Michigan Department of Environmental Quality
Surface Water Division

Tollgate Stormwater Wetlands Monitoring Project

Section 319 Final Report

Prepared for:
Michigan Department of Environmental Quality
Surface Water Division

Prepared by:
Patrick E. Lindemann
Ingham County Drain Commissioner

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Tollgate Stormwater Wetlands Monitoring Project

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With technical assistance from
Tetra Tech MPS, Inc.

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EXECUTIVE SUMMARY

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
SURFACE WATER DIVISION
TOLLGATE STORMWATER WETLANDS MONITORING PROJECT

Stormwater runoff from urban watersheds transports a variety of nonpoint source pollutants to receiving waterbodies. These pollutants include nutrients, metals, sediment, oxygen-demanding wastes, and toxic organic chemicals. Urban stormwater runoff also affects the natural hydrology of receiving waters by changing the frequency and volume of peak flows. Constructed wetlands have recently become an attractive alternative to expensive, traditional structural facilities to control and treat urban stormwater while providing green space and urban wildlife habitat. Further documentation of the benefits of stormwater wetlands can help facilitate adoption by communities who need to develop stormwater management programs.

One such stormwater wetland facility, the Tollgate Wetlands, was built in 1998 in Lansing Township, Michigan, as a low-cost alternative to stormwater treatment. The Tollgate Wetlands receive stormwater runoff from 234 acres of residential and commercial properties, are 12 acres in size, and consist of a series of stepped ponds, waterfalls, wetlands, spillways, and a peat/sand filter. In 1999, the Ingham County Drain Commissioner received a Section 319 grant from the Michigan Department of Environmental Quality to study the Tollgate Wetlands. As a result, a short-term water-quality monitoring project was conducted from April to September 2000. The purpose of this project was to characterize the stormwater runoff entering the wetland, to increase public education regarding nonpoint source pollution prevention and the purpose of the wetland, and to document the operation and maintenance requirements to support the wetland.
Water samples and flow measurements were collected at three inflow sampling stations which each receive stormwater from a different land use including single-family residential, multi-family residential, and commercial development. One station was chosen at the outfall of the wetland, where treated water discharges. Each sampling station included an ISCO 6700 automated sampler and bubbler flow meter. Composite samples were taken for analysis of nutrients (ammonia nitrogen, nitrate + nitrite nitrogen, total Kjeldahl nitrogen, and total phosphorus), total metals (cadmium, copper, and lead), and total suspended solids. Mass loadings into and out of the wetland as well as the removal efficiencies of the wetland were calculated. In addition, acreage-adjusted loadings were calculated to compare loading contribution from each of the three inflow stations.

While the data from this study period are somewhat limited due to operational problems and the short study period, results indicate that the commercial areas within the Tollgate drainage district are responsible for the majority of the nonpoint source pollutant contribution, followed by single-family residential areas, and finally multi-family residential areas. The total mass of nonpoint source pollutants exported from the wetlands was significantly less than loading entering the wetland, indicating that the wetland was successful at reducing nonpoint source pollutant loads. In addition, it appears that the presence of the wetland appreciably reduces the volume of water that leaves the drainage district as surface runoff.

Numerous presentations given by Patrick Lindemann, Ingham County Drain Commissioner, as well as interactive trailmarkers around the Tollgate Wetland promoted the function and value of the Tollgate Wetlands and helped educate citizens about nonpoint source pollution prevention. The labor, equipment, materials, and mileage costs of maintaining the wetland were documented to assist in estimation of these costs for future expense projections.
INTRODUCTION

Stormwater runoff from urban watersheds transports a variety of nonpoint source pollutants to receiving waterbodies. These pollutants include nutrients, metals, sediment, oxygen-demanding wastes, and toxic organic chemicals. In addition to the health and environmental risks posed by nonpoint source pollution (NPS), urban stormwater runoff usually affects the natural hydrology of receiving waters by changing the frequency and volume of peak flows. Thus, municipalities must adopt management programs that address both the quality and quantity aspects of urban runoff. Stormwater programs typically employ a suite of structural practices, such as detention basins and infiltration ditches, in combination with nonstructural practices, such as street sweeping and public education, with the goal of maintaining natural flow conditions in surface waters and reducing nonpoint source loadings. Constructed wetlands have recently become an attractive alternative to traditional structural facilities, because these systems mimic the functions of natural wetlands, particularly the storage and treatment of stormwater, and are usually cheaper to build. Constructed wetlands can also provide green space and urban wildlife habitat and have been shown to increase property values and rental income (U.S. EPA, 1995). Further documentation of the benefits of stormwater wetlands in a variety of environmental, economic, and regional settings will facilitate adoption by communities who must develop stormwater management programs.

When the Tollgate Drainage District in Lansing Township, Michigan, was required to separate their combined sewer system, the community could not afford the more traditional approach to stormwater management, which was to redirect runoff to a nearby river by laying miles of pipe. Instead, the community chose to build a constructed wetland system that cost significantly less than the other options. In combination with redesigned water hazards in an adjacent golf course, the wetlands store and treat 99% of the drainage district’s runoff. This report describes the results of a pilot study to measure the efficiency of the wetlands system (not including the golf course water hazards) at removing nonpoint source pollutant loading. The study also includes an examination of the costs associated with maintaining the wetlands system and a list of activities
necessary for that maintenance. This information will be useful to other small communities considering the use of constructed wetlands as part of their storm water facilities. In addition, the pilot study provides the foundation for further research into how storm water wetlands function and how these systems can be integrated into existing neighborhoods.
BACKGROUND

The Tollgate Wetland facility in Lansing Township, Michigan, was created as a low cost alternative for combined sewer separation that included stormwater treatment of the separated flow. The Tollgate Wetland was designed in 1994 and constructed in 1996-1998 at a cost of $5 million, compared to the estimated $14 to $20 million pricetag of discharging the separated flow to rivers in the vicinity.

The Tollgate Drainage District is a 234-acre watershed consisting of single-family residential, multi-family residential, and commercial properties. The new, separated storm sewers direct runoff to 12 acres of constructed wetlands located to the west of the neighborhood. The constructed wetlands include a series of stepped ponds, waterfalls, wetlands, spillways and a peat/sand filter. These sequential best management practices (BMPSs) were designed to use biological and physical processes to reduce solids and sediments, buffer the pH, increase dissolved oxygen, reduce nutrient loads, and remove pathogens. During high flow events, water flows out of the lower pond of the wetland system into the redesigned water hazards of an adjacent golf course. The Tollgate Wetland also serves as a passive recreation and education amenity for the neighborhood.

In 1999, the Ingham County Drain Commissioner (ICDC) received a $37,840.00 Section 319 grant from the Michigan Department of Environmental Quality (MDEQ) to study the efficiency of the Tollgate Stormwater Wetlands at removing stormwater pollutants commonly found at high levels in urban runoff. The ICDC added in excess of $54,366 of in-kind contributions in the form of labor, supplies, and payment for contract services to augment the grant dollars. The funding was used to implement a short-term water-quality monitoring program from April to September 2000. The results of this short-term monitoring project are summarized in this report.
PROJECT GOALS AND OBJECTIVES

The project proposal submitted to MDEQ lists the following objectives to study pollutant loadings to and from the wetland and the operational and maintenance requirements of the system:

- To determine the quality and quantity of stormwater runoff from the drainage district to the Tollgate Wetland,

- To determine the treatment efficiency of the wetland at removing urban nonpoint source pollutants,

- To increase public participation and education regarding wetland function and nonpoint source pollution prevention, and

- To document the operation and maintenance requirements and associated costs for the wetland.
METHODS

TOLLGATE SAMPLING DESIGN

The Quality Assurance Project Plan (QAPP, Appendix I) describes the methods employed in this study; the QAPP was developed in conjunction with MDEQ and approved before project implementation. The QAPP served as the guiding document for all methods described below. The treatment efficiency of the constructed wetlands was evaluated by measuring pollutant loading entering and leaving the system. Previous studies on urban NPS have documented increased concentrations of nutrients, metals, and total suspended solids in storm water runoff. Reported concentration ranges for these pollutants in stormwater are listed in Table 1. The water quality parameters measured in the Tollgate study were chosen based on the information in Table 1 and available funding for laboratory analyses. The following water quality parameters were monitored in this study: ammonia-nitrogen (NH$_3$-N), nitrate + nitrite nitrogen (NO$_2$+3-N), total Kjeldahl nitrogen (TKN), total cadmium (Cd), total copper (Cu), total lead (Pb), total suspended solids (TSS), and total phosphorus (TP). Laboratory analyses were conducted by Fibertec, Inc. of Holt, Michigan, and the laboratory QAPP was submitted to the MDEQ with the project QAPP.

Water samples and flow measurements were collected at four sampling stations which were located to adequately represent the character and quantity of storm water flow. Storm water is conducted into the wetland via storm sewers. Under low flow conditions, water flows from the drainage district into a sand grit chamber and is then pumped to a waterfall at the top of the wetland system. During large storm events, some runoff bypasses the pump chamber at a weir in the sewers and flows directly to the lowermost detention pond of the system. To capture all runoff from the drainage district under both high- and low-flow conditions, three sampling stations were established in storm sewers upstream of the overflow weir. A single outlet in the detention pond directs overflow water from the wetlands system into the Groesbeck Golf Course, and a sampling station was established in the outlet sewer.
INSERT TABLE 1
The three stations above the wetlands allowed examination of stormwater runoff from three different land uses (single-family residential, multi-family residential, and commercial). The three inflow samplers were located at the corners of Magnolia Avenue and Hopkins Avenue (Magnolia/Hopkins), Fairview Avenue and Woodruff Avenue (Woodruff), and Fairview Avenue and Marguerite Avenue (Fairview/Marguerite). The Magnolia/Hopkins station drains single family residential areas, Woodruff drains multi-family residential areas (such as duplexes and apartments), and Fairview/Marguerite drains commercial areas. The outflow sampler was installed at the outfall pipe to the Groesbeck Golf Course water hazards, located under Wood Street. These four sampling locations are indicated on Figure 1, Station Location Map.

Each sampling station included an ISCO 6700 automated sampler and bubbler flow meter. The samplers were located in above-ground locked boxes at the Woodruff and Wood stations and on shelves in the storm sewers at the Magnolia/Hopkins and Fairview/Marguerite stations. Sampler intakes and bubbler lines were installed on stainless steel scissor-type O-rings mounted against the walls of the storm sewers. The samplers required marine batteries, which were loaned to the project by MDEQ. The samplers were programmed to calculate flow using Manning’s equation for round pipes with a roughness coefficient of 0.013 for concrete pipe. The four samplers collected flow-weighted composite samples during the months of April to October 2000.

Samplers were outfitted with three 2-liter bottles preserved in the following manner: 1) nitric acid for metals, 2) sulfuric acid for nutrients, and 3) no preservation for total suspended solids. These bottles were pre-acidified at the contract laboratory (Fibertec) to prevent microbial transformation of constituents while the bottles were in the field. Samples were taken at flow-weighted intervals, with samplers originally programmed to composite 100 ml samples every 0.075 Mgal. ICDC crew checked the sample bottles weekly and after storm events and collected samples when bottles were at least half full. Regular observation of the bottles was necessary because the samplers shut down when the bottles were full. During the study period, the original settings for flow intervals and sample volume were adjusted for some sites to increase sampling frequency.
After storms, ICDC crew collected bottles from the samplers and replaced them with clean bottles that had been washed and acidified by Fibertec. Each collected sample container was labeled in the field with a sampling station location ID and the type of preservative in the container. These samples were then transported on ice to Fibertec, who performed the analyses and forwarded the results to Tetra Tech MPS. During each visit to a sampler, field conditions, equipment problems, and cumulative flow volume data were recorded on prepared data sheets.

A rain gauge was also installed at the Tollgate Wetland to measure the frequency and volume of precipitation events. Because this rain gauge malfunctioned and was vandalized throughout the study project, a substitute rain gauge was needed to provide precipitation data. The Harton Street pump station rain gauge was deemed the best substitute because of its proximity to the wetlands.

Precipitation and discharge data were downloaded each time the samplers were visited, regardless of whether samples were collected each time, using an ISCO Rapid Transfer Device (RTD). The RTD and field sheets were delivered to TTMPS, where flow and precipitation data were downloaded and maintained in the project database.

**FLOW AND WATER QUALITY DATA ANALYSIS**

Concentration values were copied from each Fibertec analytical report and entered into the project database. Mass loading values were then calculated for each composite sample date for each station as follows. The cumulative flow volume (in Mgal) was summed at each site for each composite sample interval. Each resulting total flow was first multiplied by the corresponding concentration (mg/l) and then by a conversion factor (8.327) to transform the number into a mass loading value (in lbs). For non-detectable concentrations, a value of \( \frac{1}{2} \) the constituent’s detection limit (as defined by Fibertec) was used, with the corresponding mass loading calculations performed as above. These detection limits were set at 0.05 mg/l for NH\(_3\)-N, 0.1 mg/l for NO\(_2\),NO\(_3\)-N and TKN, 0.0005 mg/l for Cd, 0.025 mg/l for Cu, 0.003 mg/l for Pb, 2 mg/l for TSS, and 0.02 mg/l for TP.
For those composite sampling dates where the cumulative flow volume was not recorded, the following procedure was followed to estimate corresponding mass loading values at a station. At the conclusion of the project, mass loadings were calculated as above for each constituent where cumulative flow data were recorded for a composite sample date. Then, the ratio of concentration value to corresponding mass loading value was calculated for each composite sampling date. The average of these calculated ratios was then calculated for each constituent. This average ratio was then used to calculate mass loadings for those concentrations where cumulative flow volume was not available. This procedure was deemed the most feasible and logical method for estimating mass loads where the flow variable was not recorded. This method of estimating mass loads was used at each station where conditions were appropriate.

After the calculation and/or estimation of mass loadings for all constituents was performed, the mass loadings for each constituent were summed at each site to determine the total load of that constituent over the study period. The mass loadings for the three stations supplying stormwater into the Tollgate Wetland (input stations Fairview/Marguerite, Magnolia/Hopkins, and Woodruff) were then summed to determine the mass loadings of each constituent into the wetland (Mass_{in}). The mass loadings for the only output station, Wood, were used for mass loadings out of the wetland (Mass_{out}). The removal efficiency of the Tollgate Wetland for each of the eight constituents was then calculated using the following formula:

\[
\left(\frac{\text{Mass}_{\text{in}} - \text{Mass}_{\text{out}}}{\text{Mass}_{\text{in}}}\right) \times 100\% = \text{Removal efficiency}
\]

The removal efficiency reflects the percentage reduction in pollutant mass as a result of flow through the wetland system.

These total mass loadings were then standardized for accurate comparisons of contributions from the different land uses. This standardization was performed by...
dividing the mass loading for each constituent at an inflow station by the acreage of the
drainage area corresponding to that station. Fairview/Marguerite has a drainage area of
37.40 acres, Magnolia/Hopkins has a drainage area of 117.10 acres, and Woodruff has a
drainage area of 47.15 acres.
RESULTS AND DISCUSSION

WATER QUALITY MONITORING PROGRAM

Precipitation
Although the Tollgate rain gauge experienced problems that prohibited its function throughout much of the study period, use of the Harton Street rain gauge provided complete precipitation data for the entire study period. Appendix II illustrates the Harton Street precipitation data that was recorded during the study period. Review of Appendix II indicates that over 30 storm events occurred during the study period.

Flow
Appendix III contains hydrographs illustrating the patterns of flow at each of the four sites. Sampler problems delayed the onset of consistent and reliable collection of flow data at Magnolia/Hopkins, Woodruff, and Wood. Fairview/Marguerite was the only station to have flow data from the first month of the project. The samplers also experienced sporadic problems throughout the remainder of the study period, resulting in discontinuous flow data for the study period and/or missed storm sampling. The majority of these problems occurred in the first half of the study period (to July) and generally involved either batteries with insufficient power or reversed battery polarity, which damaged ISCO samplers, requiring removal and repair as a result. Fewer battery problems were experienced in the second half of the study period. Low battery voltage affected some of the sites for a few days at a time, but the samplers successfully collected flow and sample data for the vast majority of the second half of the study period.

Review of the hydrographs in Appendix III indicates that the three inflow stations, Fairview/Marguerite, Magnolia/Hopkins, and Woodruff, responded similarly to storm events. At these three stations, flow peaks and recedes very quickly during storm events, with little flow occurring during non-storm events. Throughout the study period, peak flows were between 40 and 50 cubic feet per second (cfs).
These hydrographs illustrate typical flow patterns for storm sewers draining urban areas. During and after a storm, runoff flows quickly off impervious areas and fills the storm sewers rapidly, resulting in the large pulse of water measured at sampling stations above the wetland. These flow patterns contrast with those seen at the outflow station Wood. Through the majority of the study period, Wood experienced maximum flow peaks of approximately 4 cfs. The timing of peak flow was not directly related to storm events or the peak flows observed at inflow stations because of the storage capacity of the wetlands. Peak flows at the Wood station are consistently one order of magnitude less than the peak flows recorded at the three inflow stations. The Wood hydrographs also illustrate that outflow water recedes much more gradually than the flashier inflow stations. In late September, field staff removed a large amount of debris that had collected in the outlet pipe near the ISCO sampler at Wood. After the removal of this debris, Wood flow peaked at 32 cfs before slowly returning over the next few days to previously observed flow levels around 4 cfs. The gradual recession curve after peak flow is most pronounced after this debris removal.

**Concentration**

Appendix IV lists the concentrations of the constituents as measured at the four stations throughout the study period from mid-April to September 2000. Review of Appendix IV indicates several patterns among the stations and land uses. Magnolia/Hopkins had the widest range of concentrations for NH$_3$-N, with a maximum concentration of 8.0 mg/l. Both Fairview/Marguerite and Woodruff experienced smaller concentration ranges, each having similar maximum values of 1.5 mg/l and 1.4 mg/l, respectively. The outflow station, Wood, experienced a similar range of concentrations as Fairview/Marguerite and Woodruff, with a maximum value of 1.1 mg/l.

All three inflow stations consistently experienced detectable levels of NO$_2$+3-N. Magnolia/Hopkins experienced the widest range of values (0.9 to 130 mg/l), followed by Woodruff (1.40 to 8.40 mg/l). Fairview/Marguerite experienced the smallest range of values (0.8 to 1.90 mg/l) compared to the other three inflow stations. Wood experienced a wide range of values from non-detectable to 9.30 mg/l.
Non-detectable values were reported for all four stations for TKN. Magnolia/Hopkins had the widest range of values and the highest concentration (2.80 mg/l), followed by Fairview/Marguerite (2.70 mg/l) and then Woodruff (2.20 mg/l). Wood had the smallest range of concentrations, with a maximum measurement of 1.20 mg/l.

All four stations also experienced non-detectable concentrations of Cd. While Woodruff had a consistent range of concentrations up to 0.006 mg/l, much higher values of 1.3 and 5.5 mg/l were also measured at this site. Both Magnolia/Hopkins and Fairview/Marguerite experienced similar ranges, with maximum values reaching 0.0092, and 0.008 mg/l, respectively. Concentrations at Wood reached a maximum value of 0.0043 mg/l.

All four stations experienced non-detectable concentrations for Cu. However, Magnolia/Hopkins was the only station of the four to have also experienced detectable concentrations of Cu, ranging from 0.028 to 0.390 mg/l.

Non-detectable values were also observed at all four stations for Pb, but all three inflow stations also experienced detectable concentrations. Fairview/Marguerite had the widest range of concentrations, with a maximum value of 5.40 mg/l. Magnolia/Hopkins had a smaller range of concentrations, with a maximum value of 0.029 mg/l, followed by Woodruff, which had a maximum value of 0.018 mg/l. Wood was the only station to have experienced non-detectable concentrations of Pb throughout the study period.

Measured concentrations for TSS varied widely among the four sites. Fairview/Marguerite had the widest range of concentrations, from non-detectable to 320 mg/l. Magnolia/Hopkins had a smaller range, from 3 to 179 mg/l. Woodruff also experienced non-detectable concentrations, with a maximum value of 38 mg/l. Wood experienced values ranging from 9 to 31 mg/l.
Magnolia/Hopkins experienced the widest range of concentrations for TP, from 0.035 to 0.550 mg/l. Fairview/Marguerite followed, with a range of 0.04 to 0.42 mg/l. Both Woodruff and Wood experienced non-detectable concentrations of TP, with maximum values of 0.31 and 0.19 mg/l, respectively.

Magnolia/Hopkins experienced the highest concentrations for all nutrients measured in this study (NH$_3$-N, NO$_{2+3}$-N, TKN, and TP). This station drains an area of single-family residential development, where the use and possible overapplication of fertilizers to maintain larger, greener lawns is most likely a source of nutrients. In contrast, both commercial and multi-family residential development, where fertilizer application is most likely reduced, have a lower range of concentration values. TSS concentrations were greatest at Fairview/Marguerite, which drains commercial areas. Each of the three inflow stations experienced the highest concentration value for one of the three metals measured during the study period.

**Mass Loadings and Removal Efficiency**

Mass loadings were calculated as described in the previous Methods section. However, cumulative flow measurements at each site as estimated by flow meters were not recorded by field crew personnel until the beginning of June 2000. As a result, mass loadings could not be definitively calculated for several composite sample dates. Mass loadings for these dates were calculated using the alternative method as described in the Methods section. Appendix V lists the calculated and/or estimated mass loadings for each constituent for each composite sample date. Those mass loadings that were estimated are indicated by an asterisk (*).

The total mass loadings for each constituent by site are presented in Table 2. In addition, Table 2 also shows the total mass loadings combined for all three input stations compared to the one outlet station as well as the calculated removal efficiency for each constituent. Table 3 presents the acreage-adjusted loadings for each constituent for each of the three inflow stations. Figures 1 through 4 illustrate the data shown in these tables.
INSERT TABLES 2 AND 3 (SAME PAGE)
Figures 2 and 3 illustrate the total mass loadings and acreage-adjusted loadings, respectively, for nutrients (NH$_3$-N, NO$_{2+3}$-N, TKN, and TP). For ease of interpretation, the land use corresponding to each station is also placed on the graph. Magnolia/Hopkins (single-family residential land use) contributed the most NH$_3$-N into the wetland, followed by Fairview/Marguerite (commercial land use), and then Woodruff (multi-family residential land use). A 98.39% removal efficiency for NH$_3$-N was calculated for the study period. When adjusted for acreage, however, Fairview/Marguerite contributed the most NH$_3$-N per acre (15.018 lbs/acre), followed by Magnolia/Hopkins (12.866 lbs/acre), and then Woodruff (3.753 lbs/acre).

Magnolia/Hopkins contributed the most NO$_{2+3}$-N into the wetland over the course of the study period. Woodruff contributed the second-greatest amount, with Fairview/Marguerite contributing the least. The removal efficiency for NO$_{2+3}$-N was 95.74%. The same contribution pattern is observed with acreage-adjusted loadings, with Magnolia/Hopkins contributing the most per acre (89.824 lbs/acre), followed by Woodruff (31.604 lbs/acre), and then Fairview/Marguerite (21.436 lbs/acre).

All three stations had relatively similar loading contributions for TKN during the study period. Magnolia/Hopkins contributed the most TKN, but only slightly more than Fairview/Marguerite. Woodruff contributed the least TKN, and removal efficiency for TKN was 90.81%. When adjusted for acreage, however, Fairview/Marguerite contributed the most TKN per acre (8.440 lbs/acre), followed by Woodruff (5.745 lbs/acre), and then Magnolia/Hopkins (3.042 lbs/acre).

Magnolia/Hopkins contributed the most TP to the wetland over the course of the study period. Fairview/Marguerite contributed the second-greatest load of TP followed by Woodruff. A 73.69% removal efficiency was calculated for TP. Review of the acreage-adjusted loadings indicate that Fairview/Marguerite contributed the most TP to the wetland per acre (2.919 lbs/acre), followed by Magnolia/Hopkins (2.083 lbs/acre), and Woodruff (0.829 lbs/acre).
Figures 4 and 5 illustrate the total mass loadings and acreage-adjusted loadings, respectively, for total metals (Cd, Cu, and Pb) and TSS. Woodruff contributed the most Cd over the study period, more than 325 times the contribution of Magnolia/Hopkins, the second-highest contributor, and over 1200 times the contribution of Fairview/Marguerite. Removal efficiency of Cd was 99.88%. The same pattern is apparent when adjusting the loadings for acreage, with Woodruff contributing the most per acre (6.753 lbs/acre), followed by Magnolia/Hopkins (0.008 lbs/acre), and Fairview/Marguerite (0.007 lbs/acre).

Magnolia/Hopkins contributed the most Cu to the wetland over the study period, followed by Fairview/Marguerite, and then Woodruff. A 92.05% removal efficiency was calculated. After adjusting the mass loadings for acreage draining to each station, the same pattern emerges. Magnolia/Hopkins contributed the most per acre (0.706 lbs/acre), followed by Fairview/Marguerite (0.222 lbs/acre), and Woodruff (0.103 lbs/acre).

Fairview/Marguerite contributed the most Pb to the wetland over the study period. Magnolia/Hopkins contributed the second-greatest loadings, and Woodruff contributed the least. Removal efficiency of Pb was calculated at 99.75%. The same patterns of contribution are seen after adjusting the loadings for acreage. Fairview/Marguerite contributed 9.522 lbs/acre, Magnolia/Hopkins contributed 0.046 lbs/acre, and Woodruff contributed 0.030 lbs/acre.

Fairview/Marguerite contributed the most TSS to the wetland over the study period, followed by Magnolia/Hopkins. Woodruff contributed the least loading of TSS into the wetland. A removal efficiency of 59.37% was calculated. Review of the acreage-adjusted loadings indicates that Fairview/Marguerite also contributed 526.785 lbs/acre, Magnolia/Hopkins contributed 166.242 lbs/acre, and Woodruff contributed 51.612 lbs/acre.

Review of Table 3 indicates that acreage-adjusted loadings for most constituents (NH$_3$-N, TKN, TP, Pb, and TSS) are greatest at Fairview/Marguerite, the station draining
commercial areas. Magnolia/Hopkins, draining single-family residential areas, contributed the greatest acreage-adjusted loadings for NO$_{2+3}$-N and Cu. Woodruff, draining multi-family residential areas, contributed the greatest acreage-adjusted loadings for Cd and contributed the lowest acreage-adjusted loadings for NH$_3$-N, Cu, Pb, TSS, and TP.

In general, those stations that contributed the greatest acreage-adjusted loadings for a constituent also tended to experience the highest measured concentrations. Likewise, those stations that had the lowest acreage-adjusted loadings for a constituent tended to have the lowest measured concentrations for that constituent. Exceptions include NH$_3$-N, TKN, and TP.

**Discussion of Water Quality Monitoring Results**

Review of the data collected during the study period indicates that Fairview/Marguerite, contributed the greatest acreage-adjusted loadings for five of the eight constituents of concern (including most nutrient constituents, Pb, and TSS). Magnolia/Hopkins contributed either the greatest or the second-greatest acreage-adjusted loadings for seven of the eight constituents (excluding TKN). Woodruff consistently contributed the lowest acreage-adjusted loadings for five of the eight constituents and the greatest loading for Cd. While the data from this study period are somewhat limited due to operational problems and the short study period, these results indicate that the commercial areas within the Tollgate drainage district are responsible for the majority of the NPS contribution, followed by single-family residential areas, and then multi-family residential areas.

The total mass of NPS exported from the wetlands was significantly less than loading into the wetland for most constituents, indicating that the wetland was successful at reducing NPS pollutant loads (see Table 2). However, the Wood station composite sample taken after removal of the debris dam resulted in anomalously high mass loading values for this period of time, particularly for nutrients, total suspended solids, and total
phosphorus, when compared to other samples during the study period at this site. Concentration values for TSS and TP were within the normal range of values seen during the study period, and concentration values for nutrients were non-detectable. The large amount of water leaving the wetland during this composite sample period, however, transformed these concentration values into high mass loading values for this period. The removal of the debris dam caused a surge of water to leave the wetland, possibly disturbing sediment in the lower detention pond. Because of the short time period of this study, the concentration spike after clearing the outfall pipe may have resulted in overestimating the normal export load of the wetlands, and thus an underestimation of the removal efficiency of some constituents.

It is difficult to make direct comparisons of pollutant removal efficiencies because storm water wetlands design varies so dramatically from site to site. Important variables affecting potential removal efficiency of a storm water wetland include size, design volume, depth, vegetation, and residence time (Schueler, 1992; Kadlec and Knight, 1996; Kuehn and Moore, 1995). For example, an extended detention wetland may, by nature of its design, exhibit lower removal efficiencies for nutrients than shallow marshes or pond/wetland systems (Schueler, 1992). In addition, climatic conditions and precipitation volumes are not consistent for studies described in the literature. Two other factors make cross-study comparisons of removal efficiencies difficult. First, some studies base their removal efficiencies on concentrations, not loads, and many of these studies do not list the formula used to make those calculations. Secondly, the study period varies from project to project, and seasonal variations in pollutant removal rates may be significant. Nevertheless, the results of this study compare favorably with the range of removal efficiencies reported in other studies. In a handbook on the design of storm water wetlands, Schueler (1992) presents a table of removal efficiencies culled from the literature. In the studies summarized in that table, efficiencies for TSS ranged from 20-98%, TP from –2-97%, NO₃ from 4-95%, TKN from –10-40%, and Pb from 6-90%. Clearly, more research into the processes that have contributed to the high removal efficiency of the Tollgate Wetlands would improve the design of these systems in other locations in the Great Lakes region. Kuehn and Moore (1995) found that performance of
treatment wetland ponds designed to be identical is fairly consistent in similar environments, and thus, the Tollgate Wetlands could be a model for other communities in this region.

In general, several environmental benefits of storm water wetlands are tentatively confirmed by this study. First, the hydrographs illustrate that the large volume of stormwater that rushes into the Tollgate Wetland during a storm event is detained by the wetland and is slowly discharged over a period of time after the storm. Since the study period occurred during the growing season, the difference in flow into and out of the wetland may be a combined effect of storage and evapotranspiration, as well as infiltration into the groundwater system. Continuation of monitoring over several years would provide an opportunity to more fully develop a water budget for the wetlands system to examine seasonal differences.

A second benefit of the Tollgate Wetlands shown by these results is the reduction in NPS loadings as storm water moves through the system. Mechanisms for pollutant removal in constructed wetlands include uptake by vegetation and microbes, filtration and sedimentation, sorption on vegetation and particulate matter, and transformations that remove the pollutant from the system (i.e., denitrification) (Kadlec and Knight, 1996; Schueler, 1992). Some of these processes are biological and should thus be expected to exhibit seasonal variations. For example, release of NPS pollutants when vegetation dies off and decays after the growing season has been documented in several wetlands (Raisin and Mitchell, 1995). Again, seasonal variability in removal efficiencies at the Tollgate wetlands could be described by continuous monitoring over several years. Further monitoring targeted at some of the specific processes mentioned above would also provide a better understanding of the mechanisms responsible for pollutant removal.

**PROBLEMS ENCOUNTERED**

As previously mentioned, several problems occurred during the study period. Remedies were employed, however, that corrected most of the problems and allowed the project to proceed effectively.
Poor quality of field notes at the beginning of the project resulted in the loss of flow data essential to the calculation of precise mass loadings into and out of the Tollgate Wetland system. Upon being deployed on the project, Tetra Tech MPS implemented methods for proper data collection techniques, including the use of standardized field data sheets. Once these new methods were incorporated, more reliable data were generated.

The ISCO samplers suffered a series of battery problems, traced to the supplier, which resulted in no collection of data for periods of time during the first half of the study period. Once the problems were detected, the batteries that were faulty were replaced, and the samplers that were damaged were repaired. After these corrections, data collection occurred consistently. In addition, increasing the frequency of visits to the stations by the ICDC Crew enabled early detection of failing batteries and prevention of data loss.

Throughout the course of the project, several adjustments were made to the sampler programs to change the sampling interval or volume of sample taken in an attempt to coordinate bottle collection from all stations at the same time. While improvements were made in this respect towards the end of the project, it will never be possible to perfectly coordinate samplers to collect the same volume of water over the same time period. This is due in part to size and land cover variations among drainage areas, and also to the fact that there is no way to anticipate the volume of precipitation, and thus flow, that will occur during a particular time period. If more funding had been available for laboratory analyses, sample volumes would have been increased and bottles would have been collected more frequently. However, the samples may then have been serially correlated, so some further compositing or averaging would have been required. Because the main objective of this study was to evaluate the removal efficiency of the wetland over the entire study period, collecting sample bottles from samplers at different intervals should have no effect on the results as long as cumulative flow measurements coincide with sample collection.
The rain gauge at the Tollgate Wetland system did not function for a large portion of the study period. Unfortunately, the gauge was repeatedly vandalized and sent to ISCO for repairs, and towards the end of the project it would not download properly. Data from the Harton Street pump station three miles from the Tollgate Wetland system was used as a substitute to depict adequately the frequency and intensity of storm events within this area.

Removal of the debris dam in late September allowed some pollutants to become resuspended in the flow leaving the wetland. This resuspension caused higher levels of pollutants to be detected at Wood than would most likely be present under normal flow conditions. For future monitoring events, it is recommended that small debris dams be cleared out as soon as observed to prohibit similar pollutant-laden discharges. In addition, observing the effect of this removal also illustrates the need for diligent maintenance and dredging of wetland sediment.

PUBLIC INVOLVEMENT

Since the beginning of 1999, the Ingham County Drain Commission has conducted over 60 presentations regarding nonpoint source pollution and the benefits of the Tollgate Wetland facility as a man-made feature that can help remove nonpoint source pollution from urban stormwater. Appendix VI, Public Involvement and Public Outreach, lists the numerous presentations given by Patrick Lindemann regarding the Tollgate Wetland from January 1999 to December 2000. These presentations were given to widely-varying audiences, including elementary school children, college students, non-profit organizations, and governmental officials. In addition, these presentations were held across the region, giving the Tollgate Wetlands exposure to those living outside of the Tollgate Drainage District.

In addition, as an intern with the ICDC, John Lindley created the Tollgate “Living Classroom,” which consists of a series of informational signs posted along the wetland path, to educate the visiting public about the purpose, features, and processes of the Tollgate Wetland.


OPERATIONS AND MAINTENANCE

The Tollgate Stormwater Wetlands are operated as a stormwater facility, not as a park, so operational activities are geared towards maintaining wetland functions and public safety, rather than a park-like setting. Maintenance activities over the past two years were conducted primarily during the growing season. The perimeter of the wetland was mowed every 30-45 days as needed. Trash was picked up approximately once every 30 days. The limestone cascades were inspected for algae build-up at the same time and cleaned as needed. Pumps and control panels were checked every month, or more frequently if problems were encountered. Both pumps were rebuilt in 2000. The reeds in the first two ponds were trimmed in Fall 1999 by Michigan State University students performing community service for their role in the 1999 riots. Cattails were removed from the outlet of the first pond in 2000 to improve flow into the second pond. Signage was inspected every six-eight weeks and replaced if needed. The relief pipes from the sand/peat filter were cleaned occasionally. The grit chamber has been cleaned once since construction, and approximately one foot of sediment, litter and leaves were removed. Some of the stonework was remortared in 1999. Local cattails and bulrushes were transplanted from an ICDC wetland in Meridian Township to the sand/peat filter. Muskrats were trapped and removed approximately 10-12 times during 1999 under a special MDEQ operations permit. During 1998, which was not part of this grant period, the summer was so dry that the ICDC crew watered upland trees by injecting water to the roots 7-8 time over the summer months. Wood duck and bluebird boxes were built and installed on the island and in trees within the first pond in both 1999 and 2000.

Appendix VII lists the expenses incurred during 1999 and 2000 for operation and maintenance of the Tollgate Wetland. In 1999, 290 labor hours (at a cost of $10, 892.73) were spent at the Tollgate Wetland, compared to 96.5 labor hours ($3,630.44) in 2000. A total of 181 hours of equipment use ($2,229.35) were charged in 1999, and 85.5 hours ($948.39) were charged in 2000. A total of 1461 miles, translating to a cost of $430.66, were documented during 1999, while 716 miles ($214.80) were documented in 2000. The cost of materials that were used to maintain stability and flow through the wetland

Tollgate Stormwater Wetlands Monitoring Project
cost $378.13 in 1999 and $983.23 in 2000. These materials included grass seed, straw, redimix, topsoil, fittings, foam, sandbags, floats, and circulation pumps.
CONCLUSIONS

This short-term monitoring program, conducted from mid-April to September 2000, had four main goals and objectives:  1) to determine the quality and quantity of stormwater runoff from the drainage district to the Tollgate Wetland, 2) to determine the treatment efficiency of the wetland at removing urban nonpoint source pollutants, 3) to increase public participation and education regarding wetland function and nonpoint source pollution prevention, and 4) to assess the short-term operation and maintenance costs of the wetland.

The results of the water quality monitoring section of this project (Objectives 1 and 2) suggest that the wetlands system may significantly improve the quality of storm water from the Tollgate Drainage District, as well as appreciably reducing the volume of water that leaves the drainage district as surface runoff. More long-term study is necessary to fully understand the temporal variability of the wetland’s treatment functions and the processes responsible for pollutant removal.

The third objective was to increase public participation and education regarding wetland function and nonpoint source pollution prevention. Over 60 presentations were given by Patrick Lindemann to various audiences throughout Michigan regarding the Tollgate Wetland and its functions in 1999 and 2000. In addition, a series of permanent, educational signs installed along the path around the wetland educates the visiting public about the physical and biochemical features of the wetland.

The fourth objective was to assess the short-term operation and maintenance costs of the wetland. Documentation of tasks needed to maintain wetlands function, along with labor, equipment, materials, and mileage costs for 1999 and 2000, are presented to assist in estimation of these costs for future expense projections.
This project was a success in that it demonstrated several theoretical benefits of wetlands, such as nonpoint source pollutant removal and detention of stormwater flow through wetland processes. The project allowed improved insight into the characteristics of the Tollgate Drainage District, such as the spatial and temporal distribution of NPS pollution in stormwater runoff. By providing information on flow patterns and mass loading values, more specific questions regarding stormwater quality and quantity are prompted and can become the focus for future long-term monitoring projects. In addition, characterizing the constituents that are being contributed by the drainage areas can allow specific educational and preventative efforts can be focused towards people living in each of these drainage areas.

The information presented in this final report can be used as a basis for pursuing grants for proposed long-term monitoring projects, such as the National Demonstration Grant Program. Ideally, a long-term monitoring program would be designed to measure more rigorously the quality and quantity of nonpoint source pollutants generated, transported, retained, and transformed in an urban watershed and stormwater wetlands system. The educational and public participation information can be used as a basis for developing a program to evaluate the motivating factors and effect of human behavior change over time in support of water quality improvement.
BIBLIOGRAPHY


Appendix I
Quality Assurance Project Plan (QAPP)
Appendix II
Harton Street Precipitation Data
Appendix III
Flow Data for the Four Stations
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Concentration Data for the Four Stations
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Mass Loading Values for the Four Stations
Appendix VI
Public Involvement and Outreach Activities
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Operations and Maintenance Information