

Water Quality Assessment

NR216/NR151 TSS Reductions

City of Baraboo, Wisconsin

MSA Project No. 350711

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1.0 EXECUTIVE SUMMARY

This report documents the findings of a study conducted for purposes of determining the City of Baraboo's compliance with Total Suspended Solids reductions in accordance with NR216.07(6)(b) and NR151.13. The standards outlined within these two chapters require that regulated communities, including the City of Baraboo, achieve a 20% reduction in total suspended solids in runoff that enters waters of the state as compared to no controls by 2008, and implement programs and practices to achieve a 40% reduction in total suspended solids in runoff that enters waters of the state as compared to no controls, by March 10, 2013.

The findings of this study are taken from a detailed P8 (version 3.4) water quality model of the City. The model was used to evaluate TSS reduction provided by 88 natural and constructed stormwater storage areas within the City's stormwater drainage system, including 85 detention ponds. The model was also used to evaluate the City's current street sweeping program. This study found the following:

City of Baraboo Current Total Suspended Solids Reduction Performance

No Controls Annual Regulated Load	351.5 tons/yr
TSS Removed by Allowable Structural Practices	51.5 tons/yr
Additional TSS Removed by Street Sweeping ¹	3.2 tons/yr
Total TSS Removed	54.7 tons/yr
TSS Reduction Rate	15.6%

1. Actual stand-alone street sweeping removal is approximately 3.9 tons/yr.

With its current management practices, the City of Baraboo falls short of both the 2008 20% TSS reduction requirement and the 2013 40% TSS reduction requirement. The P8 model was used to evaluate eight alternative street sweeping programs and 34 potential alternative structural stormwater management practices in order to develop a plan for compliance with both the 2008 20% TSS reduction requirement and the 2013 40% TSS reduction requirement.

City of Baraboo Options for Increasing Total Suspended Solids Reduction Performance To Meet 2008 20% TSS Reduction and 2013 40% Reduction Targets

Current Program	15.6%
Current Program + Improved Street Sweeping	25.4%
Current Program + 34 Additional Detention Ponds	61.1%
Current Program + Sweeping + Ponds	62.8%

The minimum program that could be implemented to achieve 20% TSS reduction would be for the City to purchase a high efficiency vacuum street sweeper and sweep the City on a weekly basis. There would be no need to enforce parking controls on sweeping days (although it will be necessary to continue parking controls downtown). With the existing detention ponds, this would achieve a TSS reduction rate of 20.5%.

The minimum program that could be implemented to achieve 40% TSS reduction would be for the City to construct the eight highest ranking detention ponds and replace the City's existing mechanical street sweeper with a high efficiency vacuum sweeper. There would be no need to change the current sweeping schedule. This program would achieve a TSS reduction of 40.2%. Alternatively the City could construct the top nine highest ranking detention ponds and leave the current street sweeping practices in place. This would achieve a TSS reduction of 42.0%.

The estimated capital cost necessary to achieve the 40% TSS reduction target ranges from \$1.2M to \$4.5M. The low end cost could be achieved if the City is able to construct all eight priority ponds. The high cost estimate is a worst-case scenario condition where no ponds except the lowest efficiency ponds are able to be built.

2.0 INTRODUCTION

The City of Baraboo is required to obtain a Wisconsin Pollution Discharge Elimination System (WPDES) Phase II permit to discharge stormwater runoff from the City's Municipal Separate Storm Sewer System (MS4) and comply with the standards specified in Wisconsin rules NR151 and NR216. NR216.07(6)(b) and NR151.13(2)(b) collectively require communities to achieve a 20% reduction in total suspended solids in runoff that enters waters of the state as compared to no controls by 2008, and to achieve a 40% reduction in total suspended solids in runoff that enters waters of the state as compared to no controls, by March 10, 2013. This report documents the findings of a modeling study conducted for purposes of determining the City of Baraboo's compliance with TSS reductions standards.

3.0 WATER QUALITY MODELING

The findings of this study are taken from a detailed P8 Urban Catchment Model Version 3.4 of the City's stormwater management system. P8 is a WDNR approved model recommended for use in determining TSS removal rates from stormwater management practices for assessment of compliance with WPDES requirements (see notation NR216.07(6)(b) – "The department believes that computer modeling is the most efficient and cost effective method for calculating pollutant loads. Pollutant loading models such as SLAMM, P8 or equivalent methodology may be used to evaluate the efficiency of the design in reducing total suspended solids"). 'P8' abbreviates "Program for Predicting Polluting Particle Passage Through Pits, Puddles, and Ponds."

The P8 model predicts the generation and transport of pollutants in stormwater runoff from urban watersheds. Continuous water-balance and mass-balance calculations driven by hourly rainfall and daily air temperature time-series data are performed on the stormwater management system. P8 was initially calibrated to runoff quality and particle settling velocity data collected under the EPA's Nationwide Urban Runoff Program. Subsequent calibrations were developed for Wisconsin urban watersheds. Input data required by P8 for each model application describe watersheds, devices (BMPs), sediment particle classes, and water quality components.

TSS reduction achieved through street sweeping was estimated using the WinSLAMM model. 'WinSLAMM' abbreviates "Source Loading and Management Model [for Windows]" Like P8, WinSLAMM is a WDNR approved model recommended for use in determining TSS removal rates from stormwater management practices. The reason WinSLAMM was used for modeling of street sweeping practices is that it is much more flexible in its application of different types (efficiencies) of street sweepers and allows the implementation of a parking ban during periods of sweeping. The street sweeping efficiency predicted by WinSLAMM was applied as a percentage reduction to the TSS loads predicted by P8 to watersheds not treated by a more efficient structural BMP (detention pond).

3.1 RAINFALL AND TEMPERATURE DATA

P8 simulations are driven by hourly rainfall and mean daily air temperature. The WDNR requires the use of an 'average year's' data for rainfall and temperature in all water quality assessments. The WDNR has determined that the climate record for the Madison gauging station for the year 1981 represents the best available data representing a 'typical year'. The WDNR and the P8 author have provided specific guidance in the application of this data; specifically, the model should be solved from September 1, 1980 through September 30, 1981, however, data should only be kept from October 1, 1980 on (this allows the model to normalize prior to actual simulations).

Note: Model simulations were actually started on September 1979, per instruction by DNR stormwater staff, so that wet ponds modeled as "general devices" were at their expected normal pool elevations prior to the beginning of the period of analysis for the typical year.

3.2 WATERSHEDS

Watersheds are the sources of runoff and TSS particles simulated by the program. Necessary input data includes drainage area, impervious fraction, depression storage, SCS Runoff Curve Number (RCN) for pervious areas, percent of impervious area served by street sweepers, and street sweeping frequency. The model simulates runoff and TSS generation from pervious and impervious surfaces; although impervious surfaces produce substantially more TSS and runoff than do pervious surfaces.

Watershed areas, impervious fractions, and pervious area RCN data was developed for 254 watersheds using GIS data provided by the City of Baraboo. Several of these subareas were further subdivided according to information obtained from engineering plans for the many development projects that have occurred within the City. The table titled 'Model Land Use' included in the appendix of this report documents drainage areas, impervious fractions, and runoff curve numbers used in the study.

Street sweeping frequency data was provided by the City of Baraboo street department. According to the department, the City's sweeping program allows for two full sweeps of the community per year. The downtown area is swept weekly. The City owns a mechanical sweeper. On average the City begins sweeping operations on April 15 and stops for the winter season on November 1.

Values for depression storage were set to standard default values in the model.

3.2 DEVICES

Devices are structural elements of the stormwater drainage and management system that provide collection, storage, and/or treatment of stormwater. Devices include dry and wet storage basins, infiltration basins, swales, buffers, pipes, and flow splitters. All devices modeled by this study were treated as 'general' devices and were defined within the model by a user-defined rating curve that correlated water depth to volume of storage and discharge rate out of the device.

The P8 modeling for existing conditions encompassed 88 natural and constructed stormwater storage areas within the City's stormwater drainage system and included three natural low areas. Note that the natural low areas provided both flow and TSS reduction; however, because the natural low areas are not constructed management practices, and were likely located within waters-of-the-state, they TSS reductions achieved by the low areas were not counted. Device geometry was taken from one of three primary sources, the City provided a GIS database consisting primarily of detailed 2-foot contour interval topographic maps, construction plans from various development and

reconstruction projects, and field inspections (primarily of device outlet structures). The full geometric configuration of all 88 devices is fully described in a HydroCAD hydrologic model of the City's stormwater management system that was developed independently of this study and is not documented here.

3.3 PARTICLE CLASSES

Particle classes are defined according to land use types and reflect factors controlling watershed export of TSS particles. For impervious areas the particle class relates accumulation and wash off parameters; for pervious surfaces the particle class relates fixed runoff concentrations. Particle class affects street-sweeping efficiency and effectiveness of structural management practices. Several default values for particle classes are included by the model; at the direction of the WDNR, the NURP50.PAR file was used in this study.

3.4 WATER QUALITY COMPONENTS

Water quality components are defined based upon their weight distribution across particle classes (mg/kg). The only component modeled in this study was Total Suspended Solids (TSS). Several default values for water quality components are included in the model; at the direction of the WDNR, the NURP50.PAR file was used in this study.

4.0 APPLICATION OF WATER QUALITY MODEL

The WDNR has provided very specific guidance in the application of water quality models for the assessment of compliance with the TSS reductions required by NR151 and NR216. This guidance is documented in a June 16, 2005 memorandum from Gordon Stevenson and Eric Rortvedt, titled, "Developed Urban Areas and the 20% and 40% TSS Reductions." This memorandum documents several key issues regarding the determination of regulated land uses within the corporate limits of a regulated municipality; several key statements from the guidance memo are reproduced below:

"The total suspended solids control requirements of s. NR 151.13(2)(b)1.b. and 2., Wis. Adm. Code, may be achieved on an individual municipal basis. Control does not have to apply uniformly across the municipality."

"Areas Required to be Included in the Calculations

A municipality must include the following areas when calculating compliance with the developed urban area standard (s. NR 151.13, Wis. Adm. Code):

1. *Any developed area that was not subject to the post-construction performance standards of s. NR151.12 or 151.24, Wis. Adm. Code, that went into effect October 1, 2004 and that drains to the MS4 owned or operated by the municipality.*
2. *...*
3. *Any undeveloped (in-fill) areas under 5 acres. These areas must be modeled as fully developed, with a land use similar to the properties around them.*
4. *...*
5. *...*
6. *...*
7. *..."*

The language under item #1 above refers to the need to include all land areas NOT regulated by the standards of NR151.12 or NR151.24 developed prior to October 1, 2004. While it is not specifically stated here, subsequent information made available by the WDNR has clarified this statement to also mean that all development, which

has occurred on or after October 1, 2004, and was regulated by NR151.12 or NR151.24 must NOT be included in the calculations.

“Areas Prohibited from Inclusion in the Calculations

Areas and loadings that shall not be included:

1. *Lands zoned for agricultural use and operating as such.*
2. *Pollutant loadings from an upstream MS4*
3. *Any internally drained area with natural infiltration.*
4. *Undeveloped land parcels over 5 acres within the municipality. These areas will be subject to s. NR 151.12 or 151.24, Wis. Adm. Code, when developed”*

Item #2 above refers to pollutant loadings, and not runoff. It is necessary to account for stormwater runoff from areas outside a regulated municipality that flow into the municipality so that the effect of the hydraulic loading from these areas that passes into a management practice (detention pond, etc.) is properly accounted for (i.e. effects on pollutant removal efficiency). Similarly, runoff, but not pollutants, from areas within the regulated municipality that are prohibited from inclusion in the calculations must be accounted for. *Note that a reader might not infer the previous requirement from reading the guidance in the June 16, 2005 memo. MSA has discussed this specific issue with the WDNR and was given this direction.*

“Optional Areas to Include in the Calculations

Areas a municipality may, but is not required to, include in the developed urban area load calculation:

1. *Property that drains to waters of the state without passing through the permittee’s MS4.*
2. *Any area that discharges to an adjacent municipality’s MS4 without passing through the jurisdictional municipality’s MS4.*
3. *Industrial facilities subject to a permit under subch. II of ch. NR 216, Wis. Adm. Code.”*

All of the optional areas were included in this analysis. Further discussion of this item is included in the recommendations section of the report.

4.1 MODEL STUDY LIMITS

The water quality modeling study area extends from the upstream edge of all watersheds draining into the City, but stops at the City limits for watersheds draining out of the City. The figure titled ‘Major Watersheds – Existing Conditions’ included in the appendix of this report identifies the limits of the study area and their subwatershed. A similar figure titled, ‘Major Watersheds – Proposed Conditions’ shows how watersheds were further subdivided to determine drainage areas to possible new water quality detention ponds.

The area included in the study limits is described in the following table:

**City of Baraboo
Water Quality Model Study Areas**

Description	Area (acres)
Study Limits	7035.5
City Limits	3635.6
Regulated Area	2778.5

4.2 MODEL LAND USE AND EXEMPT AREAS

Base conditions land uses within the City were determined according to the City's 2005 stormwater utility database. Specifically individual parcels and sections of right-of-way were evaluated according to the total amount of measured impervious area according to the stormwater utility database. Additional discussion on the division of pervious and impervious surfaces is included in the following section.

The figure in the appendix titled 'P8 modeled Land Use' identifies the land use conditions used as input for the P8 model.

For purposes of complying with the June 16, 2005 memorandum documenting model prohibitions the model land use map was further altered to identify 'excluded' areas. These included areas where development or redevelopment had occurred since October 2004 that was also regulated by NR151.12 or 151.24. Eric Rortdvedt, the Southcentral WDNR water resources engineer, provided a list of all construction activities (through April 2007) that the WDNR had permitted under NR141.12 and NR151.14. This list was shared with City engineering staff who identified a number of additional projects within the City that according to the nature and extent of development should also have appeared on the WDNR's list of permitted projects.

Those areas within the City limits were coded within the model land use map as 'excluded' areas and are shown on the figure in the appendix labeled 'Excluded Areas.' Also shown on this map are all areas within the study limits that are also outside the City limits. These areas were coded as 'excluded' also, in compliance with the June 16, 2005 guidance document.

It bears repeating to note that excluded areas were included in the P8 model for purposes of properly accounting for the stormwater runoff from these areas so that the efficiency of downstream treatment devices could be properly evaluated. Additionally, treatment devices within excluded areas were also included in the model, also to properly account for their effect on stormwater runoff routing. However, pollutant loads for excluded areas were suppressed. It is for this reason that many of the devices in the summary tables included in the appendix show no trapped load and N/A for treatment efficiency.

4.3 LAND USE AND IMPERVIOUS AREA

P8 requires data for impervious area as a primary input parameter. In April 2005 the City of Baraboo adopted a stormwater utility. At that time all non-residential parcels within the City had had their impervious area determined through a detailed GIS assessment using recent aerial photography. A statistically significant random sample of residential parcels was also evaluated such that the average impervious area associated with residential parcels could be determined. This data was used as the basis for determining watershed impervious area within the City:

- All residential parcels were assigned an average impervious area equal to the City's stormwater utility *Equivalent Residential Unit* data.
 - Single Family Residential parcels were found, on average to be 27% impervious.
 - One-third (33.33%) of impervious area on SFR parcels was assumed to be unconnected impervious area.
 - Multifamily Residential parcels were found on average to be 40% impervious.
 - All impervious area on MFR parcels was assumed to be unconnected.
- All non-residential parcels that were developed prior to April 2005 were assigned an

impervious area equal to the amount of impervious measured on that parcel as identified in the City's stormwater utility database. All impervious area is assumed to be directly connected.

- All non-residential parcels that were developed after implementation of the City's stormwater utility were assigned an impervious area equal to 73% of the parcel area, as this was the average impervious fraction of all non-residential parcels in the City's stormwater utility database. All impervious area is assumed to be directly connected.
- All roadway rights-of-way were assigned 50% imperviousness according to the area of each individual the right-of-way. All impervious area is directly connected.

4.4 STREET SWEEPING

TSS reduction achieved through street sweeping was estimated using the WinSLAMM model. The street sweeping efficiency predicted by WinSLAMM (applied as a percentage after the fact in watershed not draining to a structural BMP) P8 was then solved to determine the combined TSS removal of street sweeping and structural BMPs (ponds).

WinSLAMM is capable of modeling both mechanical and high-efficiency (vacuum) street sweeping. Sweeping intervals may be altered and sweeping may be evaluated with and without parking restrictions. Parking restrictions assume that cars are not allowed to park on streets on days when sweeping is to occur.

Street sweeping frequency data was provided by the City of Baraboo street department. According to the department, the City's sweeping program allows for two full sweeps of the community per year. The downtown area is swept weekly. The City owns a mechanical sweeper.

On average the City begins sweeping operations on April 15 and stops for the winter season on November 1. Note however, that WDNR modeling protocols require model simulations, and hence street sweeping durations, span the entire 'non-winter' season; for the Baraboo area the 'non-winter' date range is March 12 through December 2.

5.0 FINDINGS AND DISCUSSION

5.1 MODEL RESULTS

The table below demonstrates the significance of application of the various exemptions and exclusions documented in the WDNR modeling guidance memorandum.

**City of Baraboo
Baseline Annual Total Suspended Solids Loads**

Description	Area (acres)	Annual TSS Load (tons/yr)
Study Limits	7035.5	509.1
City Limits	3635.6	367.3
Regulated Area	2778.5	351.1

The water quality model found the following:

**City of Baraboo
Current Total Suspended Solids Reduction Performance**

No Controls Annual Regulated Load	351.5 tons/yr
TSS Removed by Allowable Structural Practices	51.5 tons/yr
Additional TSS Removed by Street Sweeping	3.2 tons/yr
Total TSS Removed	54.7 tons/yr
TSS Reduction Rate	15.6%

With its current management practices, the City of Baraboo falls short of both the 2008 20% TSS reduction requirement and the 2013 40% TSS reduction requirement.

5.2 STREET SWEEPING EFFECTIVENESS

WinSLAMM modeling results showed much greater TSS reductions for high-efficiency sweepers relative to mechanical sweepers. Modeling also shows greater TSS reductions for sweeping practices when parking controls are in effect. However, the results of modeling street sweeping showed that while the 2008, 20% TSS reduction requirement could be met by improved street sweeping practices, the 2013 target, of 40%, could not.

The following table compares the relative efficiencies of several street sweeping scenarios for the City of Baraboo.

**City of Baraboo
Alternative Street Sweeping Programs
TSS Reduction Performance**

Program	Frequency ¹	Method	Parking Controls	Stand-alone Citywide Reduction	Citywide Reduction w/Existing Ponds
Existing	Biannual	Mechanical	No	1.1%	15.6%
Alternative 1	Biannual	Vacuum	No	1.9%	16.2%
Alternative 2	Biannual	Vacuum	Yes	3.2%	17.2%
Alternative 3	Monthly	Mechanical	No	1.4%	15.6%
Alternative 4	Monthly	Vacuum	No	2.8%	16.8%
Alternative 5	Monthly	Vacuum	Yes	5.6%	18.6%
Alternative 6	Weekly	Mechanical	No	4.0%	17.4%
Alternative 7	Weekly	Vacuum	No	8.3%	20.5%
Alternative 8	Weekly	Vacuum	Yes	15.5%	25.4%

¹ Downtown areas are swept weekly under all scenarios.

The figure in the appendix titled 'Effective Areas for Street Sweeping' illustrates the areas in the City where the greatest benefit is achieved through street sweeping practices. This figure identifies street areas within the study area that are not exempt due to regulations or modeling protocols and are not draining to an existing structural management practice (detention pond).

5.3 CONSTRUCTION OF ADDITIONAL WET DETENTION PONDS.

The P8 model results for the 34 potential alternative wet detention ponds found that the basins were individually capable of removing between 0.1% and 5.2% of the City's regulated TSS load. Cumulatively, the 34 basins could remove as much as 47.6% additional TSS from the City's regulatory load.

The tables included in the appendix of this report document the individual TSS reductions achieved by each of the existing and proposed structural BMPs.

It should be noted that as more wet detention basins are constructed, street sweeping as a TSS reduction management practice becomes less effective. This is because even the lowest-efficiency (33.2%) detention pond has a higher TSS reduction efficiency than even the most efficient sweeping alternative (15.5%). As additional ponds are constructed, there is no additional TSS reduction gained by sweeping streets within that ponds drainage area. This situation is illustrated in the following table:

**City of Baraboo
Comparison of Street Sweeping Programs
With Existing and Proposed Structural BMPs in Place**

Program	Citywide Reduction w/Existing Ponds	Citywide Reduction w/Existing and Proposed Ponds
Existing	15.6%	61.1%
Alternative 1	16.2%	61.2%
Alternative 2	17.2%	61.3%
Alternative 3	15.6%	61.1%
Alternative 4	16.8%	61.3%
Alternative 5	18.6%	61.6%
Alternative 6	17.4%	61.4%
Alternative 7	20.5%	61.9%
Alternative 8	25.4%	62.8%

The maximum difference in overall TSS reduction achieved by improved street sweeping under existing conditions is 9.8% (Alternative 8 vs. Existing conditions). If all 34 ponds were to be constructed the maximum improvement due to improved street sweeping would be only 1.7%.

5.4 DRY POND PERFORMANCE ESTIMATES

The WDNR has expressed concerns regarding the accuracy of water quality modeling tools (including SLAMM and P8) in estimating the efficiency of TSS removal in situations where subsequent runoff events could scour, or resuspend TSS collected in a structural BMP by a previous rainfall event. Of particular concern to the WDNR are dry detention facilities.

The WDNR has issued Conservation Practice Standard 1001 Wet Detention Pond which is a design guideline for construction of wet detention ponds. One design requirement identified in this practice standard is that the average water depth of the permanent pool shall be a minimum of 3 ft., excluding the safety shelf area and sediment storage depth. Presumably if a pond does not meet the minimum requirements for classification as a wet pond, it might be viewed by the WDNR as a (quasi-) dry pond.

Of the 88 ponds modeled in this study, 63 ponds have permanent pool depths less than 3 feet. Fifty-five ponds have permanent pool depths less than one foot. The WDNR has unofficially stated that at some point in the future they may apply a maximum effective TSS removal rate to dry detention facilities to account for the potential for resuspension of sediment. They have even discussed the possibility of allowing no credit for dry ponds. Obviously this could have an enormous impact on the TSS reduction performance of the City's existing stormwater management system.

6.0 RECOMMENDATIONS

The minimum program that could be implemented to achieve 20% TSS reduction would be for the City to purchase a high efficiency vacuum street sweeper and sweep the City on a weekly basis. There would be no need to enforce parking controls on sweeping days (although it will be necessary to continue parking controls downtown). With the existing detention ponds, this would achieve a TSS reduction rate of 20.5%.

The minimum program that could be implemented to achieve 40% TSS reduction would be for the City to construct the eight highest ranking detention ponds and replace the City's existing mechanical street sweeper with a high efficiency vacuum sweeper. There would be no need to change the current sweeping schedule. This program would achieve a TSS reduction of 40.2%. Alternatively the City could construct the top nine highest ranking detention ponds and leave the current street sweeping practices in place. This would achieve a TSS reduction of 42.0%.

The estimated construction cost to construct the eight most efficient wet detention ponds is \$1.2 million. However, in MSA's experience with water quality master planning we have found that it is unlikely that all recommended projects will be able to be constructed, so this represents a minimum project cost. Since there are a large number of combinations of detention ponds that might be constructed to reach the 40% TSS reduction goal, it is impractical to speculate on a likely actual project cost. However, as a way to bracket the possible actual project cost, if only the least efficient ponds are able to be built to meet the 40% TSS requirement it will require construction of 27 ponds with a total estimated cost of \$4.5 million.