MITIGATING URBAN WETLAND IMPACTS ON DOWNSTREAM WATER RESOURCES

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Abstract. Wetlands in older urban areas have often been integrated into stormwater management systems and exhibit severe degradation from receiving decades of untreated and uncontrolled urban runoff. Vegetative diversity is often poor and dominated by a few hardy species such as cattail (Typha latifolia) or reed canary grass (Phalaris arundinacea). These wetlands may also be affected by legacy impacts from agricultural uses that predate the urban development. Heavily impacted urban wetlands can become nutrient exporters, potentially degrading downstream water resources.

Wetland 639W in Crystal, Minnesota, lies just upstream of Upper Twin Lake, which is an Impaired Water (EPA 303(d) list) for excess nutrients. The wetland receives stormwater from a 1,010 acre urban watershed. The concentration of total phosphorus at the wetland outlet is roughly double the concentration at the wetland inlet, indicating the wetland is exporting phosphorus. Evapotranspiration by the dense cattail stands in the wetland basin significantly draws down surficial groundwater levels during the summer growing months, speeding soil mineralization and leaving the soil surface friable. Sheet flow over the wetland during storm events releases dissolved phosphorus from the mineralized soil and detaches and mobilizes soil particles and plant detritus.

In winter 2010-2011 the City of Crystal will modify the wetland outlet to limit outflow and restore a more natural wetland hydrology. This will reduce the periods of extended soil dryness and limit the direct discharge of phosphorus during smaller storm events. An upstream weir and overflow channel will provide a bypass for overflow and higher flows. The project is expected to reduce phosphorus export by an average 300 pounds per year.

INTRODUCTION

Wetlands are complex systems that provide a variety of ecological, chemical, and physical functions. From a surface water quality perspective, wetlands can be sinks, or repositories of pollutants such as phosphorus; they can be sources of pollutants; and they can be transformers, converting one form of chemical into another. Many wetlands perform all of these functions over the course of a hydrologic season.

These functions can be disturbed by both natural and human-induced change. Some of that change can be catastrophic to wetland functions: draining, filling, ditching, excavation, or other physical alterations to the wetland can significantly alter hydroperiod, vegetation, and soils. Wetland functions can also be disturbed through landscape changes that impact the wetland's surface and groundwater hydrology and alter the chemical and physical composition of water flowing into the wetland.

Increases in nutrients and sediment flowing into a wetland can saturate wetland soils with phosphorus, reducing the soil's capacity to adsorb new phosphorus and the wetland's function as a nutrient sink.

Land cover changes in the watershed such as increased impervious surface from urban development or agricultural drain tiling can increase the volume of runoff discharged to a wetland and alter the wetland's natural hydroperiod. These changes may also reduce groundwater recharge and lower surficial groundwater levels, which may alter groundwater contributions to wetlands or change their drawdown characteristics. Together these physical and landscape changes can transform wetlands from nutrient sinks to nutrient sources.

BACKGROUND

The Shingle Creek Watershed Management Commission, a joint powers board representing nine cities in suburban Twin Cities, Minnesota, is responsible for protecting and improving water resources in a 43 square mile, fully developed urban watershed. The presettlement prairie and savanna landscape was first converted to agriculture in the 1860's and then to urban and suburban uses in the 20th century. The lakes, streams, and wetlands in the watershed are heavily disturbed, and degraded by increased stormwater runoff, reduced groundwater recharge, and excessive nutrient and sediment loads.

The Watershed Commission and its member cities have for a number of years investigated ways to improve the Twin Lake chain of four lakes, especially the first lake in the chain, Upper Twin Lake (Figure 1), which is hypereutrophic, with excessive and prolonged algal blooms throughout the summer growing season. Summer clarity measured by Secchi depth can be as low as 0.2 meters. Upper Twin is connected by a short channel to the next lake in the chain, and outflow from the lake is the largest single source of total phosphorus to Middle Twin Lake.

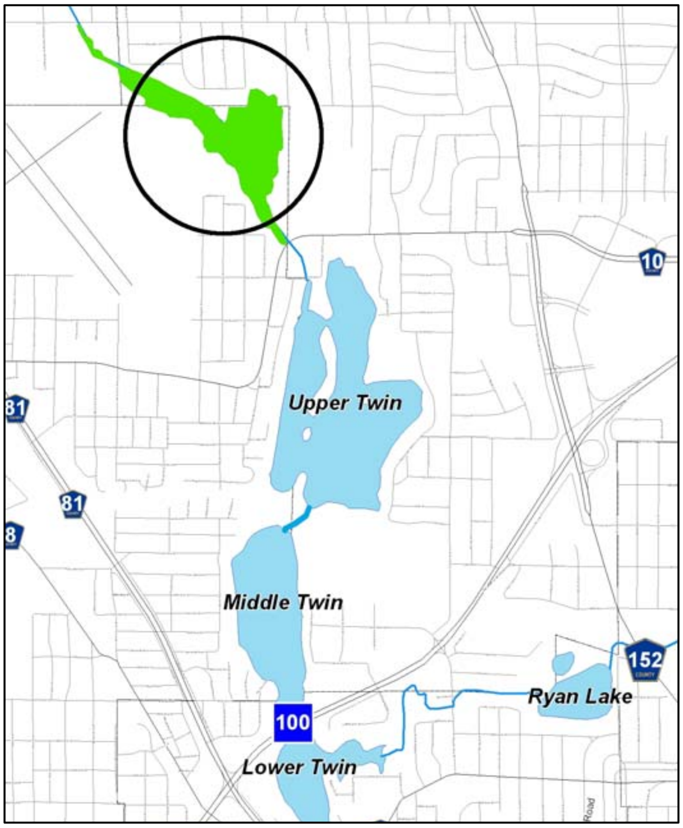

Figure 1. Wetland 639W is located just upstream of the Twin and Ryan Lakes chain.

Modeling and monitoring at lake outfalls in 1999 suggested that the subwatershed that outlets through a large flow-through wetland, which is known by its Minnesota Department of Natural Resources number, wetland 27-639W, was exporting more phosphorus to the lake than would be expected based on land use. Monitoring upstream and downstream of the wetland in 2002 confirmed that the 50-acre wetland was the likely source of the excess phosphorus, but the exact mechanism causing that export was not known. The Twin and Ryan Lakes nutrient TMDL estimated that the wetland exports 300 to 600 pounds of total phosphorus per year. The Upper Twin Lake TMDL requires an average annual load reduction of 750 pounds of total phosphorus per year. Diagnosing the cause of phosphorus export from wetland 639W and identifying a solution to reduce or minimize that export is the highest-priority implementation action in the TMDL.

DIAGNOSING THE PHOSPHORUS EXPORT MECHANISM

The Watershed Commission hypothesized that one or more of the following conditions were causing the export of phosphorus from the wetland:

1. Stormwater is conveyed through the upper wetland in a ditch (see Figure 2). At the wetland midpoint, just above the central wetland basin, channel flow diffuses into sheet flow. This sheet flow moves more slowly across the wetland basin, and becomes deoxygenated as vegetation and soils capture and use more dissolved oxygen than photosynthesis and reaeration can provide. Anoxia at the soil-water interface causes the reduction of iron compounds in the mineral soils, releasing adsorbed phosphorus in a dissolved form into the water column.
2. The wetland vegetation and soil dries out in summer, becoming friable. Periodic large events mobilize and flush organic material and detached soil particles out of the wetland and into the lake.
3. The wetland soils are saturated with phosphorus due to the transport of sediment and nutrients to the wetland from historic agricultural and urban stormwater and thus have reduced ability to adsorb phosphorus.

MONITORING PROGRAM AND RESULTS

The channel monitoring conducted in 2002 assessed flow, total phosphorus, orthophosphorus, total and volatile suspended solids, and nitrate. To better understand conditions in the wetland, in 2008 the Commission repeated the flow and water quality monitoring, adding a station at the wetland midpoint where the defined channel ends. In addition, groundwater elevations were monitored at various points in the wetland and the upland fringe, and soil cores were taken and analyzed.

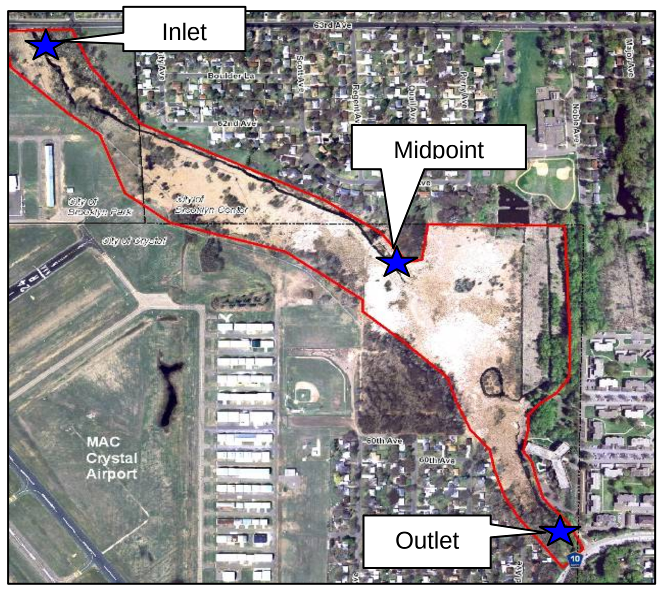

Figure 2. Surface water monitoring locations.

Flow and Water Quality Monitoring. Flow and water quality monitoring was conducted at the locations shown in Figure 1. 2008 was a very dry year (total annual precipitation = 20.5", compared to 28"-32" in an average year). In the spring and in the fall there was water in the channel at all three locations, but throughout the summer for the most part the stream was dry and no sampling occurred. In comparison, 2002 was a wet year (total annual precipitation = 43.3"), with flow in the channel season-long and nearly twice as many water quality samples taken. However, even in the dry year when there outflow from the wetland is much lower, total and dissolved phosphorus concentrations in channel flow increase significantly between the inlet and the outlet, indicating a net export of phosphorus.

Table 1. Wetland channel monitoring results.

		2002	2008
Inlet	Sampled flow (cfs)	11.6	0.88
	TSS (mg/L)	13.4	10.8
	VSS (mg/L)	7.2	10.5
	TP (mg/L)	0.15	0.24
	OP (mg/L)	0.06	0.10
Mid-point	Sampled flow (cfs)	n/a	0.47
	TSS (mg/L)	n/a	13.1
	VSS (mg/L)	n/a	10.3
	TP (mg/L)	n/a	0.18
	OP (mg/L)	n/a	0.06
Outlet	Sampled flow (cfs)	7.75	0.19
	TSS (mg/L)	50.3	11.6
	VSS (mg/L)	29.8	10.0
	TP (mg/L)	0.36	0.36
	OP (mg/L)	0.12	0.09

Soil Chemistry. Wetland soils serve as the medium in which chemical transformations take place and are the primary storage of available chemicals. Composition of a wetland's soil is dependant on both the parent material and the extent and duration of its saturation with water (Reddy and Delaune 2008).

The nature and extent of chemical transformation in wetlands is dependant on the chemical composition of the wetland organic and mineral soils. As the wetland becomes saturated, pore spaces in the soil fill with water and oxygen is no longer able to diffuse through, causing anaerobic or reduced conditions. The chemical transformation in the wetland is then driven by the redox potential of the wetland soils (Mitsch and Gosselink 2000).

To better understand the chemical transformations occurring in wetland 639W, soil cores taken at several monitoring well locations were analyzed by US Army Corps of Engineering staff at the Eau Galle Aquatic Ecology Laboratory in Spring Valley, Wisconsin. Sequential phosphorus fractionation was performed to determine the types of transformations occurring in the wetland.

In general, the soil cores were relatively high in organic content. The iron-bound phosphorus fraction was fairly high at monitoring sites MW-1, MW-2, MW-3, and MW-6 (Figure 3). This indicates that oxygen dynamics may be an important factor in the release of phosphorus from the wetland sediments. In addition, the testing revealed high concentrations of total phosphorus in the soil cores, which is indicative of saturation. The cores also exhibited a fairly low refractory component, which is indicative of high mineralization potential.

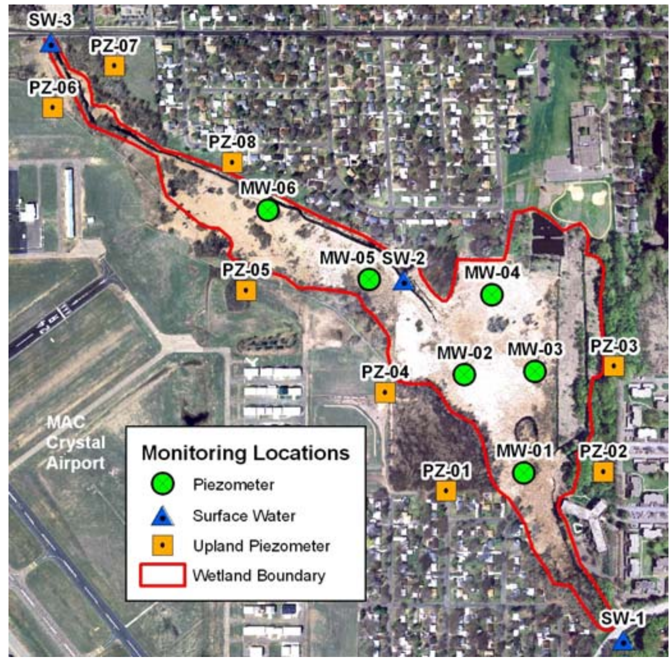

Figure 3. Groundwater monitoring locations.

Groundwater Elevation Monitoring. Groundwater plays an essential role in wetland hydrology and influences wetland biogeochemistry.

Wetlands transform and store phosphorus when plants uptake nutrients from the soil and from surface water. When the plants senesce and the remains accumulate in the wetland, the stored phosphorus becomes bound in the poorly degraded plant material or peat (Mitsch and Gosselink 2000). Peat stores phosphorus because the mineralization of the plant material is slow in the anoxic water of the wetland. When wetland soils are not saturated with water, the plant biomass is quickly broken down in the oxygenated conditions, increasing the rate of mineralization and making more inorganic phosphorus available for release as dissolved phosphorus.

Groundwater elevation was monitored at various locations in the wetland and in the upland fringe as a measure of soil saturation and to better understand how groundwater flows through the wetland. Figure 3 shows the locations where piezometers tracked changes in groundwater elevation, some throughout the entire monitoring period, and others for shorter periods or as part of a short-term monitoring of a transect across the wetland.

The groundwater elevation monitoring records at MW-1, 2, 3, and 6 in the central basin are striking. First and most obvious is a steep decline in groundwater elevation that starts in the spring and continues to about the end of October, as shown on Figure 4 for Monitoring Well 1.

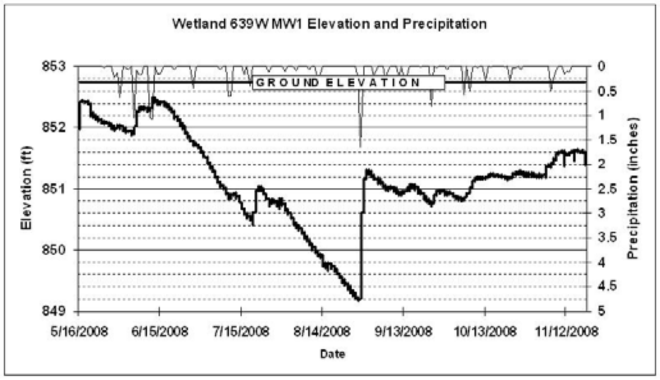

Figure 4. Groundwater elevation at MW-1, May-November 2008.

There are occasional ticks upward following rain events, but the elevation immediately starts to decline again. The second and less obvious feature is that by October the groundwater elevations, while varying with precipitation, generally level off. A wetland that is discharging to groundwater would be continually declining at a relatively steady rate, and at a lesser rate than what was measured during the summer.

The groundwater elevations and transects indicate that the general movement of groundwater in the wetland is from all directions to the central basin. This movement of groundwater to the central basin could be expected to stabilize groundwater elevations at that point. However, the elevations at MW-1 and MW-2 in the central basin indicate that groundwater elevations there drop just as much or even more rapidly as elevations elsewhere in the wetland.

Clearly there is some factor other than groundwater discharge that is causing the steep declines in groundwater elevation in the central basin of wetland 639W.

Typical of degraded urban wetlands, the vegetative diversity in wetland 639W is low. The central basin of the wetland is dominated by broadleaf cattail (Typha latifolia). The evapotranspiration crop coefficient for cattail is 1.20, compared to 0.85 for mowed turf grass in the warm season (ASCE 1996). A crop coefficient is the ratio between the maximum evapotranspiration of a species at a given stage in its growth and the potential evapotranspiration. The high crop coefficient for cattails, which is similar to rice, cotton, and clover hay, reflects their significant rate of evapotranspiration.

During periods of lower precipitation and runoff, when there is little to no standing surface water, cattails rely on groundwater for the water necessary for photosynthesis. 2008 was a very low precipitation year, and the groundwater monitoring measured a 2-3 foot drop in surficial groundwater over the summer growing season. The main basin of the wetland experienced extended periods of soil dryness, so then when rain events did occur, pulses of phosphorus were discharged from the wetland to the lake. These pulses were high in orthophosphate, which is the form of phosphorus that is most readily available for plant uptake and which fuels lake algal blooms.

CONCLUSIONS

A detailed analysis of the monitoring data presented in above and observation of conditions in wetland 639W suggests that the likely reason phosphorus is released from the wetland is the de-saturation of the central basin during the summer, likely by the dense cattails that dominate the basin.

This drying out has two effects. First, during the periods when groundwater is drawn down and is no longer saturated with water, the soil may become aerobic, and mineralize faster than it would were it saturated. Thus, instead of tying up organic phosphorus in slowly decomposing peat, the phosphorus is transformed into an inorganic form that is bound with iron as ferric phosphate. When the soil becomes flooded again, the ferric iron is reduced to more soluble ferrous compounds that are released into the water column and discharged in outflow from the wetland. Second, the vegetation and soil become friable, and as noted in the initial hypotheses, stormwater sheet flowing across the wetland mobilizes the organic material and mineralized soil particles and conveys them and the associated phosphorus load downstream to Upper Twin Lake.

MITIGATION STRATEGY

The Watershed Commission considered several options to reduce phosphorus export from wetland 639W. Complicating the effort was the wetland's location immediately adjacent to an airport. Any option that might result in increased areas of open water attractive to waterfowl would not be allowed. Removal of the cattails would not be allowed under Department of Natural Resources rules. Rerouting of stormwater, chemical treatment of outflows, and other engineering solutions were considered and rejected due to cost or ongoing maintenance issues.

Since the phosphorus export appears to be directly related to soil moisture conditions in the wetland, several options were considered to keep the soils wetter. There currently is no managed outlet for wetland 639W, which discharges into an outlet channel and then into Upper Twin Lake. The simple solution was to modify the outlet to retain more water in the wetland. This would be accomplished through the construction of a sheet pile weir along the “bottom” of the wetland (Figure 5).

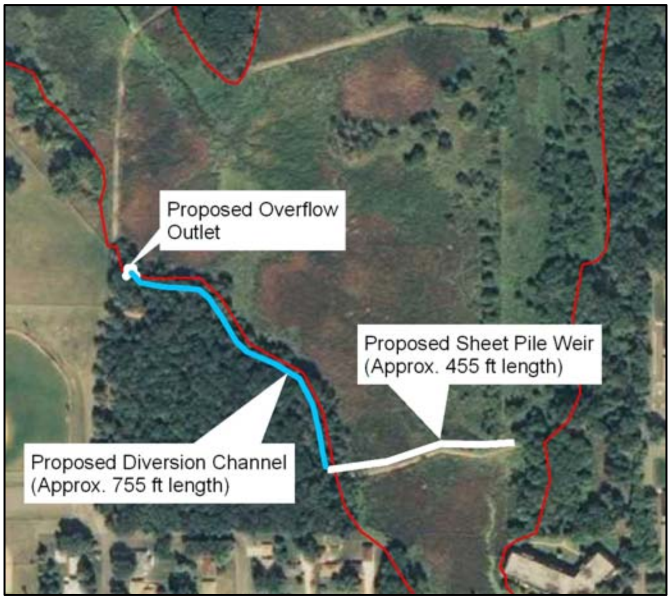

Figure 5. Proposed wetland outlet modification.

Because there are adjacent residential properties at low elevations, a new overflow outlet would be constructed at a point upstream of the central basin. This new outlet would discharge into a new channel to be constructed at the edge of the upland wooded area adjacent to the wetland. The channel would outlet through an existing swale downstream of the sheet pile weir. Water would be stored in the wetland until the elevation exceeds the elevation of the upper outlet, which would then begin to discharge into the channel. During larger events, the wetland would discharge both through the channel and over the top of the sheet pile weir. The project is expected to reduce phosphorus export by an average 300 pounds per year, a significant fraction of the 750 pound annual load reduction identified in the Upper Twin Lake TMDL.

This project will be constructed in 2011. Follow-up monitoring will be performed for a year following construction to document the success of the modified outlet structures in reducing the export of phosphorus from wetland 639W.

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