Final Report
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Monitoring the Long-term Effectiveness of Metropolitan Cold Weather BMPs, Long-term Assessment of Phosphorus Free Fertilizers and Golf Course BMPs.

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Objectives: The objective of this project was to evaluate the effectiveness of select alternative urban best management practices (BMPs) including infiltration areas called rain gardens, the effects of adoption of a municipal phosphorus free fertilizer ordinance on phosphorus loss from lawns to surface waters, a stormwater treatment train on golf course runoff quantity and quality, and a three-cell nutrient detention basin.

I. Lawn Fertilizer Runoff Monitoring – Paired Watershed Study

Methods

Six small residential sub-watersheds were monitored from 2001 to 2006 to characterize residential runoff and track changes in phosphorus concentration and export associated with the use of phosphorus free fertilizer. The study design utilized a paired-watershed approach where three of the sub-watersheds were located in the city of Plymouth, Minnesota where the use of lawn fertilizer containing phosphorus was restricted in 1999, (treatment watersheds); the remaining three sub-watersheds were located in Maple Grove, Minnesota where phosphorus fertilizer restrictions were not initiated until 2004, (control watersheds). These sub-watersheds were carefully selected to include one newly developed area less than 5-years old, (P1 and MG1), one development between 5 and 15-years old (P2 and MG2), and one neighborhood older than 15-years, (P3 and MG3), within each of the municipalities, (Figures 1 and 2). The sub-watershed areas were located within 10 kilometers of each other to minimize differences in precipitation patterns, soil types, and aerial phosphorus loading.

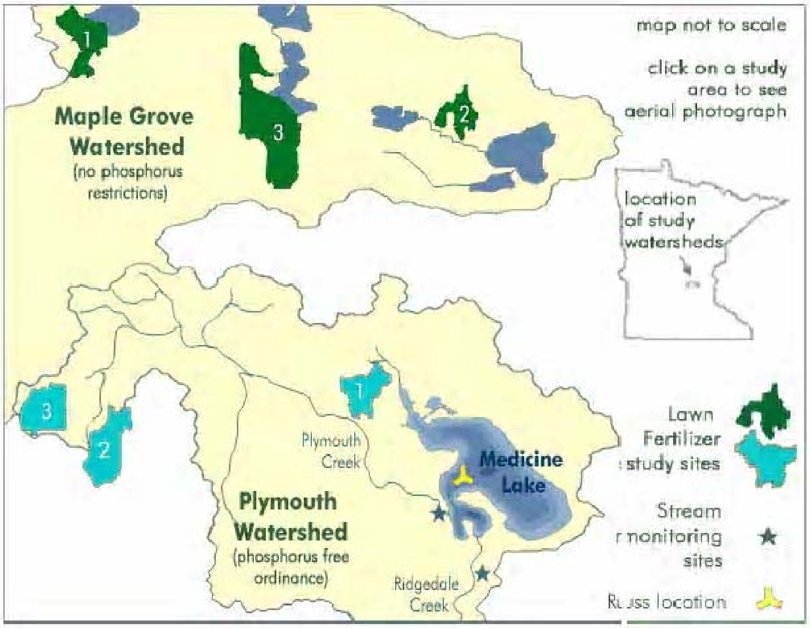

Figure 1: Map showing the relative location of the study sub-watersheds in Plymouth (south) and Maple Grove (north), MN.

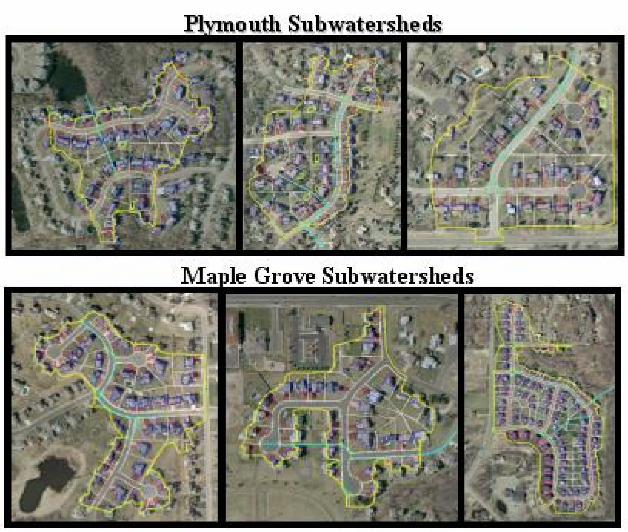

Figure 2: Maps of the six sub-watersheds (P1-MG1, P2-MG2, and P3-MG3 sequentially),monitored from 2001 to 2006.

To ensure similarity in physical characteristics of the sub-watersheds, the amount of impervious and connected impervious surface area in each sub-watershed was measured, (Table 1), the soil phosphorus fertility concentration was measured, and lawn-care practices including fertilizer use were determined, (Table 2). Impervious area was measured with aerial photography and desktop geographic information system software,

and field verification. Public surveys were administered to a portion of the homeowners by local high school students to characterize lawn-care practices including fertilizer application, watering, mowing, and soil aeration. Soil fertility characteristics were determined through soil sample collection at 10% of lawns within the sub-watersheds. These samples were analyzed for nutrient levels, organic matter, particle size, pH, and soil compaction.

Table 1. Selected physical characteristics of Plymouth and Maple Grove sub-watersheds.

Sample site	Size (Ha)	Number of homes	Impervious area (%)	Connected Impervious (%)
P1	5.1	43	38	23.9
P2	6.8	47	35.1	22.9
P3	5.6	37	27.3	17.8
MG1	5.5	49	40.5	26.2
MG2	3.5	36	38.8	25.9
MG3	16	108	34.8	21.1

Stormwater runoff from each of these residential areas drained into catch basins and was transported off site by underground storm sewer pipes. Automated monitoring equipment (computer data logger with associated velocity/level sensor slaved to an automatic sampling unit) was installed in each storm sewer system at the outlet point of each sub-watershed. The data logger recorded water level and water velocity in the storm sewer at 15 minute intervals from approximately April 15 to November 1 each year during the study period.

A stage-discharge relationship for each site was developed from the Mannings equation for each storm sewer. Discharge estimated from the Mannings equation was verified by periodically measuring the velocity of storm water flow utilizing a pulse Doppler velocity sensor. Calibration of the velocity probes was completed utilizing a portable velocity meter calibrated in the laboratory. Level readings for each probe were verified by staff gauge readings taken weekly during the monitoring period.

Stormwater samples were collected during rainfall runoff events and baseflow conditions at discrete flow volume intervals. The discrete samples collected during a specific rainfall event were discharged into a single container to produce a flow weighted sample for the event. Samples were removed from the monitoring devices at each site within 12 hours following the end of the runoff event. The samples were placed on ice in the dark and transported to the laboratory. Analysis of samples was completed within 48 hours of receipt by the laboratory. Laboratory analytical protocol and chain of custody protocol follow requirements of the Minnesota Department of Health Laboratory Certification requirements.

For each sampled flow event, the load of total phosphorus, dissolved phosphorus, total nitrogen, and suspended solids from each watershed were calculated using the observed flow-weighted event mean concentration and the total event flow volume.

Table 2. Soil phosphorus concentrations and fertilizer use in six residential sub-watersheds in Plymouth and Maple Grove, MN, in 2001.

Sample site	Soil phosphorus concentration (% of lawns)			Fertilizer applied	Phosphorus fertilizer applied
	>50 ppm	**25 – 50 ppm**	**<25 ppm**	**%**	**%**
P1	**36**	**57**	**7**	**100**	**44.4**
P2	**90**	**10**	**0**	**72**	**20**
P3	**89**	**11**	**0**	**76**	**21**
MG1	**92**	**8**	**0**	**100**	**64**
MG2	**78**	**22**	**0**	**89**	**83**
MG3	**43**	**26**	**30**	**92**	**74**

Lawn Fertilizer Runoff Monitoring – Paired Watershed Study

Results

Runoff samples and flow data were collected from approximately 570 rain events during the monitoring period, equally distributed among the six sites. The data showed that areal runoff volume increased substantially for rainfall events greater than 2 cm (Figure 3). For rainfall events less than 2 cm, the runoff volume could be accounted for by estimating the rainfall volume falling on impervious surfaces such as streets, driveways and rooftops. For events greater than 2 cm, however, runoff from impervious surfaces alone could not account for the total runoff volume, indicating that runoff from pervious surfaces (lawns) was occurring. All six sub-watershed sites showed a similar pattern.

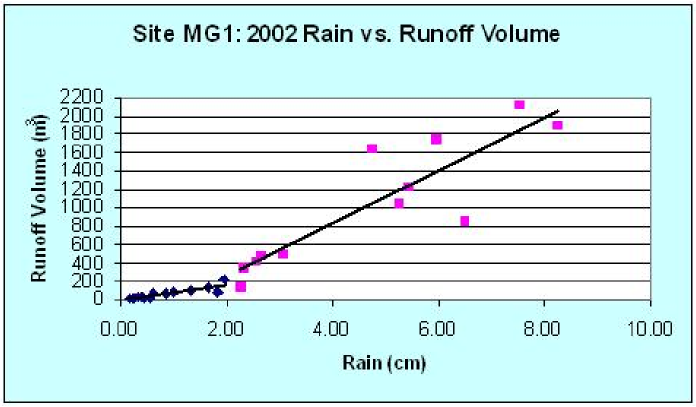

Figure 3: Relationship between rain event total (cm) and runoff volume total (cubic meters) for site MG1 in 2002.

As noted in Table 1, the three Maple Grove sub-watersheds had a larger percentage of both total and connected impervious surface area than the three Plymouth sub-watersheds. Consequently, the average unit runoff volume was higher for the Maple Grove sites, (27.8 m3/ha/cm rainfall) than for the Plymouth sites (20.1 m3/ha/cm rainfall). In addition, the total annual runoff volume (m3/ha)at the MG3 site (Maple Grove sub-watershed #3) was substantially greater than for any of the other five sites. The high runoff volume was a result of the high baseflow recorded at the monitoring station, typically greater than 3000 cubic meters/day, caused by basement sump pumps discharging into the storm sewer system.

There were significant differences in the total phosphorus (TP), soluble reactive phosphorus (SRP) and total nitrogen (TN) event mean concentrations in runoff from rainfall events greater and less than 2 cm, (Table 3). The total phosphorus and total nitrogen concentrations were higher in rainfall runoff from events less than 2 cm, but the SRP concentration was higher in events greater than 2 cm. The TSS concentration was higher for rainfall events greater than 2cm, but the difference was not significant.

Table 3: Mean Concentrations of selected parameters in runoff from small (<2 cm) and large (> 2 cm) rainfall events in six sub-watersheds in Plymouth and Maple Grove from 2001 to 2006.

Parameter	Rainfall < 2 cm	Rainfall >2 cm	Significance
Mean TP (µg/L)	310	240	0.000
Mean SRP (µg/L)	111	142	0.014
Mean TN (mg/L)	3.02	2.23	0.000
Mean TSS (mg/L)	109	81	0.045

There was no significant difference in the event mean total phosphorus or total nitrogen concentration between the two municipalities over the six year monitoring period, (Table 4). However, the event mean soluble reactive phosphorus concentration in runoff from the three Plymouth sites (phosphorus free fertilizer used) was significantly lower than the concentration in the three Maple Grove sites. Conversely, the total suspended solids concentration was significantly higher in the Plymouth sites, 110 mg/L, than the Maple Grove sites, 70 mg/L.

Table 4: Mean concentration (with standard errors) of selected parameters in runoff from six sub-watersheds in Plymouth and Maple Grove, MN from 2001 to 2006.

Parameter	Plymouth P-free fertilizer	Maple Grove P -fertilizer	Significance
Mean TP (µg/L)	262 ± 14.0	278 ± 11.6	0.865
Mean SRP (µg/L)	112 ± 6.5	135 ± 8.6	0.007
Mean TN (mg/L)	2.69 ± 0.10	2.61 ± 0.12	0.631
Mean TSS (mg/L)	111 ± 10.9	64 ± 5.8	0.004

There was a large amount of variability in the event mean concentrations for all parameters during the study period. Total phosphorus concentrations ranged from 56 to 1516 µg/L, and total nitrogen concentrations ranged from 0.20 to 13.60 mg/L. The high variability made detection of real differences in the EMC between the two treatments difficult. Consequently, the constituent export/unit area were calculated for the two treatments and compared to detect differences between the two municipalities. As shown in Table 5, phosphorus export from Maple Grove sites (phosphorus fertilizer used) was significantly greater than phosphorus export from Plymouth sites (phosphorus free fertilizer used). However, as noted in Table 3, it was observed that Maple Grove sites tended to have greater runoff volume per unit area than the Plymouth sites, probably a result of the slighter higher impervious surface area. To normalize the data, therefore the unit area export per unit runoff was calculated, (g/ha/cm).

As indicated previously, the City of Plymouth initiated phosphorus fertilizer use restrictions beginning in 1999, but Maple Grove did not implement restrictions until adoption of the Minnesota Phosphorus Lawn Fertilizer Law in 2004. Therefore, data collected from 2001 to 2003 were examined to detect differences in nutrient export that could have resulted from the use of phosphorus free fertilizer in Plymouth. There was no difference in the area-weighted total or soluble phosphorus loading between the two municipalities for rain events less than 2cm, (Table 5). A comparison of the area-weighted phosphorus loading from each city during large rain events (>2cm) showed significantly lower area-weighted total and soluble phosphorus loading in Plymouth (Table 5). Differences in the area-weighted soluble phosphorus loading between the two municipalities were larger than the total phosphorus differences.

Table 5: Phosphorus Export (g/ha/cm rainfall) from Plymouth, MN (phosphorus free fertilizer used) and Maple Grove, MN, (phosphorus fertilizer used) from 2001 to 2003.

	TP		SRP	
	0-2cm	>2cm	0-2cm	>2cm
Mean Event Export (P-used)	**N=34**	**N=31**	**N=31**	**N=31**
(g/ha)	3.9 ± **1.7**	23.5 ± **6.7**	2.0 ± **1.3**	16.0 ± **4.9**
(g/ha/cm runoff)	33.2 ± **15.9**	23.1 ± **3.2**	11.3 ± **7.4**	15.2 ± **2.8**
Mean Event Export (P-free)	**N=41**	**N=28**	**N=34**	**N=24**
(g/ha)	3.4 ± **0.08**	12.6 ± **4.1**	1.4 ± **0.5**	5.9 ± **1.9**
(g/ha/cm runoff)	35.9 ± **7.9**	18.7 ± **2.3**	12.5 ± **3.8**	7.9 ± **1.9**
Mean Paired Event Difference	**N=35**	**N=25**	**N=30**	**N=25**
(g/ha)	0	12.6 ± **8.7**	0	12.4 ± **5.7**
(g/ha/cm runoff)	0	5.2 ± **3.8**	0	8.1 ± **3.5**
		(P-free sites lower)		***(P-free sites lower)***
% Annual Reduction*	**12-16%**		**24-34%**	

***Based upon 2001-2003 daily rainfall record for St. Louis Park, MN and observed rainfall vs. export relationship from monitored watersheds with and without phosphorus fertilizer use.**

The mean phosphorus export for all monitored rainfall events from 2001 to 2003 was 30.5 g/ha/cm from the Maple Grove (phosphorus fertilizer used) sites and 25.5 g/ha/cm from the Plymouth sites (phosphorus free fertilizer used). As stated earlier, the Minnesota Phosphorus Lawn Fertilizer Law was adopted in 2004 and restricted the use of phosphorus fertilizer in Maple Grove as well as Plymouth. The mean phosphorus export from Maple Grove sites decreased from 30.5 g/ha/cm to 24.9 g/ha/cm (p=0.172) in 2005 and 2006 following adoption of the statewide phosphorus fertilizer restriction. Phosphorus export from the Plymouth sites remained relatively constant between the two periods, 25.5 and 26.4 g/ha/cm in 2001 to 2003 and 2005 to 2006 respectively.

Discussion

The data collected from the paired-watershed study showed a significant reduction in the phosphorus export resulting from implementation of a phosphorus lawn fertilizer restriction in the city of Plymouth, MN. Determination of the magnitude of the difference was complicated by a number of factors. Initial calculations showed that the Plymouth sub-watersheds (treatment sites) exported approximately 25 to 30 percent less phosphorus than the Maple Grove sub-watersheds (control sites). However, some of that difference resulted from the higher areal runoff volume at the Maple Grove sites, presumably because of the greater percent impervious surface area in the sub-watersheds. Both the SLAMM and P8 Models estimated a higher rainfall runoff volume for the Maple Grove sites because of the impervious surface area difference. To determine the portion of the phosphorus export difference that could be attributed to the phosphorus fertilizer

restriction, the export per unit area per rainfall volume was calculated. This calculation showed a reduction of 12 to 15 percent from the Plymouth (phosphorus free fertilizer) sites compared to the Maple Grove sites and is believed to more accurately reflect the effectiveness of the phosphorus fertilizer restriction.

The second complicating factor was the similarity in the mean phosphorus concentration between the treatment and control sites utilizing pooled data for all rainfall events. The difference in the calculated phosphorus export rates (g/ha/cm) between the treatment sites, (Plymouth) and the control sites (Maple Grove) were minimal using the pooled data. However, it was recognized that phosphorus concentrations in runoff from impervious surfaces would not be affected by the phosphorus lawn fertilizer restriction, and phosphorus export from impervious surfaces would be similar between the treatment and control sites. The data shown in Table 5 confirmed this assumption. Determination of differences in phosphorus export attributable to the phosphorus lawn fertilizer restriction required estimating runoff from turf areas.

Because the runoff volume (m3/ha) increased substantially for rainfall events >2cm at all six sites, it was assumed that runoff from pervious surfaces (lawns) occurred at 2cm of rainfall. Therefore, phosphorus export rates were calculated for rainfall events greater and less than 2cm. As shown in Table 5, there was no difference between the control and treatment sites for events <2cm, but a significant difference in the phosphorus export rate for events >2cm. To estimate the effect of the lawn fertilizer restriction on annual phosphorus export, the reported difference shown in Table 5 was multiplied by the annual runoff volume from rain events >2m.

The final factor affecting the magnitude of the difference in phosphorus export rates between the two municipalities was the excessive runoff volume measured at the MG3 sub-watershed. As noted earlier, baseflow from this sub-watershed averaged approximately 3000 m3/day during the study period, presumably as a result of basement sump pumps and groundwater seepage discharging into the storm sewer system. When the flow data from this sub-watershed were included in the calculations, a difference of over 50% in the phosphorus export rate between Plymouth and Maple Grove was determined. Since this difference was believed to be a function of groundwater flow not affected by fertilizer use, data from the MG3 site was excluded from the final phosphorus export calculations.

It should also be noted that the long term effectiveness of a phosphorus lawn fertilizer restriction may be greater than the 12 to 15 percent shown in Table 5. As indicated by the homeowner survey, approximately 25% of Plymouth (treatment sites) continued to use fertilizer containing phosphorus after implementation of the restriction in 1999, and approximately 25% of Maple Grove homeowners used phosphorus free fertilizer. By 2001, phosphorus free fertilizer was available in a few of the retail outlets in Maple Grove, and some homeowners were obviously purchasing it. The study results, therefore, represent phosphorus export reductions from a 50% reduction in the use of phosphorus containing fertilizer. Presumably, the reduction would be greater if 100% compliance with the restriction could be achieved.

The data showed a significantly higher mean TSS concentration in runoff from the Plymouth sites than the Maple Grove sites. This was unexpected since the SRP

concentration in Plymouth samples was significantly higher than in the Maple Grove sites, and high phosphorus concentrations in runoff water are typically correlated with high suspended solids concentrations. For this study, there was actually an inverse relationship between soluble reactive phosphorus and suspended solids concentrations. A similar relationship was observed in a previous study, (Barten and Jahnke, 1997). Some horticulturists have expressed concerns that phosphorus fertilizer restrictions could result in reduced turf vigor and increase soil wash-off from lawns. This could ultimately increase the phosphorus export from turf areas. However, data collected in this and the referenced previous study found that increased suspended solids loss did not increase the phosphorus loss from residential area.

It should also be noted that a portion of observed difference in the TSS load between Plymouth and Maple Grove could be a result of street sweeping practices in the respective communities in 2001 to 2003. According to information provided by the Public Works Departments in the two communities, street sweeping in Maple Grove occurred three to four times each year, including during fall leaf drop. Street sweeping in Plymouth occurred only in early spring to remove sand spread for snow and ice control. No sweeping during fall leaf drop occurred.

Conclusions

The data collected by this study strongly suggest that restricting the use of phosphorus lawn fertilizer reduces the export of phosphorus from urban residential developments by 12 to 15 percent. The reduction in phosphorus export appears to be mainly attributable to reductions in the concentration of soluble phosphorus. Typical stormwater BMPs do not tend to reduce SRP concentrations. Thus, this BMP appears to be a new tool for municipalities and watershed management organizations to help achieve SWPP and non-degradation objectives. The observed phosphorus export reduction is financially significant because typical storm water BMP construction costs approach $500/pound of phosphorus removed. The cost of implementing fertilizer restrictions in Plymouth was negligible. The study results show that restricting the use of phosphorus lawn fertilizers can be an effective and financially sound best management practice for areas with substantial residential development.