FDM 10-35-1 Stormwater Quality Practice Selection

October 22, 2012

1.1 Introduction

A Stormwater Control Measure (SCM) has been defined as "a combination of land use, conservation practices, and management techniques which, when applied to a unit of land, will result in the opportunity for a reasonable economic return with an acceptable level of water quality." When selecting SCMs, several considerations must be evaluated in order to meet this definition. These considerations are discussed below. There are generally two reasons to implement SCMs from a water quality standpoint:

1. To protect the water quality from future degradation.
2. To correct existing water quality problems. In this case, SCMs are implemented as remedial measures.

Almost without exception, changing an open or agricultural land use to an urban land use will affect water quality. Even if the actual concentration of pollutants does not increase, the total loading of pollutants can increase many times. This is because the volume of runoff must be considered in addition to the concentration of pollutants.

SCMs are typically site specific and depend upon many factors including proper design, installation, maintenance, and characteristics of the storm involved. In general, higher efficiencies can be expected for very small storms and lower efficiencies expected for very large storms.

It is usually necessary to use a combination of practices to meet water quality goals rather than relying upon just one practice.

1.2 Project Scoping for Stormwater Quality

The selection and placement of stormwater quality control practices begins at the project scoping stage. The scoping engineer, regional stormwater engineer and project development section must first determine the reduction goals for TSS, if any, and if the 2-year peak flow level must be maintained between the existing conditions and the proposed conditions. Once these requirements have been determined, the designer should select and evaluate control practices as described in the design process in FDM 10-35-1.8, but using the planning level percent TSS reductions listed for each control practice in the WisDOT stormwater control treatment efficiencies matrix (FDM 10-25 Attachment 1.2). At this point in the process it is also important to verify that the selected control practices will be properly maintained because practices that will not be maintained will receive no TSS reduction credit. By using this process, the designer can estimate the percent TSS reduction possible for the project at a planning level.

1.3 Physical Site Suitability

SCMs should only be used in areas where the physical site characteristics are suitable. Some of the physical characteristics that are important are soil type, watershed area, water table, depth to bedrock, site size and topography. If these conditions are not suitable, a practice can lose effectiveness, require excessive maintenance, or stop working altogether after a short period of time. Sometimes, unfavorable site conditions can be overcome with special design features. For example, the bottom of a detention pond can be sealed to prevent seepage into permeable soils at a site where a permanent pool is desired. In other cases, a practice will be excluded from consideration for a site because of conditions that are not practical to overcome. An example of this would be where a high water table or clay soils eliminate an infiltration basin from consideration.

1.4 Cost Effectiveness

Economics are an important consideration in the selection of SCMs. An economic analysis will identify the mix of SCMs that will achieve the water quality goal at the least cost. This should be considered when selecting SCMs and deciding how they will be implemented. To properly compare alternatives, all costs for the design life of a SCM should be included. These include expected maintenance costs as well as the initial costs for land, engineering and construction. For example, the use of grass swales in place of storm sewer pipes should be accounted for as a cost reduction. To create a true picture of the "cost" of a SCM, benefits other than water quality and flood prevention may also be considered. Some benefits such as increases in land values for property adjacent to an attractive detention pond are direct economic benefits. Other benefits such as incidental recreation benefits or wildlife benefits may be more difficult to quantify.

1.5 Maintenance Requirements

SCMs Maintenance is an important part in the operation of any SCM. The initial design of the SCM should take maintenance requirements into account. The cost of long-term maintenance should be evaluated during the selection process. In addition, responsibility for maintenance should be clearly assigned for the life of the system, because if a practice is not maintained, then it cannot receive a stormwater quality reduction credit. Typical maintenance requirements include:

- Inspection of basins and ponds after every major storm for the first few months after construction and annually thereafter;
- Mowing of grass filter strips and swales to prevent woody growth and promote dense vegetation;
- Removal of litter and debris from dry ponds, forebays, and water quality inlets;
- Regrading and revegetation of eroded areas;
- Periodic removal and replacement of filter media from infiltration trenches and filtration ponds;
- Deep cleaning of infiltration basins to maintain infiltration capability;
- Frequent (at least quarterly) vacuuming or jet hosting of porous pavements or concrete grid pavements;
- Quarterly clean-outs of water quality inlets;
- Periodic removal of floatables and debris from catch basins, water quality inlets, and other collection-type controls; and
- Periodic removal and proper disposal of accumulated sediment (applicable to all practices). Sediments in infiltration devices need to be removed frequently enough to prevent premature failure due to clogging.

1.6 Effect on Other Resources

When planning a SCM, consider the effect it will have on other resources. Without proper design, it is possible to shift a water quality problem to some other location. Ground water can be adversely affected by improperly designed SCMs.

1.7 Public Acceptance

In an urban environment, aesthetics are an important consideration for gaining public acceptance of SCMs. In many cases, practices such as wet detention ponds can be an asset visually to the surrounding area. However, if a detention pond is designed in a square shape with uniform slopes, it will not appear natural and can detract from the surround area. Odor, insects, weeds, turbidity and trash are also important to residents who live near structural SCMs. With regular maintenance, these problems can usually be overcome or are very temporary.

1.8 Suspended Solids Reduction Design Process

The general design approach is to apply the simplest, most cost-effective practices first and evaluate the suspended solids reduction from these practices. If the suspended solids reduction goal has not been met after doing this, add additional practices to increase the suspended solids reduction percentage for the project. If additional practices have been added to the project, but the goal has not been reached and it is not practicable to add additional treatment practices, then the project has been treated to the maximum extent practicable (MEP). The determination of MEP should be reviewed and confirmed by the Regional Stormwater Engineer.

Follow the process described below to determine the most cost effective suspended solids reduction system during the project design phase and when developing the project scoping analysis described above. When placing practices, considerations such as available right-of-way, soil type, water table, drainage area, slope, type of cross section, available head or other issues may affect the feasibility of the practice(s), and the location and placement of control practice(s). Coordinate to select the appropriate treatment practices for the project. Refer to the FDM section for each control practice for additional information on possible constraints or considerations.

1. Begin by determining the drainage areas for all grass swales along the project corridor. Properly designed and maintained swales have a vegetated embankment on the slope from the pavement to the swale, and will remove by design 80% of the suspended solids from the highway. Review proposed FDM 10-35-5 (*not complete yet*) to see the design criteria and detail for grass swales. Enter the required information in the WQ-Grass Swales worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27.

2. If the goal has not been met, review the project limits to determine if filter strips are appropriate control

practices in any project area. Note that filter strips may only be used for areas that have not been included as swale drainage areas. Review FDM 10-35-10 (*not complete yet*) to see the design criteria and detail for filter strips. Enter the required information in the WQ-Filter Strips worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27.

3. If the goal has not been met and there are urban areas in the project with curb and gutter, consider using street cleaning as a control practice. This practice will require a maintenance agreement with the appropriate local unit of government. Use the design guidelines in FDM 10-35-25 (*not complete yet*) to evaluate the suspended solids removal rates for street cleaning. Enter the required information on the WQ-Street Cleaning worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27. *TSS control from street cleaning shall not be applied in areas where TSS control is achieved through catchbasins with sumps, nor should catchbasins with sumps be applied in areas where TSS control is achieved through street cleaning.*
4. If the goal has not been met and there are urban areas in the project with curb and gutter, and inlets or catchbasins, add sumps to the catchbasins and inlets. Review FDM 10-35-20 to see the design criteria and process for catchbasins. Enter the required information in the WQ-Catchbasins worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27.
5. If the goal has not been met, look for areas of the project that can accommodate biofilters, rain gardens or swale drainage with engineered soils. Use the design guidelines in FDM 10-35-30 (*not complete yet*) to evaluate the suspended solids removal rates for these systems. Enter the required information on the WQ-Biofilter worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27.
6. If the goal has not been met, look for areas of the project that can accommodate wet detention ponds. Use the design guidelines in FDM 10-35-15 to evaluate the suspended solids removal rates for these systems. Enter the required information on the WQ-Wet Detention Ponds worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27.
7. If the goal has not been met and there are control practices on the project that do not fit any of the other categories, compete the worksheet WQ-Other. Use the guidelines in FDM 10-35-35 (*not complete yet)* to evaluate the suspended solids removal rates for these systems. Enter the required information on the WQ-Other worksheet and then review the Summary worksheet. If the percent TSS reduction by treatment type value for the total project drainage basin is equal to or greater than the suspended solids reduction goal, then the design process is complete. Enter the appropriate narrative information in lines 23, 25 and 27.

If it becomes impractical to add stormwater control practices to reach the suspended solids reduction goal, which means the project has been treated to the maximum extent practicable (MEP), document this on the WQ-Summary worksheet.

1.9 Effectiveness in Reducing Peak Discharges

Peak discharge control is a concern from a water quality standpoint because of the channel erosion problems that uncontrolled runoff from urban areas can cause. Requirements for peak discharge control are normally regulated by a local watershed district or water management organization. SCMs such as detention ponds can be very effective for reducing peak discharges. The effectiveness of a SCM for peak flow reduction varies depending upon the design and location of the structure.

1.9.1 2-Year Design Flow Peak Discharge Analysis

Peak TRANS 401.106(4) requires designers to maintain the existing 2-yr design storm discharge peak rate for new highway facilities. To meet this requirement, the water surface elevation in the receiving water may increases by no more than 0.01 ft compared to the existing condition. To evaluate the water surface elevation, typically a water surface profile model like HEC-RAS is used. This requirement does not apply to project sections that discharge directly into a lake over 5,000 acres or to a stream or river segment draining more than

500 square miles, refer to:

http://dnr.wi.gov/topic/stormwater/documents/Modeling_Post-Construction_Guidance_2011.pdf

The highway reconstruction exemption means that only those projects that are on a new alignment, or have new alignment sections totaling more than 1.5 miles, need to meet the 2-year peak flow discharge requirement.

If the 2-year peak discharge requirement applies to a project, then the analysis is typically part of the standard drainage design process, except that in addition to evaluating the 10-year, 25-year, and possibly the 50-year rainfall events, the designer will also evaluate the 2-year rainfall event. If the peak discharge for the post construction 2-year rainfall event is greater than the peak for the existing discharge, then the designer can either lengthen the time of concentration, modify the soil to reduce the discharge rate, or provide detention storage. Each of these options is discussed below.

1. Lengthen the Time of Concentration. Options include:
   - Increasing the flow path length
   - Flattening the ditch line
   - Widening the ditch
   - Adding ditch checks if the ditch is out of the clear zone.
2. Modify the Soil to Reduce the Discharge Rate. Options include:
   - Adding sand, peat, compost, or mulch to the soil to increase the soil porosity and lower the discharge rate.
   - Increase the soil porosity by subsoiling (soil ripping) and planting deep rooted native plants.
   - Adding a drain tile in a ditch with engineered soil to reduce the peak discharge from the ditch.
3. Provide Detention Storage. Options include:
   - Providing small depressions in a widened conveyance swale.
   - Wet or dry detention ponds.

FDM 10-35-5 Grass Swales *March 28, 2014*

5.1 Description and Purpose

Vegetated or grass swales are shallow channels with a dense stand of vegetation established in them. They are designed to promote infiltration and trap pollutants. The combination of low velocities and vegetative cover provides an opportunity for pollutants to settle out or be treated by infiltration. In addition to pollutant removal, this practice can result in reduced runoff volumes and peak discharges.

5.2 Target Pollutants

Grass swales can be used to trap solids such as sediment, associated particulate pollutants, and organic matter from runoff. Grass swales can also be effective for runoff volume reductions, peak flow-rate reductions, metals, and soluble pollutant removal, but only to the extent that runoff infiltrates into the soil and pollutants are filtered or become attached to soil particles.

5.3 Planning Issues

5.3.1 WisDOT Design Requirements

Per TRANS 401.106(3):

- For transportation facilities first constructed after 2002, where there was previously no transportation facility, total suspended solids (TSS) discharges shall be reduced, when compared with no stormwater quality discharge controls, by the maximum extent practicable, up to 80%, based on an average annual rainfall.
- Highway reconstruction and non-highway redevelopment projects must reduce TSS discharges by the maximum extent practicable, or up to 40%.
- Projects classified as minor reconstruction do not require TSS removal.

See the Region Stormwater Engineer or FDM 10-35-1 for guidance on setting the correct TSS reduction level for a project. Off-site pollutant loads, however, are typically excluded from the analysis because the source of the pollutants (from off the DOT right-of-way) is not controlled by the DOT. If the highway has an ADT of more than 2,500 vehicles per day and runoff from the transportation facility directly enters an outstanding resource water, exceptional resource water, 303(d) listed water or waters with targeted performance standards (such as TMDLs), then the designer should work with the Region Stormwater Engineer and the WDNR Liaison to determine how to meet water quality standards.

Grass swales must have a design velocity of less than 1.5 ft/sec, using the 2-year design storm, for the swale to achieve the 80% reduction described in TRANS 401.106(10). These values can be determined by applying the design flow to each swale segment using the WisDOT Grass Channel design spreadsheet described in FDM 13-30-15.

5.3.2 Site Assessment

Conduct and document a site assessment to determine where grass swales are appropriate. The primary issues affecting their use are:

- Swale length
- Bottom width
- Design flow depth
- Slope and vegetation type

because this information will affect how the swale performs. Generally, if the swale slopes are greater than 4%, the swale will not effectively remove pollutants from the adjacent roadway runoff unless other measures such as permanent ditch checks are included in the design. To evaluate grass swales, identify the proposed drainage area for each swale section. The drainage area is defined by distance between the roadway crown and the top of the back slope draining to the swale and by the length of the highway that drains to the swale. Grass swale drainage areas can extend past the highway right-of-way depending upon the slope of the land, and can include significant areas outside of the right-of-way, depending upon local topography. Grass swale drainage areas should also be divided when soil types or swale treatments or geometries change. For example, if a section of the grass swale has permanent ditch checks or a different bottom width than other sections, then this section should be considered as a separate grass swale section.

5.3.3 Grass Swale Design Considerations

Planning considerations are intended to suggest to the designer issues that may be of concern for a project. If you believe that a consideration may affect your project, contact your regional stormwater engineer for additional guidance. If the channel is unstable, you have the following options:

- Flatten the longitudinal slope by modifying the slope grade, alternating longer flatter sections with short, steep riprap lined sections, or putting in permanent ditch checks that are not in the clear zone. If you use properly spaced permanent ditch checks, assume a longitudinal slope of 1%. Ditch checks should be spaced such that the base of the upstream check is at the same elevation as the top of the downstream check.
- Flatten the side slopes and/or widen the ditch bottom to decrease the flow depth.

5.4 Design Recommendations

The design guidelines described below provide a set of methods to calculate the percent TSS reduction from a grass swale. These guidelines assume that the swale will reduce TSS by 80% if the swale velocity is less than or equal to 1.5 feet per second and that the swale length is at least 200 feet.

1. Flow: Compute runoff flows from sources within the right-of-way separately from those contributing from outside the right-of-way. The Q2 water quality design storm, Q10 for erosion, and ditch capacity design flow rate as required in FDM 13-10 Attachment 1.1 need to be computed from both sources within and outside of the right-of-way. Each grass swale transition location should be evaluated for these flows; however, transition locations need not be evaluated closer than 200 feet apart.

2. Side slopes: The side slopes should be flat as possible to aid in providing pretreatment for lateral incoming flows and to maximize the channel-filtering surface. Steeper side slopes are likely to have erosion gullying from incoming lateral flows. A maximum slope of 3:1 is recommended; a 4:1 slope or flatter is preferred where space permits.

3. Channel longitudinal slope: The slope of the channel should be steep enough to ensure uniform flow and which can be constructed using conventional construction equipment without ponding, but not steeper than 4.0%. A desirable minimum slope of between 1.0% to 0.5% is recommended, and the absolute minimum slope is 0.3% where necessary.

5.4.1 Grass Swale Water Quality Analysis using the WisDOT Stormwater Report Spreadsheet

WisDOT has prepared two spreadsheets that incorporate the design guidelines and calculations needed to determine if a project meets the required TSS load reduction. The first spreadsheet, the Stormwater Report, has a series of worksheets that a designer can use to methodically prepare and summarize an analysis of the water quality benefits of the various stormwater quality practices used on a project.

The WQ-Grass Swales Worksheet in the Stormwater Report provides a place for the designer to describe and summarize the performance of any grass swales used in a project. The use of the complete spreadsheet to summarize water quality performance for a project is described in FDM 10-30-1. The second spreadsheet is the grass lined channel design spreadsheet developed for FDM 13-30-15. This spreadsheet is used to determine the velocity of the flow in the channel for the 2-yr design storm. The spreadsheet is part of the documents that can be downloaded at:

https://wisconsindot.gov/rdwy/fdm/files/WisDOT-Stormwater-Drainage-WQ-Channel-Spreadsheets.zip

The grass swale analysis procedure described below uses the grass swale analysis summary worksheet "WQ-Grass Swales" shown in Attachment 5.1. The worksheet is only used to summarize the grass swale data in an organized fashion - it does not calculate grass swale performance, but instead selects the TSS reduction value based upon the design variable, the velocity of the 2-yr design storm.

To use WQ-Grass Swale Worksheet, enter data into the appropriate worksheet cells. The worksheet is designed so that you can insert additional columns before the final Total column, as needed. Do NOT enter information in the grey cells because they contain formulas that should not be modified. However, you will have to modify the formula in the row 22 Totals column to correctly calculate the total percent reduction per unit ROW area.

On a plan view of the drainage system, delineate the drainage area for each grass swale section that will be providing water quality benefits designed in accordance with this standard. Number the sections, determine their station and if they are left, right or in the center median. Enter this information on lines 7 through 10 of the worksheet, and then determine the following information and enter it on the appropriate line of the worksheet.

Line 12 - The length of the grass swale adjacent to the highway, which will typically be the difference between the starting and ending station numbers entered in lines 8 and 9.

Line 13 - The average drainage area width outside of the right-of-way. The area this width is calculated from includes all areas outside of the right of way that drain to the grass swale.

Line 14 - The average right-of-way width. The average distance from edge of right-of-way to edge of right-of-way for the highway segment the grass swale drains. If there are grass swales or other treatment devices in either the median or the other side of the highway, then extend this distance from the edge of the right-of-way to the limit of the treatment area (eg, the crown of the highway). If there are no other treatments for this drainage area segment, use the total right-of-way width. If there is more than one swale in a highway segment (for example, a median swale and a left side swale) use two separate drainage basins.

Line 15 - The average swale slope.

Line 16 - The swale segment 2-year design flow rate. This value can be determined using an appropriate method described in FDM 13-10-5.

Line 17 - The swale segment 2-year design flow velocity. This value can be determined from line 55 of the Grass Channel Design Spreadsheet described in FDM 13-30-15.

The worksheet will determine the percent reduction for each basin in Line 18.

If you need to record comments about the design for any of the drainage areas, enter them in the comment boxes below the worksheet. Add more comment boxes if necessary.

5.4.2 Other Design Criteria

1. This design approach isn't intended for riprap channels. Appropriate soil-stabilization methods, such as mulch, mats or blankets, should be used before establishment of vegetation
2. Avoid convergence of flows that may result in erosion or gullies. Convergence points shall be treated with additional practices like permanent ditch checks or sediment traps.
3. If permanent ditch checks are used to reduce the channel slope, then the permanent ditch checks must meet the following criteria:
    1. They must be spaced by installing one permanent ditch check for every two feet of drop.
    2. Assume a 0.5% slope for properly spaced ditch checks when calculating flow velocity.
    3. They must not be in the clear zone.

5.5 Maintenance

5.5.1 Maintenance Requirements

Properly designed grass swales should require little maintenance. Typical loading rates to swales from the highway surface on a per foot basis are lower than the rate necessary to clog the swale. If clogging does occur, it is usually due to off right-of-way erosion, or from an embankment or swale failure within the right-of-way, which should be addressed before repairing the grass swale. Other causes of swale damage include tire rutting due to a car driving over the embankment into a swale, or by a spill along the highway. Minor repairs are managed by the WisDOT region maintenance staff. If swale damage does occur, it should be repaired in a timely manner.

5.5.2 Maintenance Plan

A maintenance plan is typically unnecessary for grass swales because regular highway maintenance and inspection practices detect and repair shoulder, embankment and swale problems. Standard WisDOT maintenance practices include:

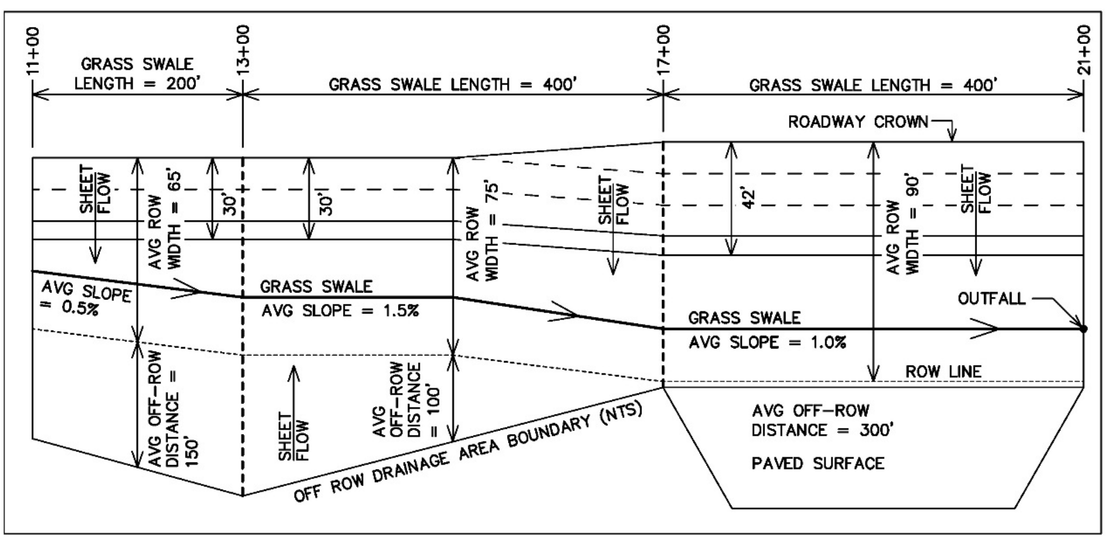
1. Grading the shoulder one to two times per year, typically in the spring and the fall. Grading consists of blading the shoulder away from the edge of the pavement, returning it, settling and then compacting it with rubber tired rollers.
2. Inspecting embankments while mowing and during routine maintenance surveillance. Rilling or other embankment problems are then repaired on a spot basis.

5.6 Grass Swale Water Quality Design Example

Vegetated swales should be maintained to keep the grass dense. The grass should be mowed occasionally, but

Given the drainage areas and site conditions described below, determine the water quality reduction percentage using grass swales for the highway section.

Problem - One thousand feet of a highway corridor is drained by a standard V-ditch grass swale, as shown in the drawing below. Determine the percent reduction of TSS due to the swale. To do this, determine the velocity of the flow for each segment of the grass swale system and then enter the data from the table below into the Grass Swale tab of the Stormwater Report spreadsheet. Assume that the ROW width extends only from the roadway crown to the ROW line.



STA – STA	11+00 - 13+00	13+00 - 17+00	17+00 - 21+00
Paved Area (ac)	200’ x 30’ = 0.14 ac	400’ x 32 = 0.29 ac’	400’ x (42’+300’) = 3.14 ac
Unpaved Area (ac)	200’ x (65’-30'+150’) = 0.85 ac	400’ x (75’-32’+100’) = 1.31 ac	400’ x (90’-42’) = 0.44 ac
Composite Runoff Coefficient	0.37	0.39	0.87
Rainfall Intensity	2-yr, 24-hr. 4.0 in/hr		
Flow	1.5 cfs	2.5 cfs	12.5 cfs
Cumulative Flow	1.5 cfs	4.0 cfs	16.5 cfs
Swale Geometry	V-Ditch, 6:1, 4:1 Side Slopes		
Safety Factor	1.0		
Retardance Class	C		
Vegetation Condition	Good		
Growth Form	Turf		
Soil Type	Cohesive		
ASTM Soil Class	SC		
Plasticity Index	16		

Solution - First complete the Grass Channel Design spreadsheet using the data listed above. The purpose of the analysis is to determine the velocity of the flow for the 2-yr design storm in each swale segment. Note that for this example, the spreadsheet (shown below) has been slightly modified to include the average velocity (line 55) for each segment. For assistance using the Grass Channel Design spreadsheet, review FDM 13-30-15. For an illustration of a typical grass swale cross section, see Figure 10.1 of FDM 13-30-10. The results of the analysis show that the first two segments, at STA 11+00 and 13+00, have average velocities that are less than 1.5 ft/sec, while the last segment, at STA 17+00, does not. This means that, for the initial design, only the first two segments will receive the 80% reduction.

The example Grass Channel Design spreadsheet below also includes a second column for the swale at STA 17+00 to demonstrate how to use the spreadsheet to evaluate different swale options. If it were possible to increase the width of the swale bottom to 12 feet, then the swale section at STH 17+00 would also meet the average velocity requirement.

7	STA	11+00	13+00	17+00	17+00
8	Left, Center or Right	R	R	R	R
9	***Channel/Ditch Geometry***				
10	Channel Slope, S_o (ft/ft)	0.005	0.015	0.01	0.01
11	Channel Bottom Width, B (ft)	0	0	0	12
12	Channel Side Slope, z_1	6	6	6	4
13	Channel Side Slope, z_2	4	4	4	4
14	Flow Depth, d (ft) Solve iteratively	0.79	0.79	1.42	0.75
15	Safety Factor, SF	1.0	1.0	1.0	1.0
16	***Vegetation/Soil Parameters***				
17	Vegetation Retardance Class	C	C	C	C
18	Vegetation Condition	good	good	good	good
19	Vegetation Growth Form	turf	turf	turf	turf
20	Soil Type	cohesive	cohesive	cohesive	cohesive
21	D_{75} (in) (Set at 0.00 for cohesive soils)				
22	ASTM Soil Class	SC	SC	SC	SC
23	Plasticity Index, PI	16	16	16	16
24	***Results Summary***				
25	Design Q (ft^3/s)	1.5	4.0	16.5	16.5
26	Calculated Q (ft^3/s)	1.5	4.0	16.6	16.4
27	Difference Between Design & Calc. Flow (%)	-1.4%	-0.5%	0.7%	-0.3%
28	**Stable (Yes or No)**	YES	YES	YES	YES
29	***Channel Parameters***				
55	Average Velocity, V (ft/s)	0.48	1.28	1.64	1.47

Figure 5.1 Example Grass Channel Design Sheet

Once the velocity of each swale segment has been determined, complete the Grass Swale Analysis Summary spreadsheet. The project information (lines 2 - 5) will be filled in when you enter project information on the summary tab of the stormwater report. Define the grass swale sections in lines 7-10 of the Grass Swale Analysis Summary Spreadsheet, (Attachment 5.1). Next, enter the site and calculated data into lines 12 - 17 of the spreadsheet.

Once the data have been entered, the worksheet will determine the overall TSS reduction due to grass swales. This value is transferred to the Water Quality Summary worksheet to include the grass swale TSS reduction with the reductions from any other stormwater quality control practices used on the project.

7	Drainage Area Basin Number	1	1	1		Total
8	Grass Swale Ending Station Number	13+00	17+00	21+00		
9	Grass Swale Starting Station Number	11+00	13+00	17+00		
10	Left, Center, or Right	R	R	R		
11	***Site Assessment***					
12	Grass Swale Length (ft)	200	400	400		
13	Average Drainage Area Width Outside of ROW (ft)	150	100	300		
14	Average ROW Width (ft)	65	75	90		
15	Average Swale Slope	0.50%	1.50%	1.00%		
16	Swale Segment Q2 Flow Rate (cfs)	1.5	4.0	16.5		
17	Average Swale Velocity (ft/s)	0.48	1.28	1.64		
18	Percent Reduction	80.0%	80.0%	0.0%	80.0%	
19	***Results Summary***					
20	Drainage Area (ac)	0.99	1.61	3.58	0.00	6.18
21	ROW Area (ac)	0.30	0.69	0.83	0.00	1.81
22	Percent Reduction per unit ROW Area	80.0%	80.0%	0.0%	80.0%	43.5%

Figure 5.2 Stormwater Report WQ Grass Swales Worksheet

5.7 References

Claytor R and Schueler T, Design of Stormwater Filtering Systems. Center for Watershed Protection, Silver Spring, MD, prepared for the Chesapeake Research Consortium, Inc. with supplemental funding of U.S. EPA Region 5. 1996.

Caraco D and Claytor R. Stormwater BMP Design Supplement for Cold Climates. U.S. EPA Office of Wetlands, Oceans and Watersheds. 1996.

Schueler T. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, D.C. 1987.

Vegetated Infiltration Swales (1005) Interm Technical Standard, Storm Water Post-construction Technical Standards, Wisconsin Department of Natural Resources, updated May 10, 2007.

Wisconsin State Legislature, Revisor of Statutes Bureau, Wisconsin Administrative Code; for information on the codes of state agencies, including WDNR, see http://www.legis.state.wi.us/rsb/code.htm.

LIST OF ATTACHMENTS

Attachment 5.1	Grass Swale Analysis Summary Spreadsheet

FDM 10-35-10 Filter Strips *December 20, 2013*

10.1 Description and Purpose

Filter strips are grass strips or other close growing vegetation designed to receive overland or sheet flow and reduce the stormwater runoff volume and stormwater pollutant concentrations and mass discharges. The vegetation slows and infiltrates the runoff (and associated pollutants) and further traps particulate pollutants in the exiting overland flow. Highway embankments can act as filter strips if they are graded to not concentrate runoff after it flows off a roadway surface and if the flow path across the embankment is sufficiently long and of low or moderate slope. Refer to typical filter strip illustration in Figure 10.1.

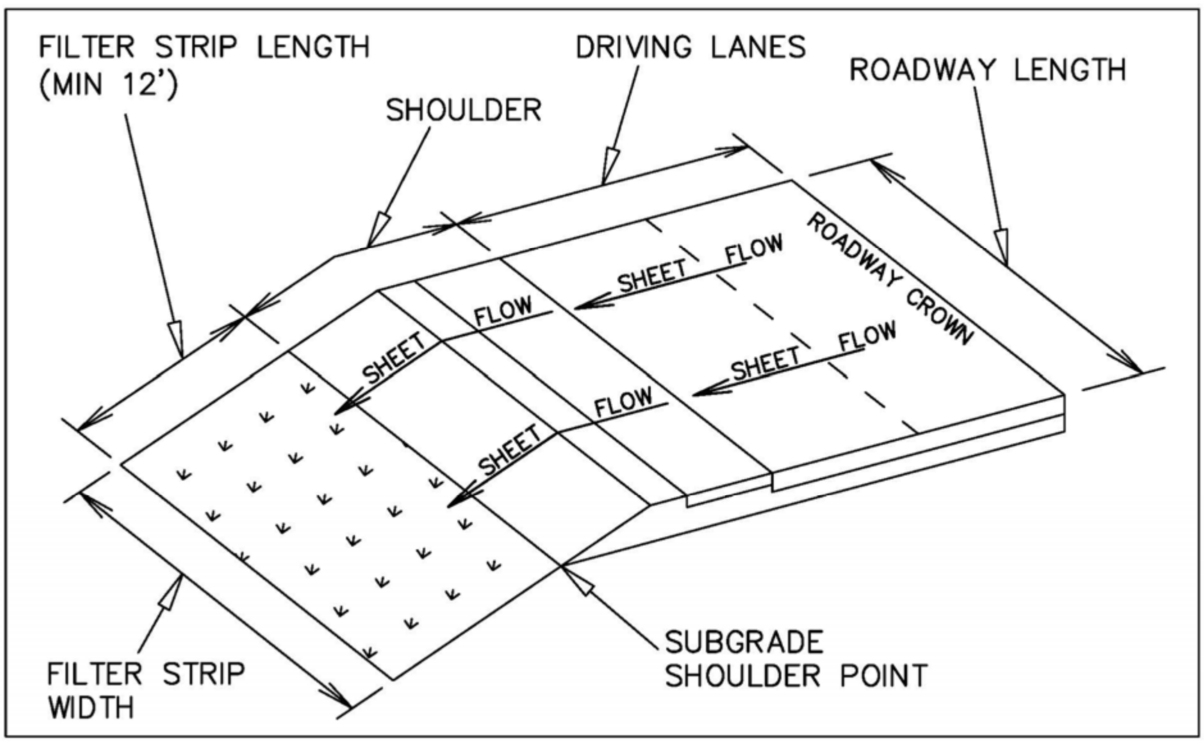


***Figure 10.1* Typical Filter Strip**

10.2 Targeted Pollutants

Filter strips can be used to trap solids such as; sediment, associated particulate pollutants, trash, and organic matter from runoff. Filter strips can also be effective for runoff volume and peak flow rate reductions, and soluble pollutant removal, but only to the extent that runoff infiltrates into the soil.

10.3 Effectiveness

The effectiveness of filter strips for pollutant removal is a function of the length and, to a lesser extent, the slope of the filter strip, the soil permeability, the size of the drainage area, and the height, type and density of vegetative cover. Also critical to the performance of filter strips is the distribution of overflowing water. If water is allowed to concentrate because of poor grading or uneven runoff distribution, the filter will be short-circuited and have only minimal benefit. When properly designed and maintained, highway embankment filter strips can trap 30 to 90 percent of the sediment in roadway runoff, depending upon the embankment soil type. Runoff volume reductions are determined by infiltration losses, and particulate losses are determined through particle trapping.

The runoff volume reduction is calculated using the wetted area and the dynamic infiltration rate of the filter strips for each time step of the filter strip inflow hydrograph. The calculated flow and the filter strip geometry are used to iteratively determine the Manning's n and the depth of flow in the filter strip for each time step. Using traditional VR-n (Velocity-Hydraulic Radius - Manning's n) curves based upon retardance measurements (USDA, 1954) that were extended (Kirby, et al, 2005) to cover the smaller flows found in roadside filter strips for VR values smaller than about 0.1 ft^2/sec (see Figure 10.2). For shallow sheetflows, as expected in filter strips, hydraulic radius can be approximated by the flow depth.

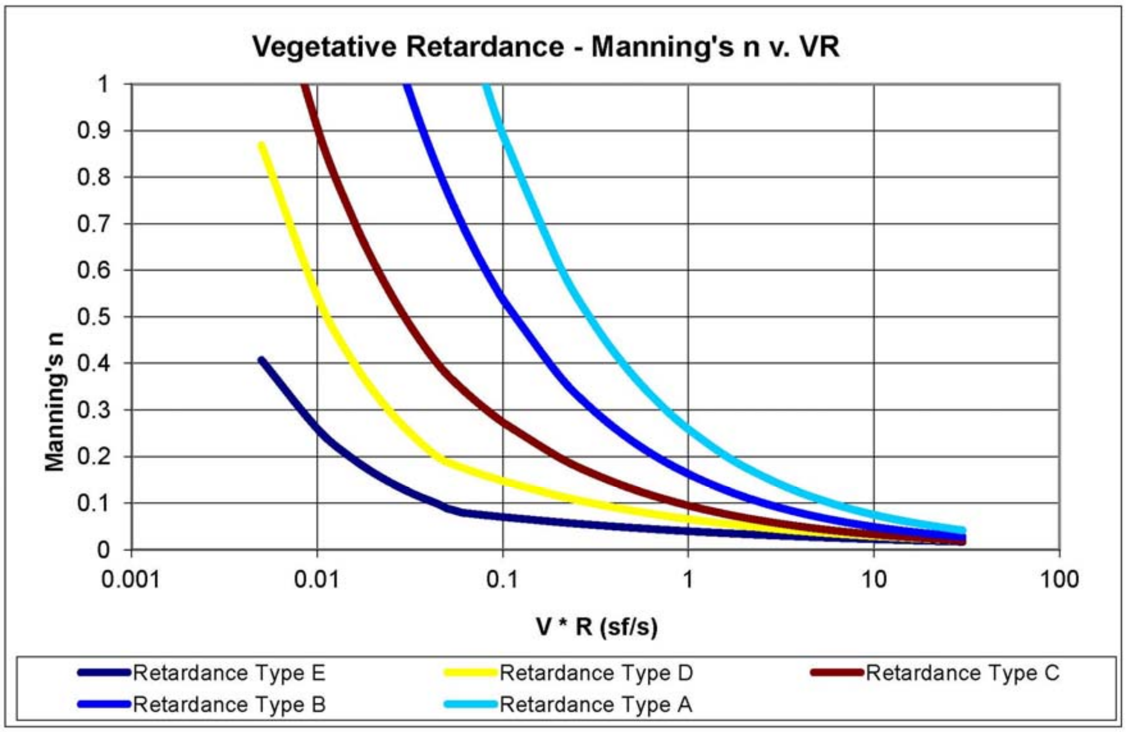


Figure 10.2 Vegetative Retardance - Manning's n vs. VR

The wetted perimeter (the width of the filter strip) is multiplied by the total effective flow length (filter strip length less 10 ft.) to determine the area used to treat the runoff. The design charts have a minimum filter strip length of 12 feet, as shown on the above illustration, which is a minimum effective length of 2 ft. As shown in the filter strip schematic, assume that the filter strip width is the same as the length of the roadway draining towards it. Stretches of a roadway directed to a mildly sloped filter strip ten feet or less in length cannot be evaluated by the procedure presented here, but would require a more detailed analysis.

The design charts in this section assume that particulate filtering is calculated for each time step of the highway surface runoff hydrograph using the average flow length to the end of the filter strip and the calculated depth of flow for each time step of the hydrograph. The depth of grass also affects the particulate trapping in the filter strip. The depth of flow is used to calculate the flow velocity, which in turn is used to determine the travel time, and particulate settling frequency for the average filter strip length in the project area for each particle size increment. Particulate trapping is based on the settling frequency: what is the probability that a particle of a given size would be able to completely settle during the length of the filter strip. Particles with a higher probability of settling in the filter strip (the large particles) are much more likely to remain trapped in the filter strip, while particles that settle less frequently have a greater probability of moving through the filter strip. Taller grass is also more effective in trapping the particles than shorter grass, though current data limitations preclude the analysis of grasses greater than four inches in height.

10.4 Planning Issues

10.4.1 WisDOT Design Requirements

Per TRANS 401.106(3):

- for transportation facilities first constructed after 2002, where there was previously no transportation facility, total suspended solids (TSS) discharges should be reduced, when compared with no stormwater quality discharge controls, by the maximum extent practicable, up to 80%, based on an average annual rainfall.
- for highway reconstruction and non-highway redevelopment projects TSS discharges must be reduced by the maximum extent practicable, or up to 40%.

See FDM 10-35-1 for guidance on setting the correct TSS reduction level for a project. Off-site pollutant loads, however, are typically excluded from the analysis because the source of the pollutants (from off the WisDOT right-of-way) are not controlled by WisDOT. If the highway has an ADT of more than 2,500 vehicles per day and runoff from the transportation facility directly enters an:

- Outstanding resource water
- Exceptional resource water
- 303(d) listed water or
- Waters with targeted performance standards (such as total maximum daily load (TMDLs))

then the designer should work with the DNR Liaison to determine how to meet water quality standards.

It is critical that filter strips are designed and constructed so that runoff flows uniformly across the filter. In order to accomplish this, the top edge of the filter should be even. Any depressions will concentrate runoff and short circuit the filter. In some cases, a shallow stone trench can be used to uniformly distribute runoff at the top of the filter. If a filter has been used to trap sediment during construction, it may be advisable to regrade and reseed the top of the filter. Otherwise, sediment accumulations may cause runoff to concentrate in certain locations.

10.4.2 Site Assessment

Conduct and document a site assessment to determine where embankment filter strips are appropriate. The primary issue affecting their use is the length of the filter strip. Generally, if the filter strips flow path is less than 12 feet, the filter strip will not effectively remove pollutants from adjacent roadway runoff. Do not use enhancements to the filter strip such as sub-soiling, incorporating sand into the embankment to improve drainage, or adding a drain tile interceptor into the embankment if the filter strip is steeper than 4:1 because of slope stability issues. To evaluate filter strips, collect the following information to characterize the drainage area for each filter strip for the water quality analysis.

1. Identify the proposed drainage area for each filter strip section. The drainage area is defined by the highway and shoulder surface drainage to the filter strip along with the filter strip area. Filter strip drainage areas should be split when soil types or soil treatments change. For example, if a section of the embankment soil has subsoiling and compost or sand enhancement, then this section should be considered as a separate filter strip section.
2. The filter strip soil type affects the filter strip performance because it determines the infiltration rate of the embankment. The five soil types for filter strips and the corresponding dynamic infiltration rates are listed in the table below. The infiltration rates are default values determined for state of Wisconsin highway projects. When selecting the appropriate design chart to determine filter strip pollutant removal effectiveness, also select the soil type from the table that is most similar to the project soils. Since it is sometimes difficult to determine the embankment soil type during design, especially when different soil types on a long corridor project may be mixed, engineers should use their best judgment to determine the appropriate infiltration rate.

Soil Type	Dynamic Infiltration Rate
Sand	1.8 in/hr
Loamy Sand	0.82 in/hr
Sandy Loam	0.25 in/hr
Loam	0.12 in/hr
Silty Clay Loam	0.04 in/hr

10.4.3 Filter Strip Design Considerations

Design considerations are intended to suggest to the designer issues that may be of concern for a project. If you believe that a consideration may affect your project, contact your region stormwater engineer for additional guidance.

1. Enhancing Soil - If the embankment soil type limits the effectiveness of the filter strip, consider enhancing the soil by subsoiling and adding sand or compost to the embankment, if the embankment slope is equal to or flatter than 4:1. If 30% sand, by volume, is added to the sandy loam, loam or silty clay loam typical soil types described in this section, then assume the soil infiltration rate is the equivalent of loamy sand. See Attachment 10.3 for a discussion of the infiltration curves used to develop this value. The sand must be mixed with the site soils to a depth of at least 20 inches using the Subsoiling Filter Strips special provision (SPV). The subsoil limits on the embankment should begin two feet from the swale flow line, can extend no more than five vertical feet towards the highway, and end no closer than 10 feet from the subgrade shoulder point. The actual filter strip length begins at the subgrade shoulder point and continues to the downgradient edge of the subsoiled filter strip.

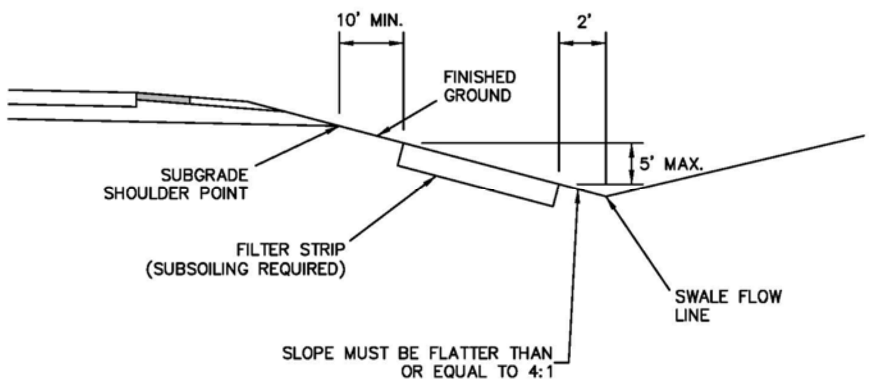


Figure 10.4 Typical Enhancing Soil Diagram

10.5 Design Recommendations

The design guidelines described below provide a method to calculate the percent TSS reduction from a filter strip. These guidelines use a series of curves that describe the percent TSS reduction based upon the number of lanes draining to the filter strip, the filter strip soil type and the filter strip length. They were developed using the NURP (National Urban Runoff Program) particle size distribution in WinSLAMM v 10.0. Each of the curves was developed assuming a seven-foot wide shoulder in addition to the twelve foot wide driving lanes. If the project is using filter strips with significantly different pavement contributing areas or soil types with known, different infiltration rates that cannot be characterized using the design curves, then the pollution control effectiveness of the device should be modeled using a pollutant loading model such as WinSLAMM, P8, or an equivalent acceptable methodology.

10.5.1 Filter Strip Design Charts

There are four design charts in Attachment 10.1. Each chart describes the percent TSS reduction for one to four highway lanes, as a function of filter strip length and soil type.

10.5.2 Filter Strip Water Quality Analysis Using the WisDOT Stormwater Report Spreadsheets

WisDOT has prepared a spreadsheet that incorporates the design guidelines and calculations needed to determine if a project meets the required TSS load reduction. The spreadsheet has a series of worksheets for a designer to methodically prepare and summarize an analysis of the water quality benefits of the various stormwater quality practices, including filter strips, used on a project. The WQ-Filter Strips worksheet provides a place for the designer to describe and summarize the performance of any filter strips used in a project. The use of the complete spreadsheet to summarize water quality performance for a project is described in FDM 10-30-1. The spreadsheet is part of the working documents that can be downloaded (refer to FDM 10-35-5.4.1).

The filter strip analysis procedure described below uses the filter strip analysis summary worksheet WQ-Filter Strips shown in Attachment 10.2. The worksheet is only used to summarize the filter strip data in an organized fashion - it does not calculate filter strip performance, which is determined from the design charts.

To use this spreadsheet, enter data into the appropriate worksheet cells. The worksheet is designed so that you can insert columns between the last column and the first column and then select the cells in a data column from rows 7 to 25 and drag them across to create columns for additional filter strip sections. Do NOT enter information in the grey cells because they contain formulas that should not be modified.

On a plan view of the drainage system, delineate the drainage area for each filter strip section that will be providing water quality benefits designed in accordance with this standard. Number the sections, determine their station and if they are left, right or in the center median. Enter this information on lines 7 through 10 of the spreadsheet, and then determine the following information and enter it on the appropriate line of the spreadsheet. For convenience, some of the items can be selected using a drop down menu list on the spreadsheet.

Line 12 - The width of the filter strip parallel to the highway, which will typically be the difference between the starting and ending station numbers entered in lines 8 and 9.

Line 13 - The average drainage area width (feet). This distance extends from the crown of the road to the toe of the filter strip. This area includes all areas both within the right of way and outside of the right of way that includes the filter strip.

Line 14 - The average right of way width that the filter strip is in (feet). The average distance from edge of right-of-way to edge of right-of-way for the highway segment the filter strip is in. If there are filter strips or other treatment devices in either the median or the other side of the highway, then extend this distance from the edge of the right-of-way to the limit of the treatment area (eg, the crown of the highway). If there are no other treatments for this drainage area segment, use the total right-of-way width.

Line 15 - Use the drop down menu to enter the number of lanes of pavement (not including the shoulder) that drain to the filter strip.

Line 16 - Enter the length of the filter strip (feet) from the edge of the shoulder to the toe of the filter strip. This distance should include the 10 foot length (minimum) from the shoulder to the subsoiled filter strip edge if the filter strip is subsoiled.

Line 17 - Use the drop down menu to select the filter strip soil type.

Line 18 - Use the drop down menu to select the Filter Strip design chart number you used to determine the percent TSS reduction.

The design charts are organized by typical cross section as follows:

- Chart 1 - One paved freeway or highway lane draining to the filter strip
- Chart 2 - Two paved freeway or highway lanes draining to the filter strip
- Chart 3 - Three paved freeway or highway lanes draining to the filter strip
- Chart 4 - Four paved freeway or highway lanes draining to the filter strip

Each of these charts was developed using WinSLAMM v 10.0 for the conditions described in the chart. To get a specific percent reduction, interpolate the appropriate value from a chart.Line 19 - Enter the percent reduction from the design chart (Attachment 10.1) based on the information entered and lines 15, 16, and 17.

If you need to record comments about the design for any of the drainage areas, enter them in the comment boxes below the worksheet. Add more comment boxes if necessary.

10.5.3 Other Design Criteria

There must be no impediment in the roadway or shoulder to prevent the roadway surface runoff from sheet flowing off the roadway, onto the shoulder, and then onto the embankment. For example, a curb and gutter system would typically preclude the use of filter strips because they channel and concentrate runoff from the roadway.

10.6 Maintenance

10.6.1 Maintenance Requirements

Properly designed filter strips require little maintenance. The loading rates to filter strip from the highway surface on a per foot basis are usually lower than the rate necessary to clog the filter strip.

The only exception to this is if concentrated flow occurs, causing rills. This could be caused by tire rutting due to a car driving over the embankment or by a spill along the highway. Typically, minor grading along the shoulder should eliminate this problem. If rilling or other embankment erosion does occur, it should be repaired in a timely manner.

10.6.2 Maintenance Plan

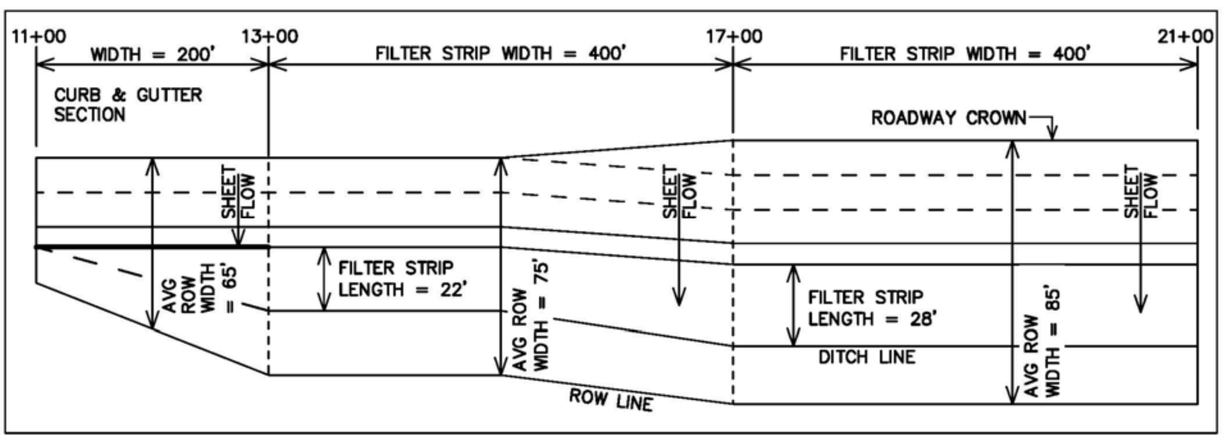
A maintenance plan is typically unnecessary for embankment filter strips because regular highway maintenance and inspection practices detect and repair shoulder and embankment problems. Standard WisDOT maintenance practices include:

1. Grading the shoulder is typically a component of routine maintenance, and performed as needed. Grading consists of blading the shoulder away from the edge of the pavement, returning it, settling, and then compacting it.
2. Inspecting embankments while mowing and during routine maintenance surveillance. Rilling or other embankment problems are then repaired on a spot basis.

10.7 Filter Strip Water Quality Design Example

Given the drainage areas and site conditions described below, determine the water quality reduction percentage using filter strips for the site.

- <u>Problem</u> - One thousand feet of a highway corridor has an embankment that may act as a filter strip. Two hundred feet of this section is a curb and gutter section, as illustrated in the drawing below. Determine the percent reduction of TSS due to the embankment acting as a filter strip. Enter the data from the table below into the Filter Strip Performance tab of the Stormwater Report spreadsheet. Assume that the ROW width extends only from the roadway crown to the ROW line.



7	Drainage Area Basin Number	1	2	3
8	Filter Strip Ending Station Number	13+00	17+00	21+00
9	Filter Strip Starting Station Number	11+00	13+00	17+00
10	Left, Center, or Right	R	R	R
	Site Assessment	Curb & Gutter		
12	Filter Strip Width parallel to Highway (ft)	200	400	400
13	Average Drainage Area Width (ft)	50	56	66
14	Average ROW Width (ft)	65	75	85
15	Number of Treated Freeway Lanes	2	2	3

16	Filter Strip Length perpendicular to Highway (ft)	0	22	28
17	Filter Strip Soil Type	Sandy Loam	Sandy Loam	Sandy Loam
18	Design Chart Number	2	2	3
19	Percent Reduction of Treated Area	0%	85%	86%

- Solution - The project information (lines 2 - 5) is entered as project information on the summary tab of the stormwater report. Define the filter strip sections in lines 7-10 of the Filter Strip Analysis Summary Spreadsheet, (Attachment 10.2). Next, enter the site data into lines 12 - 19 of the spreadsheet. On lines 12 - 16, enter the numeric values for widths, number of lanes and filter strip lengths. Use the drop down menus to enter the soil type in line 17 and the Design Chart Number in line 18.

  Enter a 0% reduction for drainage basin 1 because it is in a curb and gutter area, and so no treatment is allowed.

  Use Chart 2 for the filter strip in drainage basin 2. Based upon the filter strip length and the soil type, enter an 85 percent reduction in line 19.

  Use Chart 3 for the filter strip in drainage basin 3. Based upon the filter strip length and the soil type, enter an 86 percent reduction in line 19.

As illustrated in Attachment 10.2, the TSS reduction result from this example shows that, when all the areas are combined, the total reduction is 60.8%. This result includes the curb and gutter section that, by definition, does not get any TSS reduction.

10.8 References

Kirby, Jason T., “Determination of Vegetal Retardance in Grass Swales Used for the Remediation of Urban Runoff”, Masters Thesis, Graduate School of the University of Alabama, Tuscaloosa, Alabama, 2003.

Kirby, Jason T., S. Rocky Durrans, Robert Pitt, Pauline Johnson, “Hydraulic Resistance in Grass Swales Designed for Small Flow Conveyance”, ASCE Journal of Hydraulic Engineering, January, 2005.

Nara, Yukio, and Robert Pitt, Alabama Highway Drainage Conservation Design Practices – Particulate Transport in Grass Swales and Grass Filters, University Transportation Center for Alabama, The University of Alabama, Tuscaloosa, Alabama, Project Number 04117, November 6, 2005.

USDA, 1954, Handbook of Channel Design for Soil and Water Conservation, Washington, D.C., USDA Technical Paper TP-61.

Pitt, R. and J. Voorhees, “WinSLAMM, the Source Loading and Management Model for Windows version 10.0,” PV and Associates, LLC, 2012.

Wisconsin State Legislature, Revisor of Statutes Bureau, Wisconsin Administrative Code; for information on the codes of state agencies, including WDNR, see http://www.legis.state.wi.us/rsb/code.htm

LIST OF ATTACHMENTS

Attachment 10.1	Filter Strip Water Quality Design Charts
Attachment 10.2	Filter Strip Analysis Summary Spreadsheet
Attachment 10.3	Filter Strip Sand Amendment Analysis

FDM 10-35-15 Wet Detention Pond Stormwater Quality Design — October 22, 2012

15.1 Description and Purpose

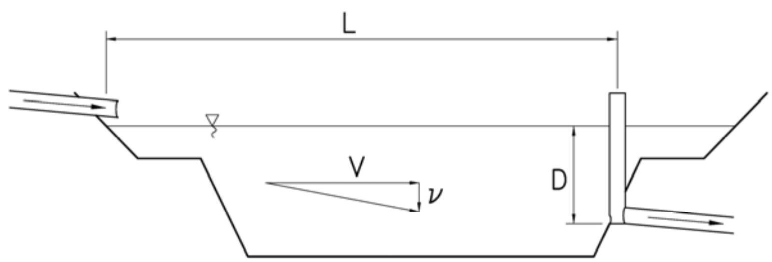
A wet detention pond is a permanent pool of water with designed dimensions, inlets, outlets, and storage capacity that is constructed to collect, detain, treat and release stormwater runoff. The primary purposes of this practice are to improve water quality and reduce peak flow rates. This stormwater quality control practice usually applies to urban areas where stormwater runoff pollution due to particulate solids loading and attached pollutants is a concern. It also applies where increased runoff from highway improvements is a concern. Site conditions must allow for runoff to be directed into the pond so that a permanent pool of water is maintained.

15.2 Target Pollutants

Wet detention ponds are most effective at removing suspended solids and associated particulate forms of pollutants. A well designed pond can remove as much as 85% - 90% of the TSS (total suspended solids) entering the pond. Pollutants associated with TSS, such as the particulate forms of metals like cadmium, copper, lead and zinc may also be removed at relatively high rates, as are hydrocarbons. Wet ponds are less effective at removing dissolved contaminants, such as some forms of phosphorus and nitrogen nutrients, and bacteria such as coliform and e.coli.

15.3 Effectiveness

Wet detention pond performance is calculated by assuming flow through a quiescent settling area. The particulate removal in this settling area is assumed to occur due to ideal settling as described by Stokes Law (for laminar flow which is most common for stormwater ponds), or Newton's law (for turbulent flow that may occur for very large particulates). The path of the settling particles is the vector sum of the particle velocity through the pond and the settling velocity of the particle. It is assumed (and verified by field monitoring) that particles settling to the pond bottom before the outlet zone is reached are captured in the pond. Therefore, if the water velocity is slow, slowly falling particles can be retained. If the water velocity is fast, then only the heaviest (fastest falling) particles are likely to be retained. The critical ratio of water velocity to particle settling velocity must therefore be equal to the ratio of the sedimentation pond length (L) to depth to the bottom of the outlet (D), as shown in equation (1) and the illustration below.



$$\frac{V}{\nu} = \frac{L}{D} \qquad (1)$$

The water velocity is equal to the water volume discharge rate (Q, such as measured by cubic feet per second) divided by the pond cross-sectional area (a, or depth times width: DW, in equation (2):

$$V = \frac{Q}{a} \quad \text{, or,} \quad V = \frac{Q_{out}}{DW} \qquad (2)$$

Where:

L = pond length

D = Outlet Depth

V = Water velocity through Pond

v = settling velocity

Q_{out} = Outlet from Pond

a = Pond Cross Sectional Area

The pond outflow rate equals the pond inflow rate under steady state conditions. The critical time period for steady state conditions is the time of travel from the inlet to the outlet. During critical portions of a storm, the inflow rate (Q_{in}) will be greater than the outflow rate (Q_{out}) due to freeboard storage. Therefore, the outflow rate controls the water velocity through the pond. Substituting this definition of water velocity into the critical ratio to results in equation (3):

$$\frac{Q_{out}}{DW\nu} = \frac{L}{D} \qquad (3)$$

and cancel D to get:

$$\frac{Q_{out}}{W\nu} = L \quad \text{or} \quad \frac{Q_{out}}{\nu} = LW \qquad (4)$$

Where:

L = pond length

D = Outlet Depth

V = Water velocity through Pond

v = settling velocity

Q_{out} = Outlet from Pond

a = Pond Cross Sectional Area

However, pond length (L) times pond width (W) equals pond surface area (A). Substituting leaves:

$$\frac{Q_{out}}{\nu} = A \qquad (5)$$

Solving for the settling velocity results in the conventional surface overflow rate equation:

$$\nu = \frac{Q_{out}}{A} \qquad (6)$$

Therefore, for an ideal sedimentation pond, particles having settling velocities less than this settling velocity will be removed. Only increasing the surface area or decreasing the pond outflow rate will increase pond settling efficiency. Increasing the pond depth does lessen the possibility of bottom scour, decreases the amount of attached aquatic plants, and decreases the chance of a winter fish kill. Deeper ponds may also be needed to provide sacrificial storage volumes for sediment between pond cleaning operations.

Since the settling velocity increases as particle size increases (using Stokes or Newton’s law and appropriate shape factors, specific gravity and viscosity values), the pond water quality performance (or percent removal) is determined from the particle size distribution of the solids in the runoff entering the pond. This is done by determining the settling velocity and then calculating the particle size associated with that settling velocity, which is referred to as the critical particle size. The percent of the particles that will settle is then determined from the particle size distribution of the total suspended solids (TSS) concentration of the sediment in the stormwater runoff. The particle size distribution, which is called the NURP (National Urban Runoff Program) particle size distribution, used for stormwater runoff in Wisconsin is illustrated below.

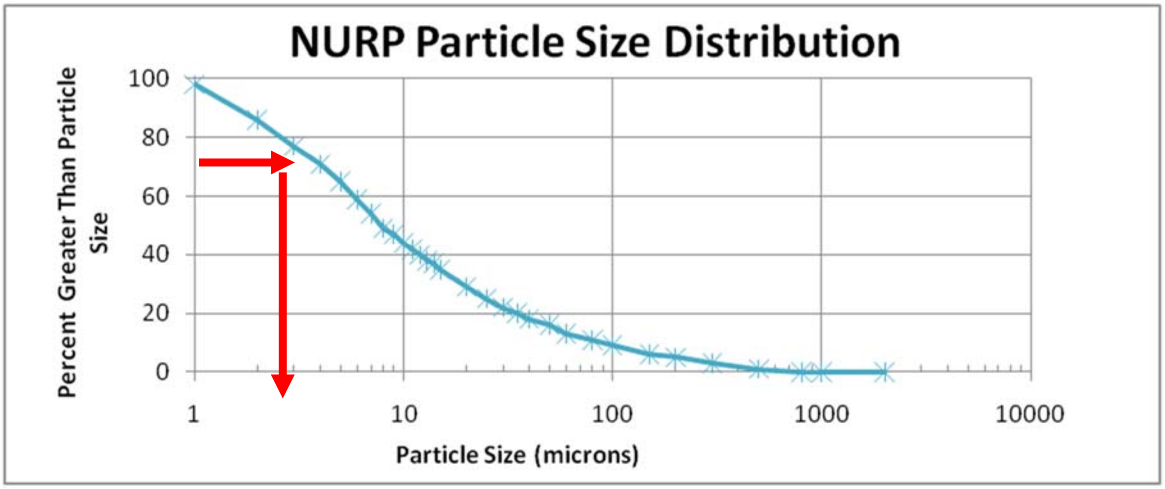


Figure 15.1 NURP Particle Size Distribution Curve

By inspection of this NURP particle size distribution, all particles greater than three microns would need to be trapped to achieve 80% particulate solids control of the stormwater runoff entering a pond.

15.4 Planning Issues

15.4.1 Initial Coordination

Assess potential environmental impacts as part of the NEPA/WEPA project assessment process. Contact the WisDOT regional environmental coordinator and see FDM Chapter 21. The assessment should use historical information about the site to determine if the potential for environmental hazard exists, e.g., contaminated soils, contaminated groundwater, abandoned dumps or landfills. For questions regarding other planning considerations, contact the regional stormwater engineer.

15.4.2 DOT Design Requirements

Per TRANS 401.106(3), for transportation facilities first constructed (previously no transportation facility) after 2002, reduce total suspended solids (TSS) discharges, when compared with no stormwater quality discharge controls, by 80% or to the maximum extent practicable, based on an average annual rainfall. Highway reconstruction and non-highway redevelopment projects must reduce TSS discharges by 40% or to the maximum extent practicable. Runoff entering a pond from outside of the DOT right of way (off-site run-on) will affect the performance of the pond and must be accounted for during the pond design.

15.4.3 Federal State and Local Laws

The location and use of wet detention ponds may be limited by regulations relating to stormwater management, navigable waters (Ch. 30, Wis. Stats.), floodplains, depth to groundwater, wetlands, buildings, wells and other structures, or by land uses such as waste disposal sites and airports. The pond embankment may be regulated as a dam under Ch. 31, Wis. Stats., and further restricted under NR 333, Wis. Adm. Code, which includes regulations for embankment heights and storage capacities. Review the project with DNR liason and regional stormwater engineer. Specific regulatory concerns include wellhead protection areas, ponds near airports and pond sediment disposal as described below.

1. Wellhead protection area pond liner requirements - Some municipalities have wellhead protection areas and all municipalities have source water protection areas delineated by WDNR. If a pond is proposed near a well, first consider using other stormwater control practices. If no other options are feasible, consult with the local community about when a liner will be needed if a pond is located within one of these areas. According to NR 811, Wis. Adm. Code, wet detention ponds shall be constructed 400 feet from community wells and 25 feet from non-community and private wells. The 25 foot setback from non-community and private wells is a final construction distance. This may not be sufficient to prevent running over the well with heavy equipment during construction of the pond. Refer to FDM 10-35-15.5 for pond liner requirements.
2. Any ponds proposed for areas near airports should be evaluated for wildlife attractive hazards.
3. Sediment should be disposed of according to NR 528, Wis. Admin. Code (Management of Accumulated Sediment from Stormwater Management Structures).

15.4.4 Site Assessment

Conduct and document a site assessment to determine the site characteristics that will affect the placement, design, construction, and maintenance of the pond. Document the pond design. Items to assess include:

1. On a site map with the pond location identified:
    a. Identify buildings and other structures, parking lots, property lines, wells, wetlands, 100-year floodplains, surface drains, navigable streams, known drain tile, roads, and utilities (both overhead and buried) showing elevation contours and other features specified by the applicable regulatory authority.
    b. Show location of soil borings and test pits on site map, characterize the soils, seasonally high groundwater level, and bedrock conditions to a minimum depth of 5 feet below the proposed bottom of the pond or to bedrock, whichever is less. Conduct one test pit or boring per every 2 acres of permanent pool footprint, with a minimum of two per pond. Include information on the soil texture, color, structure, moisture and groundwater indicators, and bedrock type and condition, and identify all by elevation. Characterize soils using both the USDA and USCS classification systems. (Note: USCS characterization is used for soil stability assessment while USDA soil characterization identifies the soil's potential permeability rate.)
    c. Investigate the potential for karst features nearby by contacting nearby sources or by checking the Wisconsin Geological and Natural History Survey at http://wisconsingeologicalsurvey.org/karst.htm ,or by contacting the Bureau of Technical Services Hydrogeologist.
2. In the watershed, on a watershed map:
    a. Identify predominant soils, the drainage ways, navigable streams and floodways, wetlands, available contour maps, land cover types and known karst features. Identify the receiving surface waters, or whether the drainage basin drains directly to groundwater.
    b. Show channels and overland flow (before and after development), contours, and property lines.
    c. Show the Tc (time of concentration) flow paths and subwatershed boundaries used in runoff calculations.
3. Ponds should not be located on navigable waters. Consult with DNR liaison to determine if the water body is navigable.

15.4.5 Planning Considerations

1. Additional conservation practices should be considered if the receiving water body is sensitive to temperature fluctuations, oxygen depletion, excess toxicants, or nutrients.
2. Determine if the control of the accumulation of floating trash or the use of vortex controls or hydrodynamic settlers are appropriate.
3. Watershed size and land cover should be considered to ensure adequate runoff volumes to maintain a permanent pool. If adequate volume is a concern, evaluate the pond using an annual water balance approach.
4. Aesthetics of the pond should be considered in designing the shape and specifying landscape practices. Generally, square or rectangular ponds are aesthetically unappealing.
5. If downstream flood management or bank erosion is a concern, consider conducting a watershed study to determine the most appropriate location and design for bank stability measures, including consideration of potential downstream impacts on farming practices and other land uses.
6. Consider vegetative buffer strips along drainage ways leading to the detention pond and around the pond perimeter to help filter pollutants.
7. After the site assessment is complete, review and discuss it with the WisDOT regional stormwater engineer to determine and agree on the appropriate pond design for the site.
8. Conduct a groundwater boring to 15 feet below the pond and consider the historic capillary fringe "mottling marks" in assessing groundwater levels.
9. Where the soils are fine, consider groundwater monitoring if the groundwater table is less than 10 feet below the bottom of the wet pond because the water table may fluctuate seasonally. Other impacts on the groundwater table elevation may be from seasonal pumping of irrigation wells or the influence of

other nearby wells. Monitoring or modeling may be necessary in these situations to identify the groundwater elevation.

10. Consider conducting additional test pits if needed to determine the variability of the soil boundary or to identify perched water tables due to clay lenses. For the soils analysis, provide information on soil thickness, groundwater indicators - such as soil mottle or redoximorphic features - and occurrence of saturated soil, groundwater, or disturbed soil.
11. Consider direct and indirect impacts to area wetland hydrology and wetland hydroperiod due to area hydrologic modifications that result from routing wetland source waters through a wet detention pond or releasing the discharge from a wet detention pond directly into a wetland.
12. If public access is provided to the pond, determine how the access will be controlled.

15.5 Design Recommendations

These design guidelines described below provide a method to demonstrate that a wet detention pond achieves 80% total suspended solids (TSS) reduction and peak flow control. Pollutant loading models such as WinSLAMM, P8, DETPOND or an equivalent methodology may also be used to evaluate the efficiency of the design in reducing TSS. When performing a wet detention pond water quality analysis, either use a model to evaluate a proposed pond or use these guidelines. However, it is recommended that engineers use the most current version of a modeling program because the manual evaluation process described in this section uses an iterative and potentially conservative design approach. Attachment 15.4 Figure 1 is a plan view schematic drawing of a typical pond design and Figure 2 is a schematic of a typical pond cross section.

15.5.1 Water Quality Design Guidelines

Pollutant reduction (TSS and particulate forms of phosphorus) is a function of the permanent pool area and depth, the outlet structure and the active storage volume. The following criteria apply:

1. Permanent Pool - The elevation below which runoff volume is not discharged and particles are stored.
    a. Develop an initial estimate of the necessary area needed for a water quality pond using Attachment 15.1 for the initial estimate of the permanent pool area based on drainage area. If there is enough land area available for the pond, proceed to step b.
    b. Design ponds to include a permanent pool of water. The surface area of the permanent pool is measured at the invert of the lowest outlet. The minimum surface area of the permanent pool must address the total drainage area to the pond. Use Attachment 15.1 for the initial estimate of the permanent pool area based on drainage area. Prorate values for mixed land uses as described in the Attachment. Use Equation 1 to solve for qo and iterate as needed.
    c. The permanent pool surface area is sized based on the desired particle size to be retained and the peak outflow during the 1-yr., 24-hour design storm using Equation 1:

$$S_a = 1.2 * (q_o / v_s) \qquad 1(a)$$

$$q_o = (v_s * S_a) / 1.2 \qquad 1(b)$$

Where:

S_a = Permanent pool surface area measured at the invert of the lowest outlet of the wet detention pond (square feet)

q_o = Post-construction peak outflow (cubic feet/second) during the 1-yr., 24-hour design storm for the principal outlet

v_s = Particle settling velocity (feet/second)

1.2 = EPA recommended safety factor

    d. Particle settling velocities (vs) shall be based on representative particle sizes for the desired percent TSS reduction.

80% (3 micron): v_s = 1.91 x 10-5 ft/sec

60% (6 micron): v_s = 7.37 x 10-5 ft/sec

40% (12 micron): v_s = 2.95 x 10-4 ft/sec

Note: Particle settling velocities were calculated assuming a specific gravity of 2.5, a water temperature of 50 degrees Fahrenheit (10 degrees C) and a kinematic viscosity of 0.01308 cm2/sec, and the appropriate unit conversions (Pitt, 2002). The calculations also assume discrete and quiescent settling conditions during laminar flow per Stoke's Law.

2. Active Storage Volume - Volume above the permanent pool that is released slowly to settle particles. Calculate the volume with the following method:

   Use a hydrograph-producing method, such as the one outlined in Natural Resources Conservation Service (NRCS), Technical Release 55 (TR-55), to determine the storage volume for detention ponds. This can be accomplished by using Attachment 15.2 where:

   q_o = Peak outflow during the 1-yr., 24-hour design storm for the principal outlet calculated using Equation 1. The one-year, 24-hour design storm rainfall depths are listed in Attachment 15.3, Tables 2 or 3.

   q_i = Calculated the post-construction peak inflow or runoff rate during the 1-yr., 24-hour design storm using TR-55.

   V_R = Volume of runoff from the 1-year, 24-hour design storm for the entire contributory watershed area draining to the pond, as calculated using TR-55.

   V_S = The required active storage volume determined using Attachment 15.2.

   Note: This method may require iterative calculations because the calculated storage volume may not be consistent with the initial pond surface area assumption.

3. Depth - The average water depth of the permanent pool shall be a minimum of 3 ft., excluding the safety shelf area and sediment storage depth. The maximum depth should be 10 feet to limit fish populations.

4. Length to Width - Maintain a length to width ratio of between 3:1 and 5:1 to prevent short-circuiting, poor circulation and dead zones (areas of stagnant water). The flow path is considered the general direction of water flow within the pond, including the permanent pool and forebay. Avoid open water areas that are non-circulating.

5. Sediment Forebay - A sediment forebay should be located at each inlet (unless inlet is < 10% of total inflow or an equivalent upstream pretreatment device exists) to trap large particles such as road sand. The storage volume of the sediment forebay should be consistent with the maintenance plan, with a goal of 5%-15% of the permanent pool surface area. The sediment forebay should be a minimum depth of 3 ft. plus the depth for sediment storage. Refer to Attachment 15.4, Figures 1 and 2 for a conceptual forebay illustration.

6. Sediment Storage - After all construction has ceased and the contributory watershed has been stabilized, one of the following applies:

   a. A minimum of 2 ft. shall be available for sediment storage (for a total of 5 ft. average depth, excluding the safety shelf area). For ponds greater than 20,000 sq. ft., 50% of the total surface area of the permanent pool shall be a minimum of 5 ft. deep. For ponds less than 20,000 sq. ft., maximize the area of 5 ft. depth.

   b. Less than 2 ft. of sediment storage is allowed if modeling shows that for 20 years of sediment accumulation, less than 2 ft. sediment storage is needed (not to be less than 0.5 feet).

   c. A minimum of 4 ft. shall be available for sediment storage if the contributory area includes cropland not stabilized by any other practice, such as strip cropping, terraces and conservation tillage.

7. Side Slopes Below Safety Shelf - All side slopes below the safety shelf shall be 2:1 (horizontal:vertical) or flatter as required to maintain soil stability, or as required by the applicable regulatory authority.

8. Outlets - Wet detention ponds shall have both principal water quality outlet(s) and an emergency spillway.

   a. Prevent Damage - Incorporate into outlet design trash accumulation preventive features, and measures for preventing ice damage and scour at the outfall and beyond to prevent secondary impacts downstream of the pond. Direct outlets to channels, pipes, or similar conveyances designed to handle prolonged flows.

b. Principal Water Quality Outlet - Design the outlet to control the proposed 2-yr., 24-hour discharge from the pond within the primary principal outlet without use of the emergency spillway or other outlet structures. If a pipe discharge is used as the primary principal outlet, then the minimum diameter shall be 4 inches. Where an orifice is used, features to prevent clogging must be added.

c. Backward Flow - Any storm up to the 10-yr., 24-hour design storm shall not flow backward through the principal water quality outlet or principal outlet. Flap gates or other devices may be necessary to prevent backward flow.

d. Emergency Spillway - All ponds shall have an emergency spillway. Design the spillway to safely pass peak flows produced by a 100-yr., 24-hour design storm routed through the pond without damage to the structure. The flow routing calculations start at the permanent pool elevation. If at all possible, locate the spillway on native material, not fill.

e. Peak Flow Control - Design the peak flow control to maintain stable downstream conveyance systems and comply with local ordinances or conform with regional stormwater plans where they are more restrictive than this standard. At a minimum:
   - The post-development outflow shall not exceed pre-development peak flows for the 2-yr., 24-hour design storm.
   - Use a hydrograph-producing method such as TR-55 for all runoff and flow calculations.
   - When pre-development land cover is cropland, use the runoff curve numbers in Table 1 below, unless local ordinances are more restrictive.
   - For all other pre-development land covers, use runoff curve numbers from TR-55 assuming “good hydrologic conditions.”
   - For post-development calculations, use runoff curve numbers based on proposed plans.

Note: If the project requires control of larger storm events than the 2-yr., 24-hour storm, additional or compound outlets may be required.

Table 15.1 Maximum Pre-Development Runoff Curve Numbers for Cropland Areas (from TRANS 401.106(4), Table 2)

Hydraulic Soil Groups	A	B	C	D
Runoff Curve Number	56	70	79	83

15.5.2 Other Pond Criteria

1. Inflow Points - Design all inlets to prevent scour during peak flows produced by the 10-yr., 24-hr. design storm, such as using half-submerged inlets, stilling basins and rip-rap. Where infiltration may initially occur in the pond, the scour prevention device shall extend to the basin bottom.

2. Side Slopes - All interior side slopes above the safety shelf shall be 3:1 (horizontal:vertical), or flatter if required by the applicable regulatory authority.

3. Ponds in Series - To determine the overall TSS removal efficiency of ponds in series, the design shall use an approved model such as DETPOND or P8 that can track particle size distribution from one pond to the next. If the ponds follow one after another without any additional inflow, then the largest pond will remove the most sediment.

4. Earthen Embankments - Earthen embankments (refer to Attachment 15.4, Figure 3) shall be designed to address potential risk and structural integrity issues such as seepage and saturation. All constructed earthen embankments shall meet the following criteria.

   a. Vegetation - Remove the parent material (including all vegetation, stumps, and topsoil, etc.) beneath the proposed base of the embankment.

   b. Core Trench or Key-way - For embankments where the permanent pool is ponded 3 ft. or more against the embankment, include a core trench or key-way along the centerline of the embankment up to the permanent pool elevation to prevent seepage at the joint between the existing soil and the fill material. The core trench or key-way shall be a minimum of 2 ft. below the existing grade and 8 ft. wide with a side slope of 1:1 (horizontal:vertical) or flatter. Follow the construction and compaction requirements detailed in 15.5.2.4c below for compaction and fill material. Also refer to Attachment 15.4, Figure 3.

c. Materials - Construct all embankments with non-organic soils and compact to 90% standard proctor according to the procedures outlined in AASHTO T-99 or by using compaction requirements of DOT Standard Specification 207.3.6.3, Special Compaction. Do not bury tree stumps or other organic material in the embankment. Increase the constructed embankment height by a minimum of 5% to account for settling.

d. Freeboard - Ensure that the top of embankment, after settling, is a minimum of 1 vertical foot above the flow depth for the 100-yr., 24-hr. storm.

e. Pipe Installation, Bedding, and Backfill - If pipes are installed after construction of the embankment, the pipe trench shall have side slopes of 1:1 or flatter. Bed and backfill any pipes extending through the embankment with embankment or equivalent soils. Compact the bedding and backfill in lifts and to the same standard as the original embankment.

f. Seepage - Take measures to minimize seepage along any conduit buried in the embankment. Measures such as anti-seep collars, sand diaphragms, or use of bentonite are acceptable.

g. Exterior side slopes shall be 2:1 (horizontal:vertical) or flatter, with a minimum top width of the embankment of 4 ft., or 10 ft. if access for maintenance is needed. The embankment must be designed for slope stability.

5. Topsoil and Seeding - Spread topsoil on all disturbed areas above the safety shelf, as areas are completed, according to the standard specifications. Stabilize according to the permanent seeding criteria in Standard Spec 630, Seeding. To maximize safety and pollutant removal, spread topsoil along the safety shelf to promote plant growth.

6. Liners - Highway land uses are classified as ‘dirty source areas’ when determining the type of pond liner for highway runoff. If groundwater wells are located near a project as described in 15.4.3(1) of this procedure, use a liner with permeability of 10^{-7} cm/sec. Otherwise, the liner needs to have a permeability of 10^{-6} cm/sec. If synthetic liners are used, see the liner requirements in the Wisconsin DNR Wet Detention Pond Design Standard 1001. If a liner is used, provide a narrative that sets forth the liner design and construction methods. Modify SPV.0035 (Pond Clay Liner) with the appropriate permeability value to bid the liner. If the pond will be constructed in native soil that meets the permeability requirement, then no liner is needed.

7. Bedrock - If blasting in bedrock is performed to construct a wet detention pond in bedrock, then a liner with a permeability of 10^{-7} cm/sec is required if located near a well or 10^{-6} cm/sec elsewhere.

8. Access - Include maintenance access features in the pond design including:

   a. A maintenance right of way or easement must be provided to a pond from a public or private road.

   b. Maintenance access should be at least 12 feet wide, having a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.

   c. The maintenance access must extend to the forebay, safety bench, riser, and outlet and, to the extent feasible, be designed to allow vehicles to turn around.

   d. Provide access to the riser by lockable manhole covers, and manhole steps within easy reach any of valves and other controls

9. Wetlands - For wet detention ponds that discharge to wetlands, use level spreaders, gabions, rip-rap or other methods to prevent channelization and erosion and to reduce sedimentation in the wetlands.

10. Mosquito (Vector) Control - Maximize the amount of deeper open water to promote mosquito control while maintaining the maximum depth of 10 ft.

11. Consult a geotechnical engineer if stability of the embankment is a concern or to justify slopes steeper than 2.5:1.

15.5.3 Safety Requirements

1. Side Slopes – All interior side slopes above the safety shelf shall be 3:1 (horizontal:vertical), or flatter if required by the applicable regulatory authority.

2. All outlet structures should have trash racks.

3. Include a safety shelf (or aquatic shelf) that extends a minimum of 8 ft. from the edge of the permanent pool waterward with a slope of 10:1 (horizontal:vertical) or flatter. The maximum depth of the permanent pool of water over the shelf shall be 1.5 ft.
4. Provide a safety barrier of vegetation that would discourage access to the pond upgradient of the safety shelf. Do not mow the pond perimeter or allow grass down to the pond edge to discourage geese.

15.5.4 Design Considerations

1. For ease of maintenance, consider incorporating a pond draw down system including a pipe and gate valve.
2. Consider a hard surface for the bottom of the forebay to ease sediment removal.
3. If sand is used in the winter on highways in the pond drainage area, consider increasing the sediment storage depth or area.
4. Consider providing a method to facilitate dewatering for accumulated sediment removal.
5. Baffles may be used to artificially lengthen the flow path in the pond. In some designs, a circular flow path is set up in a pond even when the inlet and outlet are next to each other and no baffles are used. Then the flow path can be calculated using the circular path.
6. Consider providing additional width to the safety shelf, above or below the wet pool elevation, to enhance safety.
7. To prevent damage or failure due to ice, all risers extending above the pond surface should be incorporated into the pond embankment.
8. The use of underwater outlets should be considered to minimize ice damage, accumulation of floating trash or vortex control.
9. For wet detention ponds with surface area more than 2 acres or where the fetch is greater than 500 feet, consider reinforcing banks, extending the safety shelf, vegetating the safety shelf or other measures to prevent erosion of embankment due to wave action.
10. To prevent failure, consider reinforcing earthen emergency spillways constructed over fill material to protect against erosion.
11. All flow channels draining to the pond should be stable to minimize sediment delivery to the pond.
12. Consider using backflow preventers to minimize fish entrapment.
13. Consider providing a terrestrial buffer of 10-15 feet around the pond if it has low or no embankments.
14. Consider additional safety features beyond the safety shelf where conditions warrant them.
15. Design so that the 10-yr., 24-hour design storm does not flow through the emergency spillway. The 10-yr. design criteria protects the embankment from premature failure due to frequent or long-duration flows through the emergency spillway.
16. For partially or fully submerged inlet pipes, consider using pipe ties or some other method to keep pipes from dislodging during frost movement.
17. Submerged and emergent aquatic vegetation can play an important role in pollutant removal in a stormwater pond. It can also enhance the appearance of the pond, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris. Therefore, wetland plants should be encouraged in a pond design, along the safety bench and side slopes, and within shallow areas of the pool itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within 6 inches (plus or minus) of the normal pool elevation.

15.6 Maintenance

15.6.1 Maintenance Requirements

Maintenance Agreement - A wet detention pond requires both regular and long-term maintenance. These requirements are defined in a maintenance plan that typically includes the maintenance issues listed below. If the DOT transfers maintenance responsibility for a pond and its buffer to a responsible authority such as a municipality by means of a legally binding and enforceable maintenance agreement, then the agreement should include a discussion of both regular maintenance and pond dredging requirements. It should also reference the maintenance plan to provide a clear guideline for what work is needed to maintain the water quality and quantity control purposes of this practice. Coordinate the plan development with the WisDOT project manager so that it is included in the maintenance agreement. Contact the planning section in your region for additional information on maintenance agreement requirements.

Regular Maintenance - Regular maintenance items can include the following, as appropriate for the site:

1. Berm Settlement. If any part of the berm has settled 4 inches lower than the design elevation it should be built back to the design elevation.
2. Piping. If water flow is discernible through pond berm or ongoing erosion is observed, have a geotechnical engineer inspect and evaluate the condition and recommend appropriate repairs.
3. Tree Growth. Tree growth on emergency spillways reduces spillway conveyance capacity and may cause erosion elsewhere on the pond perimeter due to uncontrolled overtopping. Tree growth on berms over 4 feet high may lead to piping through the berm, which could lead to failure of the berm and related erosion or flood damage. Such trees should be removed. If the root system is small (base less than 4 inches), the root system may be left in place; otherwise, the roots should be removed and the berm restored. A licensed civil engineer should be consulted for proper berm/spillway restoration.
4. Emergency Spillway Lining. If only one layer of rock exists above native soil in area 5 square feet or larger or native soil is exposed at the top of outflow path of spillway, then the rocks and pad depth should be restored to the design condition.
5. Trash and Debris. Clear trash and debris from the site when accumulations exceed 5 cubic feet (about equal to the amount of trash needed to fill one standard-size garbage can) per 1,000 square feet. In general, there should be no visual evidence of dumping. If debris accumulation is less than this threshold level, then the trash and debris should be removed as part of the next scheduled maintenance.
6. Poisonous Vegetation and Noxious Weeds. Poisonous, noxious or nuisance vegetation may constitute a hazard to maintenance personnel or the public. Remove this vegetation and apply the requirements of adopted integrated pest management policies for the use of herbicides.
7. Rodent Holes. For facilities acting as a dam or berm, if rodent holes are evident or there is evidence of water piping through dam or berm via rodent holes, destroy the rodents and repair the dam or berm.
8. Side Slope Erosion. If eroded damage is over 2 inches deep and the cause of damage is still present, or there is potential for continued erosion, stabilize slopes using appropriate erosion control measures (such as rock reinforcement, planting of grass, and compaction). If erosion is observed on a compacted berm embankment, review the proposed erosion control measures with an erosion control specialist.
9. Pond Dredging. Sediment removal in the forebay should occur every five to six years or after 50% of total forebay capacity has been lost. In the main sediment accumulation areas of the pond, sediment removal should occur once the average depth of the permanent pool is 3.5 ft. Sediment should be disposed of according to NR 528, Wis. Admin. Code (Management of Accumulated Sediment from Stormwater Management Structures).

15.6.2 Maintenance Plan

Develop an operation and maintenance plan that is consistent with improving stormwater quality, the wet detention pond’s intended life, safety requirements, and the criteria for its design. The operation and maintenance plan will:

1. Identify the responsible party for operation, maintenance, and documentation of the plan.
2. Require sediment removal once the average depth of the permanent pool is 3.5 ft. At a minimum, include details in the plan on inspecting sediment depths, frequency of accumulated sediment removal, and disposal locations for accumulated sediment (NR 528, Wis. Adm. Code).
3. Include inlet and outlet maintenance, keeping embankments clear of woody vegetation, and providing access to perform the operation and maintenance activities.
4. Identify how to reach any forebay, safety shelf, inlet, and outlet structures.
5. Address weed or algae growth and removal, insect and wildlife control and any landscaping practices.
6. If a liner is used, show how the liner will be protected from damage during sediment removal or when the liner is undergoing repair.

7. Prohibit excavation below the original design depth unless geotechnical analysis is completed in accordance with FDM 10-35-15.4.4,1b. and c.
8. Use of algaecides, herbicides or polymers to control nuisance growths or to enhance sedimentation may require a permit under NR 107, Wis. Adm. Code. Contact the appropriate WisDOT regional stormwater engineer.

15.6.3 Maintenance Considerations

Consider using low fertilizer inputs on the embankments and collecting the clippings.

15.7 Wet Detention Pond Water Quality Analysis Using the WisDOT Stormwater Report Spreadsheet

1. WisDOT has prepared a spreadsheet that incorporates the design guidelines and calculations needed to determine if a project meets the required TSS load reduction. The spreadsheet has a series of worksheets for a designer to use to methodically prepare and summarize an analysis of the water quality benefits of the various stormwater quality practices, including wet detention ponds, used on a project. The WQ-Wet Detention Ponds worksheet provides a place for the designer to describe and summarize the performance of any ponds in a project. The use of the complete spreadsheet to summarize water quality performance for a project is described in FDM 10-30-1. The spreadsheet is located at FDM 13-30 Attachment 15.2.
2. The wet detention analysis procedure described below uses the wet detention analysis summary worksheet WQ-Wet Detention Ponds shown in Attachment 15.5. The worksheet is only used to summarize the wet detention data in an organized fashion - it does not calculate pond performance, which is determined from the design analysis procedure or from model output.
3. To use this spreadsheet, enter data into all the white cells. The spreadsheet is designed so that you can easily add additional columns for additional ponds. To do this, follow these steps:
    1. Highlight the number of columns you want to add,
    2. Right-mouse click,
    3. Select insert,
    4. Select shift rows right, and
    5. Press the ‘OK’ button. Only enter data in the white boxes on each worksheet.
4. On a plan view of the drainage system, delineate the drainage area for each pond that will be providing water quality benefits. Number the ponds, determine the starting and ending station of their drainage areas and if they are left, right or in the center median. Enter this information on lines 7 through 11 of the spreadsheet, and then determine the following information and enter it on the appropriate line of the spreadsheet.
5. Line 13 - The length of the highway segment treated, which is typically the difference between the starting and ending stations that define the limits of the drainage area.
6. Line 14 - The drainage area of the pond. This area includes all areas both within the right of way and outside of the right of way that drain to the pond.
7. Line 15 - The drainage area of the pond within the right of way.
8. Line 16 - Enter the percent reduction from the analysis or computer model output.

The percent reduction entered for each pond is then transferred to the summary worksheet, where it is used to help determine the total loading reduction for the project.

If you need to record design comments about the design for any of the drainage areas, enter them in the comment boxes below the worksheet. Add more comment boxes if necessary.

15.8 References

R. Pitt and J. Voorhees, The Design and Use of Detention Facilities for Stormwater Management Using DETPOND, 2000.

United States Department of Agriculture, Natural Resources Conservation Service, Conservation Practice Standard 378, Pond, July 2001.

United States Department of Agriculture, Natural Resources Conservation Service, Engineering Field Handbook.

United States Department of Agriculture, Natural Resources Conservation Service, Ponds – Planning, Design, Construction, Agriculture Handbook 590, revised September 1997.

United States Department of Agriculture, Natural Resources Conservation Service, Technical Release 55, Urban Hydrology for Small Watersheds, 1986.

United States Department of Agriculture, Natural Resources Conservation Service, Wisconsin Field Office Technical Guide, Section IV.

United States Department of Commerce, Weather Bureau, Rainfall Frequency Atlas of the United States, Technical Paper 40.

University of Wisconsin - Extension, The Wisconsin Storm Water Manual, Part Four: Wet Detention Basins, Publication No. G3691-P.

Wisconsin State Legislature, Revisor of Statutes Bureau, Wisconsin Administrative Code; for information on the codes of state agencies, including WDNR, (http://www.legis.state.wi.us/rsb/code.htm).

LIST OF ATTACHMENTS

FDM 10-35-20 Catchbasin Design and Maintenance October 22, 2012

20.1 Description and Purpose

Catchbasins are chambers or sumps installed in a storm sewer, usually at the curb, which allow surface runoff to enter the sewer. Catchbasins have a sump area below the outlet intended to retain captured sediment. By trapping coarse sediment, the catchbasin prevents trapped solids from clogging the downstream sewer or being washed into receiving waters. The sumps must be cleaned out periodically to maintain their sediment trapping ability. If the sumps are not cleaned, then the catchbasin does not provide any water quality benefit and does not provide any total suspended solids pollutant reduction.

20.2 Target Pollutants

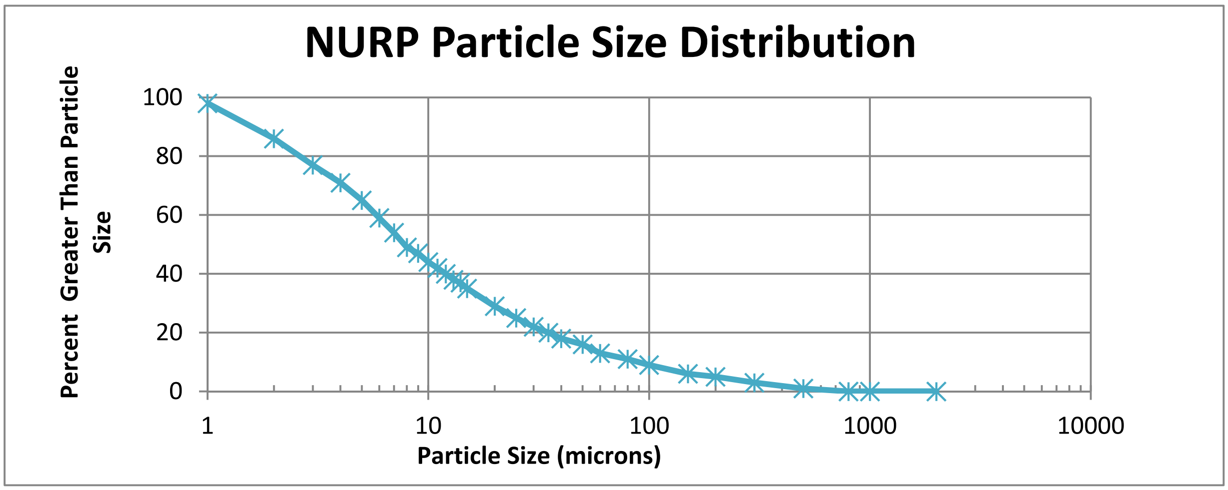
Catchbasins with sumps are effective for trapping coarse sediment and large debris and trash. If outfitted with hoods over the outlets, the capture of floatables and other litter can also be improved. In addition to reducing sediment loads, catchbasin cleaning may also reduce particulate nutrients, metals, and other pollutants in a particulate form and the load of oxygen demanding substances that reach surface water. However, in the absence of suitable cleaning, catchbasins may make water quality worse due to the degradation of captured material and subsequent flushing of material into the downstream system. Therefore, it is important for designers to coordinate with WisDOT maintenance regarding the cleaning schedule or develop a maintenance agreement with the community in which the catchbasins are located (refer to Planning Considerations).

20.3 Effectiveness

Catchbasin performance is calculated by assuming flow through a settling area defined by the surface area of the catchbasin. The particulate removal in this settling area is assumed to occur due to ideal settling as described by Stokes Law (for laminar flow), or Newton’s law (for turbulent flow). Catchbasin performance has been monitored during many field trials through EPA-sponsored research, and by other international researchers. For example, Lager, et al. (1977) developed an idealized catchbasin geometry based on laboratory and field experiments.

Properly designed catchbasins can withstand extreme flows with little scouring losses and no significant differences between the water quality of the water retained in catchbasins between events and runoff quality (Pitt, 1985). They will trap the bed-load from the stormwater (especially important in areas using sand for traction control) and will trap a low to moderate amount of suspended solids (about 30 to 45% of the annual loadings). The largest size fractions of the sediment in the flowing stormwater will be trapped (typically larger than 50 µm), in preference to the finer material that has greater amounts of associated pollutants. Their hydraulic capacities are designed using conventional procedures (grating and outlet dimensions), while the sump is designed based on the desired cleaning frequency. Pitt and Khambhammettu (2006) reviewed the performance of catchbasins from many studies, and recommended a basic catchbasin configuration having an appropriately sized sump with a hooded outlet, though the hood is not a typical component of WisDOT catchbasin design.

If the water velocity through the catchbasin is slower, smaller (slowly falling) particles can be more easily retained. If the water velocity is faster, then only the heaviest (fastest falling) particles are likely to be captured and retained. The critical particle settling velocity is a function of the ratio of the discharge water rate to the surface area of the catchbasin. Particles having settling velocities greater than this ratio will be removed. Only increasing the surface area or decreasing the outflow rate will increase settling efficiency. Increasing the catchbasin sump depth does lessen the possibility of bottom scour and increases the estimated time between sump cleanings, though this may not be possible due to utility conflicts, high groundwater levels, or other site conditions. Since the settling velocity increases as particle size increases (using Stokes or Newton's law and appropriate shape factors, specific gravity and viscosity values), the catchbasin water quality performance (or percent removal) is determined from the particle size distribution of the solids in the runoff entering the catchbasin. This is done by determining the settling velocity and then calculating the particle size associated with that settling velocity, which is referred to as the critical particle size. The percent of the particles that will settle is then determined from the particle size distribution of the total suspended solids (TSS) concentration of the sediment in the stormwater runoff. The particle size distribution, which is called the NURP (National Urban Runoff Program) particle size distribution used for stormwater runoff in Wisconsin, as illustrated below.



Field test results indicate that the performance of catchbasins is strongly related to the inflowing water rate relative to the surface area of the catch basin. The standard surface-overflow-rate (SOR) approach used in water and wastewater treatment facilities, and in sedimentation controls in WinSLAMM, normalizes the inflowing water rate with the surface area of the catchbasin. Detailed scour tests (computational fluid dynamics modeling and full-scale tests) were conducted to verify this approach and to measure critical scour conditions (Avila, H., R. Pitt, and S.E. Clark, 2011).

Note that while the NURP particle size distribution is both required in Wisconsin and is suitable for an outfall particle size distribution, source area and inlet monitored samples usually contain larger particles not included as part of total suspended solids (TSS). These particles, which would be captured in catchbasin sumps, would mostly be deposited in conventional drainage systems if there were no catchbasins. With short highway drainages near streams, these larger particles would likely be delivered to the outfall and therefore to the stream, if not captured in a catchbasin. This means that catchbasins with sumps can be especially useful reducing the coarse sediment load to water bodies.

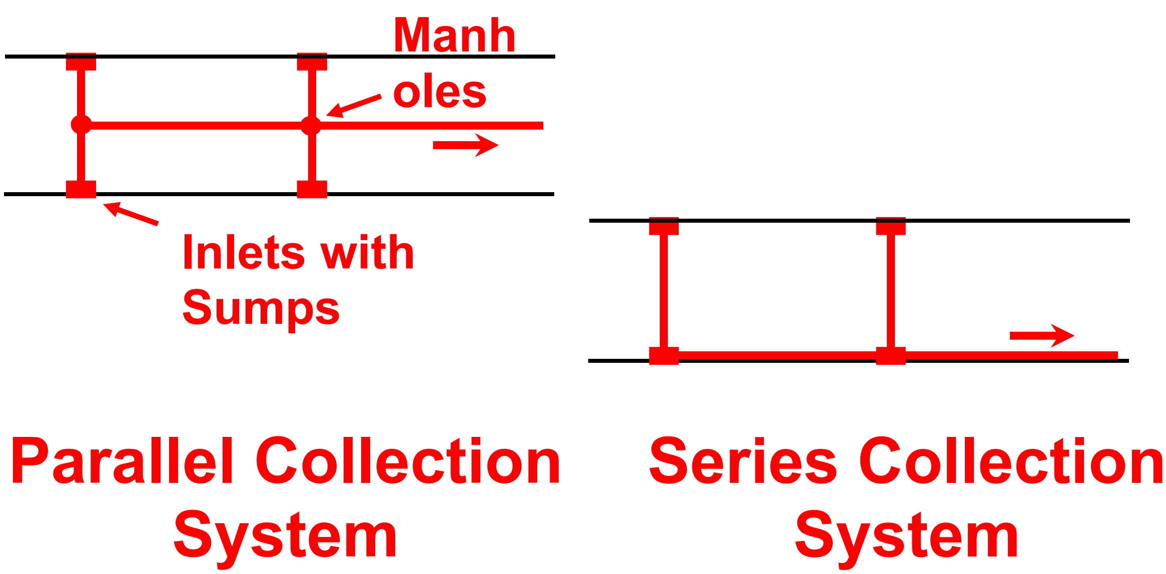
Based on the NURP particle size distribution, all particles greater than 80 µm would need to be trapped to achieve 15% particulate solids control of the stormwater runoff entering a catchbasin, which is the planning level control allowed for catchbasins for WisDOT projects, as described in FDM 10-25-1. However, the high level of turbulence in a catchbasin sump usually restricts the capture of sediment to particles larger than 50 µm. Also, scour of previously captured material likely occurs when the overlying water depth over the captured sediment is less than about one foot (Avila, et al, 2011). The methods for calculating the performance of catchbasins have been verified during several field monitoring projects where inlet and effluent samples were collected and analyzed under widely varying conditions (see Pitt and Field 2004 for a summary of these monitoring activities and results).

20.4 Planning Issues

20.4.1 DOT Design Requirements

Per TRANS 401.106(3), for transportation facilities first constructed after 2002, where there was previously no transportation facility, reduce total suspended solids (TSS) discharges, when compared with no stormwater quality discharge controls, by the maximum extent practicable, up to 80%, based on an average annual rainfall. Highway reconstruction and non-highway redevelopment projects must reduce TSS discharges by the maximum extent practicable, or up to 40%. Refer to FDM 10-25-1 for guidance on setting the correct TSS reduction level for a project. Runoff entering a catchbasin from outside of the DOT right of way (off-site run on) will affect the performance of the catchbasin and must be accounted for during the catchbasin design. Off-site pollutant loads, however, are typically excluded from the analysis because the source of the pollutants (from off the DOT right-of-way) is not controlled by the DOT.

Catchbasin layouts in storm sewer systems are classified as either in series or in parallel, although typical layouts are usually a combination of both types. The diagrams below illustrate the difference between these two systems. Catchbasins placed in series mean that the water leaving one catchbasin enters the next downstream catchbasin through the storm sewer system. For the series collection system example, the lower (downstream) two inlets convey water not only from the direct surface runoff, but also convey water through pipes from upstream inlets. This can dramatically reduce their sediment capture performance because the influent flows are larger, which reduces sedimentation while increasing the scour potential. When catchbasins are placed in parallel, only surface runoff enters each catchbasin, and the water is discharged through laterals to the main drainage system. For the parallel collection system, each inlet only collects direct surface water; none of them convey water through pipes from other inlets. The catchbasin performance charts in this section assume that the collection system is set up in parallel.



20.4.2 Site Assessment

Conduct and document a site assessment to determine how to place, design, and maintain catchbasins. The starting point for the water quality analysis is typically the design developed to accommodate the appropriate design flow from the highway. For catchbasins, this design will be developed from the inlet spacing guidelines described in FDM 13-35-30, the Hydraulic Design of Inlets. Collect the following information to characterize the drainage area for each catchbasin for the water quality analysis.

1. Identify the proposed drainage area for each catchbasin. The drainage area can extend outside of the right of way. Determine the distance between each catchbasin. This should already have been done when developing the initial inlet spacing for drainage (based on FDM 13-35-30).

2. Classify the highway cross section as either a Type 5 or a Type 8 cross section by matching as closely as possible the proposed cross section with the two available types. These two typical cross section types are illustrated in Attachments 20.1 and 20.3. The Type 5 cross section, which includes two lanes of traffic, a parking lane and a paved median, can also be used for three lanes of traffic with no parking. The Type 8 cross section, which includes two lanes of traffic, can also be used for one lane of traffic and a parking lane.

3. Classify the type of land use in the drainage area outside of the right of way as either largely impervious, as in strip mall or paved parking, or as largely pervious, as in a residential area with grass swale drainage.

20.4.3 Catchbasin Design Considerations

Planning considerations are intended to suggest to the designer issues that may be of concern for a project. If you believe that a consideration may affect your project, contact your regional stormwater engineer for additional guidance.

1. Determine whether the drainage system should be designed with a parallel or series collection system. The series collection system may be less expensive because it requires fewer structures or might be more constructible given traffic control considerations, but the water quality requirements of the project might require a parallel drainage system to maximize system performance.
2. Determine if the control of the accumulation of floating trash using hooded outlets or the use of vortex controls or hydrodynamic settlers are appropriate.

20.5 Design Recommendations

The design guidelines described below provide a method to calculate the percent TSS reduction from a catchbasin or inlet with a sump in a WisDOT urban cross section. These guidelines use a series of curves that describe the percent TSS reduction based upon the characteristics and size of the contributing drainage area. They were developed using WinSLAMM v 9.4, using the NURP particle size distribution. The curves were developed for four standard size WisDOT structures - the Type 3 Inlet (2' x 3'), the Type 1 Catchbasin (4' diameter), a 5' diameter catchbasin and a Type 5 Catchbasin (6' diameter). If the project is using devices with different footprints or the drainage area cannot be characterized using the design curves, then the pollution control effectiveness of the device should be modeled using a pollutant loading model such as WinSLAMM, P8, DETPOND or an equivalent methodology.

20.5.1 Catchbasin Design Charts

There are ten design charts in Attachments 20.2 and 20.4. Each set describes the percent TSS reduction for a cross section type and catchbasin of a different surface area as a function of the length of highway draining to the catchbasin. The design charts are setup to account for the following criteria and assumptions:

1. The surface area of the catchbasin (a Type 3 Inlet (2' x 3'), a Type 1 Catchbasin (4' diameter), a five foot diameter Catchbasin or a Type 5 Catchbasin (6' diameter)).
2. The drainage area of the catchbasin as described by the width of the highway from the crown of the road to edge of the drainage basin and the distance between inlets.
3. The cross section type (either one lane of pavement or two lanes of pavement).
4. The inlets are placed in a parallel drainage system so that flow does not accumulate from one inlet to the next.

20.5.2 Catchbasin Water Quality Analysis Using the WisDOT Stormwater Report Spreadsheet

WisDOT has prepared a spreadsheet that incorporates the design guidelines and calculations needed to determine if a project meets the required TSS load reduction. The spreadsheet has a series of worksheets for a designer to methodically prepare and summarize an analysis of the water quality benefits of the various stormwater quality practices, including catchbasins, used on a project. The WQ-Catchbasins worksheet provides a place for the designer to describe and summarize the performance of any catchbasins used in a project. The use of the complete spreadsheet to summarize water quality performance for a project is described in FDM 10-30-1. The link to the spreadsheet is located at FDM 13-1-10 Attachment 10.1.

The catchbasin analysis procedure described below uses the catchbasin analysis summary worksheet WQ-Catchbasin shown in Attachment 20.5. The worksheet is only used to summarize the catchbasin data in an organized fashion - it does not calculate catchbasin performance, which is determined from the design charts.

To use this spreadsheet, enter data into the appropriate worksheet cells. The worksheet is designed so that you can insert columns between the last column and the first column and then select the cells in a data column from rows 7 to 24 and drag them across to create columns for additional catchbasins or inlets. Do NOT enter information in the grey cells because they contain formulas that should not be modified.

On a plan view of the drainage system, delineate the drainage area for each catchbasin that will be providing water quality benefits designed in accordance with this standard. Number the catchbasins, determine their station and if they are left, right or in the center median. Enter this information on lines 7 through 10 of the spreadsheet, and then determine the following information and enter it on the appropriate line of the spreadsheet. For convenience, many of the items can be selected using a drop down menu list on the spreadsheet.

Line 12 - The distance downstream to the next catchbasin (or the total length of roadway draining to the catchbasin if it is located in a sag section of the vertical profile).

Line 13 - The drainage area of the catchbasin. This area includes all areas both within the right of way and outside of the right of way that drain to the catchbasin.

Line 14 - The drainage area of the catchbasin within the right of way.

Line 15 - The cross section type, either Type 5 or Type 8. Select the type that is most similar to the project cross section using the drop down menu. Refer to Attachment 20.1 for an illustration of cross section Type 5 and Attachment 20.3 for an illustration of cross section Type 8. Other cross section types are rural cross sections that do not typically use catchbasins as treatment practices.

Line 16 - Select the catchbasin or inlet size/type using the drop down menu, labeled as 'DD Menu' in the cell.

Line 17 - Select the predominant cover type - either 'Mostly Impervious' or 'Mostly Pervious' using the drop down menu. Select "Mostly Impervious" if the predominant cover type is more than 50% impervious surface.

Line 18 - Enter the design chart number used to evaluate the catchbasin or inlet.Select the chart based upon the cross section type, inlet or catchbasin type, and predominant cover type.

Line 19 - Enter the percent reduction from the design chart (Attachment 10.2) based on the information entered and lines 12, 15, 16, 17 and the average drainage area width (Line 21).

If you need to record design comments about the design for any of the drainage areas, enter them in the comment boxes below the worksheet. Add more comment boxes if necessary.

The design charts are organized by typical cross section as follows:

Cross Section Type 5:

- Chart 1 – Type 3 Inlet: 2' x 3' (6 sf)
- Chart 2 – Type 1 Catchbasin: 4' diameter (13 sf)
- Chart 3 – Catchbasin: 5' diameter (20 sf)
- Chart 4 – Catchbasin: 6' diameter (28 sf)
- Chart 5 – All Types, Mostly Pervious Beyond Curb Line

Cross Section Type 8:

- Chart 6 – Type 3 Inlet: 2' x 3' (6 sf)
- Chart 7 – Type 1 Catchbasin: 4' diameter (13 sf)
- Chart 8 – Catchbasin: 5' diameter (20 sf)
- Chart 9 – Catchbasin: 6' diameter (28 sf)
- Chart 10 – All Types, Mostly Pervious Beyond Curb Line

Each of these charts was developed using WinSLAMM v 9.4 for the conditions described in the chart. To get a specific percent reduction, interpolate the appropriate value from a chart.

20.5.3 Other Design Criteria

Sump depth (the distance between the outlet invert and the bottom of the catchbasin) must be at least three feet. If the sump is less than one foot deep, then it has no water quality benefit due to scour. If the sump is less than three feet deep, but greater than one foot, then the designer should determine the cleaning frequency of the system using a stormwater quality model.

20.5.4 Design Considerations

1. If sand is used in the winter on highways in the drainage area or there are other consistent sources of coarse material, consider increasing the sump depth.
2. Performance can be enhanced by modifications to the catchbasins, including:
   a) Using a hood over the outlet that submerges the outlet restricting the loss of floatables from the catchbasin,
   b) Restricting the outlet diameter to be more in-line with optimized catchbasin geometry, if the flow capacity reduction can be accommodated, or
   c) Inserting an effective inlet filter into the catchbasin.

20.6 Maintenance

20.6.1 Maintenance Requirements

The DOT typically transfers maintenance responsibility for catchbasin cleaning to a responsible authority such as a municipality by means of a legally binding and enforceable project or maintenance agreement. These agreements should include a clear statement of regular maintenance requirements and, if necessary, should reference a maintenance plan. If a maintenance plan is developed it should provide a clear guideline for what work is need to maintain the water quality and quantity control purposes of this practice. Check with your regional office planning section for additional information on maintenance agreement requirements.

Regular maintenance includes clearing sediment, trash and debris from the sump. Cleaning should occur when accumulations are within 1.5 feet of the distance from the pipe outlet invert elevation to the top of the sediment. This requirement typically means that catchbasins need to be cleaned once every one to three years. Typically sediment is disposed of at a licensed landfill. Cleaning sump trash and debris may need to be more frequent (such as every 6 months) if significant organic debris or trash accumulates in the sump to prevent degradation of the material and worsening sump water quality.

20.6.2 Maintenance Plan

Develop a project or operation and maintenance plan that is consistent with improving stormwater quality, fall and spring bypass requirements for salt contamination minimization (FDM 10-35-35 - Winter Bypass Options to Reduce Chloride Contamination (*not complete yet*), safety requirements and the criteria for its design. The operation and maintenance plan will at a minimum:

1. Identify the responsible party for operation, maintenance, and documentation of the plan.
2. Require that the depth of sediment in the catchbasins be inspected and recorded annually.
3. Include a cleaning frequency requirement that addresses the sediment depth requirements described above. The cleaning frequency must be adjusted to reflect the actual sediment accumulation rate for the catchbasins, as determined by the inspections.

20.6.3 Maintenance Considerations for Mosquito Prevention

A preventative measure includes the use of mosquito donuts that can be placed in mesh bags and secured to small anchors and placed in the sumps. These normally last for several months and may only be needed late in the summer months.

20.7 Catchbasin Water Quality Design Example

Given the drainage areas and site conditions described below, determine the percent water quality reduction using catchbasins for the site. Assume there is a maintenance agreement with the local municipality to clean the sumps at least annually.

- Problem - Two catchbasins located at Station 10+00 and 12+00 (R), with primarily impervious drainage areas of 0.3 acres (200 ft to the next drainage area) and 0.45 acres respectively (250 ft to the next drainage area). There are small silty/clayey pervious areas within the STA 10+00 catchbasin drainage area and significant silty/clayey areas within the STA 12+00 drainage area. The area within the right-of-way for both catchbasins is 0.2 acres. The cross section at STA 10+00 most closely resembles a Type 5 cross section, and the cross section at STA 12+00 most closely resembles a Type 8 cross section. Both catchbasins will be Type 3 Inlets with a three foot sump.
- Solution - The project information (lines 2 – 5) will be filled in when you enter project information on the summary tab of the stormwater report. Define the catchbasins in lines 7-9 of the Catchbasin Analysis Summary Spreadsheet, (Attachment 10.3). Next, enter the site data into lines 12 – 18 of the spreadsheet. On lines 12 – 14, enter the numeric values for distance and area. Use the drop down menus to enter values in lines 15 – 18. Use the drop down menu to enter the design chart number in line 18 based upon the cross section type, catchbasin or inlet type/size and predominant cover type entered in lines 15 – 18.

  Use Chart 1 for the inlet at STA 10+00 because this chart is for a Type 3 Inlet in Cross Section Type 5 with little pervious area. The worksheet will calculate, in line 21, the average drainage area width. Use that width (in this example, 65 ft), to interpolate a percent reduction of 22%.

  Use Chart 10 for the inlet at STA 12+00 because this chart is for a Type 3 Inlet in Cross Section Type 8 with significant pervious area. The worksheet will calculate, in line 21, the average drainage area width. Use that width (in this example, 78 ft), to interpolate a percent reduction of 23%. Enter both values into line 19. The worksheet will calculate the overall percent reduction of TSS for the right-of-way area, which in this case is 19.0%

20.8 References

Avila, H., R. Pitt, and S.E. Clark. “Development of effluent concentration models for sediment scoured from catchbasin sumps.” Journal of Irrigation and Drainage Engineering. (http://dx.doi.org/10.1061/(ASCE)IR.1943-4774.0000183). Vol. 137, No. 3. pp 114-120. March 2011.

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Pitt, R. and J. Voorhees, “WinSLAMM, the Source Loading and Management Model for Windows version 9.4,” PV and Associates, LLC, 2010.

Wisconsin State Legislature, Revisor of Statutes Bureau, Wisconsin Administrative Code; for information on the codes of state agencies, including WDNR, refer to http://www.legis.state.wi.us/rsb/code.htm.

LIST OF ATTACHMENTS

Attachment 20.1	Typical Cross Section Type 5 Illustration
Attachment 20.2	Catchbasin Water Quality Design Charts for Cross Section Type 5
Attachment 20.3	Typical Cross Section Type 8 Illustration
Attachment 20.4	Catchbasin Water Quality Design Charts for Cross Section Type 8
Attachment 20.5	Catchbasin Analysis Summary Spreadsheet