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ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 558

Total Daily Maximum Daily Load Demonstration Study

Final Report for the Project:
Performance of Low Impact Development Practices on Stormwater Pollutant Load Abatement

by

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Abstract

The P8 watershed water quality model was used to model performance of stormwater best management practices (BMPs) in the Lake Como watershed. Lake Como has a draft TMDL that will require 60% retention of the phosphorus that is currently discharging into the lake. The model indicates that current stormwater BMPs are retaining 32% of phosphorus discharge, if properly maintained. This will fall to 21% if sufficient maintenance is not performed. The ponds in the Lake Como watershed do not have as much of a decrease in performance if maintenance is not performed, but also do not remove as high a percent of the incoming phosphorus. To achieve the draft TMDL goals, approximately 20.5 acre-ft of infiltration practices or enhanced sand filters will need to be strategically placed in the watershed.

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Introduction

This report describes a total maximum daily load (TMDL) demonstration study that was performed as outlined in Objective D of the Minnesota Pollution Control Agency's (MPCA) 319 Implementation project entitled "Performance of Low Impact Development Practices on Stormwater Pollution Load Abatement." Objective D consists of four tasks that are summarized below.

Task D.1	Selection of study site and model
Task D.2	Data acquisition and model calibration
Task D.3	Model simulation and data analysis
Task D.4	Incorporation of results as a case study in the online manual

In brief, the goals of Objective D include calibrating a computer model with a watershed using available monitoring data. Once calibrated, additional goals (within Task D.3) include:

- Modeling different stormwater best management practice (BMP) scenarios, including with and without BMPs and BMP deterioration with time, to determine the long-term impact on sediment, phosphorus, and metal loads,
- Determining types and locations of BMPs needed to meet TMDL requirements,
- Estimating the impact of groundwater pollution from increased infiltration,
- Coupling the results with the MPCA project "Assessment and Maintenance of Stormwater BMPs" groundwater model to calculate pollutant loads to water bodies for sediment, phosphorus, hydrocarbons, pathogens, and bacteria.

Selection of Study Site and Model

The computer model P8 was chosen for the TMDL demonstration study due to its availability (http://www.wwwalker.net/p8/), and widespread use in the State of Minnesota.

In order to successfully complete the TMDL demonstration study, the study site had to meet two criteria: 1) include sufficient available monitoring data to allow P8 to be calibrated and 2) the receiving water body had to have a developed TMDL. Como Lake within the Capitol Region Watershed District (CRWD) was chosen due to the large amount of monitoring data already collected and the fact that Como Lake has a published draft TMDL (CRWD and Emmons and Olivier Resources, Inc. 2010).

Como Lake, located near St. Paul, MN, has a watershed of over 1700 acres. Several stormwater BMPs such as ponds, rain gardens, and infiltration trenches are located within the watershed, many of which are monitored by CRWD for flow, contaminant loading, and BMP performance. For more information on the Como Lake watershed and CRWDs monitoring efforts, see published reports made available by CRWD at http://www.capitolregionwd.org/reports.html.

Data Acquisition and Model Calibration

CRWD has provided much support for this project including providing all available monitoring data and P8 models. Further investigation of the Como Lake reports and data made available by CRWD revealed that CRWD had already modeled the Como Lake watershed with P8 and calibrated the model with years of monitoring data for flow volumes, pollutant loading, and BMP performance. CRWD willingly shared their calibrated P8 model.

The calibrated P8 model obtained from CRWD included 51 sub-watersheds with a total watershed area of approximately 1770 acres. BMPs included in the model were:

- Gottfried's Pit (a stormwater detention pond)
- Eight (8) infiltration trenches
- Eight (8) rain gardens
- An underground infiltration and storage facility (Arlington-Hamline Underground Storage Facility)
- A 0.15 acre infiltration basin (Como7 HMRain)
- A 1.25 acre pond at the Como Golf Course in sub-watershed 7
- A 0.3 acre surface area pond near sub-watersheds 3, 4, and 5
- A 2.3 acre pond (Como48)

In P8, BMPs are entered as a "device," however all devices in P8 are not BMPs. Some devices are pipes, which provide no stormwater treatment in the model but trigger P8 to report flow and pollutant data at that location. All watersheds must flow to a device or the flow is routed out of the system and is no longer accounted for in the model. The spatial interrelationship of watersheds and devices in the calibrated P8 model obtained from CRWD is shown in Figure 1. To reduce clutter on Figure 1, some subwatersheds that drain directly to Como1 are not shown.

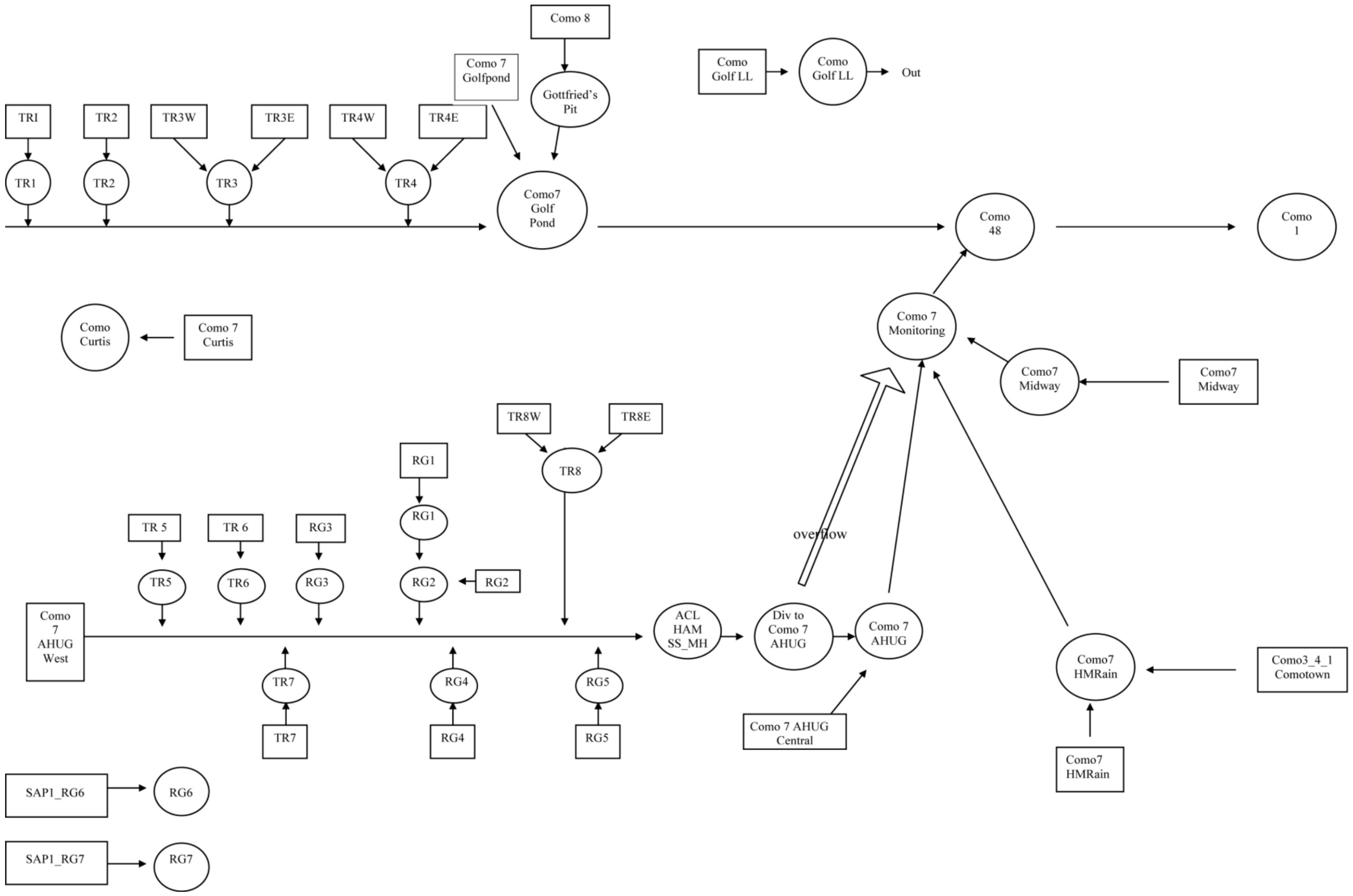

Figure 1. Watersheds (rectangles) and devices (ovals) of calibrated P8 model obtained from Capitol Region Watershed District (from CRWD).

Model Simulation and Data Analysis

Unless otherwise noted, model simulations were performed using air temperature and rainfall data from the Minneapolis-St. Paul International Airport for the 1959 water year (October 1, 1958 to September 30, 1959). This year was chosen because it represents an average water year with regards to precipitation amounts and is recommended for use in P8 documentation (Walker 1990).

To determine the impact that the existing BMPs have on pollutant loading to Como Lake, the calibrated P8 model was run for the 1959 water year and the contaminant loads of sediment, phosphorus, copper, lead, and zinc were recorded. The BMPs in the P8 model were then converted to pipes, which effectively eliminated any contaminant treatment provided by the BMPs, and the contaminant loads without BMPs were recorded. The difference in contaminant loading between these two scenarios is the impact on pollutant loading provided by the BMPs. The results are shown in Table 1.

Table 1. Impact of stormwater BMPs on contaminant loading of sediment (TSS), phosphorus (P), copper (Cu), lead (Pb), and zinc (Zn) to Como Lake.

Overall w BMPs				
	Inflow (lb)	**Outflow (lb)**	**Lb removed**	**% Removed**
TSS	383655	194171	189484	49
P	782	521	261	33
Cu	88	57	32	36
Pb	38	20	18	47
Zn	204	130	73	36
Overall NO BMPs				
	Inflow (lb)	**Outflow (lb)**	**Lb removed**	**% Removed**
TSS	383655	383655	0	0
P	782	782	0	0
Cu	88	88	0	0
Pb	38	38	0	0
Zn	204	204	0	0

As shown in Table 1, the BMPs reduce contaminant loading to Como Lake by 189,484, 261, 32, 18, and 73 lbs for sediment, phosphorus, copper, lead, and zinc, respectfully for the average water year.

BMP Performance with no Maintenance

In order to model the deterioration in BMP performance with time, P8 was run in yearly increments for a total of 30 years. Again, for each year increment, precipitation and air temperature data for the 1959 water year was used. This was done in order to eliminate variability in the results due to variable weather. As a result, any differences in model results over the 30 year span were due solely to changes in BMP performance. At the end of each water year, the P8 model was stopped and the amount of sediment (pounds) captured by each BMP was converted to a volume of sediment using a density of 75 lbs/ft^3 (Scarborough and Mensinger 2005). The volume of sediment within each BMP was distributed evenly over the bottom area of the BMP and appropriate adjustments for bottom elevation, storage volume, etc. were made in the P8 model. Also, to simulate clogging of media, all infiltration rate values in P8 were reduced yearly by an amount equal to 10 percent of the initial infiltration rate value. Thus, in year 9 all infiltration rate values were only 10 percent of their initial value and in year 10 (and all subsequent years) all infiltration rate values were zero. Thus, the 30 year time span that was modeled represents a scenario in which no maintenance was been performed on any of the BMPs. If, in any year, maintenance was performed and the BMPs were restored to their initial condition, performance and model results would return to year 1 values. The ponds were assumed to infiltrate water, with a reduction that is similar to infiltration basins, i.e. 10% of the initial infiltration rate per year.

Over the 30 year modeling period, the deterioration in performance of the rain gardens all followed a similar pattern. The same is true for the infiltration trenches and also for the ponds. Thus, due to the large number of BMPs in the P8 model and the fact that reporting results for all BMPs would be repetitious and not add information or value, results for a portion of the BMPs that, all together represent every BMP within the model, are reported. Results related to pollutant capture rates of the BMPs are shown in Figures 2 through 9.

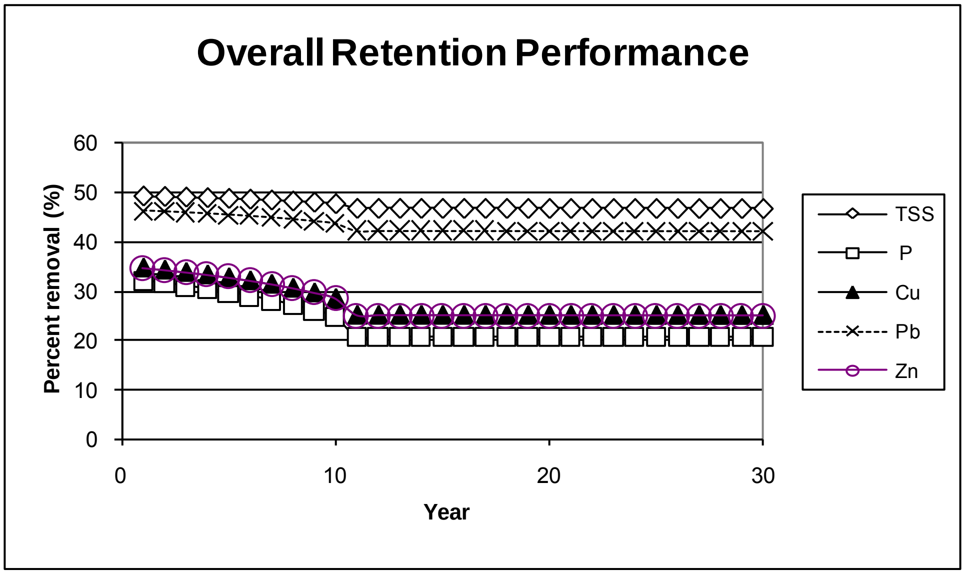

Figure 2. Pollutant capture in entire Como Lake watershed based on P8 modeling.

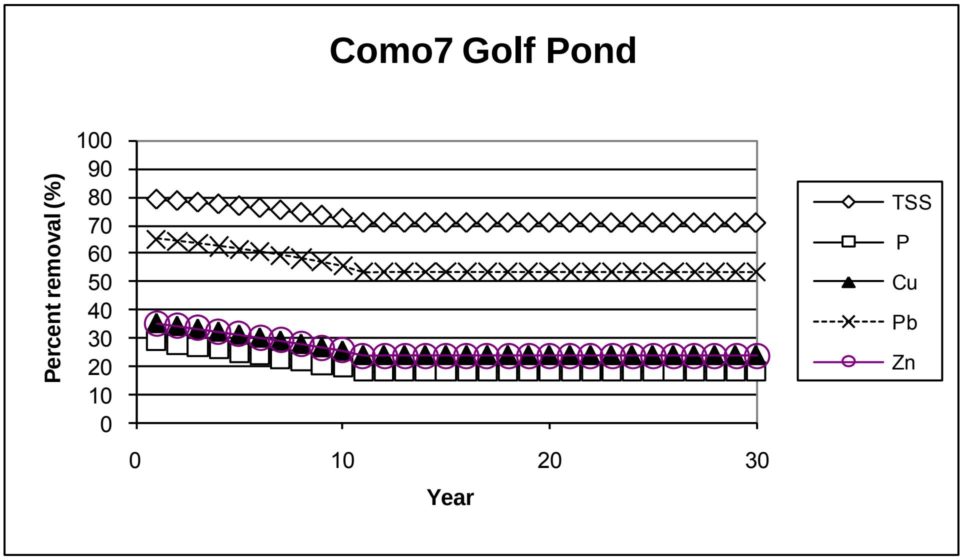

Figure 3. Pollutant capture by the Como 7 Golf Pond based on P8 modeling.

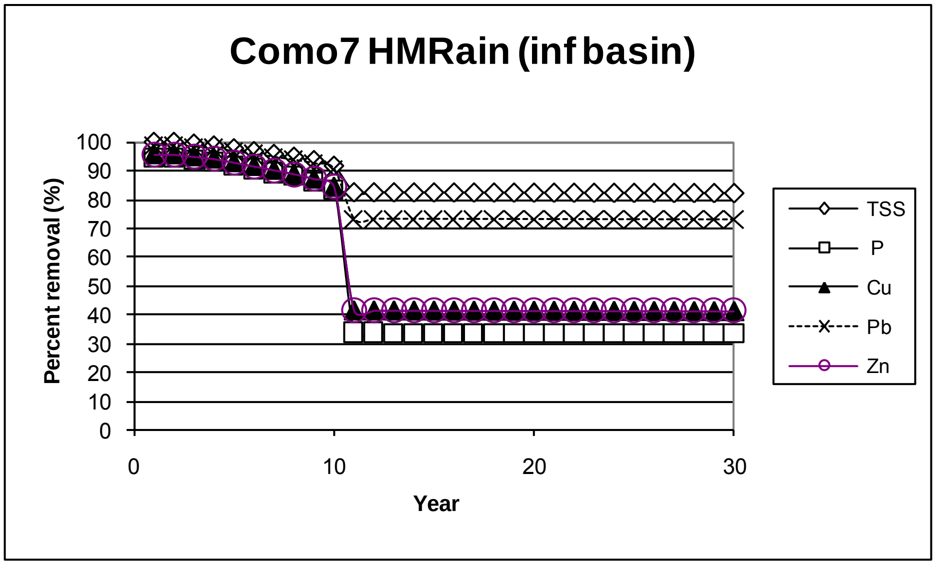

Figure 4. Pollutant capture by the Como 7 HMRain infiltration basin based on P8 modeling.

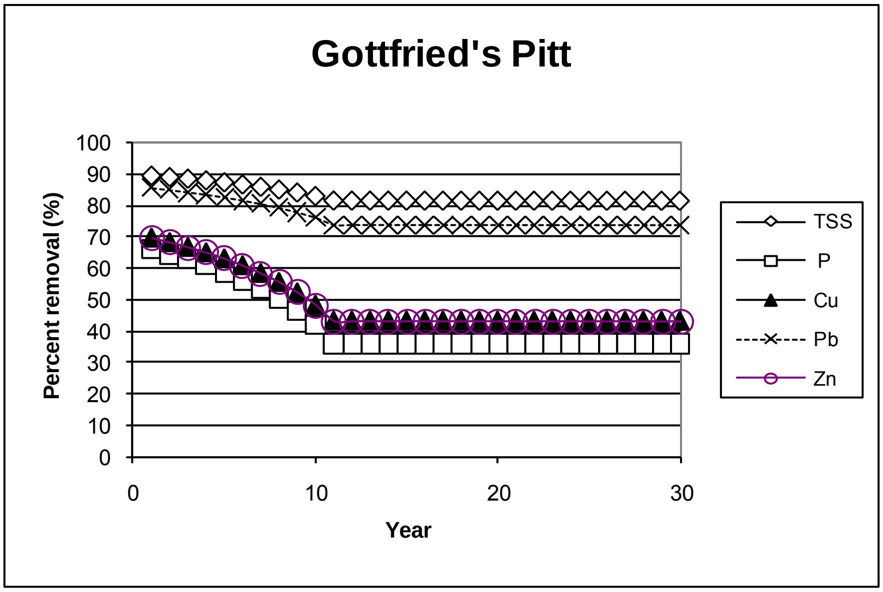

Figure 5. Pollutant capture by Gottfried's Pit based on P8 modeling.

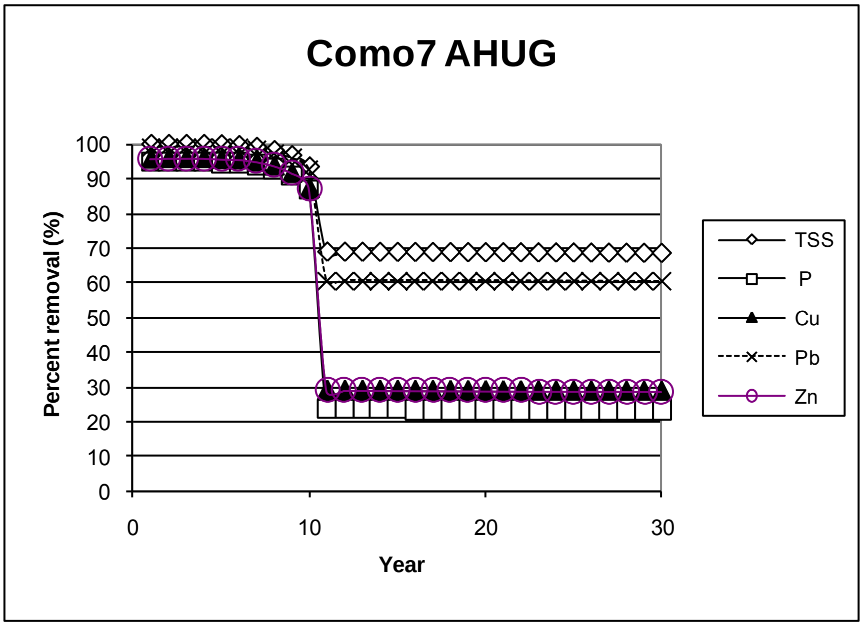

Figure 6. Pollutant capture by the Arlington-Hamline Underground Storage Facility based on P8 modeling.

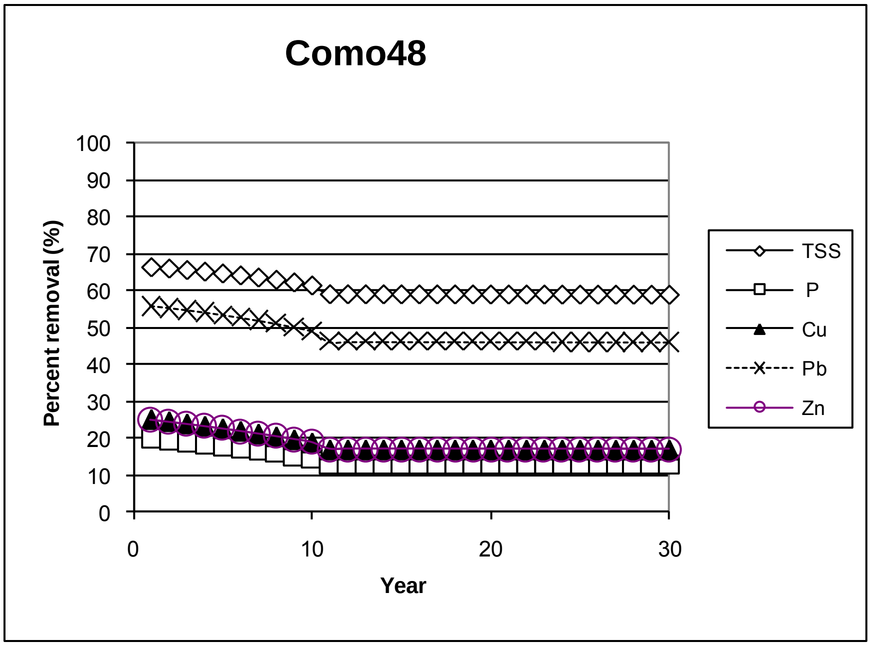

Figure 7. Pollutant capture by the Como 48 pond based on P8 modeling.

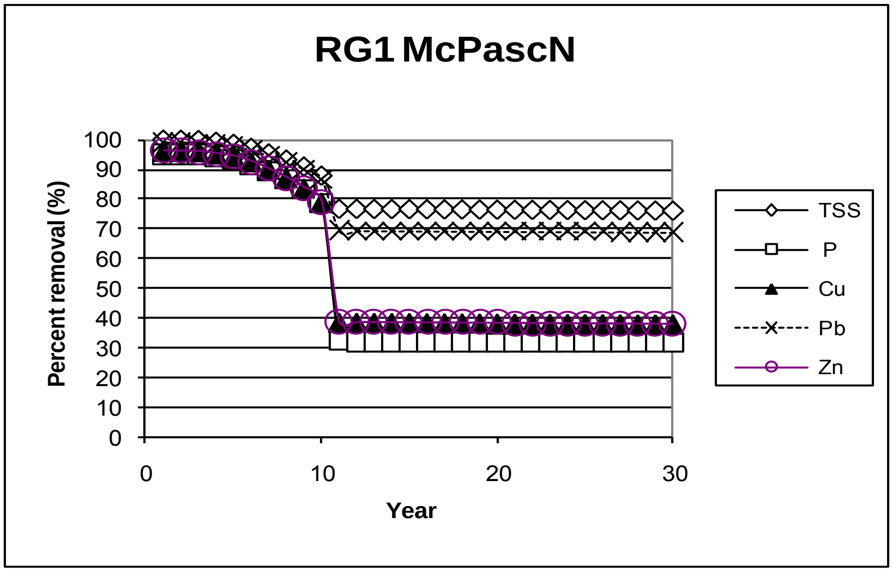

Figure 8. Pollutant capture by Rain Garden #1 based on P8 modeling.

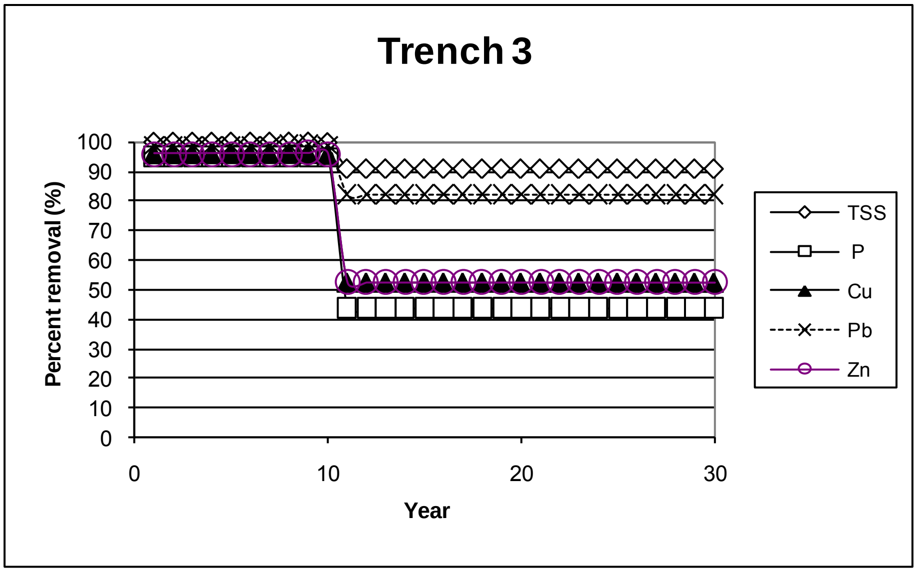

Figure 9. Pollutant capture by Infiltration Trench #3 based on P8 modeling.

Figures 2 through 9 reveal the impact sediment accumulation and reduced infiltration can have on BMP performance. First, however, note that the overall watershed retention performance shown in Figure 2 begins at below 50 percent for all contaminants yet the pollutant capture rates for all BMPs typically, but not always, begins at values much larger (i.e. upwards of 80 to 90 percent). This difference is due to the fact that the BMPs in the model are located in only part of the 1700 acre Como Lake watershed, which results in a significant portion of the runoff receiving limited or no treatment.

Figure 3 shows the noticeable and significant decrease in pollutant capture achieved by the golf course pond in years 1 through 10 but with only a slight drop in performance during subsequent years. This reveals the importance of infiltration in the pollutant capture of ponds and indicates that, for this watershed and with the assumptions of the P8 model, performance reduction due to sediment accumulation is delayed in the golf course pond because of its relatively large ratio of area to inflow. The impact of the larger size ratio can also be seen in the performance relative to the Como 48 pond.

Figures 2 through 9 also show the importance of maintaining a minimum level of infiltration in rain gardens, infiltration basins, and infiltration trenches. The performance of such BMPs drops gradually as the infiltration rate begins to drop 10 percent each year from the initial value (see Figures 4, 6, 8, and 9) but, after the 10th year when the infiltration rate was reduced to zero, each BMP that relies primarily on infiltration has a drastic drop in its pollutant capture rate. This drop is evidenced by the nearly vertical segment of the performance curves of infiltration practices after year 10. At that point the infiltration practices would act similar to a small pond, and retain some limited amount of sediment and associated pollutants. The ponds also experience some drop in pollutant capture as their infiltration rate drops but, because ponds rely primarily on sedimentation for pollutant capture, the drop is more gradual even when infiltration is reduced to zero.

Stormwater BMPs to Meet TMDL Requirements

Another goal of of this report is to determine the types and locations of stormwater BMPs needed to meet TMDL requirements. As stated in the draft TMDL for Como Lake (CRWD and Emmons and Olivier Resources, Inc. 2010), phosphorus loading to Como Lake from watershed runoff must be reduced by 60 percent in order to meet the TMDL. For the 1959 water year with existing stormwater BMPs, phosphorus loading from watershed runoff was estimated by P8 to be 521 pounds. Thus, to meet the phosphorus TMDL, loading must be reduced 60 percent to 208 pounds. Phosphorus in stormwater runoff can be in dissolved or particulate form and runoff usually contains a portion of each. A fraction of the particulate form can be removed through sedimentation of solids in ponds but a pond will not remove a significant portion of the dissolved phosphorus fraction. In order to reduce the phosphorus loading due to the dissolved fraction, stormwater runoff must be infiltrated into the soil or filtered by an enhanced sand filter (Minnesota Filter) with the capability to adsorb dissolved phosphorus (Erickson et al. 2007).

In order to reduce phosphorus loading by 60 percent, ponds were initially included as additional stormwater BMPs in the P8 model. Due to the inability of ponds to remove dissolved phosphorus, however, the impact of the ponds on the total phosphorus load was limited and the required size and number of ponds was deemed too large. Thus, ponds were not used to meet TMDL requirements but instead devices were added to P8 that could represent infiltration basins or enhanced sand filters. These devices were sized to achieve 80 percent removal of total phosphorus. This value was selected because sand filters can remove over 80 percent of suspended solids (MPCA 2008) and enhanced sand filters can capture over 80 percent of the dissolved phosphorus load, even after decades of use (Erickson et al. 2007). Infiltration practices can be assumed to reduce the phosphorus in surface runoff that is infiltrated by 100 percent (MPCA 2008), so 80 percent removal may be a conservative value for infiltration basins.

In the P8 model, the new devices or stormwater BMPs all were given infiltration rate values of 2.0 inches/hour (4 feet/day), which is slightly higher than the recommended saturated hydraulic conductivity (K) value for the design of stormwater filtration systems of 1.75 inches/hour (3.5 feet/day) (Claytor and Scheuler 1996). The recommended design value of 1.75 inches/hour (3.5 feet/day) is considered the lowest acceptable value for a filtration practice before maintenance is required. Thus, sand filters should always have a saturated hydraulic conductivity value equal to or exceeding this value and, due to the head on the filter, even higher infiltration rates. This means that if the devices added to the P8 model (i.e. the additional stormwater BMPs) to meet the TMDL are enhanced sand filters, they must only receive the typical recommended maintenance for sand filters because Erickson et al. (2007) has shown that the dissolved phosphorus capacity will typically last over 30 years, which is beyond the design life of the filter itself. If the devices are to be infiltration basins, they must be maintained to achieve an infiltration rate of 2.0 inches per hour.

In order to achieve a 60 percent reduction in phosphorus loading due to surface runoff, seven (7) such devices were incorporated into the P8 model. All devices were also set so that surface runoff that infiltrated into the stormwater BMP was routed to the downstream device. With 80 percent removal of total phosphorus and all infiltrated runoff routed downstream, the device represents an enhanced sand filter with underdrains that collects the filtered water and conveys it downstream in the system. This was assumed as a worst case scenario because many areas cannot accept an infiltration of 2 inches per hour due to clayey soils. Specific details on the seven (7) additional stormwater BMPs added to the P8 model to meet TMDL requirements are given in Table 2.

Table 2. Additional stormwater BMPs added in order to meet phosphorus TMDL requirements.

P8 device name	Area (acres)	Storage pond volume (ac-ft)	Location
Mn Filter Bas1	1.50	9.00	Receives effluent from Como48 (the 2.3 acre pond)
Mn Filter Bas2	0.40	2.37	Just upstream of Como Lake (Como 1 in Figure 1), Receives runoff from subwatershed Como 2 (not shown in Figure 1)
Mn Filter Bas3	0.14	0.86	Just upstream of Como 1 (Figure 1), receiving runoff from subwatersheds Como3_5_1 & Como3_6_1 (not shown in Figure 1)
Mn Filter Bas4	0.83	4.42	Just upstream of Como 1 (Figure 1), receiving runoff from subwatershed Como3_4_1 (not shown in Figure 1)
Mn Filter Bas5	0.17	1.02	Just upstream of the Como7 monitoring station, receiving runoff from the Como7 Midway and Como7 South watersheds.
Mn Filter Bas6	0.17	1.02	Just upstream of Como 1 (Figure 1), receiving runoff from subwatershed Como3_2_1
Mn Filter Bas7	0.31	1.89	Just upstream of Como 1 (Figure 1), receiving runoff from subwatershed Como3_3_1
Total	3.52	20.5	

With these seven devices (each with an filtration rate of 2.0 inches/hour) and the original stormwater BMPs, the surface water phosphorus load was reduced from 521 pounds to 196 pounds, which corresponds to a 62.4 percent reduction. If, in an effort to model stormwater BMP deterioration with time, the infiltration rate of the original stormwater BMPs is decreased by 50 percent and the infiltration rate of the new stormwater BMPs is reduced to 1.75 inches/hour (i.e. the recommended minimum design saturated hydraulic conductivity for stormwater filters), the surface runoff phosphorus load to Como Lake is 206 pounds/year, which corresponds to a 60 percent reduction. Thus, in order to meet the Como Lake phosphorus TMDL, maintenance schedules must be such that existing stormwater BMPs maintain an infiltration rate of approximately 50 percent of their initial value and the new stormwater BMPs must maintain an infiltration rate of at least 1.75 inches/hour, which is the recommended minimum value of saturated hydraulic conductivity for sand filters. The relevant numbers in Table 2 are the storage pond volumes. It is unlikely that each of the basins will be as deep as given above, so the time required to infiltrate the water will be shorter than 48 hours. These simulations indicate that the Lake Como watershed requires 20.5 acre-ft of infiltration practice or enhanced sand filter to meet the draft TMDL, placed strategically within the watershed.

If the additional stormwater BMPs needed to meet the phosphorus TMDL are infiltration basins that infiltrate water into the existing soil media, the soil would filter particulate phosphorus and may adsorb some of the dissolved phosphorus. There is, however, the possibility that groundwater could be contaminated if the soil has a low capacity to adsorb phosphorus, if that capacity becomes exhausted, or if the soil is a karst soil with flow paths to the groundwater table. Indiati and Diana (2004) investigated the capacity of acidic soils to adsorb phosphorous. With initial phosphorus concentrations in the water of 75 mg P/L, soil adsorption capacities were found to range from 592 mg P/kg soil to 8805 mg P/kg soil with the degree of phosphorus saturation being time dependant. In some samples it took over 100 days for phosphorus saturation to approach 100 percent while with other samples it took approximately 10 days. The phosphorus sorption capacity was determined to have a strong correlation with the sum of aluminum and iron oxides/hydroxides extracted with the acid oxalate solution. Also, stormwater phosphorus concentrations are typically less than 1 mg/L and, as a result, soil adsorption capacities would be much lower than those reported. Thus, without detailed information for each soil type within the Como Lake watershed, it is impossible to accurately estimate the impact of groundwater pollution and when phosphorus contamination might occur.

Infiltrated metals also have the potential to contaminate groundwater. Most metals, however, adsorb to soil media within the top 40 cm. If the metal capacity of the soil is exhausted, metal ions can migrate to the groundwater. The capacity of soil with respect to metal adsorption is also highly variable and dependent of soil characteristics. The time required to exhaust the metal adsorption capacity of a soil can range anywhere from a few years to over a hundred years. In order to prevent excessively high concentrations in the soil that could lead to groundwater contamination, it has been recommended to replace the top 20 cm of soil with new soil every three to four years (Zimmerman et al. 2005). Before performing replacement, however, one could test the media for toxic metal concentrations, and compare with known capacities (Morgan, et al 2011). For more information on potential groundwater contamination and the fate of contaminants after infiltration, see Weiss et al. (2008).

Conclusions

1. To determine the impact that the existing stormwater BMPs have on pollutant loading to Como Lake a calibrated P8 model was run for the 1959 water year and the contaminant loads of sediment, phosphorus, copper, lead, and zinc were recorded. The stormwater BMPs in the P8 model were then eliminated, and the contaminant loads without stormwater BMPs were recorded. The difference in contaminant loading between these two scenarios is the impact on pollutant loading provided by the stormwater BMPs. The existing stormwater BMPs removed 49 % of the total suspended solids, 33% of the phosphorus, 36% of the copper, 46% lead and 36% of zinc loading to Como Lake. This is a substantial reduction in pollutant loading.
2. In order to model the deterioration in stormwater BMP performance with time, P8 was run in yearly increments using a representative water year for a total of 30 years. The volume of sediment within each stormwater BMP was distributed evenly over the bottom area of the BMP and appropriate adjustments for bottom elevation, storage volume, etc. were made in the P8 model. Also, to simulate clogging of media, all infiltration rate values in P8 were reduced yearly

by an amount equal to 10 percent of the initial infiltration rate value. In ten years, without active maintenance, the overall retention of phosphorus in the Como Lake Watershed was reduced from 32% to 21% of what would have discharged into Como Lake without any stormwater BMPs.

3. Phosphorus loading to Como Lake from watershed runoff must be reduced by 60 percent in order to meet the draft TMDL. This was accomplished by placing seven infiltration basins or enhanced sand filters in the watershed. The number and location of these basins is preliminary, because no site planning was involved in this study. The total volume of these basins, 20.5 acre-ft, however, provide an approximation of the total volume of basins that need to be built to meet this draft TMDL.

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