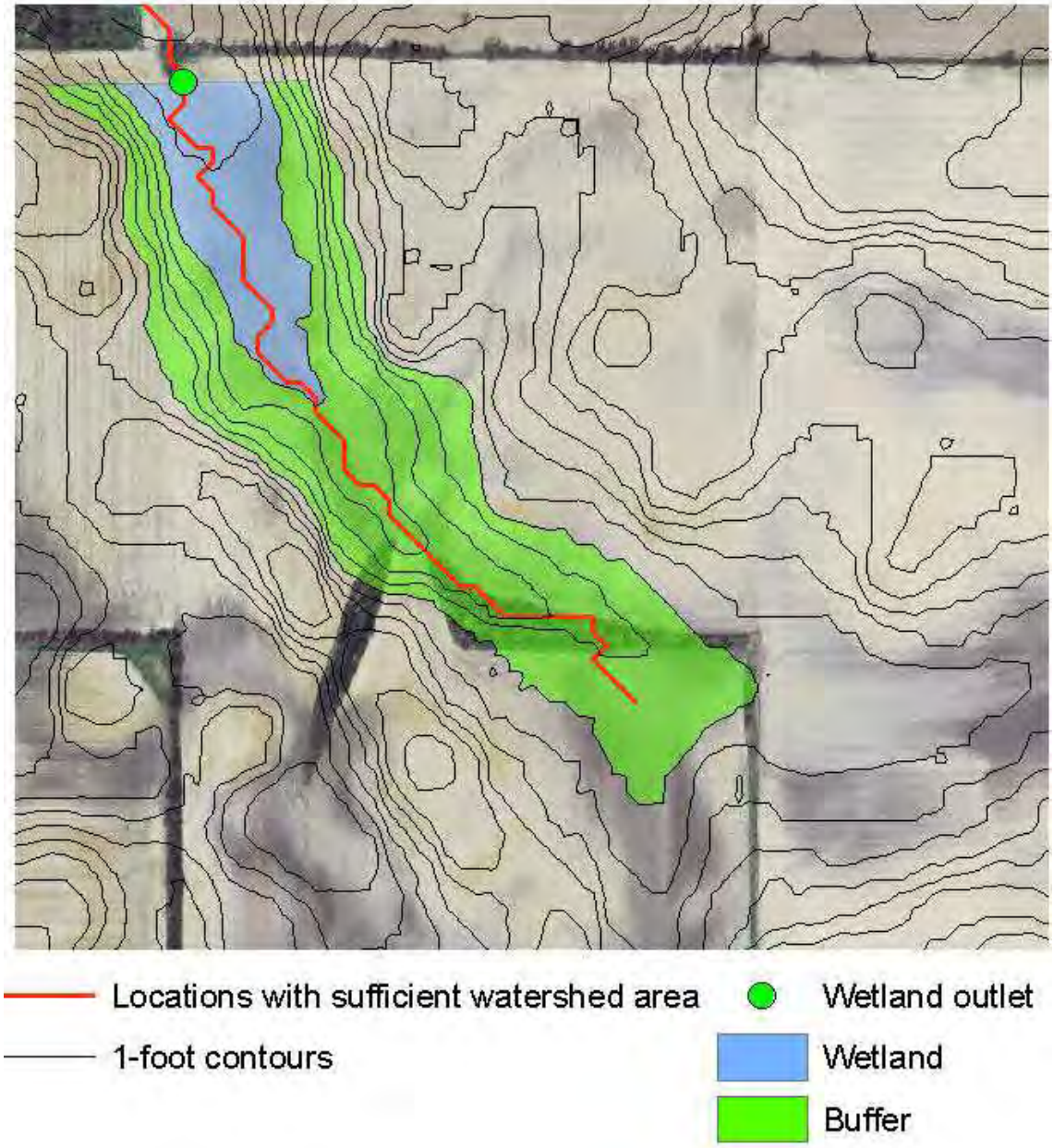

Figure 3. An example of topography that lends itself to NRW placement. The orthophotos are used to confirm that land is indeed cropland and to find the actual interface between closed and open drains. The wetland and buffer shapes are determined by dam placement and topography (Frankenberger, et. al. 2009).

In each location, the upstream drainage should be approximately 500 acres or greater of predominantly tile-drained agricultural land in order for the NRWs to treat enough water to have a measurable influence on downstream water quality. At the other end of the spectrum, NRWs should be placed in watersheds less than, approximately, 2,000 acres of same land use in order to avoid unreasonably large wetlands. The above should be understood as a "rule of thumb" with exceptions made based on local land use and topography considerations.

Once a target region of the watershed was developed, based on the drainage area criteria above, the NRW was sized in the approximate range of wetland-to-watershed area ratios used in the Iowa CREP guidelines (which indicate a wetland to be sized from 0.5 percent to 2.0 percent of its upstream watershed, based on the runoff characteristics specific to Iowa). Adjusting this range to maintain similar hydraulic loading rates between states based on comparisons of annual rainfall averages in Iowa and Ohio, an ideal wetland to watershed ratio range for Ohio would be 0.66 percent to 2.2 percent. From annual precipitation records during the period of April 2008 to March 2013, Ohio received 41.1 inches (104 cm) per year of rain. This amount is 111 percent of the 37 inches (94 cm) per year of precipitation Iowa received during the same timeframe (NOAA National Climatic Data Center). In most cases, non-agricultural land uses or topographic features such as a business or residential development, a road or a woodlot, dictated the upper or lower boundaries of potential wetland size.

Wetland to watershed ratios, used by the Iowa CREP program, are designed to ensure a wetland large enough, relative to its catchment, to have a measurable impact on water quality. At the same time a NRW should not to be so large compared to its watershed, that nutrient reduction efficiency is diminished relative to the land area and resources necessary to set aside that wetland. However, for demonstration purposes, the NRWs modeled in this study also contain a couple of outliers, in terms of wetland: watershed ratios (0.3 percent and 7.6 percent). These "outlier" wetlands illustrate the nutrient reduction outcomes associated with NRWs that are above or below the target range.
As a modeling exercise, wetlands were situated in the maximum number of areas in a watershed that fit the above siting criteria, even if that meant more than one wetland per stream. However, the goal was to have only one wetland per stream. To determine the most efficient set of NRWs for the watershed, sequences of individual wetlands were removed from the watershed one by one and, each time, the modeling was re-run to determine the impact of each individual wetland on watershed nutrient loading. The most efficient set of NRWs for each watershed was determined in this way.

Nutrient loads were determined for each watershed using annual stream flow information and nutrient concentrations for land uses within each watershed. The assumption was made that the volume of annual runoff multiplied by nutrient concentration for each land use equals a watershed's nutrient export load. This information was then modeled and derived within a combined GIS and spreadsheet framework.

Modeling Varying Wetland: Watershed Ratios for Each Wetland

The NRWs created within GIS and modeled in this report were sized as they were designed, in order to fit well within local land use, maintain contact with hydric soils and conform to the sizing and placement guidelines of CREP wetlands in general. In order to demonstrate various nutrient reduction potentials if a given NRW were sized differently with respect to its upstream watershed, the area value of each

wetland was artificially manipulated and nutrient reduction modeling calculations were re-run. The range of areas from 0.5 percent to 2.5 percent, at 0.5 percent intervals, represents nutrient reduction wetland performance when scaled to different proportions of upstream drainage area.

Determining Annual Stream Flow

Annual stream flow was determined by first looking at USGS long-term gauge data for nearby watersheds and determining their annual flow per unit area. Then, an estimate for the watershed in question was obtained by regression equations through Ohio StreamStats (StreamStats for Ohio). This figure was compared to data determined for the nearby watersheds to make sure that it was a reasonable simulation.

Nutrient Concentrations

Nutrient concentrations, for NO_3 and TP (total phosphorus), suitable for the area (as shown in Table 4) were obtained from Ohio EPA data and the literature (Lin 2004).

Table 4: Nutrient concentrations used in the study (kg/ha/yr^{-1})

Watershed	Landuse	NO_3	TP
Indian Run	Open Water	0.00	0.00
	Developed, Open Space	0.80	0.10
	Developed, Low Intensity	1.72	0.18
	Developed, Medium Intensity	1.72	0.30
	Developed, High Intensity	0.25	0.49
	Barren Land (Rock/Sand/Clay)	0.25	0.08
	Deciduous Forest	0.53	0.15
	Evergreen Forest	0.53	0.15
	Grassland/Herbaceous	0.80	0.15
	Pasture/Hay	1.90	0.40
	Cultivated Crops	7.94	0.40
Treacle Creek – Headwaters	Open Water	0.00	0.00
	Developed, Open Space	0.80	0.10
	Developed, Low Intensity	1.72	0.18
	Developed, Medium Intensity	1.72	0.30
	Barren Land (Rock/Sand/Clay)	0.25	0.08
	Deciduous Forest	0.53	0.15
	Evergreen Forest	0.53	0.15
	Grassland/Herbaceous	0.80	0.15
	Pasture/Hay	1.90	0.40
	Cultivated Crops	7.94	0.40
	Emergent Herbaceous Wetlands	0.34	0.20

Upper Riley Creek – Headwaters	Open Water	0.00	0
	Developed, Open Space	0.80	0.1
	Developed, Low Intensity	1.72	0.18
	Developed, Medium Intensity	1.72	0.3
	Barren Land (Rock/Sand/Clay)	0.25	0.08
	Deciduous Forest	0.53	0.15
	Evergreen Forest	0.53	0.15
	Grassland/Herbaceous	0.80	0.15
	Pasture/Hay	1.90	0.4
	Cultivated Crops	7.94	0.4
	Emergent Herbaceous Wetlands	0.34	0.2

Regarding nitrogen, most of the values in the table were for Total Nitrogen (TN). The values selected were converted to nitrate based on data collected for water quality monitoring and modeling purposes in each of the watersheds. The regression for the headwaters of Treacle Creek – Little Darby (Table 5) was selected to use for the whole study as it provides the most conservative (highest) value for nitrate. This may be because much of the watershed was formerly wet prairie and the native soil contained relatively high amounts of N. In addition, there are relatively fewer wood lots in this watershed and it has the highest percentage of agricultural land of the three watersheds.

Table 5: Regression equations considered for conversion of TN to NO_3 values

	Relationship of TN and Nitrate	**R2**	**NO_3/TN average. %**
	NO_3=y; TN=x		
Riley	y = 0.9599x - 0.9896	0.95	25%
Treacle	y = 0.9154x - 0.2983	0.99	75%
Indian	y = 0.8794x - 0.4989	0.95	27%

GIS Portion

Lidar Data

A Digital Elevation Model (DEM) derived from Lidar data from the OSIP program (The Ohio Statewide Imagery Program) and resampled by USGS to 1/9 arc-second (~3 meters) was obtained for each watershed area. The DEM was clipped to a buffered watershed area and used in the following model as appropriate.

GIS model

Within ArcGIS, the primary steps for determining the nutrient load for a watershed can be seen in the graphic in Figure 4 (taken from ArcGIS 10.0 model builder). A variation of this model was used during actual data determination but the steps in the figure below were ascertained to provide the most straight forward and logical order. In either case, the final data endpoints are the same.

Spreadsheet Portion

The following data was obtained from the GIS maps and data layers:

- Annual discharge (m^3 yr^{-1}) for each wetland
- Flow weighted nutrient accumulation
- Flow accumulation
- Wetland area
- Wetland's contributing basin (ha)
- Amount of nutrient present for watershed, without NRW
- Total annual nutrient load for each HUC 12
- Total watershed area for each HUC 12

This data was used to determine how much nutrient load reduction would be provided by NRWs. For nitrate, the following equation, which was developed from long term research on NRWs in Iowa, was used to determine load reductions for placed wetlands at different size suites - i.e. wetland:watershed ratios (Crumpton 2006):

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

For TP, load reduction rates were used as recommended by the Center for Watershed Protection for higher end wetlands at 50 percent and 75 percent reduction (Cappiella, 2008).

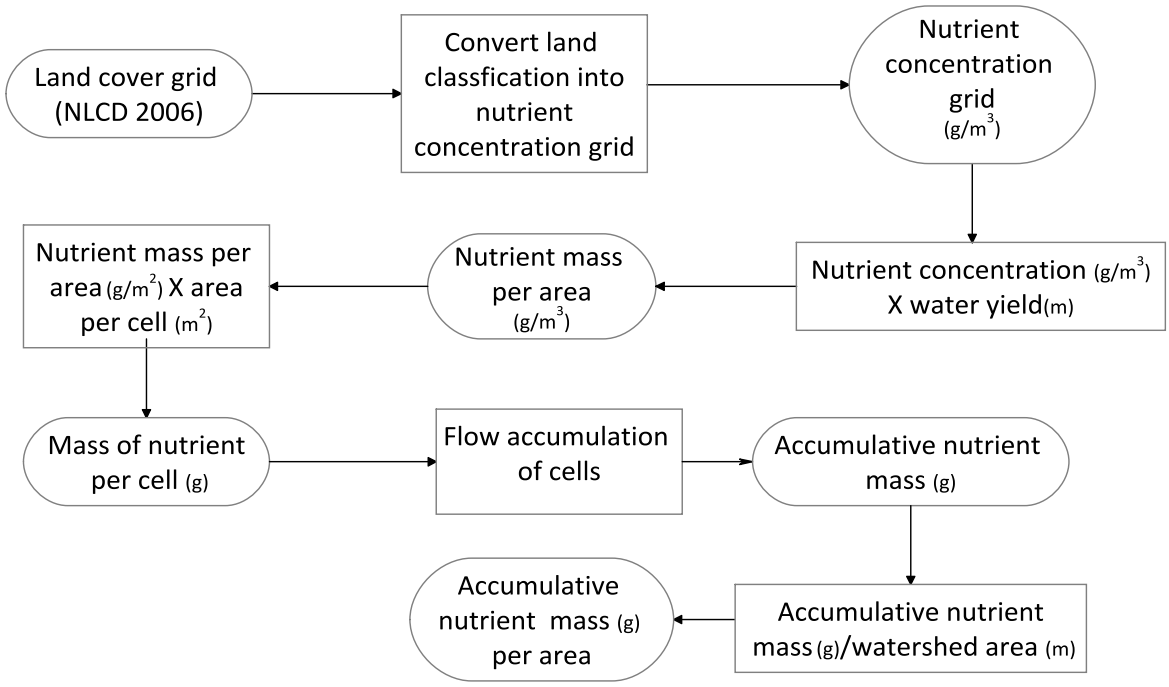

Figure 4. GIS model used for study

Results and Discussion

<u>Nitrate</u>

Mass N removal, for all three watersheds, tended to increase consistently with hydraulic loading rate (HLR) (Figure 5). The hydraulic loading rate is defined as: q = (Q/A)/100, where q is the inflowing hydraulic loading rate, which is equivalent to the depth of flooding (Q) over the treatment area (A) per unit time (inches/day) (Mitsch and Jorgensen, 2004).

It has been found that much of the variability of mass nitrate removal can be explained by HLR and flow weighted nutrient concentration (calculated by dividing the total load over the estimated time period by the total streamflow) (Crumpton, 2006). These two make up the variables in the mass N removal equation. The watersheds in this study are fairly uniform row crop landscapes – so the flow-weighted concentration will be relativity homogenous – making HLR the chief variable.

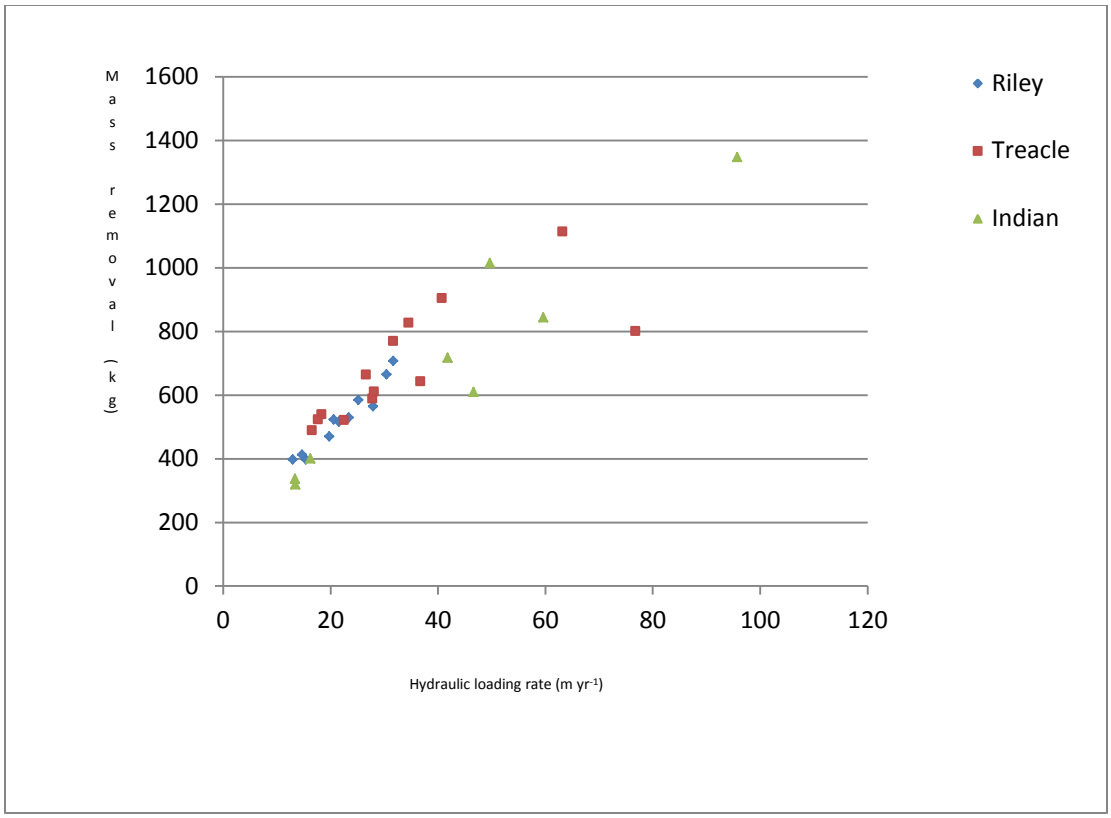

Figure 5. Mass nitrate reduction as a function of hydraulic loading rate (m yr^{-1})

As Figure 6 shows, HLR and percent nutrient removal are inversely related to each other. As HLR increases, it is an indication of increased water moving through the system. When that occurs, water has less residence time in the wetland, resulting in less opportunity for nitrate removal. Conversely with decreasing HLR, water has a higher residence time in the NRW, with a greater opportunity for denitrification because of increased soil/water contact time.

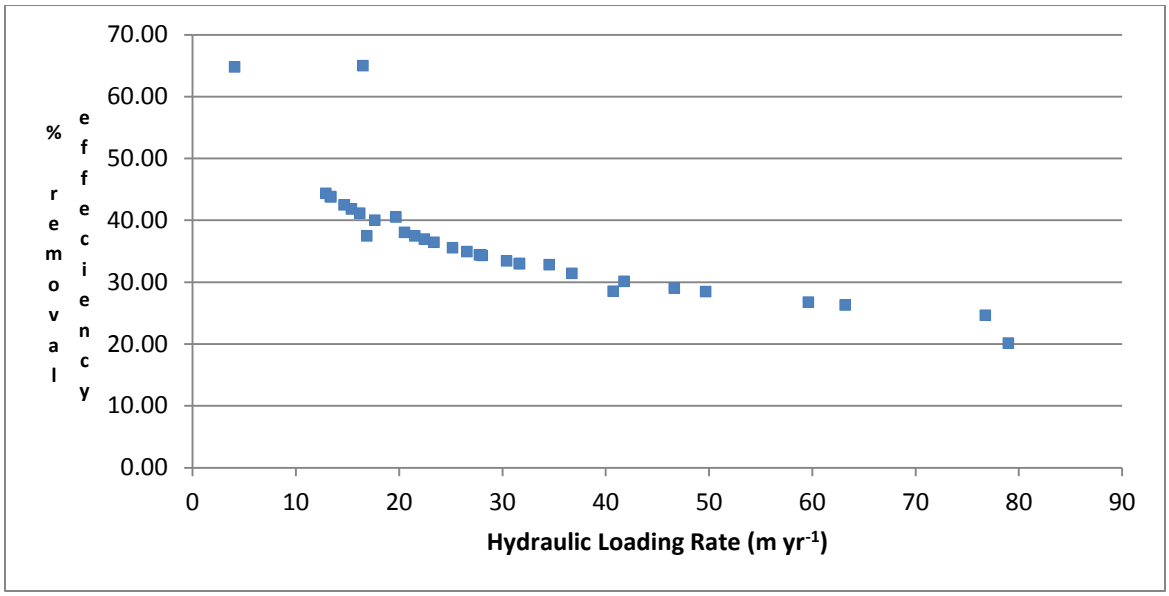

Figure 6. Percent nutrient (nitrate-N) removal efficiency as a function of HLR.

To help illustrate the effect of the HLR on nutrient loads and removal and its connection with nutrient removal efficiency, an NRW in the upper Riley watershed was designed to demonstrate the effect of restoring an NRW, that is larger in proportion to its watershed, than the suggested range of 0.5 to 2.0 percent. (In some cases, acreage availability may be more conducive to restoring a larger watershed area connected to an NRW versus several small land allotments.)

The larger NRW, 11.05 ha (27.3 acres), occupies 7.6 percent of its 352 ha (870 acre) drainage area, which is a wetland to watershed ratio that is significantly higher than the ratios generally proposed by this and similar studies. Because the upstream flow and associated nutrient load is distributed across more wetland acreage in this NRW than in other NRWs in the upper Riley Creek watershed, the hydraulic loading rate is considerably lower. This NRW has a hydraulic loading rate of 4.09 meters per year, versus the mean 22.13 meters per year hydraulic loading rate of the other NRWs in the watershed. The NO_3-N removal efficiency of the NRW is the highest of the upper Riley NRWs, at 64.72 percent, with the median efficiency of the other NRWs in the watershed at 22.27 percent (mean is 26.39 percent).

Nitrate removal efficiency is shown in Figure 7 to steadily increase with increasing wetland:watershed ratio. All the digitized wetlands from the three watersheds were plotted with percent nitrate reduction as a function of wetland:watershed ratio.

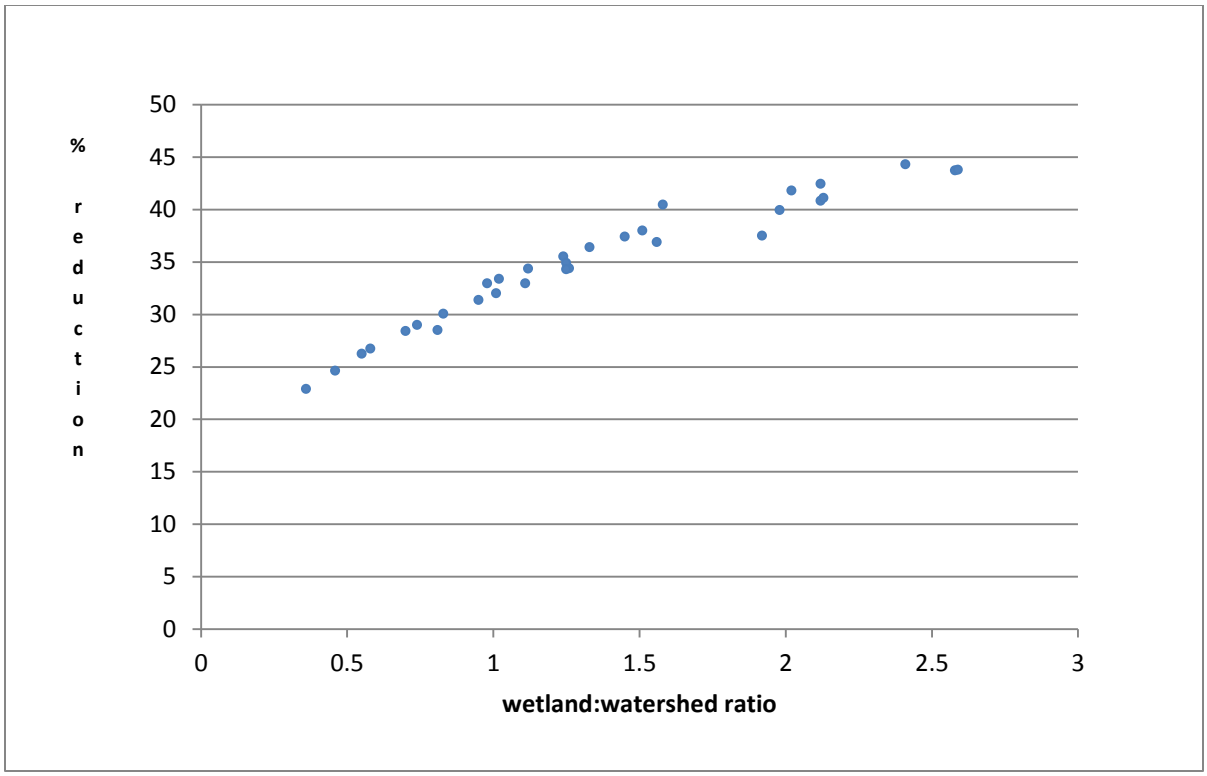

Figure 7. Nitrate reduction efficiency as a function of the wetland:watershed ratio

As outlined in the Methods section, wetlands were digitized in ArcGIS. Selected measurements and statistics for those wetlands are provided in Tables 6-8, including NRW area (ha), watershed area draining to NRW (ha), NRW area, as percent of upstream watershed and HLR (meters/year).

Riley Creek Nutrient Reduction Wetland (NRW)	Nutrient Reduction Wetland area (ha)	Watershed area draining to NRW (ha)	NRW area, as % of upstream watershed	Hydraulic Loading Rate (meters/year)
1 – Example	11.05	145.04	7.62	4.09
2	2.10	205.35	1.02	30.43
3	4.02	198.94	2.02	15.40
4	1.77	158.59	1.12	27.90
5	1.78	180.76	0.98	31.67
6	14.21	938.01	1.51	20.55
7	7.99	331.66	2.41	12.92
8	13.77	1114.19	1.24	25.19
9	5.09	352.45	1.45	21.53
10	12.85	606.26	2.12	14.69
11	3.64	230.51	1.58	19.72
12	7.52	565.38	1.33	23.40

Table 6: Properties of Riley Creek NRWs. Area, drainage area, NRW to watershed ratio and hydraulic loading rate for each NRW in the Riley Creek watershed are shown for each NRW modeled independently.

Treacle Creek Nutrient Reduction Wetland (NRW)	Nutrient Reduction Wetland area (ha)	Watershed area draining to NRW (ha)	NRW area, as % of upstream watershed	Hydraulic Loading Rate (meters/year)
1	11.05	520.63	2.12	16.52
2	3.12	562.35	0.55	63.20
3	3.03	240.69	1.26	27.81
4	3.14	329.11	0.95	36.75
5	1.00	219.44	0.46	76.77
6	2.98	239.34	1.25	26.58
7	3.26	321.71	1.01	34.55
8	2.37	214.45	1.11	31.66
9	4.71	301.93	1.56	22.47
10	1.84	228.27	0.81	40.75
11	4.73	247.09	1.92	18.30
12	4.20	211.56	1.98	17.67
13	8.37	670.09	1.25	28.08

Table 7: Properties of Treacle Creek NRWs. Area, drainage area, NRW to watershed ratio and hydraulic loading rate for each NRW in the Treacle Creek watershed are shown for each NRW modeled independently.

Indian Run Nutrient Reduction Wetland (NRW)	Nutrient Reduction Wetland area (ha)	Watershed area draining to NRW (ha)	NRW area, as % of upstream watershed	Hydraulic Loading Rate (meters/year)
1	3.48	421.19	0.83	41.81
2	2.19	605.55	0.36	95.72
3	2.33	401.28	0.58	59.64
4	3.13	449.30	0.70	49.69
5	5.66	219.63	2.58	13.43
6	6.77	317.71	2.13	16.22
7	9.78	378.00	2.59	13.37
8	3.71	499.80	0.74	46.65

Table 8: Properties of Indian Run NRWs. Area, drainage area, NRW to watershed ratio and hydraulic loading rate for each NRW in the Indian Run watershed are shown for each NRW modeled independently.

Variation in the amount of nitrate removed is a function of several factors, including HLR and wetland efficiency in nitrate removal. These are closely related to watershed size and wetland size and the interplay between these two factors. Figure 8 shows the variation in nitrate removal by the 33 different wetlands of the three watersheds, by looking at the above two mentioned factors. There is a clear trend for increased nitrate removal with increasing watershed size or wetland size. In addition, the effect of varying the individual NRW to watershed ratio (at 0.5, 1.0, 1.5, 2.0 and 2.5percents) on N O_3-N reduction for each individual NRW in each watershed is shown in Figure 9.

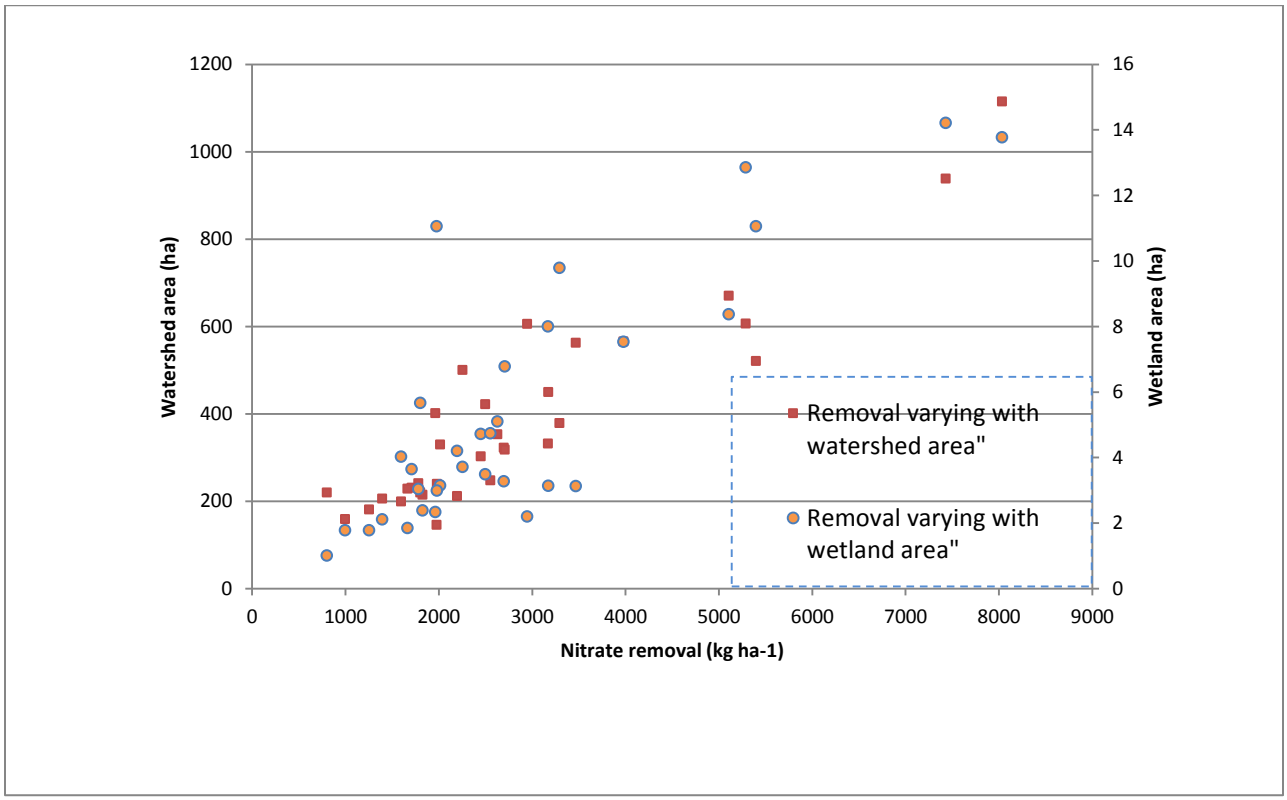

Figure 8. Nitrate removal varying with watershed size and wetland size.

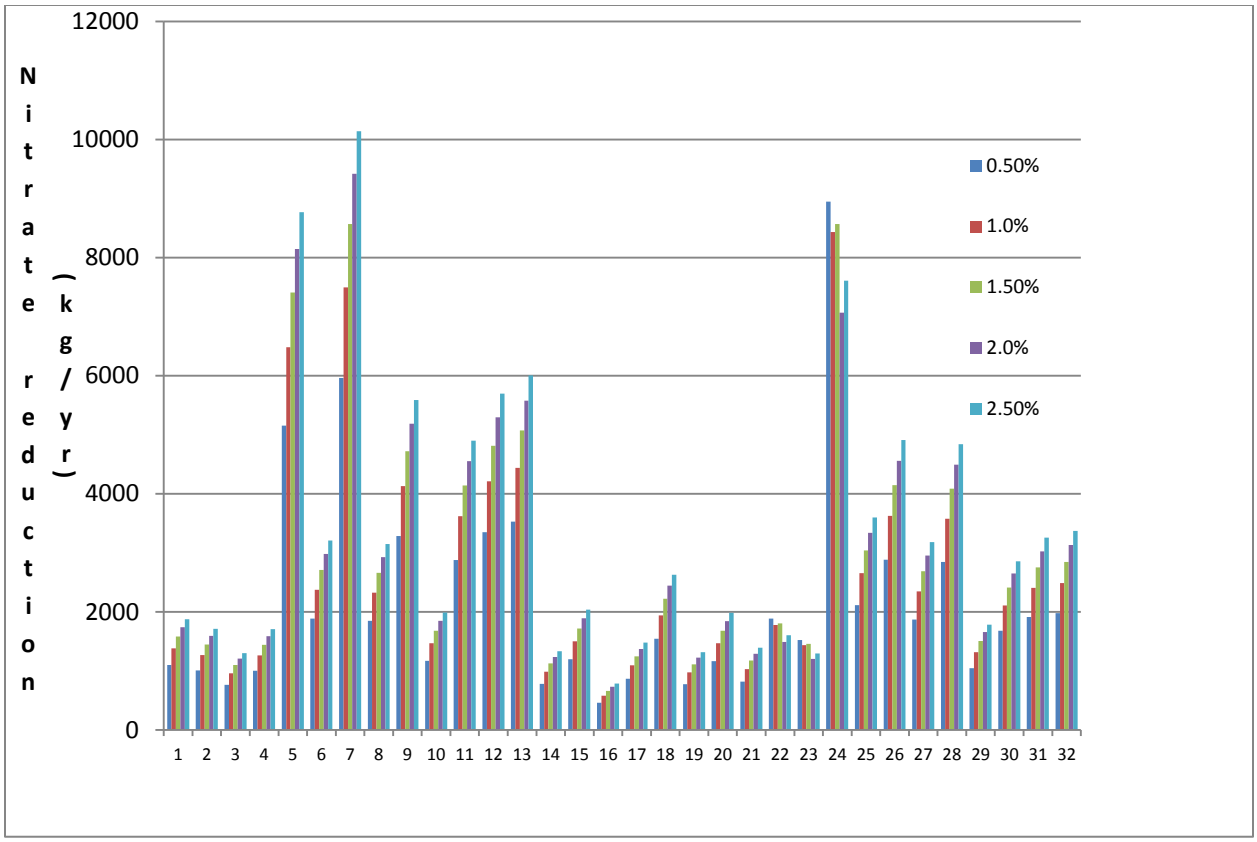

Figure 9. Mass nitrate removed by individual wetlands from the three watersheds in the study (Riley 1-12, Treacle 13-25, Indian 26-33).

One can see the general improvement in nitrate reduction for each wetland as they increase from 0.5 to 2.5 percent wetland:watershed ratio. Some wetlands remove much more nitrate than others regardless of ratio. This suggests other factors at work besides wetland:watershed ratio, such as HLR, wetland size or individual watershed size.

In each watershed, the most efficient suite of wetland combinations was also examined, to see what the total nitrate reduction potential was for each watershed (Figure 10). Different combinations were composed of wetlands that occurred once on a stream so that, for the purpose of simplicity, no two wetlands were modeled on the same stream or tributary.

For the Upper Riley Creek watershed, the most efficient combination of NRWs covered 62.93 ha or 1.7 percent of the 3,615 ha watershed. Nitrate reduction potential from this set of wetlands was more than 41 percent of the total nitrate load exported from the Upper Riley Creek watershed. This is a reduction of 29,676 kg, from a total of 71,755 kg that is exported without NRWs.

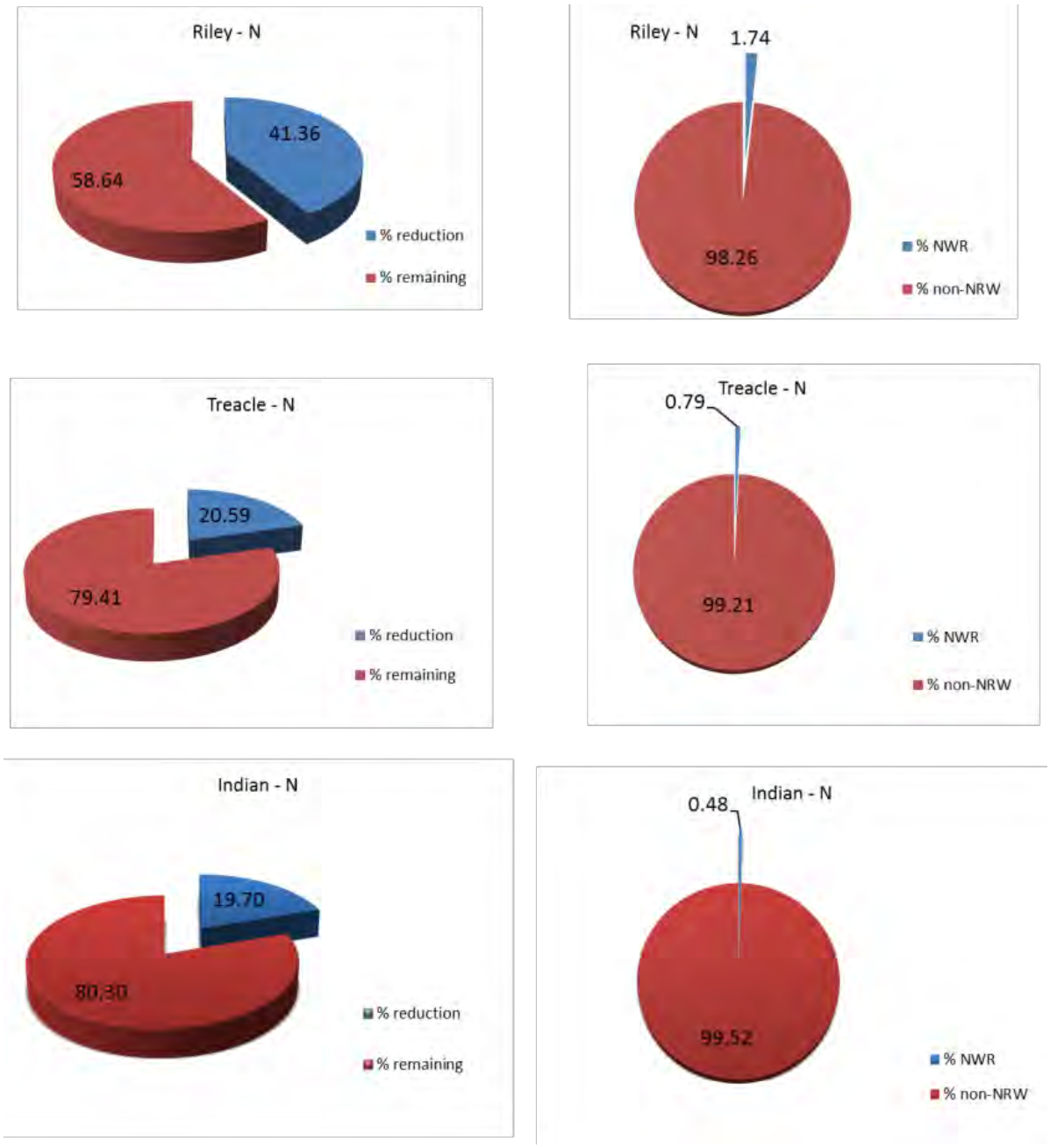

Figure 10. Nitrate reduction for most efficient set of wetlands for each watershed and the corresponding NRW area vs. total watershed area.

For Indian Run, the most efficient combination allowed for a reduction of annual nitrate loads at the mouth of the watershed by a maximum of about 20 percent, or 13,282 kg of the total 67,438 kg NO_3 exported per year. This suite of NRWs totaled 21.2 ha, or 0.48 percent of the total watershed area.

The Riley watershed NRWs had the largest percent reductions but there was also about twice as much land dedicated to NRWs than in other watersheds. The headwaters of Treacle Creek and Indian Run watersheds had similar reduction rates, although the amount of land in NRWs was significantly higher

for the headwaters of Treacle Creek. The NRWs for Indian Run were concentrated in the agricultural part of the watershed, which also had the highest nitrate exports, with the developed part probably exporting less nitrate (land in row crops vs. low or moderate development, had greater than four times the amount of nitrate export potential (Table 4).

Similar to what was done for the individual NRWs, each suite mentioned above was varied so that each NRW within the suite had a ratio to its watershed of 0.5, 1.0, 1.5, 2.0 , or 2.5percents. The change in reduction with changes in the ratio along with accompanying changes in land needed for wetlands is shown in Figure 11. The amount of land used for NRWs for the highest percentage of reduction was for the upper Riley with NRWs comprising slightly more than 2.5 percent of the total watershed area. This combination achieved greater than 50 percent N reduction, with all the NRWs having a 2.5 percent ratio to their associated watershed. The lowest amount of land used for NRWs was Indian Run with all the NRWs scaled to a wetland:watershed ratio of 0.5 percent, with a subsequent total watershed area of less than 0.3 percent, and achieving a nitrate reduction of a little less than 20 percent.

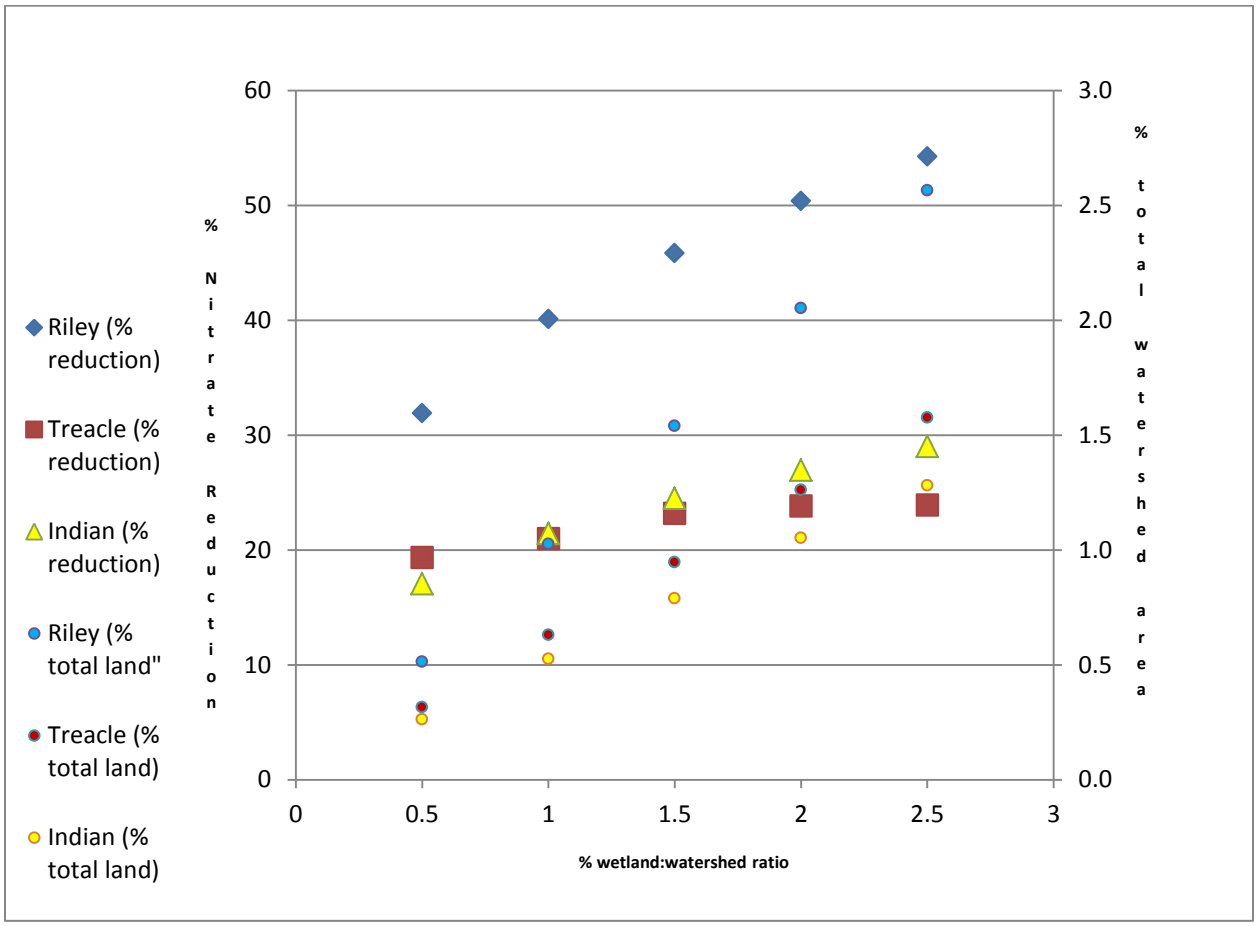

Figure 11. Percent nitrate reduction and NRWs percentage of total watershed as functions of the percent wetland:watershed ratio.

Phosphorus

The discussion for Phosphorous removal is by necessity more sparse than that for nitrate, for several reasons. Nitrogen can be exported from aquatic systems in the form of N_2 gas via microbial mediated denitrification, while natural removal of phosphorous from the water column depends upon sequestration in vegetation and sedimentation. In addition, projections for nitrate removal came from calculations developed by extensive research in Iowa and much more work has been done with nitrate and NRWs than with P.

Projections of the reduction in phosphorous (P) by NRWs were completely dependent on:

1. Available nutrient reduction wetland acreage;
2. The extent of the watershed drainage that is captured by NRWs, and;
3. Assumed P removal efficiency.

As mentioned in the methods section, phosphorous reduction rates for NRWs are based on Center for Watershed Protection estimations (Cappiella, 2008). It provided estimates of 50 percent P removal for an average NWR and 75 percent P removal for high performing NRWs. Estimates for P reduction by wetlands restored or constructed for non-point source runoff vary widely in the literature. This is indicative of how much work is yet needed in this area and how case-specific phosphorous removal efficiency can be in restored wetland systems. The consensus from reading the literature was that the above estimates are a fairly close “ball park” estimate at this time. It should be noted that the above figures are for total phosphorus (TP). In some areas of Ohio, especially where application of P through fertilizer or/and manure has been traditionally excessive or improperly carried out, dissolved reactive P (DRP) may make up a significant portion of the total P (Jones, 2012). Figure 12 shows P reductions for individual wetlands. Figure 13 shows reductions for the most efficient wetland suite for P and corresponding land percentages as NRWs needed to accomplish that reduction, as done in Figure 10 for nitrate.

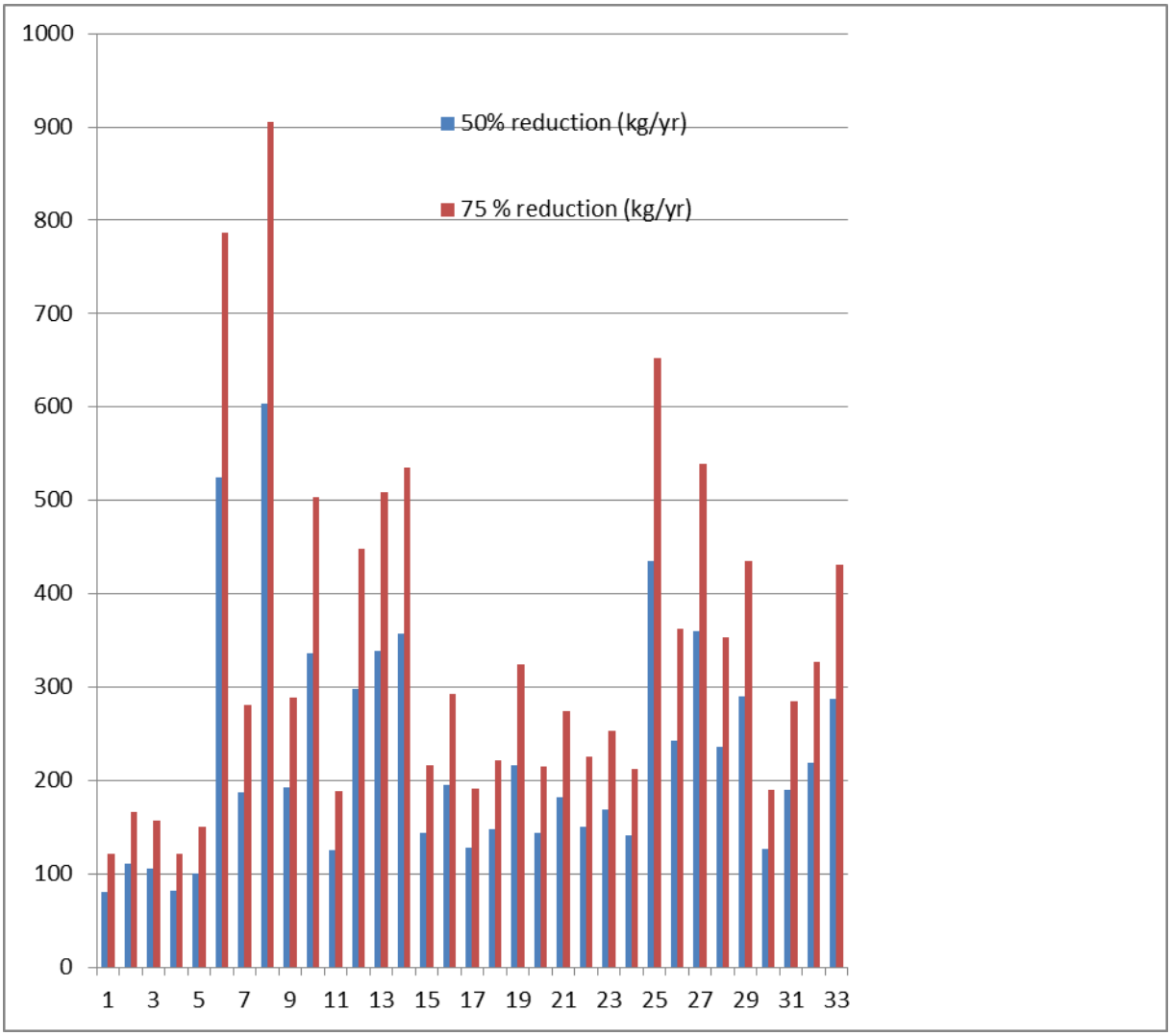

Figure 12. Mass P removed by individual wetlands from the three watersheds in the study at the 50 percent and 75 percent levels (Riley 1-12, Treacle 13-25, Indian 26-33).

One possible NRW design involves "dual use" NRWs having separate design characteristics that are customized to promote either biological removal, in the case of nitrogen, or sedimentation in the case of phosphorous. Dual use NRWs would be especially useful for an area like Ohio where excess nitrate and P can interact with one another to diminish water quality. In this design, a fore bay captures and settles suspended sediment as it first enters the NRW.

This aspect of the NRW would function very similarly to sedimentation ponds often used as a storm water management practice. After moving through the fore bay area, water slowly migrates through the NRW into a larger shallow wetland where the drainage water can spread out over the soil surface and denitrification can reduce the amount of nitrate. The fore bay can be periodically maintained to manage the amount of sediment accumulation and the larger shallow wetland can be allowed to develop as a passive treatment system. In addition to reducing nitrate loads, wetland wildlife habitat developed in the passive treatment zone adds intangible ecological and aesthetic benefits.

Provided the estimates for P reduction are reasonably close, NRWs within heavily tiled areas have the potential to provide a lot of "bang for the buck" – serving as a very powerful BMP with a relatively small percentage of the watershed removed from crop production. For example, in the upper Riley, NRWs could achieve greater than 40 percent reduction in P and nitrate, with only approximately 1.75 percent of the watershed dedicated to NRWs.

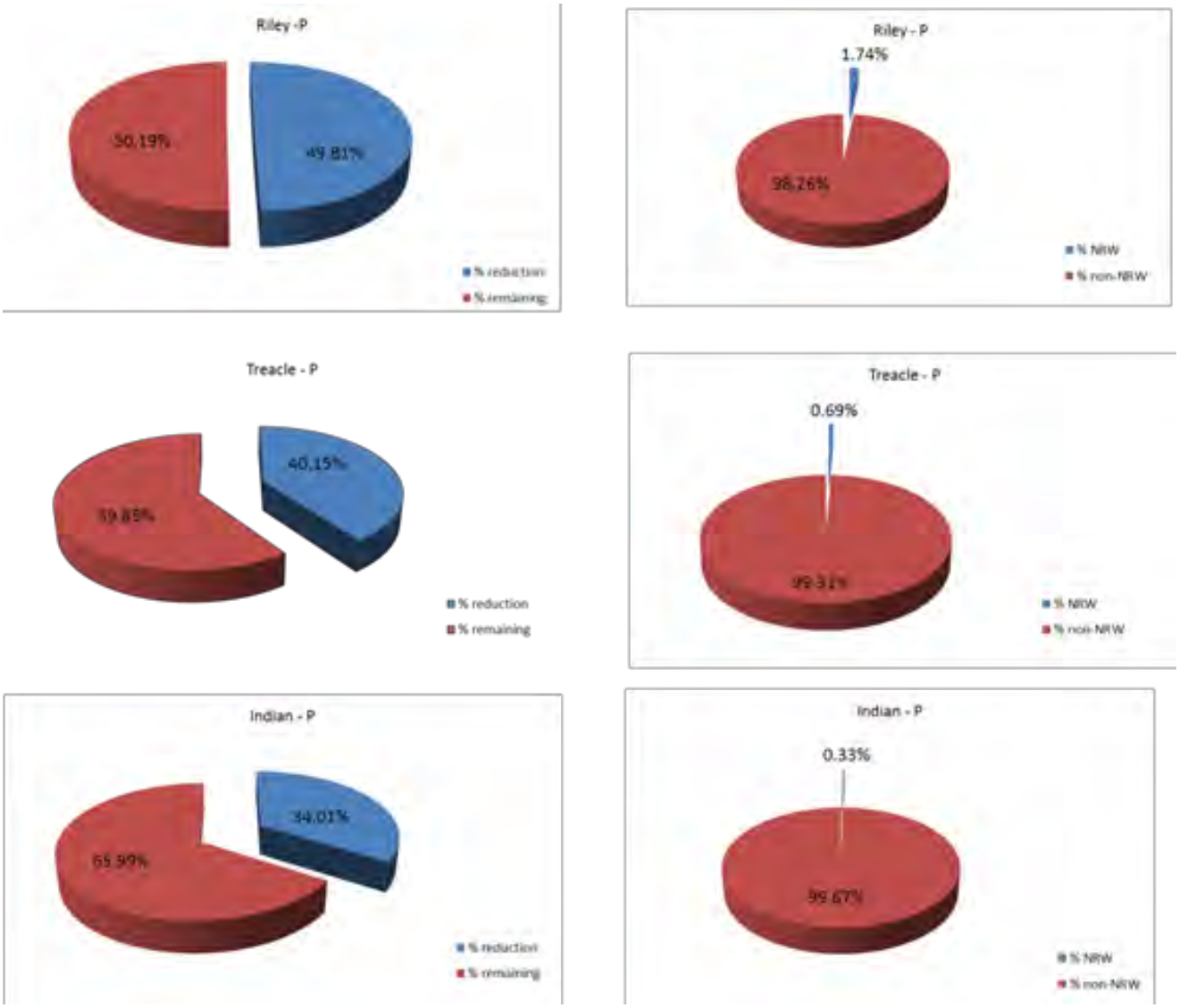

Figure 13. Wetland area vs. total watershed area and corresponding phosphorous reduction for the most efficient set of wetlands for each watershed.

The above would capture P adsorbed to sediment but would not be able to capture dissolved P. Dissolved P may in many cases be a function of the amount of adsorbed P. That is, if a watershed is very high in adsorbed P, then dissolved P would be increased. If that is the case, capturing adsorbed P could be fundamental to reducing the total amount of P coming from the watershed.

Wetland Buffers

So far in the discussion, the amount of land used by wetlands has been confined to that taken up by the wetland itself. While not the main focus of this paper, buffers deserve some mention, as they do contribute to the land that is converted from agriculture and are essential to preserving the integrity of the NRWs. Buffers are needed to help ensure proper drainage, protect wetlands from runoff from the surrounding landscape with the accompanying siltation, nutrients, pesticides, etc. They also help provide valuable habitat for wildlife and native plant populations. Criteria in Iowa's CREP program call for a buffer of up to four feet, in terms of elevation, above the wetland surface and should not exceed four times the size of the wetland. Adjusted land needs for the most efficient suite of wetlands in each watershed can be seen in Table 9 for different buffer:wetland ratios.

Watershed	Area(ha) in NRWs without buffer (% of watershed)	Area (ha) in NRWs with 1:1 buffer (% of watershed)	Area (ha) in NRWs with 1:2 buffer (% of watershed)	Area (ha) in NRWs with 1:3 buffer (% of watershed)	Area (ha) in NRWs with 1:4 buffer (% of watershed)
Riley	62.9 (1.74)	125.8 (3.48)	188.7 (5.22)	251.6 (6.96)	314.5 (8.7)
Treacle	40.4 (0.79)	80.8 (1.58)	121.2 (2.37)	161.6 (3.16)	202 (3.95)
Indian	23.1 (0.52)	46.2 (1.04)	69.3 (1.56)	92.4 (2.08)	115.5 (2.6)

Table 9: Land area needed for various NRW:buffer combinations for the most efficient combination of NRWs per watershed.*

*Where there was a difference between nitrate or P for the most efficient suite of NRWs – the suite for nitrate treatment was used.

Use of GIS Tool in Ohio

This study developed a pilot GIS tool for use in Ohio, to estimate how much nutrients can be reduced by NRWs in a watershed. This GIS tool could be used by wetland managers, researchers, watershed coordinators, regulatory agency staff, etc., to estimate nutrients and other loads that move with water (e.g., sediments or pesticides).

Suggestions have been made that the "4 Rs" of nutrient management—applying the right fertilizer source at the right rate, at the right time, and in the right place–are sufficient if applied correctly to take

care of the excess nutrient problem (www.manitobacooperator.ca/2014/03/04/four-rs-keep-the-regulators-at-bay-msss-hears/). Although they are very important for responsible fertilizer use and should not be minimized, it is likely that responsible nutrient application is but one component in an integrated approach to stabilize and reduce soil nutrients to an appropriate level that will prevent water degradation (Ohio EPA 2012). Wetlands are one potential BMP that can be used to capture nutrients before they are exported from the landscape into streams and rivers. However wetlands used for this purpose have often been associated with small watershed areas and, as a result, they have had a relatively small effect on nutrient reduction.

Wetlands associated with larger watershed areas have been researched extensively in Iowa and are currently being implemented as part of that State's CREP program. The use of a GIS mass balance model to estimate nutrient import and export from NRWs was included in that research (Crumpton, 2012).

Several aspects of a supportive framework need to be in place before widespread implementation of NRWs can take place. These include items such as: a comprehensive nutrient strategy that is accepted by major stakeholders within the state, sources of funding that can be used to help assist interested landowners, and an acceptance of NRWs as compatible with an agricultural landscape and other uses by landowners. However, in the meantime, this tool can be used to investigate the placement of potential NRWs and estimate their ability to remove nutrients from the system. They could be part of a larger GIS product where other BMPs could be visualized and their nutrient reduction capabilities determined. This would allow for strategic and logical implementation of a wide array of BMPs across the landscape and would assist in modeling their interactive impact in addressing nutrient loading.

The GIS model presented here is dynamic in the sense that, with additional knowledge of an area, a more precise tool can be developed. For example, with localized knowledge in a given area regarding actual fertilizer rates used by farmers, manuring practices, tillage methods, etc., nutrient concentrations can be adjusted for the appropriate land uses. Another example would be using this tool to investigate how nutrient loads could differ under different land uses, synthesizing different BMPs including placement of NRWs, to see how these could be fit together to form a strategic plan to lower nutrient exports. Another possibility is using this tool in planning for "what if" situations. For example, if a future possibility was that part of a HUC would be reforested – one could see how this would change the nutrient balance with this tool.

However, possibly of some importance, is the development of more accurate nutrient concentrations (i.e., export coefficients) associated with different land uses. The export coefficients used for this study were estimations taken primarily from the literature. More precise values would involve extensive and intensive nutrient monitoring within watersheds that could be related to different land uses.

The scale of surface water monitoring work typically done in Ohio, has involved looking at nutrient concentrations that measure mixed land use, complicating efforts to measure nutrient concentrations for a single land use. Estimations used for export coefficients borrowed from the literature are perhaps fair approximations. The question becomes – To develop more precise nutrient concentrations or

coefficients, is it worth the added expense and time to develop unique export coefficients for Ohio (or ecoregions of Ohio), or is it better to use the current approximations?

In order for this model to be used to develop a foundation to assess future concerns, there should be an accurate baseline for the conditions that exist now. This baseline could be developed by running the model for all applicable parts of the state. Once developed, the baseline will provide a basis for estimating how reduced fertilizer rates will affect export rates.

The following are some other examples of how this tool could be used:

- As a “nutrient calculator" to estimate where to locate NRWs and how much the nutrient load would be lowered for a watershed;
- To measure other water borne parameters such as sediments, pesticides, etc. and combining with measures of stream power to make it a more far-reaching tool;
- For wetland research: It is apparent one of the main driving factors in wetland degradation (i.e., natural wetlands other than NRWs) is excess nutrients. It could be possible to use the GIS model to estimate nutrient loads wetlands are receiving and estimate how much nutrients could be reduced with different land use or BMP scenarios. It could be part of a larger GIS product that includes an improved wetland layer with additional layers that can be used to show how land use affects wetlands and nutrient flow.
- For education and outreach: Wetlands as a water quality BMP are under-utilized in Ohio. Their power, especially when connected to larger watersheds, is not well understood. This tool could be used to emphasize their utility with regards to water quality to the general public.

Conclusion

The model indicates that, with a relatively small amount of land invested in treatment wetlands, a relatively large amount of nutrient can be diverted away from waterways. This is because these NRWs intercept tile drainage along a natural flow path and thus are treating a larger watershed than typical depressional wetlands.

Iowa State University has spent years calibrating this model to actual ground conditions. If this is to work for Ohio, it should build on Iowa’s extensive work and calibrate for Ohio’s conditions rather than building a plan “from scratch”.

In consultation with Iowa, Ohio could establish a series of trial NRWs and research their impact on nutrient export. There would have to be some refinement of the export coefficients used in the current iteration of this model that would more accurately reflect Ohio’s conditions. With localized information such as specific nutrient and manure application rates one could even fine tune the export coefficients to reflect local conditions.

A major concern that remains is how to fund the implementation of NRWs. Where possibilities of nutrient trading arise, entities such as wastewater treatment facilities and/or municipalities could be a source of funds, in essence paying landowners to put in NRWs. Iowa currently uses the CREP program to

fund NRW construction. How Ohio could fund such a program involves political and social considerations that are largely beyond the scope of this paper. Success would depend largely on the answers to these issues. Iowa's CREP program is closely linked to Iowa's nutrient strategy and the development of NRWs. For optimal results, it is recommended that any program aimed at implementing NRWs be linked in some way to a source of funding, similar to Iowa's CREP program, and that source of funding, in turn, be linked closely to Ohio's nutrient strategy.

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