Simulation of Wetland Nitrogen Removal at the Watershed Scale

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Introduction

- Nitrogen (N) losses to surface waters are of great concern on both national and regional scales.
- Large areas of hypoxia in the northern Gulf of Mexico are due to excessive nutrients derived primarily from agricultural runoff via the Mississippi River.
- Excessive N loading is also responsible for algal blooms and associated water quality problems in lakes and rivers.
- Excess nitrate in drinking water can be toxic to humans and treatment is very expensive.

Nitrogen Removal

- Scientists have proposed ways of reducing N loads to water bodies and the Gulf of Mexico:
  - ❖ Fertilizer management include improved timing of N application at appropriate rates, using soil tests and plant monitoring to split applications, diversifying crop rotations, using cover crops (Dinnes et al., 2002).
  - ❖ Creation of wetlands, riparian buffers or other biofilters (Mitsch et al., 2001; Crumpton et al., 2007); and integrated wetland riparian buffers.
  - ❖ Improved drainage management practices (Skaggs et al., 2005).
  - ❖ Integrated drainage wetland systems.
  - ❖ Other ways ?

Objective

Develop an understanding of wetland processes and their effectiveness toward non-point source pollution to enhance water quality modeling and evaluations of conservation practices at multiple scales.

Simulation of Wetland Nitrogen Removal

- **Identifying critical physical and chemical processes.**
- **Developing appropriate algorithms for simulating these processes.**
- **Defining needed parameters for model simulation.**
- **A mass balance approach is used to simulate hydrologic and water quality processes in the wetland.**

Wetland Component Development

Hydrology Balance

$$V_i = V_{i-1} + Q_{\inf low} - Q_{outflow} + P - ET - I \quad (1)$$

Where:

- **V_i = amount of water per unit area in the wetland at the end of the day (mm),**
- **V_{i-1} = amount of water per unit area in the wetland at the beginning of the day (mm),**
- **Q_{inflow} = amount of water added to the wetland during the day (mm),**
- **$Q_{outflow}$ = amount of water released from the wetland during the day (mm),**
- **P = precipitation on current day, from climate data information (mm),**
- **ET = daily evaporation or evapotranspiration (mm),**
- **I=daily infiltration, or seepage to the groundwater after inundation (mm),**

Wetland Component Development

- **All water measurements are in equivalent water depth, which is the quotient of volume and area.**
- **The wetland area is assumed to be constant during the simulation period.**
- **Wetlands should be located on concentrated flow path (reach) to intercept upland flow.**
- **Wetland can also be used in conjunction with controlled subsurface drainage to intercept subsurface drainage.**
- **Inflow to wetland can be supplied by watershed models such as AnnAGNPS and SWAT; and ET and I can also be calculated with watershed models.**

Wetland Component Development

Water Quality

$$M_i = M_{(i-1)} + M_{\inf low} - M_{outflow} - S \qquad (2)$$

Where:

- **M_i = Mass of the pollutant at the end of the day (kg),**
- **$M_{(i-1)}$ = Mass of the pollutant at the beginning of the day (kg),**
- **M_{inflow} = amount of pollutant added during the day (kg),**
- **$M_{outflow}$ = amount of pollutant released during the day (kg), and**
- **S = pollutant loss on a given day (kg).**

Note: pollutant refers to nitrogen in this study

Wetland Component Development

- **Total amount of nitrogen added to a wetland on a given day can be supplied by watershed models.**
- **Nitrogen transformations in wetlands involve complex spatial and temporal patterns.**
- **The efficiency of wetland on nitrogen removal differs greatly in literature.**
- **The nitrogen loss rate described by a temperature dependent first-order model (Crumpton et al., 1997; Crumpton et al., 2001) was used to calculate S.**

Nitrogen Loss Calculation

A temperature dependent first-order model developed by Crumpton et al., (1997) is used:

$$J = k_{20} * C * \theta^{(T-20)} \qquad (3)$$

Where:

- **J = N loss rate (g m^{-2} day^{-1}),**
- **K_{20} = the area based first order loss rate coefficient (m/day),**
- **C = the concentration of N in wetland (mg/L or g/m^3),**
- **θ = the temperature coefficient for N loss, and**
- **T = water temperature (^{o}C).**

Nitrogen Loss Calculation

$$S = \frac{J * A_{wetland}}{1000} \qquad (4)$$

Where:

- **S = N loss from the wetland on a given day (kg),**
- **J = N loss rate (g m^{-2} day^{-1}), and**
- **$A_{wetland}$ = wetland surface area (m^2)**

Simulation Sequence

- 1) Wetland N concentration is calculated using the amount of water and pollutant in the wetland at the beginning of a day which is the same as the amount of water and pollutant in the wetland at the end of the previous day.
- 2) The N loss during the day is calculated based on equations 3 & 4.

$$J = k_{20} * C * \theta^{(T-20)} \qquad (3)$$

$$S = \frac{J * A_{wetland}}{1000} \qquad (4)$$

Simulation Sequence

- **3) the hydraulic head (H) is calculated using equation 3. The hydraulic head is a function of the water in the wetland:**

$$H = \frac{V}{1000} - H_{weir} \qquad (5)$$

Where:

- **H = hydraulic head on a given day (m),**
- **V = amount of water per unit area in a wetland on a given day (mm), and**
- **H_{weir} = the height of a weir (m).**

Simulation Sequence

- **4) If H is greater than zero, the amount of flow out of the wetland is calculated based on equation 2; and the amount of N released with water is calculated using equation 8.**

$$Q_{volume\_outflow} = B * L * H^{1.5} \qquad (6)$$

$$M_{outflow} = \frac{C_{outflow} * Q_{volume\_outflow}}{1000} \qquad (7)$$

Where:

- **$Q_{volume\_outflow}$ = total volume of water flow out of the wetland on a given day (m^3),**
- **B = the weir coefficient and it is determined by a user,**
- **L = width of the weir opening (m), and**

Simulation Sequence

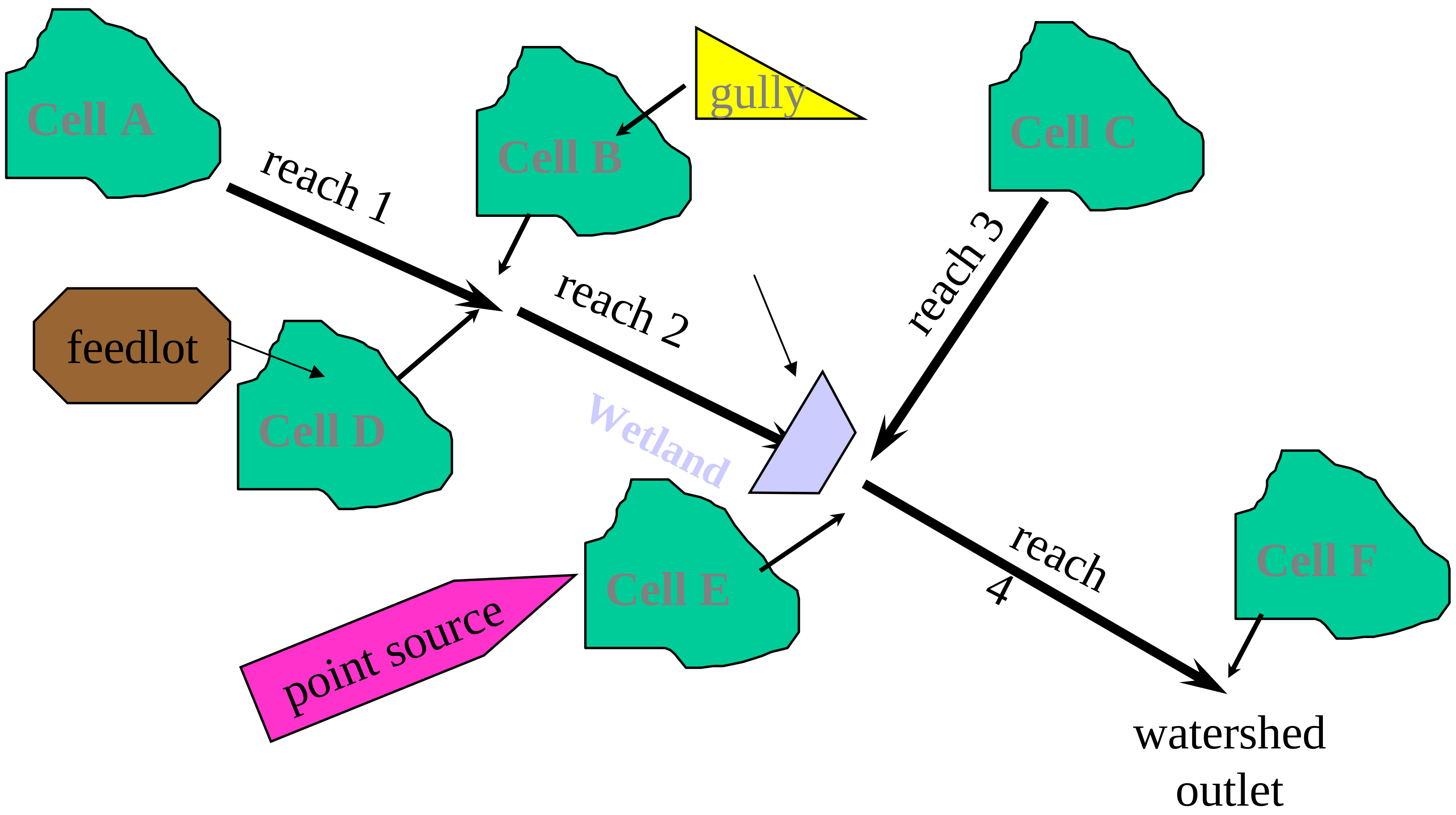
- **5) the amount of water in the wetland is updated using equation 1; and the amount of N in the wetland is updated using equation 2.**

$$V_i = V_{i-1} + Q_{\inf low} - Q_{outflow} + P - ET - I \qquad (1)$$

$$M_i = M_{(i-1)} + M_{\inf low} - M_{outflow} - S \qquad (2)$$

- **6) The steps 1-5 are repeated for next day.**

Integrating Wetland Component with Watershed Models



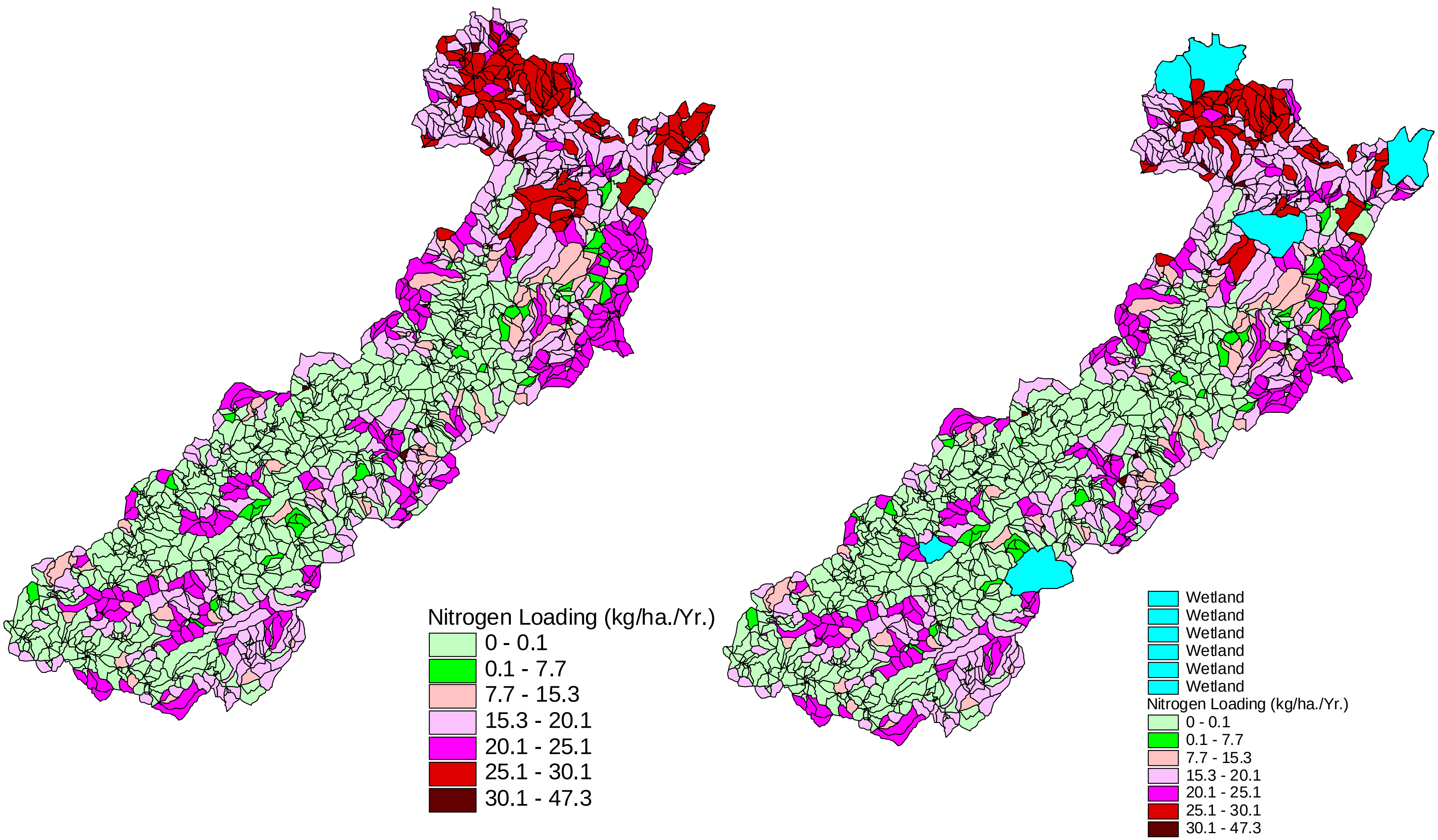
A wetland is located on reach 2, more wetlands can be constructed on other reaches such as reach 1 and 3

The Kaskaskia River Basin is 14,950 km^{2,} approximately 10.2% of the state of the Illinois.

The USGS stream gauge station 05592900 East Fork Kaskaskia River, is located in Marion County, Illinois with a drainage area of 289.3 km^2.

The dominant landuse is agriculture (61%), and the major crops are corn/soybeans. Other landuses include forest (26%), urban (9%), wetland (3%) and barren (1%).

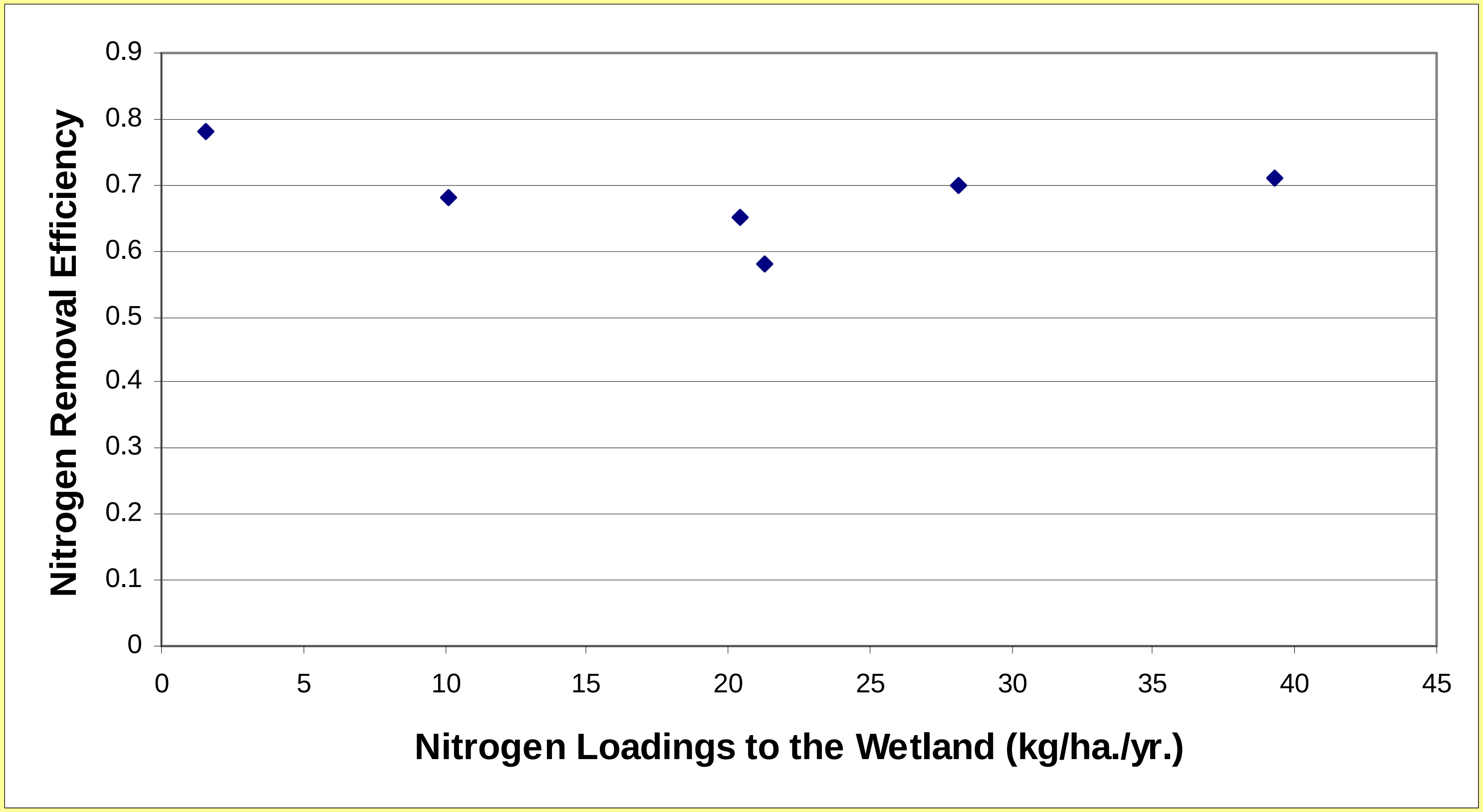
Nitrogen loading distribution based on AnnAGNPS model simulation



Wetland Nitrogen Removal Efficiency

Wetland	Drainage area (ha.)	The size of the wetland (ha.)	Total N flowing into the wetland (kg/ha/yr)	Total N flowing out of the wetland (kg/ha/yr)	N removal efficiency
1	217.1	4.3	21.3	8.9	0.58
2	389.9	7.8	28.1	8.5	0.70
3	340.7	6.8	10.1	3.2	0.68
4	375.3	7.5	20.4	7.2	0.65
5	94.1	1.9	39.3	11.5	0.71
6	384.4	7.7	1.6	0.3	0.78

Wetland Nitrogen Removal Efficiency

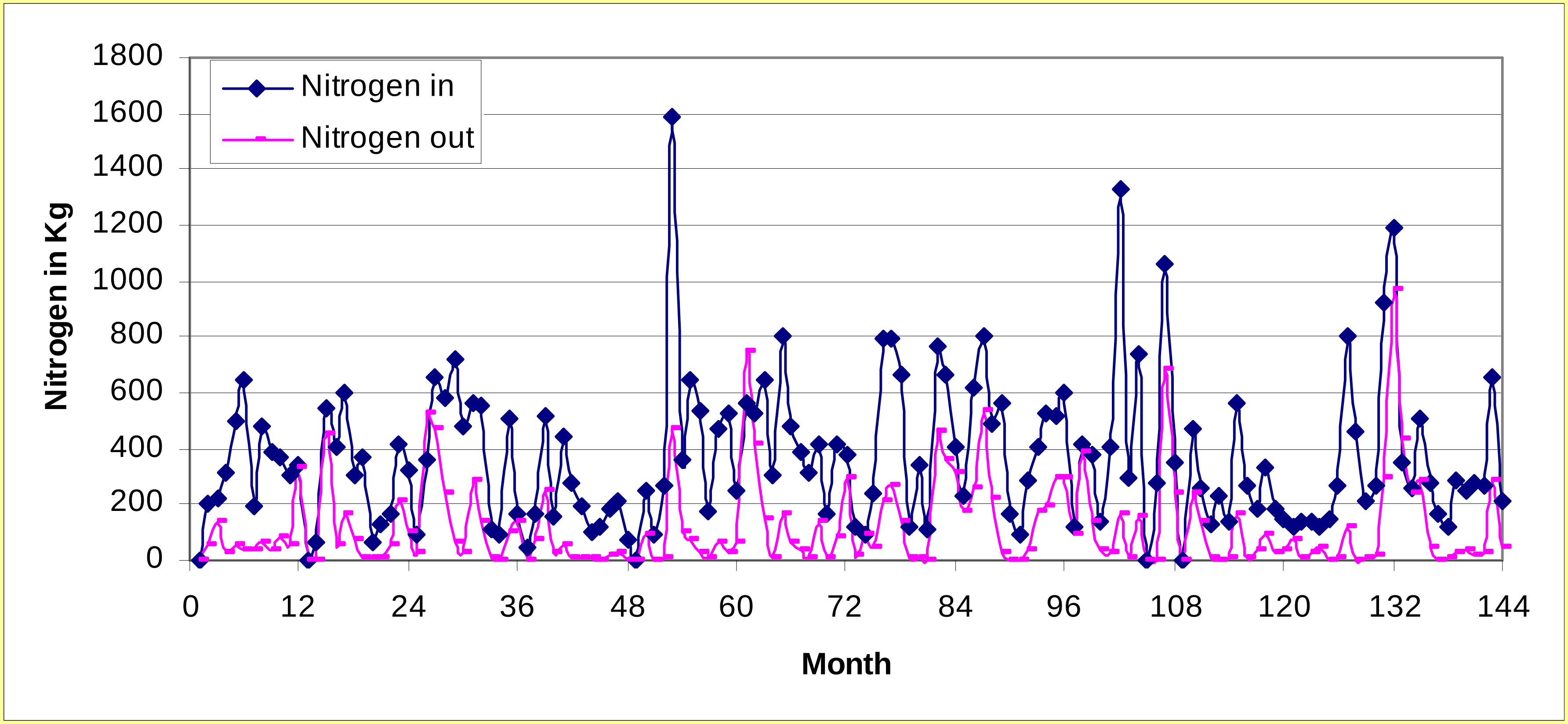


Wetland Nitrogen Removal Efficiency

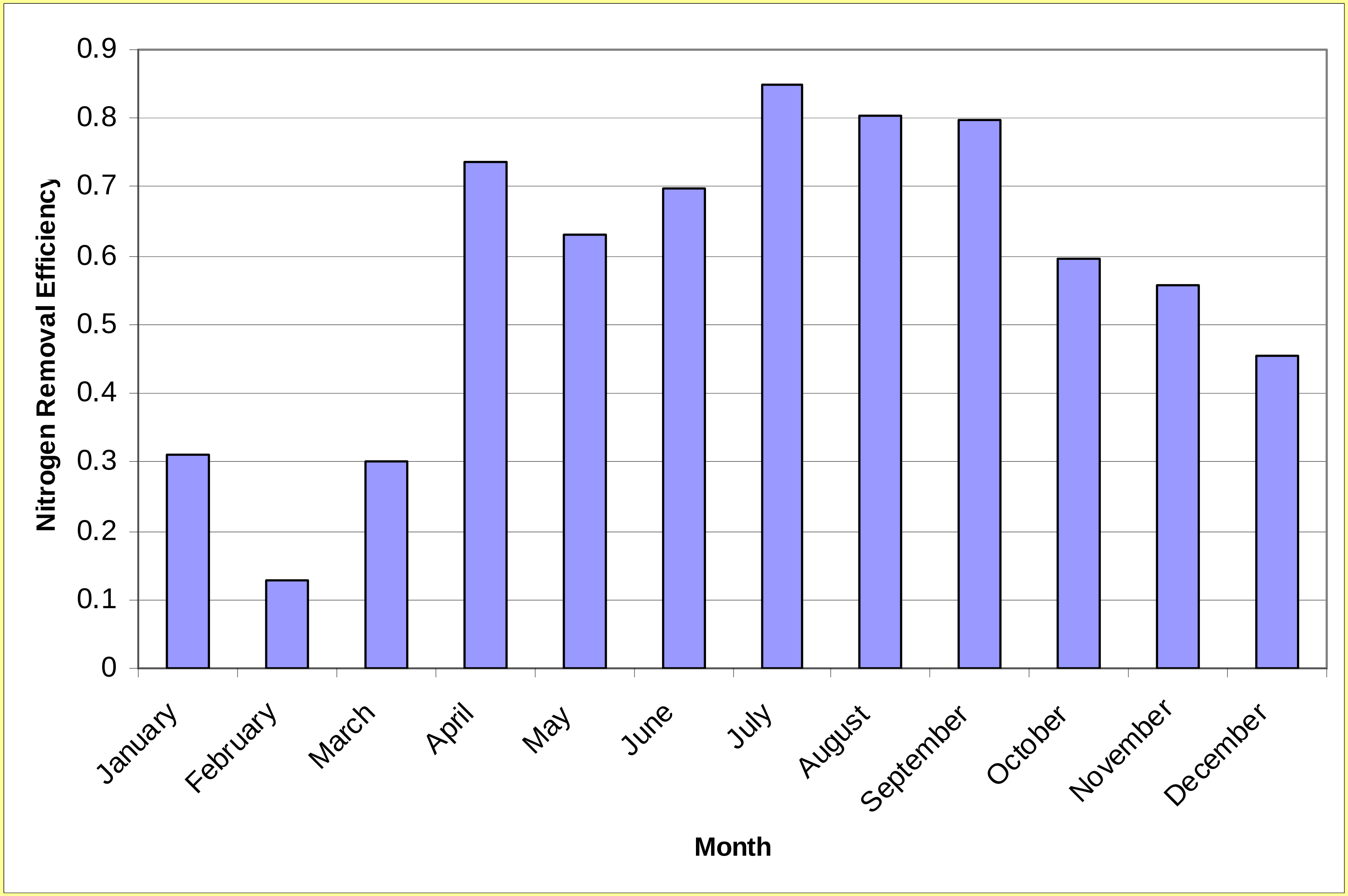
The impact of the first order loss coefficient k and size of the wetland

Wetland	Drainage area (ha.)	The size of the wetland (ha.)	Total N flowing into the wetland (kg/ha/yr)	Total N flowing out of the wetland (kg/ha/yr)	N removal efficiency
2 (k = 0.1)	389.9	7.8	28.1	11.5	0.59
2(k = 0.2)	389.9	7.8	28.1	8.5	0.70
2(k = 0.3)	389.9	7.8	28.1	7.0	0.75
4	375.3	7.5	20.4	7.2	0.65
4	375.3	1.9	20.4	10.0	0.51

Wetland Nitrogen Removal Efficiency



Wetland Nitrogen Removal Efficiency



Wetland Nitrogen Removal Efficiency

- Large wetlands, relative to the contributing drainage area, are the most effective at improving water quality.
- Wetland performance is highly sensitive to temperature and retention time which is controlled by the time series of the flow data.
- The greatest nitrogen removal efficiency can be achieved during low flow condition with a retention time of at least one-two weeks.
- Additional water quality benefits would be obtained when wetlands are incorporated with riparian buffer strips.

Directions for Future Analysis

- How do we evaluate the impact of nitrogen removal at a watershed scale or a regional scale?
- Where is the best location for establishing wetlands to achieve maximum nitrogen removal efficiency?


Questions?