RISK REDUCTION—WETLANDS FOR CONTROLLING REACTIVE NITROGEN

From Mitsch and Hey April 11

Once reactive nitrogen is released to the biosphere, the aquatic medium and specifically shallow-water wetlands and river floodplains offer the greatest opportunity for effective, efficient and sustainable control of reactive nitrogen. The argument of using these aquatic ecosystems as a principal means of control of reactive nitrogen does not diminish the importance of source control or recycling. If less reactive nitrogen is emitted, then less external control is needed. In some cases, however, source control can be ineffective, inefficient and not readily sustainable.

Restoring and creating wetland ecosystems along our streams and rivers and across our floodplains would give these landscapes a different look. Riverine shoreline morphology would need to be changed. Rather than defined riverbanks and channels, broad, shallow marshes would border slow moving, sinuous threads of open water measuring only a few feet deep. Grade controls, in the form of low weirs (e.g., beaver dams), would ensure adequate residence time for natural biochemical processes to reduce nitrogen loads. Of course the sinuous threads would need to give way to greater expanses of open water and deeper channels where other uses, such as commercial navigation, need to be accommodated. Levees would be breached (not removed necessarily) to allow the river to once again flow into and across its floodplain. Where row crop agriculture once was practiced, wetlands will be re-cultivated. No longer will there be a need to fertilize the floodplain, the reduction representing a form of source control, and the restored wetlands will reduce the load of reactive nitrogen relentlessly moving toward our coastal waters.

Not only will the morphology be changed but so will the hydrology, botanic structure and wildlife communities. Shallow water habitat encompasses the very morphology needed to maximize denitrification. The restored ecosystems, or riverine wetlands, will look, feel and function differently than the modern aquatic ecosystems. They will flood more frequently and extensively and they will retain water for longer periods of time. Plant and wildlife densities will be many times larger than those observed today. The new landscapes not only will control reactive nitrogen they will provide many other benefits: carbon, phosphorous and sediment sequestration, flood control, recreation, and biodiversity. How much land or what area of restored wetland would be required? There are two basic approaches for designing and restoring wetlands for the control of reactive nitrogen in the landscape (could use a figure; WJM can supply if needed)

1. Agricultural runoff wetlands—These wetlands receive flooded water directly from agricultural fields and remove a substantial amount of reactive nitrogen before the water reaches a ditch, stream, or river.
2. Diversion wetlands—These wetlands, which include wetland areas that occur naturally on floodplains, receive river floodwaters that naturally flood the floodplain, leaving reactve nitrogen behind or increasing denitrification as the water poinds on the floodplain or passes through the shallow groundwater.

Retention rates of nitrogen in these type of wetlands from around the world are summarized in Table x. A conservative estimate of the sustainable rate of total nitrogen retention in non-point source control wetlands such as those in these two categories from these studies is 50 g-N m^{-2} yr^{-1} (Mitsch and Gosselink, 2007). Given that retention rate, a restoration goal of 2 million ha of wetands in the Mississipppi River Basin would have the potential to retain 1 Tg of reactive nitrogen. This is 7 % of the total input of reactive nitrogen that enters the USA (CHECK: we USED 15 Tg total input). If we have a national goal of 4 million ha of restored and created wetlands as proposed by the National Research Council (1992), then wetlands could conceivably the wetlands would have a nitrogen retention of 2 Tg or 14% of the total input.

Table x. Reactive nitrogen retention in created and restored wetlands receiving low-concentration , i.e. agricultural runoff or river diversion nutrient loading from rivers, overflows, or non-point source pollution (from Mitsch and Gosselink, 2007)

Wetland, location and type	Wetland size, ha	Nitrogen, g-N m^{-2} yr^{-1}	Reference
WARM CLIMATE			
Boney Marsh, S. Florida	49	4.9	Moustafa et al., 1996
Everglades Nutrient Removal Project, S. Florida	1545	10.8	Moustafa, 1999
Restored marshes, Mediterranean delta, Spain	3.5	69	Comin et al., 1997
Constructed rural wetland, Victoria, Australia	0.045	23	Raisin et al., 1997
COLD CLIMATE			
Constructed wetlands, NE Illinois			Mitsch, 1992; Phipps and Crumpton, 1994
river-fed and high-flow	2	*11 - 38	
river-fed and low-flow	2 - 3	*3 - 13	
Artificially flooded meadows, southern Sweden	180	43 – 46	Leonardson et al., 1994
Constructed wetland basins Norway	0.035-0.09	50-285	Braskerud, 2002a,b
Created river wetlands, OH (2 wetlands; 10 years)	1	*58-66	Mitsch et al., 1998, 2005; Spieles and Mitsch, 2000
Created river diversion wetland, OH	3	32	Fink and Mitsch, 2007
Agricultural wetlands, OH	1.2	*39	Fink and Mitsch, 2004
Agricultural wetlands, IL (3)	0.3-0.8	*33	Kovacic et al., 2000

*nitrate-nitrogen only

Agricultural runoff wetlands

One of the most important applications of wetland treatment systems is the use of nonpoint source wetlands for treating subsurface and surface runoff from agricultural fields (Mitsch and Jørgensen, 2004; Mitsch and Gosselink, 2007; SEE CASE STUDY 1). Research projects illustrating the effects and functioning of these types of wetlands in agricultural watersheds have been carried out in southeastern Australia (Raisin and Mitchell, 1995; Raisin et al., 1997), northeastern Spain (Comin et al., 1997), Illinois (Kovacic et al., 2000; Larson et al., 2000; Hoagland et al., 2001), Florida (Moustafa, 1999; Reddy et al., 2006), Ohio (Fink and Mitsch, 2004), and Sweden (Leonardson et al., 1994; Jacks et al., 1994; Arheimer and Wittgren, 1994).

CASE STUDY 1 – Controlling reactive nitrogen with agricultural runoff wetlands

An agricultural runoff wetland was constructed in the spring of 1998 in Logan County, Ohio, USA, several kilometers upstream of a popular recreational lake in northwestern Ohio called Indian Lake. The multi-celled Indian Lake wetland was 1.2-ha and receives drainage from a 17-ha watershed, 14.2 ha of which was used for intensive row-crop agriculture and 2.8 ha of which was forested. Thus the wetland had a watershed ratio of 14:1. Surface inflow in 2000 was 646 cm yr^{-1} and groundwater discharge at multiple locations within the site amounted to almost the same amount of inflow (Fink and Mitsch, 2004). Surface water levels of a two-year period of study varied over 40 cm in depth; muskrat activity in one of the cells actually led to a 30 cm water level decrease in the second year of study. Overall, the wetlands retained 59% of total phosphorus, 59% of soluble reactive phosphorus, and 40% of nitrate/nitrite-nitrogen (Table x). Major storm events led to dramatic but short increases in water level of over 20 cm; these storm events, primarily in the late winter and early spring led to rapid flow. Investigation of selected storm events showed reductions of 28%, 74%, and 41% for total phosphorus, soluble reactive phosphorus, and nitrite/nitrate-nitrogen, respectively (Fink and Mitsch, 2004). The design of this wetland, with multiple cells and a watershed:wetland ratio of 14:1 appeared to be well designed to receive storm pulses of surface runoff coupled with more consistent yet also variable amounts of groundwater inflow. It was also able to accommodate some self-design imposed on the constructed basins by muskrats.

River Diversion and Floodplain Restoration

A somewhat different approach to cleaning up water is to pass river water through wetlands build on adjacent floodplains or backwaters. These are analogs of riverine oxbows or billabongs found throughout the world and have been shown to consistently improve water quality. These wetlands also are simulations of ag runoff wetlands, but with usually lower concentrations of nutrients. On the other hand, river sediment concentrations can be high, sometimes in excess of that found in agricultural runoff.

In Louisiana, the diversion of the Mississippi River at Caernarvon is one of the largest diversions in operation on the River aimed at restoring deteriorating wetlands in the Mississippi delta. The diversion structure on the east bank of the river south of New Orleans has a maximum flow of 280 m^3 sec^{-1}. Diversions such as this one in the Louisiana Delta are estimated to be key facilities for the restoration of the Louisiana Delta wetlands. The Caernarvon wetland retained 39 to 92% of nitrate by mass and concentration, depending on the sampling location in downstream Breton Sound. At the Caernarvon Louisiana sampling station that was most comparable to the Ohio diversion wetlands for loading rates, the nitrate-nitrogen retention was 55% by mass and concentration (Mitsch et al., 2005b).

In Midwestern USA, created riparian wetlands at the Des Plaines River Wetland Research Park in northeastern Illinois (Kadlec and Hey, 1994; Phipps and Crumpton, 1994 Mitsch et al. 1995) and the Olentangy River Wetland Research Park in central Ohio (Mitsch et al., 1998, 2005a,b,c) showed consistent patterns of nutrient and sediment retention have been observed over multiple years of study of these systems which both received pumped or overflow river water, thus simulating oxbow wetlands receiving dilute nonpoint source pollution. For 18-wetland years of measurements (2 wetlands x 9 years of measurements) at the Ohio experimental wetlands consistently reduced soluble reactive phosphorus and nitrate+nitrite-nitrogen about 75% 35% respectively.

One of the largest wetlands constructed for the control of nutrients in stormwater, the Everglades Nutrient Removal (ENR) project, a 1,544-ha marsh wetland systems created to remove phosphorus from waters emanating from the Everglades Agricultural Area (Reddy et al., 2006). In fact, this wetland pumps water from adjacent drainage canals so it is considered river diversion wetlands here. Over its first 6-year operating schedule (1994-99), the wetland decreased total nitrogen by 26% respectively (Gu et al., 2006).

CASE STUDY 2 Controlling Nitrogen in River Diversion Wetlands
A 3-ha created riparian wetland at the Schiermeier Olentangy River Wetland Research Park at The Ohio State University in Columbus, Ohio USA typically receives seven or eight natural weeklong flood pulses each year from the Olentangy River (Fink and Mitsch, 2007). Mean retention rates per flood pulse for nitrate-nitrite and total Kjeldahl nitrogen (TKN) were 0.71 g-N m^{-2} and 0.92 g-N m^{-2}, respectively resulting in an annual reductions of nitrate-nitrogen and total nitrogen of 74% and 41% by mass (Figure x). A greater attenuation of NO_3^- occurred in the emergent marsh section of the wetland than the open water section. Conversely TKN increased through the emergent marsh and decreased through the open water section. Overall, the created oxbow design was successful in removing nitrogen from flooding river water; it also provides an ideal migratory waterfowl habitat and has provided significant floodwater storage during flood periods.

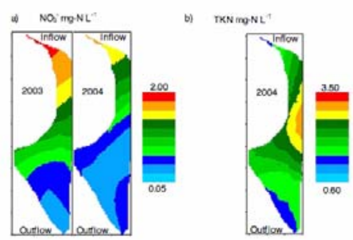

Figure x. Reduction in nitrate-nitrogen and total Kjeldahl nitrogen (TKN) in 3-ha created diversion wetland on Olentangy River in Columbus, Ohio (from Fink and Mitsch, 2007).

Restoration scale

For various reasons, wetland restoration has been proposed and the magnitude of needed restoration estimated. For the Wetland Reserve Program, the Farm Bill of 1990 set a goal, for the Wetland Reserve Program, of restoring a little over 400,000 hectare (approximately 1 million acres). The National Research Council (NRC, 1992) proposed a national goal of restoring 4 million hectares (10 million acres) of inland and coastal wetlands by 2010. The council went on to recommend that 640,000 kilometers (400,000 miles) of streams and rivers be restored by 2012 and that 400,000 hectares (1 million acres) of lakes be restored by 2000, both of which would further the control of reactive nitrogen. While none of these goals have been or are likely to be met by the recommended date, they articulated a need for wetland restoration addressing the important relationship between wetlands and water quality.

In 1994, as an answer to the enormous loss of property in the 1993 floods in the upper Mississippi River basin, 5.3 million hectares (13 million acres) of wetland restoration were proposed (Hey and Philippi, 1995). Along with the flood storage benefits, the authors noted the substantial collateral benefits to water quality. In the interest of exploring more efficient means of nitrogen and phosphorous control from wastewater treatment plants, the Water Environment Research Foundation (WERF) sponsored an economic comparison of using wetlands versus conventional treatment to meet the EPA's proposed nutrient criteria. The study showed that restored wetlands (the cost of land and restoration were included in the analysis) were more economical than conventional concrete and steel treatment, even though 200,000 acres were required. This land area represents half of the Illinois River's 160,000 hectare (400,000 acre) floodplain of which 80,000 hectares (200,000 acres) are currently leveed. The leveed lands would make ideal reactive nitrogen control points.

On a grander scale, Mitsch *et al.* (1999, 2001) and Mitsch and Day (2006) estimated that 2 million hectares (5 million acres) of restored wetlands could go a long way to controlling hypoxia in the Gulf of Mexico. A study conducted over five states of the upper Mississippi River basin: Missouri, Iowa, Minnesota, Wisconsin, and Illinois (Hey *et al.*, 2004; Table y) 9% of the five-state area falls within the Federal Emergency Management Agency's determination of the 100-year floodplain and over 43% (1.2 million hectares or 2.9 million acres) of the cropland in the floodplain were found on hydric soil. These lands would be suitable for wetland restoration and ideal for nitrogen control.

Table y. Wetland restoration opportunities in the upper Mississippi River basin (Hey *et al.*, 2004).

State	Total 100-Year Flood Zone (hectares)	Pre-settlement Wetlands (hectares)	Present Day Wetlands (hectares)	Present Day Cropland on Hydric Soil (hectares)	Total Present Day Cropland[3] (hectares)
Illinois	960,000	400,000	70,000	300,000	480,000
Iowa	2,800,000	900,000	100,000	400,000	1,100,000

Minnesota	930,000	510,000	200,000	70,000	140,000
Missouri	2,000,000	600,000	100,000	340,000	850,000
Wisconsin	810,000	370,000	200,000	110,000	230,000
Total	7,500,000	2,800,000	700,000	1,200,000	2,800,000

Project scale must be given careful consideration because its affects on the costs of hydraulic controls: pumps, berms and grading. Also, the pre-restoration land use will affect restoration costs if structures or hazardous materials must be removed. Location relative to the mass (load) and concentration of reactive nitrogen is extremely important. Further downstream, the load typically increases but the concentration of reactive nitrogen decreases and, at the same time, use conflicts and project costs increase. Morphologic changes are more expensive and difficult on larger, heavily used rivers. The closer the restored wetlands are to higher nitrogen concentrations, the more efficient the mass reduction processes will be. This would argue for restoration located further upstream in an agricultural watershed where NO_3 is concentrated in outlet ditches or near the outfall of a municipal wastewater treatment plant. Moving downstream, as reactive nitrogen becomes dilute, greater and greater wetland area will be needed for every ton of reactive nitrogen removed. Removing NO_3 from the Mississippi River at Baton Rouge, Louisiana will require a great deal more land, capital and energy than it would to remove a ton from the Skunk River at Ames, Iowa.

The availability of land, the presence of hydric soils, the access to conveyance systems (e.g. streams and rivers), and high concentrations and loads are all important factors in determining the best location for nutrient farming. Still, there are other concerns such as cost.

Summary

Restored wetlands represent the possibility of a large-scale, effective, efficient and sustainable solution to the threat of the growing presence of reactive nitrogen in the biosphere. Other control measures, such as source control, still will be needed but they do not offer the required magnitude of control and often result in adverse unintended consequences due to increased energy demand. On the other hand wetland restoration can and will result in numerous collateral consequences that are beneficial: carbon, phosphorous and sediment sequestration, flood control, wildlife habitat expansion, biodiversity maintenance, recreational opportunities and economic development. We estimate that a national strategic plan of wetland creation and restoration in the United States could lead to 2 Tg of reactive nitrogen removal in the USA, about 14% of the total atmospheric and agricultural input of reactive nitrogen to the country.

Research into the comprehensive environmental affects, economics and governance of using restored wetlands to control reactive nitrogen should be promoted. Some of the topics of particular concern include:

1. Production of greenhouse gas emissions under various design and operating conditions

2. Optimization of reactive nitrogen control
3. Bioaccumulation of such toxic substances when water is contaminated with such contaminants.
4. How this can be paid for by nitrogen farming and other mitigation approaches by municipal treatment companies and power utilities.
5. How will the wetlands created and restored be managed and monitored as to their effectiveness?

References

TO BE PROVIDED