Near West Neighborhood Stormwater Study
University of Wisconsin-Madison

Wisconsin Department of Administration
Division of Facilities Development
Madison, WI
June 8, 2017

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1 Introduction

1.1 Background

This project was completed for the Wisconsin Department of Administration (DOA) and the University of Wisconsin-Madison (UW-Madison). The project scope involves providing stormwater management planning and conceptual design for the UW-Madison campus redevelopment area approximately bounded by Willow Creek, Linden Drive, the alley east of the Seed Building, the Natatorium, and the near east playing fields (**Figure 1**).

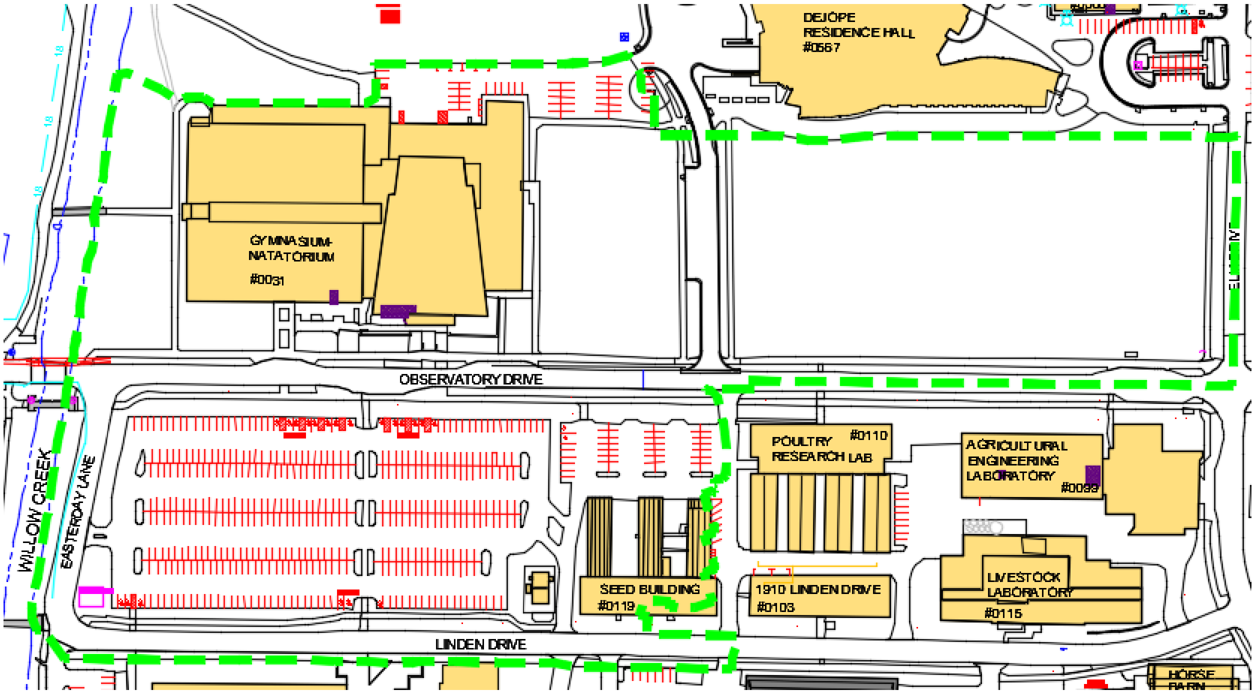


Figure 1-1. UW-Madison Near West Neighborhood study area boundary.

The project area south of Observatory Drive within the project site boundaries is slated for redevelopment with three new building projects to be constructed in the next few years. These new buildings, from west to east, are the Vet Med Building addition, a new parking ramp, and the new Meat Science Building. The Natatorium is also slated for renovation and a building addition. The campus is subject to several regulatory requirements for stormwater management as well as obligated to address the campus's own stormwater policy. The university desires to approach the stormwater management holistically with an overall plan to meet the campus permit requirements and address the campus stormwater policy.

1.2 Project Objectives and Scope

The purpose of this study is to determine an integrated, neighborhood-scale approach to stormwater management rather than managing stormwater through independent, site-by-site designs for upcoming major projects. Such a holistic plan is more likely to meet permit requirements and UW-Madison's own stringent stormwater policy.

The project scope is to conduct a hydrologic and hydraulic analysis, a water quality analysis, an appraisal of conveyance capacity, conceptual stormwater plans, and cost estimates. The project objectives include emphasizing runoff volume and Total Suspended Solids (TSS) reduction through green infrastructure methods such as bio-retention, raingardens, and other infiltration practices.

1.3 Stormwater Targets

1. The UW-Madison has adopted a policy intended to alleviate flooding in Lake Mendota recommended by Professor Kenneth Potter of the Department of Civil and Environmental Engineering. This policy is to limit the volume of runoff from newly developed and redeveloped areas be no greater than the amount that occurred under native conditions. This includes an assumption of a runoff curve number of 58 for Hydrologic Soil Group B soils.

2. The Wisconsin Division of State Facilities' Sustainable Facilities Standards (May 24, 2012 update) include the following relevant performance standards:
    - Not exceeding pre-development peak discharge for the 1.5 yr, 24 hour event, for sites where existing impervious cover is less than or equal to 50%;
    - 25% decrease in peak discharge rate and runoff volume for developments where existing impervious cover is greater than 50%;
    - 80% TSS control of for the average annual rainfall period compared to no controls

3. The Municipal Separate Storm Sewer System (MS4) permit for the UW-Madison requires a TSS reduction of 40% compared to no controls, and the Rock River Total Maximum Daily Load (TMDL) requires a TSS reduction on campus of approximately 72%.

Our analysis was designed to be consistent with the WinSLAMM analysis previously prepared for campus stormwater management. Output from these models can be obtained in terms of percent reduction as compared to no controls. Thus, the models and results are useful in demonstrating regulatory compliance. The analysis also considered additional models for best-management practices (BMPs) that are not included within the WinSLAMM model. Where appropriate, results from several models were compiled and presented in terms of runoff volume and TSS load reduction as well as percent reduction as compared to no controls.

2 Methods

In this conceptual stormwater study, we evaluated a wide range of options for a low-impact development approach to managing stormwater in the Near West Neighborhood to meet regulatory requirements and other objectives. This included assessing soil and groundwater conditions and the feasibility of stormwater infiltration. Stormwater management options were evaluated for performance for runoff volume, peak discharge, TSS reduction and planning level costs. This report presents a set of options for the neighborhood as a whole and for specific sites within the neighborhood for consideration during future detailed design phases.

2.1 Field Investigation

We reviewed historical soil boring data for past projects in the project area obtained from the UW-Madison for soil conditions and depth to groundwater. In addition, we observed installation of 8 monitoring wells installed with a Geoprobe rig operated by On-Site Environmental Services, Inc. on May 2, 2016. Six of the wells are 1-inch PVC wells installed with direct-push drilling methods, while the 2 westernmost wells are 2-inch PVC installed with hollow-stem augers to meet the needs of another nearby project. Soils encountered were generally several feet of fill materials over stratified fine sands, silts and clays though the depths and composition of soils varied significantly within the study area. These findings support the historical soil boring data and suggest low soil permeability. We measured depth to groundwater in the monitoring wells using a manual water-level indicator tape on May 4 and June 1, 2016. Groundwater is generally 7 to 12 feet below the ground with the shallowest depths occurring near Willow Creek and deepest depths occurring in the Near East playing fields.

Understanding the underlying soils and water table characteristics is important when evaluating the feasibility of stormwater management BMPs that rely on infiltration. Low-permeability soils and high water table both limit the amount of water than can be infiltrated. Understanding the groundwater hydrology conditions is also important in basement and foundation design.

2.2 Groundwater Mounding Analysis

Groundwater mounding, the localized rise in water table in response to additional recharge below infiltration practices, is a dynamic process (**Figure 2-1**). Considerations include downward unsaturated zone flow from the infiltration device to the water table and lateral and/or downward flow of groundwater away from the infiltration practice. Mounding can include a short-term “bounce” in the water table in response to recharge provided by individual runoff events and a long-term rise in average water table elevations if the average annual groundwater recharge rate across the development area increases.

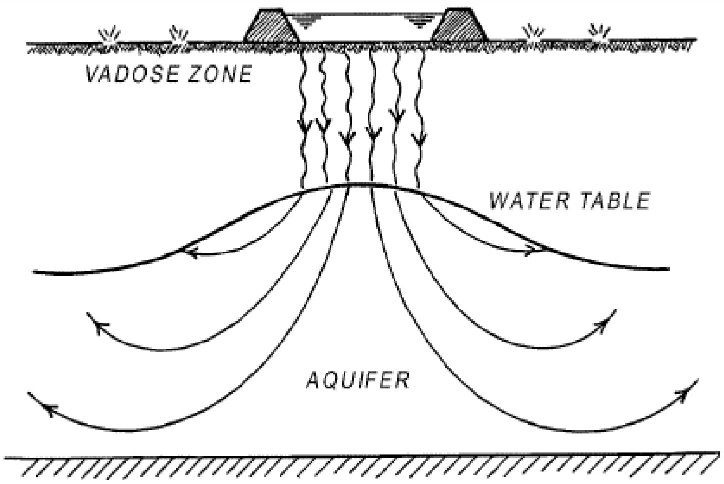


Figure 2-1. Unsaturated and saturated zone flow below an infiltration device (from Bouwer, 2002).

Short-term mounding after runoff events was computed using the analytical relationship developed by Hantush (1967) that predicts water table rise through time in response to recharge applied to the water table (**Figure 2-2**). A range of soil properties was used for this analysis based on hydraulic conductivities inferred from the soils observed in borings, and infiltration rates typical of fine-grained soils (e.g. standard values from WinSLAMM). The calculation was conducted in an online tool developed by HydroSOLVE, Inc. (http://www.aqtesolv.com/forum/cmound.asp).

Long-term rise in the water table was evaluated using the analytical relationship described by Bouwer (2002) for steady-state mounding below a circular infiltration system (**Figure 2-3**). In this study area, an increase in groundwater elevation would generate an increased water table slope toward Lake Mendota or Willow Creek, which would drive groundwater toward those waterbodies and away from infiltration areas. We calculated the increase in the recharge rate for the study area based on the volume of water infiltrated at stormwater practices and averaging this over the entire site area. Infiltrated water volume was calculated by WinSLAMM modeling (described in subsequent sections of this report), and the fraction of this water that recharged groundwater was estimated to be 45% based on previous analyses with the RECARGA model (MARS, 2008). The mounding computation was conducted in a spreadsheet.

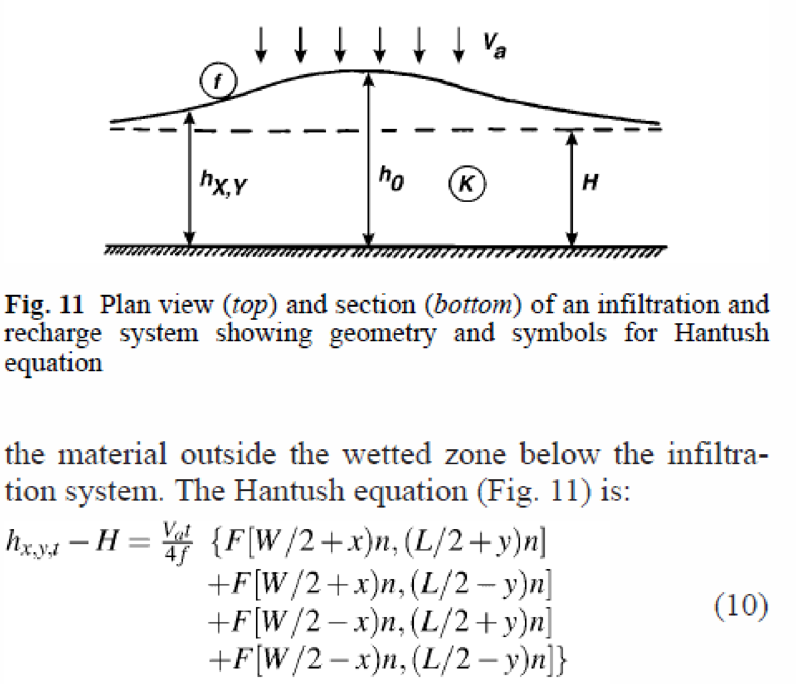
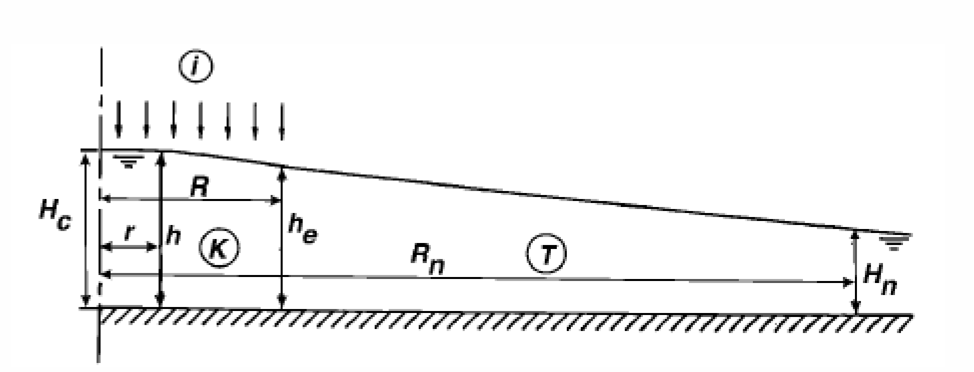


Fig. 11 Plan view (*top*) and section (*bottom*) of an infiltration and recharge system showing geometry and symbols for Hantush equation

the material outside the wetted zone below the infiltration system. The Hantush equation (Fig. 11) is:

$$h_{x,y,t} - H = \frac{V_a t}{4f} \{F[W/2 + x)n, (L/2 + y)n] + F[W/2 + x)n, (L/2 - y)n] + F[W/2 - x)n, (L/2 + y)n] + F[W/2 - x)n, (L/2 - y)n]\} \qquad (10)$$

Figure 2-2. Hantush (1967) analytical equation for transient water table mounding (from Bouwer, 2002). h is water table height at a given location and time, H is the original water table height, V is the recharge rate, t is time since start of recharge, f is fillable porosity, L and W are the length and width of the infiltration basin, and F is a function with values tabulated by Hantush.



$$H_c - H_n = \frac{iR^2}{4T}\left(1 + 2\ln\frac{R_n}{R}\right)$$

Figure 2-3. Long-term (steady-state) groundwater mounding below and flow away from a circular infiltration area (Bouwer, 2002). Hc is the mound height, Hn is the height of the water table at a fixed boundary, i is the average infiltration rate, R is the radius of the recharge area, Rn is the distance to the fixed boundary, and T is aquifer transmissivity.

2.3 Stormwater Volume and Quality Analysis

The modeling approach used in this analysis was selected to be consistent with previous stormwater management studies on campus as well as to demonstrate MS4 permit compliance. The study evaluated the 1981 rainfall series, which includes the non-frozen precipitation part of the year, as required for regulatory compliance.

Stormwater analysis for this study primarily used the current version of WinSLAMM (10.2.1) at the request of the UW-Madison to provide consistency with previous stormwater analyses on campus. WinSLAMM analyzes runoff volume and sediment loading characteristics. Models were run continuously using Madison rainfall data for the period of March 12, 1981 through December 2, 1981, as specified in NR 151, which has a total rainfall depth of 28.81 inches. The National Urban Runoff Program (NURP) 50th percentile particle file was used for pollutant analysis.

Some green infrastructure practices, including green roofs and rainwater harvesting and reuse, cannot currently be simulated with WinSLAMM. We therefore used other modeling techniques to complement WinSLAMM, as described below.

Infiltration

Surface infiltration areas were simulated as biofiltration control practices in WinSLAMM, using a native soil infiltration rate based on the soil and groundwater analysis. Biofiltration devices included 2 feet of engineered soil, underdrains, and a 2-ft-thick gravel storage layer. Subsurface storage and infiltration areas were simulated in WinSLAMM as wet detention ponds with the areas prorated based on the porosity of backfill stone to represent the correct storage volume.

Green Roofs

Since WinSLAMM version 10.2.1 does not simulate green roofs, we developed an approach to simulate a green roof within WinSLAMM with outflow routed to other practices, such as biofiltration areas. This entailed modifying the rainfall input file in an Excel spreadsheet to simulate the abstraction provided by the green roof. This was determined through simulations of green roofs using the EPA Stormwater Calculator (https://www.epa.gov/water-research/national-stormwater-calculator) and by comparison with green roof runoff monitoring data.

The EPA National Stormwater Calculator is a desktop program that runs the EPA SWMM hydrologic and hydraulic model to evaluate several low-impact development practices. The model uses local soil data, land cover, and historic rainfall records. The model uses local rainfall data from a nearby weather station and can be run for periods of 1 year or multiple years. It is not possible to input a specific rainfall series, such as the 1981 period required by local regulations, making side-by-side comparison with WinSLAMM more difficult. Nonetheless, the EPA National Stormwater Calculator proved to be a useful in our analysis.

Water Harvesting and Reuse

Rainwater harvesting was simulated for three proposed buildings in the study area, with simulation of routing roof runoff to above-ground cisterns (**Figure 2-4**) or underground storage chambers for storage and reuse. Reuse options analyzed included toilet flushing and landscape irrigation. Routing of runoff to the storage units was simulated in WinSLAMM, and water loss due to reuse was computed in a spreadsheet because the water reuse routines in WinSLAMM version 10.2.1 are not functioning properly. Losses were computed on a daily time step, tracking inflow to the storage unit, volume of water stored, and volume withdrawn for reuse (and infiltration where appropriate). Roof runoff can be captured in above ground cisterns or underground chambers. Our analyses assumed above ground cisterns would be used for the purpose of cost estimation, but the stormwater treatment performance would be similar for underground storage of comparable volume.

Reuse for toilet flushing simulated for estimates of the number of building occupants (at 200 ft^2/person) and daily water use for toilet flushes per person (**Table 2-1**). These estimates assume installation of waterless urinals. The area of roof routed to the harvesting system and the storage volume were selected for each site within the study area in a way that balanced runoff reduction benefit and the size (and cost) of the system. The size of the harvesting system was capped when the site runoff reduction reached 90%. Additional water could be harvested and reused with a larger system, however the cost per gallon of runoff reduced would increase. These simulations are intended to illustrate the potential runoff reduction benefit of rainwater harvesting and reuse; more detailed system optimization and design would be needed when detailed site designs are prepared.

Figure 2-4. Rainwater cistern at the Chicago Center for Green Technology.

Table 2-1. Estimated toilet flushing volumes

Women	4 flushes / day
Men	1 flushes / day
Volume / flush	1.3 gal
Ratio of men:women	1:1
Average flush volume	3.25 gal/day/person

Note: Assumes waterless urinals for men.

Water reuse rates for landscape irrigation were estimated by estimating the number of irrigation days during the 1981 simulation period, estimating the size of landscaped areas that potentially could be irrigated based on the concept plan for the neighborhood (0.5 acres), and calculating irrigation water demand based on local reference evapotranspiration. We assumed that irrigation could occur during the growing season on days when it has not rained and there has been no rain on the preceding day. For 1981, this yields a total of 85 potential irrigation days. Average reference evapotranspiration for each month was determined from the University of Wisconsin Extension website (http://agwx.soils.wisc.edu/uwex_agwx/sun_water/get_grid, **Table 2-2**). Irrigation demand estimates based on this method are similar to other sources, such as guidance by the Wisconsin Department of Natural Resources (1999) recommending 1 inch per week for lawn irrigation.

Table 2-2. Irrigation days and potential evapotranspiration for 1981 rainfall series.

Month	Irrigation days	Reference ET (in/d)
Jan	0	0.003
Feb	0	0.002
Mar	0	0.038
Apr	0	0.095
May	20	0.129
June	10	0.165
July	12	0.202
August	17	0.152
September	13	0.117
October	13	0.044
Nov	0	0.011
Dec	0	0.003
Total	85	

We assumed 100% TSS removal efficiency for harvesting systems, because even with system overflow there would typically be substantial residence time for particulate settling to occur.

Tree Canopy Interception

Urban trees provide aesthetic, ecological and hydrologic benefits, many of which are described by the i-Tree software tools developed by the U.S. Forest Service and other partners (www.itreetools.org). Research on rainfall interception by tree canopies indicates that the leaves and branches of a tree intercept some water before it reaches the ground surface. For very small rains, a large percentage of the rain is intercepted. The percent intercepted decreases as rainfall depth increases, with a maximum depth of intercepted water of about 0.1 inch (e.g. Xiao et al., 2000, **Figure 2-5**).

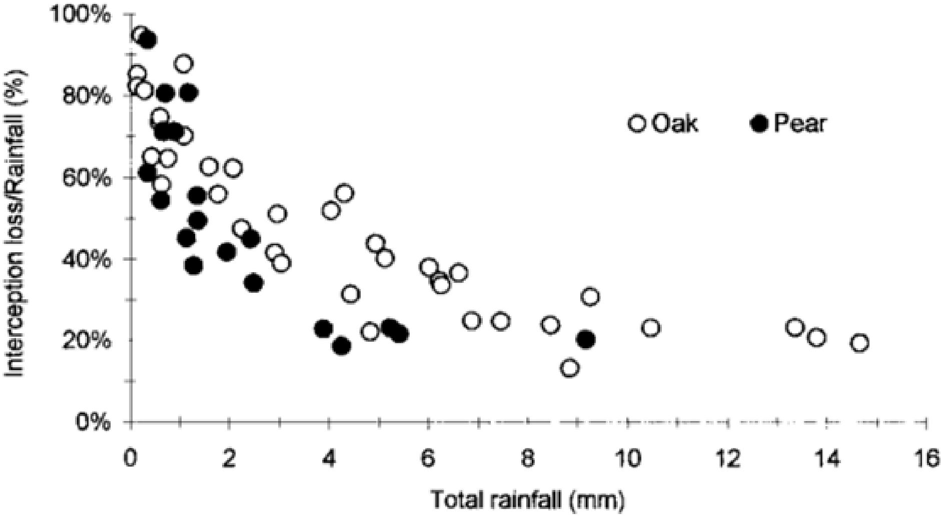


Figure 2-5. Rainfall interception by canopies of two trees in a California study (Xiao et al., 2000).

No currently available stormwater model can analyze the impact of tree canopy interception on runoff volume and quality for a development site over an annual rainfall period, such as the 1981 rainfall series required by state and local ordinances. In particular, WinSLAMM version 10.2.1 does not simulate tree canopy interception. Therefore, an approach similar to that described above for green roofs was developed to simulate canopy interception. A spreadsheet was developed to modify the 1981 daily rainfall series to simulate the amount of water that would be intercepted each day due to full tree canopy coverage. The percent of rain intercepted depends on the rainfall depth, following the relationship in **Figure 2-5**, with a maximum interception depth of 0.1 inch. The simulation assumed no interception occurs in the leaf-off season from November – March, and only 50% of maximum interception during the canopy transition months of April and October. The simulation also assumed that tree canopy covered 100% of the land surface. This process reduced annual rainfall for 1981 by 12%. The modified rainfall series was input into WinSLAMM to simulate routing of runoff from impervious surfaces covered by tree canopies to other control practices, such as biofiltration devices.

Conversion from Turf Grass to Prairie

Conversion of landscaped areas with turf grass to native prairie vegetation was discussed with DOA and UW-Madison staff as a possible runoff reduction strategy. However, prairie conversion was not explicitly modeled in this study because only small areas where this would be possible are present in the Near West Neighborhood, and modeling options to evaluate turf-to-prairie conversion are limited. Little research was identified that quantifies runoff from prairie vs. other landcovers. This is commonly simulated with the NRCS curve number method, using curve numbers representing a meadow. However, this would not necessarily adequately represent the effect of native prairie vegetation and soil, and the curve number approach is poorly suited to continuous analysis of runoff volume. In addition, WinSLAMM does not use the curve number method, and it does not have the capability to simulate native vegetation such as prairie. On a unit-area basis, we expect significant runoff reduction with conversion of landscaped areas to prairie, and this could be considered in other locations with larger landscaped areas.

2.4 Peak Discharge Analysis

Rainfall-runoff and hydraulic routing for peak discharge control review was analyzed in HydroCAD. HydroCAD uses Soil Conservation Service (SCS) TR-20 runoff hydrograph and curve number (CN) procedures, and TR-55 Time of Concentration (Tc) calculations. Storm distribution and rainfall depths were taken from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Volume 8.

2.5 BMP Costs

Capital costs for stormwater management practices evaluated in this study were estimated based on the size of the practices, key design details, and typical unit costs from the literature (**Table 2-3**). This study used mid-range costs where ranges were reported, except as noted. Operation and maintenance costs were not calculated due to lack of data, but available information is summarized below. Cost for rainwater harvesting and reuse systems were not estimated due to lack of data on typical costs and the site-specific details of disinfection and distribution plumbing costs. In general, these systems are quite expensive compared to the other stormwater control practices described in this report.

Table 2-3. Stormwater BMP unit costs used to estimate project costs.

BMP	Capitol	Annual O&M	Sources *
Hydrodynamic sumps	$20,000 EA	$500	USEPA (1991), Narayanan & Pitt (2006)
Biofilter w/ underdrain & storage	$15 / SF	Regular landscaping	MARS, CNT (2009), CRWA (2008)
Sidewalk planters	$20 / SF	2x regular landscaping	MARS, CNT (2009)
4" Green roof *	$16 / SF	$0.025 / SF	CNT (2009): mid-range green roof cost
8" Green roof *	$32 / SF	$0.412 / SF	CNT (2009): high-end green roof cost
Permeable concrete or pavers for sidewalk	$10 / SF *	Variable	MARS, SEWRPC (1991), EOR (2012), CRWA (2008), CWP (2010), CNT (2009)
Underground gravel storage	$1/ gal	$0	WDOT (2015)
Above ground cisterns	$1.50 / gal	$0.07 / gal	CNT (2009)
Underground infiltration chambers	> $2 / gal	No data	Hicks (2008)
Rainwater harvesting: disinfection & plumbing	Site specific	No data	

* Green roof unit costs include the cost of increased structural support.

3 Results

3.1 Soil and Groundwater Observations

The glacial geology map of Dane county shows the project area as glacial lake deposits consisting of sand, silt and clay layers (Clayton and Attig, 1997). Historical boring logs for the study area are consistent with the map, showing layers of sand and fine grained soils.

The 8 soil borings sampled on May 2, 2016 were distributed across the study area (**Figure 3-1**). They typically encountered several feet of mixed fill materials over native sand, silt and clay layers. Silt and clay were the dominant textures in most borings, with more sand in wells MW6 and MW8 in the east and southeast parts of the study area. Sandstone bedrock appeared to be present at a depth of about 9 feet at MW8; this limited the depth of the boring and monitoring well. Soil boring logs are included in **Appendix A**.

Depth to groundwater during the May 4 and June 1, 2016 monitoring visits ranged from approximately 6 – 12 feet below the ground surface and water levels dropped by less than half a foot between the 2 dates (**Table 3-1**). The water table elevation was estimated by subtracting the depth to water measurement from the inferred well casing elevation estimated from Dane County 2009 LiDAR elevation data. This indicates that groundwater flows northeast toward Lake Mendota. The shallow water table and fine grained soils w limit stormwater infiltration in the study area were taken into account in the infiltration analysis discussed in **Section 3.4**.

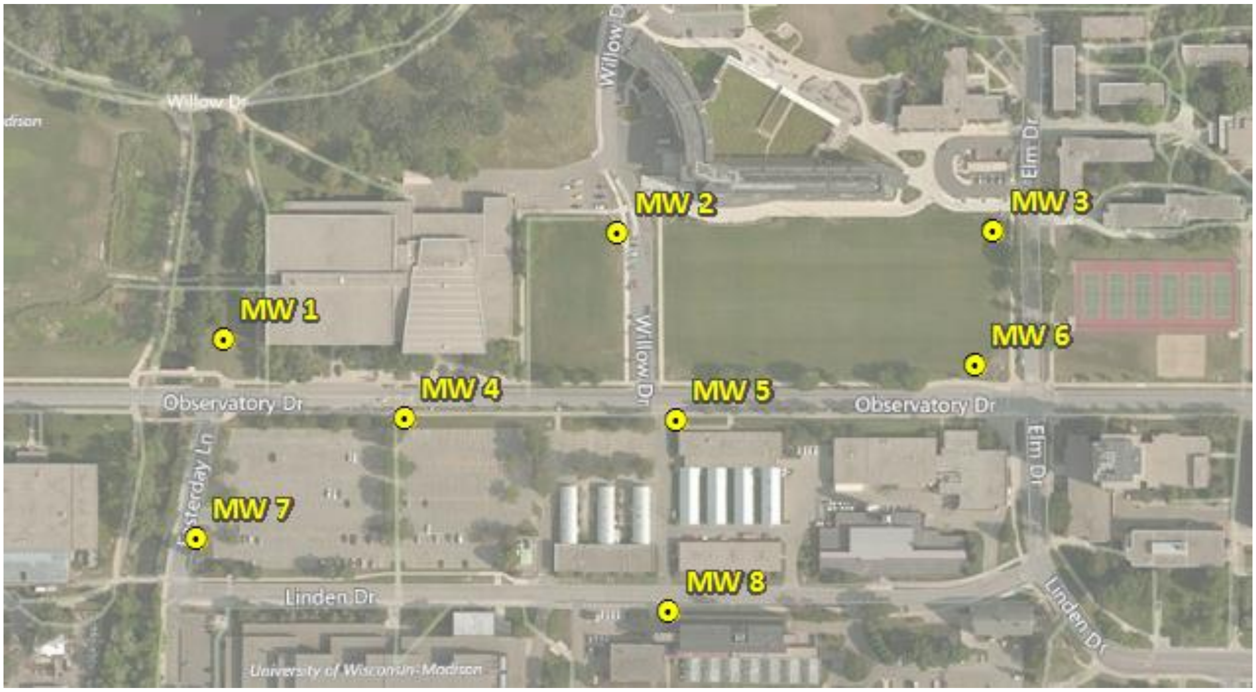


Figure 3-1. Monitoring well locations.

Table 3-1. Groundwater water level measurements.

Well	May 4, 2016		June 1, 2016	
	Depth to Water (ft)	Approx. Elev.[1] (ft)	Depth to Water (ft)	Approx. Elev.[1] (ft)
MW1	6.98	847.8	7.39	847.4
MW2	12.60	847.3	12.87	847.0
MW3	12.56	847.1	12.97	846.7
MW4	8.37	848.0	8.78	847.6
MW5	11.36	847.7	11.70	847.4
MW6	10.35	847.5	10.75	847.1
MW7	6.18	849.1	6.45	848.8
MW8	Dry[2]	--	Dry[2]	--

[1] Monitoring wells were not surveyed. Top of casing elevation was estimated using LiDAR topographic data to estimate the ground surface elevation at the well location, minus the distance from the ground surface down to the top of casing for these flush-mounted wells.

[2] The boring for MW8 encountered shallow bedrock and could not be advanced into groundwater.

3.2 Native Conditions Runoff

The runoff volume for native vegetation conditions is difficult to quantify, because there is uncertainty about the pre-settlement vegetation and topographic conditions in the area, and because of limited modeling options. The Natural Resources Conservation Service curve number method has commonly been used to simulate runoff from prairie, using a Curve Number value for meadow as an approximation of prairie conditions. This approach does not represent the deep root system in native prairie, and curve numbers have substantial error for continuous analyses because they were not developed to accurately simulate small runoff events or the effects of soil moisture fluctuations. The runoff coefficient method used in WinSLAMM is better suited for small storms, but WinSLAMM does not explicitly simulate areas with native vegetation.

We also simulated prairie runoff with the curve number method using the RECARGA model for the regulatory 1981 rainfall record. Soils in the study area are mapped as Hydrologic Soil Group C, consistent with the fine grained nature of soils observed in the borings. The runoff curve number for meadow for Hydrologic Soil Group C is 71. This generates 2.3 in of runoff for the 28.81 in of precipitation in the 1981 series, or 8% of total precipitation.

WinSLAMM was used to generate a second estimate of predevelopment runoff conditions, using landscaped areas with silt and clay soils with normal compaction as surrogates for native vegetation. These simulations predicted 1.7 in and 2.2 in of runoff, respectively, or 6% and 8% of total precipitation.

Based on this analysis, we estimated that runoff under native vegetation cover would be 2.2 inches for the 1981 analysis year.

3.3 Conceptual Stormwater Plan Overview

We evaluated a range of stormwater management options to meet the targets for runoff peak discharge and volume control and for TSS removal. Due to the challenge of meeting the campus policy of meeting native vegetation runoff volume, this evaluation included measures well beyond what are considered standard practices, including green roofs and rainwater harvesting and reuse. The performance, cost and regulatory issues associated with these options are discussed in the following sections.

The concept plan for the neighborhood shows that the total impervious coverage will increase slightly, primarily due to the Natatorium expansion (compare **Figures 3-2** and **3-3**). However, the total area of parking will decrease, while the total roof area increases. This will generate a slightly higher total runoff volume (with no controls) but a smaller TSS load due to the lower unit TSS load of roofs compared to parking lots.

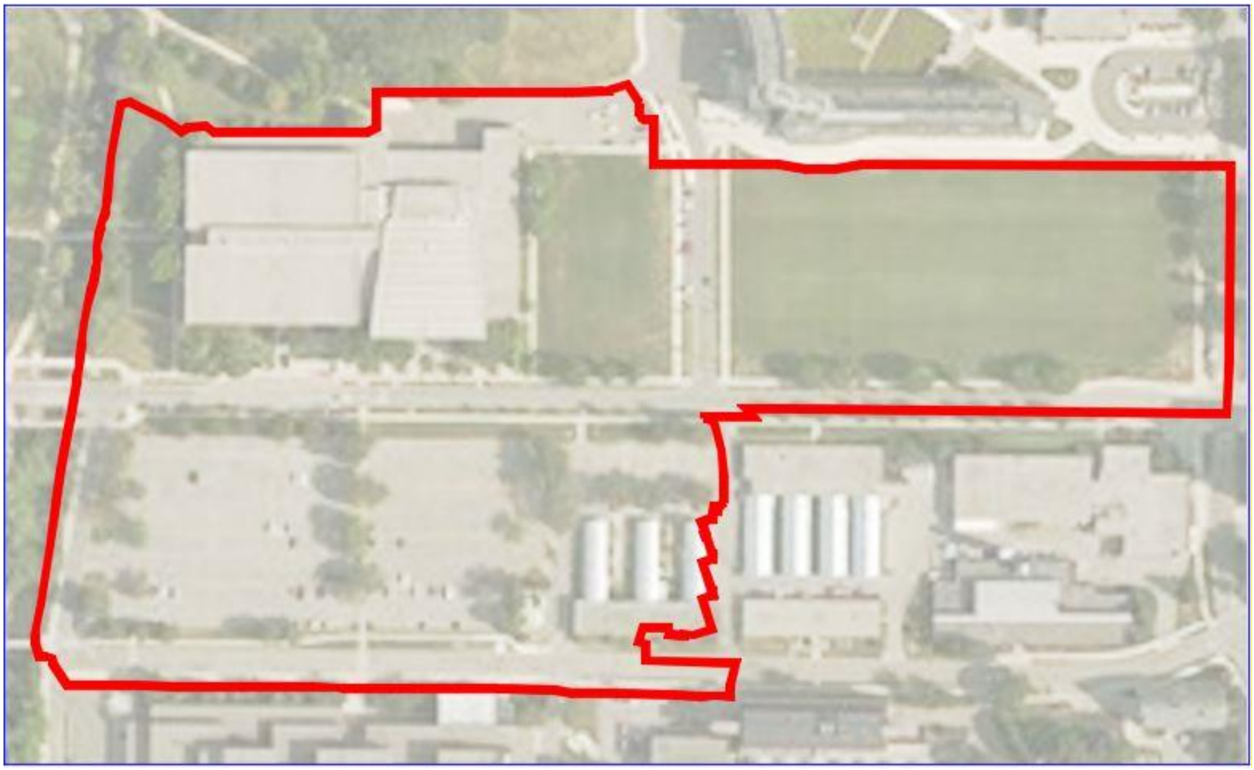


Figure 3-2. Existing land cover in study area.

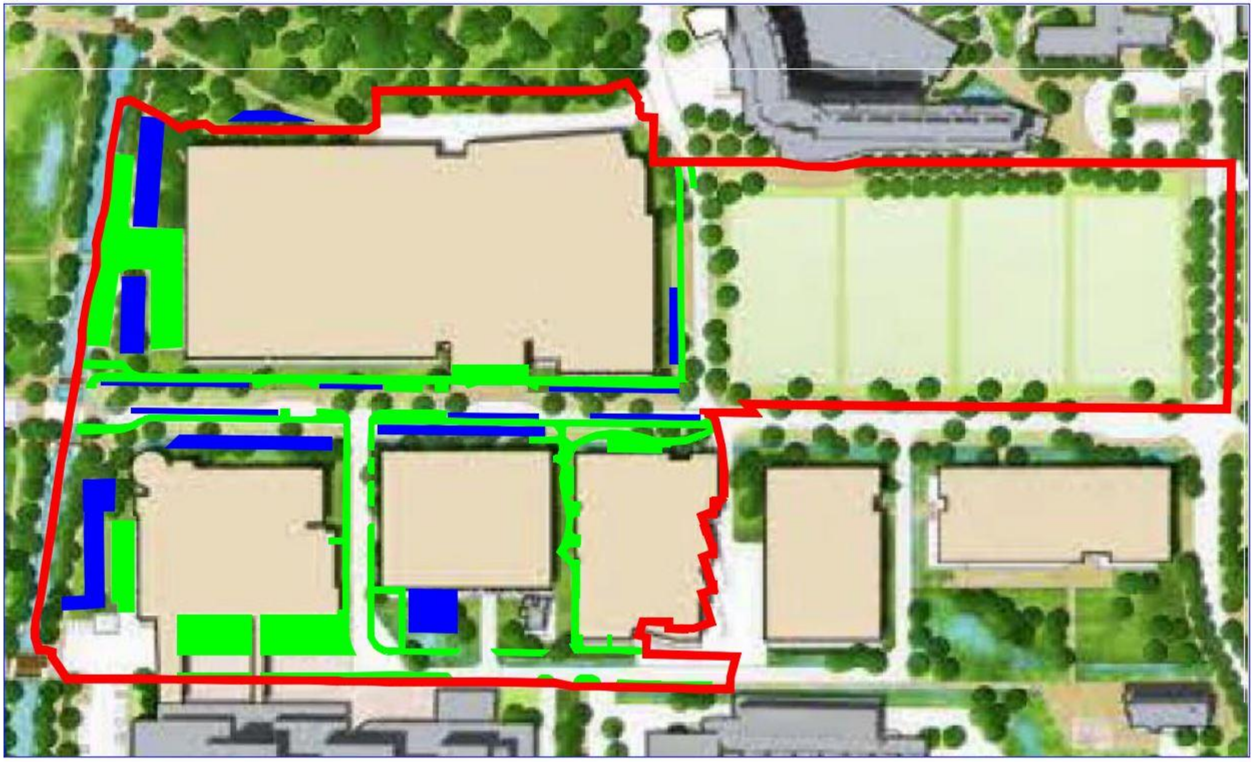


Figure 3-3. Conceptual plan for campus showing proposed land cover in study area. Potential biofilter locations shown in blue; potential permeable pavement sidewalks shown in green.

3.4 Stormwater Control Practices Overview

This section presents general results of the stormwater control practices analysis that are applicable across campus. Site-specific details of stormwater control performance within the study area is discussed in **Sections 3.6 – 3.13**.

Infiltration and Groundwater Mounding

Soil infiltration rates in the study area are likely to be low, given the abundance of fine grained soil observed in the soil borings. Based on design infiltration rates in WDNR Technical Standard 1002, typical infiltration rates in the study area could be expected to range from 0.04 in/hr (for silty clay loam) to 0.50 in/hr (for sandy loam). A representative average infiltration rate for the study area is probably between these values. Horizontal hydraulic conductivity is probably higher than these vertical infiltration rates due to the presence of abundant horizontal sand layers.

Groundwater mounding below stormwater infiltration devices was evaluated for a range of likely soil and aquifer hydraulic properties. We evaluated mounding for soil infiltration rates of 0.2 in/hr and 0.3 in/hr. The Hantush (1967) equation suggests that short-term "bounce" at the water table directly below infiltration devices could be 1 or 2 ft (**Table 3-2**). In addition, to these temporary fluctuations, a long-term rise in groundwater could be expected if stormwater infiltration is implemented widely throughout the study area. Stormwater management options relying heavily on biofiltration, described in following sections of this report, could raise the average groundwater recharge rate across the study area by 2 to 3 in/yr. Bouwer's (2002) analytical equation predicts this recharge increase would cause a steady-state water table elevation rise of 3 – 4 ft for a reasonable range of soil and groundwater properties (**Table 3-3**). In combination, these short-term and long-term rises in the water table are half or more of the depth to groundwater observed in the monitoring wells.

Table 3-2. Short-term groundwater mound height after 1 day below infiltration devices.

Vertical infiltration rate (in/hr)	Horizontal hydraulic conductivity (in/hr)	Mound height after 1 day (ft)
0.2	0.5	1.2
0.2	1.0	0.8
0.3	0.5	1.7
0.3	1.0	1.3

Note: Specific yield = 0.25, Aquifer thickness = 10 ft, and Infiltration area radius = 10 ft

Table 3-3. Long-term, average groundwater rise throughout study area

Vertical infiltration rate in WinSLAMM (in/hr)	Horizontal hydraulic conductivity (in/hr)	Mound height (ft)
0.2	0.5	3
0.2	1.0	2
0.3	0.5	4
0.3	1.0	2

Note: Aquifer thickness = 10 ft

The fine grained soils in the study area will limit infiltration rates below stormwater practices, and groundwater mounding may further reduce their performance. Accordingly, we used a soil infiltration rate of 0.2 in/hr in the conceptual stormwater design calculations described in following sections of this report. Actual conditions at the specific sites may be more limiting than analyzed in this study. Design of infiltration practices should incorporate underdrains to prevent extending ponding that would kill vegetation. In addition, over-excavation may be warranted to install gravel storage layers below infiltration practices to facilitate lateral seepage into horizontal sand layers in the native soil.

Green Roofs

Simulation of an extensive 4-inch green roof with the EPA Stormwater Calculator indicates that little to no runoff is generated for small rain events up to about 0.2 inches (**Figure 3-4**). Note that some small events do generate some runoff, with the amount presumably depending on storm intensity and antecedent moisture. Continuous simulation of a 4-inch green roof for 20 years indicates that the green roof would reduce annual runoff volume by 24% compared to a traditional roof with no runoff controls (**Figure 3-5**).

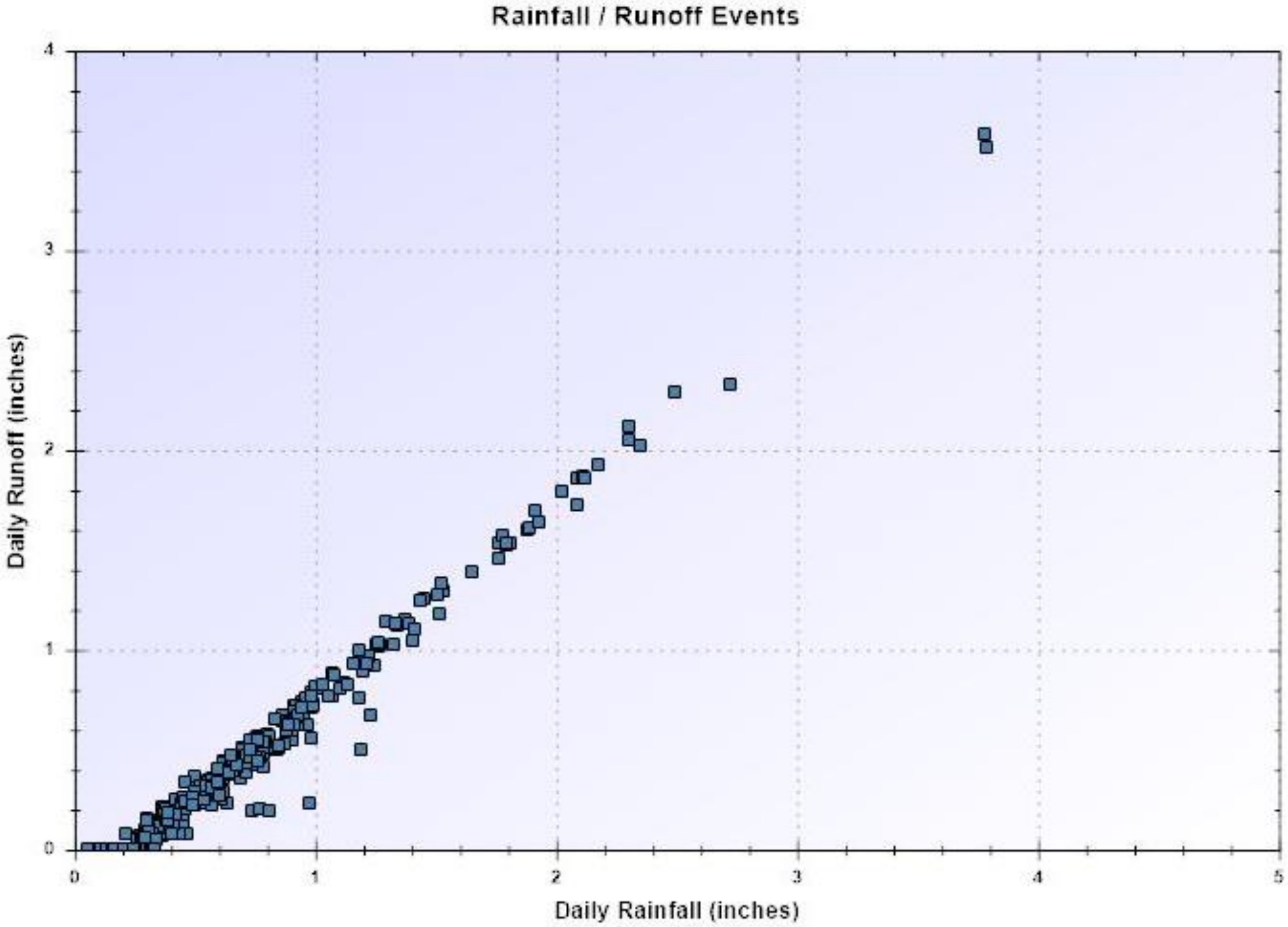
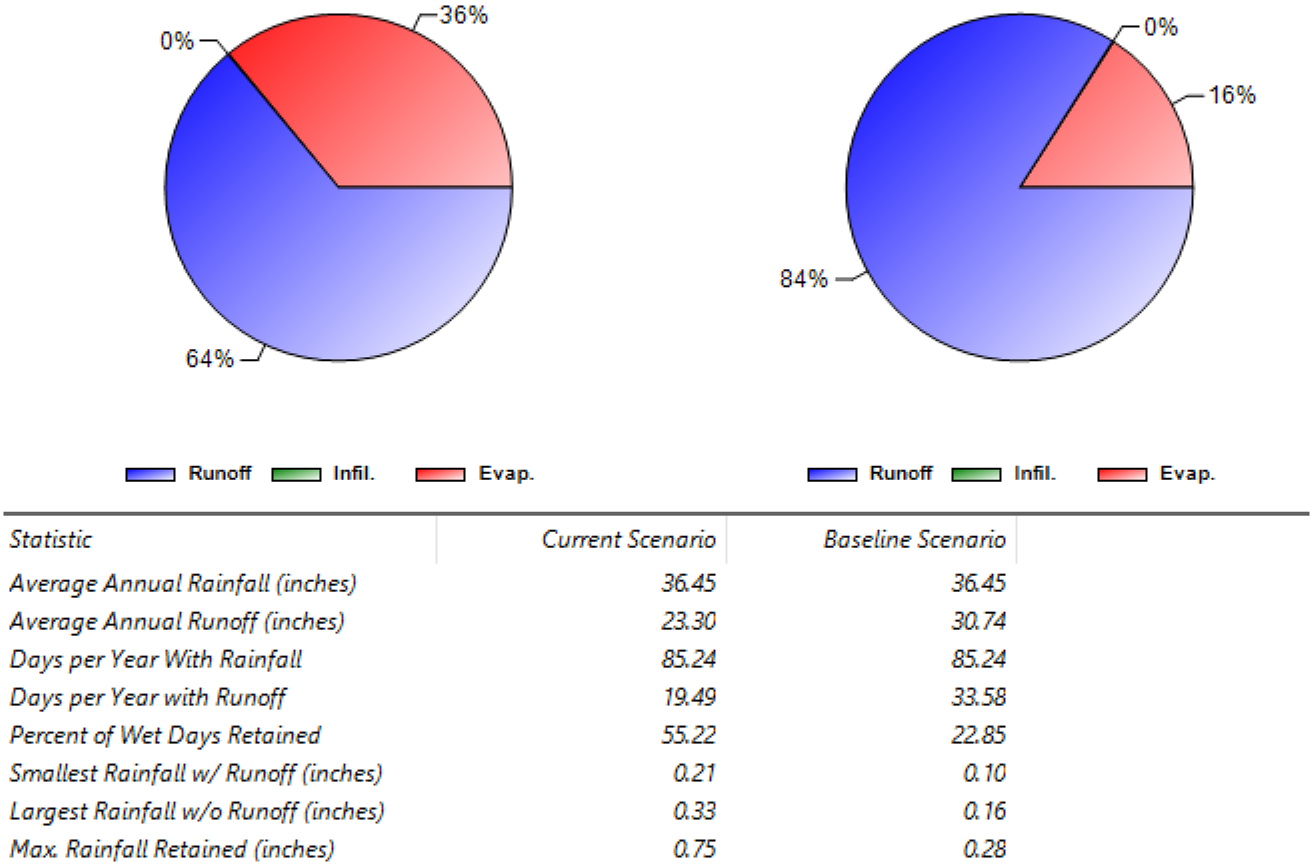


Figure 3-4. Simulation of 4-inch-thick green roof with EPA Stormwater Calculator



Statistic	Current Scenario	Baseline Scenario
Average Annual Rainfall (inches)	36.45	36.45
Average Annual Runoff (inches)	23.30	30.74
Days per Year With Rainfall	85.24	85.24
Days per Year with Runoff	19.49	33.58
Percent of Wet Days Retained	55.22	22.85
Smallest Rainfall w/ Runoff (inches)	0.21	0.10
Largest Rainfall w/o Runoff (inches)	0.33	0.16
Max. Rainfall Retained (inches)	0.75	0.28

Figure 3-5. EPA National Stormwater Calculator comparison of runoff from 4-inch green roof (left) and impervious roof (right)

Data from monitoring studies of an extensive green roof on Union South at the UW-Madison campus (**Figure 3-6**) shows runoff occurring frequently, but at much smaller volumes than a conventional roof and little to no runoff for rains below a few tenths of an inch. In small storms, runoff volume reduction was significant enough to limit the ability of automated equipment to collect samples for water quality analysis. Data from two extensive 4-inch-thick green roofs in New York City (**Figure 3-7**) show a similar rainfall-runoff relationship.

Based on this information about green roof performance, the precipitation input file for 1981 used for the WinSLAMM analysis was modified in a spreadsheet, subtracting an initial abstraction from the daily precipitation that produced the same runoff reduction indicated by the EPA Stormwater Calculator. Trial and error calculations determined an initial abstraction of 0.19 inches. The modified precipitation record was then input into WinSLAMM to evaluate the benefit of routing runoff from a green roof to other control practices.

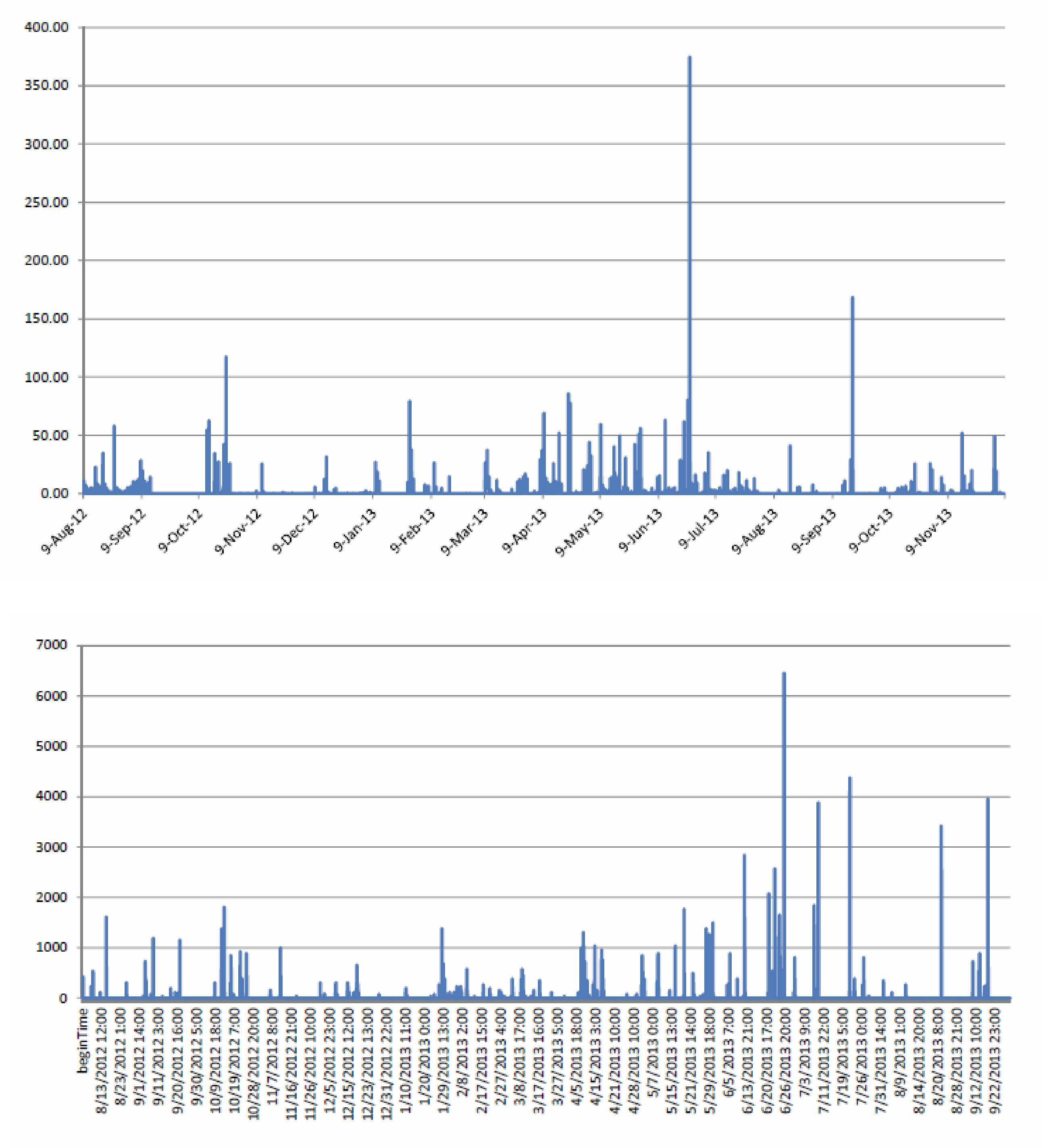


Figure 3-6. Monitored runoff from a green roof and traditional roof at Union South on UW-Madison campus (from Wisconsin DFD, 2014).

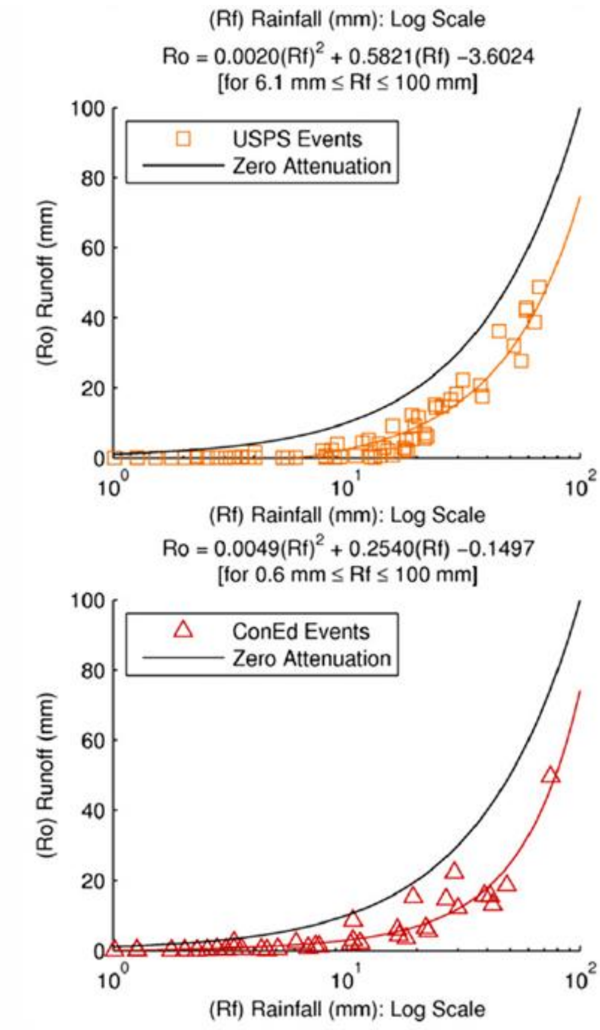


Figure 3-7. Monitored runoff from two 4-inch-thick green roofs in New York City (from Carson and others, 2013).

The EPA Stormwater Calculator was used to illustrate design tradeoffs in the thickness and extent of green roofs (**Table 3-4**). This shows that less runoff from thicker roofs, but declining incremental reductions as thickness increases. The runoff reduction performance of a 4-in green roof over an entire roof is about the same as the performance of an 8-in green roof covering half of the total roof area.

Table 3-4. Annual runoff reduction percentage for different green roof thicknesses and roof coverage.

Media thickness (in)	Roof coverage fraction					
	0.1	0.3	0.5	0.7	0.9	1.0
2	1%	2%	4%	6%	7%	8%
4	2%	6%	10%	14%	18%	20%
6	3%	9%	15%	21%	27%	30%
8	4%	12%	19%	27%	34%	38%
10	4%	13%	22%	31%	40%	45%

The benefit of routing green roof runoff to other control practices was evaluated for the Natatorium roof, as an illustrative example. More detailed analysis of the full Natatorium site is described in a later section of this report. Using WinSLAMM and the spreadsheet simulation of green roof interception described above, we compared runoff from the Natatorium roof for no controls, biofiltration, a 4-in green roof, and a 4-in green roof in series with biofiltration (**Table 3-5**). This example illustrates that combining these two control practices has substantial runoff reduction benefit. Note that the net runoff reduction is not the sum of the reductions for the individual practices. The State of Wisconsin does not currently allow TSS reduction credit for green roofs. Thus, this combination of practices is not appropriate for MS4 compliance review.

Table 3-5. Natatorium roof runoff with biofiltration and/or a green roof.

Scenario	BMP size	Runoff volume (ft^3)	Reduction %
No controls	--	395,900	--
Roof to biofiltration	7,300 ft^2	243,400	39%
Green roof without biofiltration	4.1 ac	264,200	33%
Green roof to biofiltration	7,300 ft^2 biofiltration 4.1 ac green roof	160,000	60%

Green Walls

Green walls were considered but not included in the stormwater simulations. Benefits of green walls are typically described as aesthetic, heat island mitigation, air quality, noise reduction and energy efficiency (e.g. Green Roof for Healthy Cities: http://www.greenroofs.org/index.php/about/green-wall-benefits). Reuse of rainwater for irrigating a green wall is possible, however the small area of typical green walls and limited growing season for outdoor walls would limit the volume of water that could be reused. A backup water supply would likely be needed to keep plants on a green wall alive during dry periods.

Water Harvesting and Reuse

Current state of Wisconsin Administrative Code for plumbing describes the following treatment standards for water reuse (Chapter SPS 382.70 (4)):

- Toilet flushing: 200 mg/L BOD5, 5 mg/L TSS, pH 6-9, and free chlorine residual 1 – 10 mg/L
- Irrigation: 10 mg/L BOD5 and 5 mg/L TSS

Note that this means disinfection is required for toilet flushing reuse, and this would significantly impact capital costs and operation and maintenance costs. Reusing harvested rainwater for flushing toilets would require separate distribution pipes to carry treated rainwater to toilets, essentially doubling the water distribution plumbing system in a building.

However, rainwater harvesting for use in toilets does significantly reduce runoff volume and TSS loading. The scenario analyzed for the Natatorium estimates a runoff reduction of nearly 80,000 cubic feet and a TSS load decrease of approximately 160 pounds. If policy were to change, or treatment methods decrease substantially in price, rainwater harvesting could be a more cost-effective means of stormwater management. In addition, harvesting is not subject to performances losses from low-permeability soils or increases in water table. As such, it may be appropriate in situations where green space is in short supply and soil and groundwater conditions are unfavorable.

Tree Canopy Interception

WinSLAMM analysis of street runoff using the 1981 rainfall series modified as described above to simulate the effect of tree canopy interception predicted 11% less runoff volume and 11% less TSS effluent than for no canopy coverage or other control practices. Planting trees is not included in the site-by-site stormwater analyses described below, however this analysis illustrates that maintaining tree canopy coverage over impervious surfaces can lead to modest reductions in runoff volume and particulate load. Note that current research is demonstrating that fallen leaves can lead to elevated dissolved phosphorus loads, underscoring the value of street cleaning for leaf removal.

3.5 Reporting Approach for Analysis Results

The methods described above were used to evaluate the stormwater management performance of BMPs within the study area. The study area was analyzed to determine the feasibility of regional stormwater treatment. Flat grades and utility conflicts make regional stormwater treatment difficult, however some opportunities do exist and are described below.

Site-level analyses were conducted for each proposed building site as well as Observatory Drive, Linden Drive, and the Near East Athletic Fields. For each site, multiple BMP options were evaluated. **Sections 3.6 - 3.13** describe the characteristics of the sites, simulation results, and observations on the analyses. The results are presented in terms of runoff volume reduction and TSS load reduction. The results include the contribution of individual BMPs to the overall stormwater performance for the site, as well as the efficiency of the BMP (considering only the source areas treated by that BMP). For example, in the Natatorium analysis (**Section 3.6**, ***Options 2 - 4***), permeable paver sidewalks provide only a modest decrease in overall stormwater runoff volume for the Natatorium site. Although the permeable sidewalks are predicted to generate no runoff for the 1981 rainfall series (i.e. they are 100% efficient), their small footprint limits their contribution to overall site runoff control.

Summary tables are provided for each site-level analysis. A template for interpretation of the modeling results summary is presented in **Table 3-6**.

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Table 3-6. Site BMP performance summary explanation.

Scenario	Control practices			Runoff Volume					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft3)	Runoff volume reduction (ft3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				Site runoff volume for proposed development with no controls									
Native conditions				Site runoff volume for native vegetation condition	Difference between no controls runoff and native conditions runoff	Runoff reduction required to meet native conditions runoff							
Option 1			Estimate of total BMP cost	Site runoff volume generated with BMPs listed below	Site runoff volume removed by all BMPs	Percentage of runoff site volume reduced by all BMPs		Estimated cost to remove 1 ft^3 of runoff	Site TSS load generated with BMPs listed below	Site TSS load removed by all BMPs	Percentage of site TSS load removed by all BMPs		Estimated cost to remove 1 lb of TSS
Description of BMP 1	BMP geometry	Areas treated by individual BMP	Cost estimate for individual BMP		Runoff volume removed by individual BMP	Percentage of total site runoff volume removed by individual BMP	Percentage of runoff reduced by individual BMP relative to its source area	Estimated cost to remove 1 ft^3 of runoff for individual BMP		TSS load removed by individual BMP	Percentage of total site TSS load removed by individual BMP	Percentage of TSS reduced by individual BMP relative to its source area	Estimated cost to remove 1 lb of TSS for individual BMP

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3.6 Natatorium

Description

The area considered in the Natatorium analysis includes the footprint of the proposed Natatorium addition, proposed patio areas to the west of the building, the parking lot to the north of the building and the driveway and parking west of the playing fields (**Figure 3-8**). Biofilters, permeable pavement, green roofs and rainwater harvesting were among the BMPs considered in the analysis. **Tables 3-7** and **3-8** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-8. Natatorium analysis area boundary.

Table 3-7. Source areas for proposed conditions

Source type	Area (ac)
Roof	4.13
Parking	0.42
Driveway	0.16
Sidewalks	0.49
Landscaped	1.11
Total	6.31

Observations

- The Natatorium site contains a higher percentage of pervious areas than other parts of the study area. There is room to install biofilters of adequate size to treat TSS and decrease runoff volumes with minimal interference with the conceptual plan for the area.
- Biofilters are the most cost-effective means of stormwater treatment of the BMPs analyzed.
- Although roof water contains less TSS than other source areas, the Natatorium rooftop is the largest contributor to TSS loading in the study area due to its large area. Thus, treating the rooftop runoff is an important component of achieving stormwater management goals in this area.
- Burial mounds to the north of the site may present an obstacle to providing conveyance from the north parking lot to any proposed treatment device.

Table 3-8. BMP performance summary for the Natatorium.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				483,990					1,465				
Native conditions				50,312	433,678	90%							
Option 1			**$139,500**	**291,509**	**192,481**	**40%**		**$0.72**	**921**	**544**	**37%**		**$256**
Biofiltration	9,300 ft^2	Roof, sidewalks, parking & drive	$139,500		192,481	40%	41%	$0.72		544	37%	40%	$256
Option 2			**$352,500**	**258,902**	**225,088**	**47%**		**$1.57**	**226**	**1,239**	**85%**		**$284**
Biofiltration	9,300 ft^2	Roof, parking & drive	$139,500		187,965	39%	43%	$0.74		1,065	73%	89%	$131
Permeable pavers	21,300 ft^2	Sidewalks	$213,000		37,123	8%	100%	$5.74		174	12%	100%	$1,224
Option 3			**$3,121,400**	**279,675**	**204,315**	**42%**		**$15.28**	**940**	**525**	**36%**		**$5,940**
4-in green roof	4.1 ac	Entire roof	$2,878,400		131,629	27%	33%	$21.87		0	0%	0%	--
Biofiltration	2,000 ft^2	Parking & drive	$30,000		35,563	7%	81%	$0.84		351	24%	93%	$85
Permeable pavers	21,300 ft^2	Sidewalks	$213,000		37,123	8%	100%	$5.74		174	12%	100%	$1,224
Option 4			**High***	**194,734**	**289,256**	**60%**		**High**	**196**	**1,269**	**87%**		**High**
Rainwater harvesting for toillets	31,800 gal storage	20% of roof	--		78,913	16%	83%	--		163	11%	100%	--
Biofiltration	9,300 ft^2	80% of roof, parking & drive	$139,500		173,220	36%	48%	$0.84		932	64%	91%	$150
Permeable pavers	21,300 ft^2	Sidewalks	$213,000		37,123	8%	9%	$5.74		174	12%	100%	$1,224

Notes

* Site-specific costs include cisterns, pumps, disinfection, and additional distribution plumbing

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3.7 Near East Athletic Fields

Description

The area considered in the near east Athletic Fields analysis includes the footprint of the proposed synthetic turf fields, the north half of Observatory Drive adjacent to the fields , and the west half of Elm Drive adjacent to the fields (**Figure 3-9**). Underground storage and street sweeping were among the BMPs considered in the analysis. **Tables 3-9** and **3-10** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-9. Near East Athletic Fields analysis area boundary.

Table 3-9. Source areas for proposed conditions

Source type	Area (ac)
Fields	
Grass	4.02
Sidewalks	0.06
Observatory Drive (north half)	
Street	0.20
Sidewalk	0.14
Landscaped	0.12
Elm Drive (west half)	
Street	0.10
Sidewalk	0.05
Landscaped	0.15
Total	4.84

Observations

- A pretreatment basin was modeled to provide TSS removal of the influent flows. The basin was modeled with an initial water surface 3 feet above the bottom of the basin and a bottom footprint of approximately 0.2 acres. Pretreatment could be accomplished via underground sediment tanks or other treatment designs provided that the design maintains the initial water surface elevation and storage volume described above.
- Though a 24-inch underground gravel storage layer is required to be considered pervious per City of Madison, a 6-inch layer is adequate to treat stormwater from the field and adjacent roads and generate no runoff for the 1981 annual rainfall series.
- If a 24-inch thick gravel layer is required, the fields could potentially treat as many as 10 acres of additional impervious area without generating runoff for the 1981 rainfall series.
- Treatment of the adjacent portions of Observatory Drive and Elm Drive could be accomplished via surface flow through curb cuts. This approach would require replacement of some sidewalk areas to allow stormwater to pass underneath the sidewalk and into the proposed treatment system

Table 3-10. BMP performance summary for the near east athletic fields.

	Control practices			Runoff					TSS				
Scenario	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls (existing conditions)				77,770					1,050				
Native conditions				38,652	39,118	50%							
Option 1			**$139,440**	**0**	**77,770**	**100%**		**$1.79**	**0**	**1,050**	**100%**		**$133**
6" gravel subsurface storage & infiltration	0.2 ac pretreatment & 3.8 ac infiltration	Athletic fields, Observatory Dr. & Elm Dr.	$139,440		77,770	100%	100%	$1.79		1,050	100%	100%	$133
Option 2			**$139,440**	**41,426**	**36,344**	**47%**		**$3.84**	**438**	**612**	**58%**		**$228**
Street sweeping	--	Streets			0	0%	0%			142	14%	41%	--
6" gravel subsurface storage & infiltration	0.2 ac pretreatment & 3.8 ac infiltration	Athletic fields & adjacent sidewalks	$139,440		36,344	47%	100%	$3.84		470	45%	100%	$297

Notes

No controls represented by existing conditions in this case. The proposed artificial turf has controls built-in, and WinSLAMM does not simulate artificial turf.

A 24-in-thick gravel layer would have capacity to capture and infiltrate runoff from approximately an additional 10 acres.

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3.8 Observatory Drive

Description

The area considered in the Observatory Drive analysis includes the Observatory Drive pavement surface and terraces. The analysis area was bounded to the east by the Near East Playing Fields and to the west by Willow Creek (**Figure 3-10**). Biofilters, street sweeping and permeable pavement were among the BMPs considered in the analysis. **Tables 3-11** and **3-12** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-10. Observatory Drive analysis area boundary.

Table 3-11. Source areas for proposed conditions

Source type	Area (ac)
Street	0.54
Sidewalks	0.40
Driveways	0.02
Landscaped	0.32
Total	1.28

Observations

- Implementing biofilters in the street terrace appears to be possible with minimal utility conflicts.
- Conveyance from Observatory Drive to treatment systems placed in other analysis areas (i.e the Natatorium) may be feasible as well.

Table 3-12. BMP performance summary for Observatory Drive.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				80,531					1,322				
Native conditions				10,222	70,309	87%							
Option 1			**$82,000**	**38,381**	**42,150**	**52%**		**$1.95**	**191**	**1,131**	**86%**		**$73**
Street sweeping	--	Street			0	0%	0%			273	21%	24%	
Biofiltration	4,100 ft^2	Street	$82,000		42,150	52%	90%	$1.95		858	65%	99%	$96
Option 2			**$82,000**	**24,501**	**56,030**	**70%**		**$1.46**	**104**	**1,218**	**92%**		**$67**
Street sweeping	--	Street			0	0%	0%			273	21%	24%	
Biofiltration	4,100 ft^2	Street & sidewalks	$82,000		56,030	70%	71%	$1.46		945	72%	94%	$87
Option 2			**$256,000**	**6,489**	**74,042**	**92%**		**$3.46**	**42**	**1,280**	**97%**		**$200**
Street sweeping	--	Street			0	0%	0%			273	21%	24%	--
Biofiltration	4,100 ft^2	Street	$82,000		43,678	52%	87%	$1.88		865	65%	95%	$95
Permeable pavers	17,400 ft^2	Sidewalks	$174,000		30,364	38%	100%	$5.73		142	11%	100%	$1,225

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3.9 Veterinary Medicine

Description

The area considered in the Veterinary Medicine analysis includes the proposed Veterinary Medicine building addition and courtyards, sidewalks to the west of the building, and parking area near Willow Creek (**Figure 3-11)**. Biofilters, permeable pavement, green roofs and rainwater harvesting were among the BMPs considered in the analysis. **Tables 3-13** and **3-14** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-11. Veterinary Medicine analysis area boundary.

Table 3-13. Source areas for proposed conditions

Source type	Area (ac)
Roof	1.22
Sidewalks	0.35
Driveways	0.07
Landscaped	0.86
Total	2.50

Observations

- The proposed conceptual plan indicates that the Veterinary Medicine site has ample greenspace to fit biofilters of sufficient size to treat the impervious surfaces within the analysis area.
- Rooftops are the single largest contributor of TSS loading within the analysis area.
- Rainwater harvesting for use inside the building provides a substantially higher stormwater volume reduction that does harvesting for irrigation.

Table 3-14. BMP performance summary for the Veterinary Medicine building.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				150,039					489				
Native conditions				19,981	130,058	87%							
Option 1			**$133,500**	**33,331**	**116,708**	**78%**		**$1.14**	**159**	**330**	**67%**		**$405**
Biofiltration	8,900 ft^2	Roof, parking & sidewalks	$133,500		116,708	78%	78%	$1.14		330	67%	67%	$405
Option 2			**$283,500**	**18,598**	**131,441**	**88%**		**$2.16**	**51**	**377**	**77%**		**$752**
Permeable pavers	15,000 ft^2	Sidewalks	$150,000		29,170	19%	100%	$5.14		137	28%	100%	$1,098
Biofiltration	8,900 ft^2	Roof & parking	$133,500		102,271	68%	89%	$1.31		240	49%	88%	$556
Option 3			**$984,700**	**83,917**	**66,122**	**44%**		**$14.89**	**306**	**183**	**37%**		**$5,381**
4-in green roof	1.2 ac	Entire roof	$851,200		31,236	21%	29%	$27.25		0	0%	0%	--
Biofiltration	8,900 ft^2	Parking & sidewalks	$133,500		34,886	23%	100%	$3.83		183	37%	100%	$730
Option 4			**High***	**25,876**	**124,163**	**83%**		**High**	**147**	**342**	**70%**		**High**
Rainwater harvesting for toilets	6,400 gal storage	30% of roof	--		24,117	16%	82%	--		37	8%	100%	--
Biofiltration	8,900 ft^2	70% of roof, parking & sidewalks	$133,500		100,046	67%	89%	$1.33		305	62%	89%	$438
Option 5			**High***	**39,465**	**110,574**	**74%**		**High**	**117**	**372**	**76%**		**High**
Rainwater harvesting for irrigation	6,400 gal storage	30% of roof	--		10,528	7%	36%	--		67	14%	100%	--
Biofiltration	8,900 ft^2	70% of roof, parking & sidewalks	$133,500		100,046	67%	89%	$1.33		305	62%	89%	$438

Notes
* Site-specific costs include cisterns, pumps, disinfection, and additional distribution plumbing

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3.10 Parking Ramp

Description

The area considered in the Parking Ramp analysis includes the parking ramp pavement surface, access drives, and adjacent sidewalks (**Figure 3-12)**. Biofilters, street sweeping, permeable pavement and underground storage were among the BMPs considered in the analysis. **Tables 3-15** and **3-16** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-12. Parking Ramp analysis area boundary.

Table 3-15. Source areas for proposed conditions

Source type	Area (ac)
Parking	0.96
Sidewalks	0.06
Driveways	0.11
Street	0.15
Landscaped	0.45
Total	1.73

Observations

- Sweeping of the parking lot cannot be simulated with WinSLAMM 10.2.1. Sweeping efficiency was estimated to be 24%, because UW staff indicated that the ramp is cleaned with a recirculating, pressure treated vacuum sweeper with comparable efficiency as equipment used to clean the streets. Street sweeping would remove approximately 229 lbs. of TSS per year from the parking ramp, driveway and part of the adjacent street.
- Sweeping the parking lot would likely cause a modest increase to the efficiency of the BMPs shown in Table 3-14.
- The conceptual plan indicates that there is greenspace to the south of the parking ramp. This space could be used to implement biofilter treatment systems.
- Underground storage was assumed to be pipe arches with gravel backfill. The media was assigned an average depth of 2 feet. Other underground storage types could also be used.
- A pretreatment wet detention was included in the model to provide sediment removal and prevent clogging of the storage areas. The pretreatment basin was modeled with an initial water surface 3 feet above the bottom of the basin and a bottom footprint of approximately 0.2 acres. Pretreatment could be accomplished via underground sediment tanks or other treatment designs provided that the design maintains the initial water surface elevation and storage volume described above.
- A low level outlet (used for maintenance of the system) could be designed to drain to Willow Creek with a slope of 1-2%. For normal operation, an overflow outlet should be positioned near the top of the system to maximize the storage the system can provide.
- The footprint required to treat the site is less than the footprint of the proposed parking ramp. Thus, the storage layer could be increased to provide treatment for runoff from adjacent sites (Section 3.12 evaluates using the parking ramp storage to treat the Meat Sciences building roof).

Table 3-16. BMP performance summary for the parking ramp.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				112,214					1,020				
Native conditions				10,222	101,992	91%							
Option 1			**$90,000**	**25,810**	**86,404**	**77%**		**$1.04**	**205**	**816**	**80%**		**$110**
Street sweeping	--	Parking & street	--		0	0%	0%	--		229	22%	24%	--
Biofiltration	6,000 ft^2	Parking, street, driveway & sidewalk	$90,000		86,404	77%	77%	$1.04		586	57%	74%	$154
Option 2			**$115,000**	**22,652**	**89,562**	**80%**		**$1.28**	**183**	**837**	**82%**		**$137**
Street sweeping	--	Parking & street	--		0	0%	0%	--		229	22%	24%	--
Permeable pavers	2,500 ft^2	Sidewalks	$25,000		4,875	4%	100%	$5.13		23	2%	100%	$1,095
Biofiltration	6,000 ft^2	Parking, street, driveway & sidewalk underdrains	$90,000		84,687	75%	79%	$1.06		585	57%	62%	$154
Option 3			**$327,000**	**0**	**109,240**	**97%**		**$2.99**	**42**	**978**	**96%**		**$334**
Street sweeping	--	Parking & street	--		0	0%	0%	--		229	22%	24%	--
Underground infiltration	0.2 acre pretreatment and 0.2 acre storage	Parking, street, driveways & sidewalks	$327,000		109,240	97%	100%			749	73%	77%	$437

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3.11 Meat Sciences

Description

The area considered in the Meat Sciences analysis includes the Meat Science building footprint and adjacent sidewalk (**Figure 3-10)**. The driveway and loading dock to the east of the site were omitted from the model. However, output from analysis conducted by Graef to aid the design of an underground sediment tank was incorporated into calculations to determine the overall TSS reduction of the site. Thus, the loading dock and driveway were accounted for in the results, but do not appear in the models MARS prepared for the analysis area. Permeable pavement was considered in addition to the proposed sediment tank. **Tables 3-17** and **3-18** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-13. Meat Science analysis area boundary.

Table 3-17. Source areas for proposed conditions

Source type	Area (ac)
Parking	0.91
Sidewalks	0.19
Landscaped	0.17
Total	1.27

Observations

- The sediment tank designed by Graef provides significant TSS treatment but does not provide runoff volume reduction.
- Permeable pavement provides limited effectiveness to the analysis area due to the limited sidewalk coverage within the analysis area.
- Permeable pavement provides 100% efficiency in treating rainfall that falls on the sidewalk.
- The largest TSS source in the analysis area is the rooftop.

Table 3-18. BMP performance summary for the Meat Sciences building.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				131,757					490				
Native conditions				13,209	118,548	90%							
Option 1			--	**130,650**	**0**	**0%**		--	**45**	**189**	**39%**		--
Underground settling tank *	--	Driveway east of Meat Sciences			0	0%	0%			189	39%	81%	
Option 2			--	**115,873**	**15,884**	**12%**		--	**227**	**263**	**54%**		--
Underground settling tank *	--	Driveway east of Meat Sciences	--		0	0%	0%			189	39%	89%	--
Permeable pavers	2,500 ft^2	Sidewalks	$83,000		15,884	12%	100%	$5.23		74	15%	100%	$1,116

Notes

* Underground settling tank performance per calculations provided by Graef.

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3.12 Combined Parking Ramp and Meat Sciences Treatment

Description

MARS analyzed the plausibility of using treatment systems within the parking ramp analysis area to treat runoff from the Meat Sciences building. The area considered in this combined analysis included the Parking Ramp and Meat Sciences analysis areas described above (F**igure 3-14)**. Biofilters, street sweeping and permeable pavement were among the BMPs considered in the analysis. **Tables 3-19** and **3-20** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-14. Combined Meat Sciences and Parking Ramp site boundary.

Table 3-19. Source areas for proposed conditions

Source type	Area (ac)
Roof	0.91
Parking	0.96
Sidewalks	0.25
Driveways	0.11
Street	0.15
Landscaped	0.62
Total	3.00

Observations

- To prevent clogging, a wet detention basin was modeled to provide pretreatment of the influent flows. The basin design was identical to the design described for the parking ramp pretreatment system.
- It does not appear feasible to pass stormwater from the Meat Sciences building to the proposed biofilters south of the parking ramp due to utility conflicts and shallow grades.
- An additional 0.2 acres of storage area with properties described in the Parking Ramp analysis is required to treat stormwater from the Meat Sciences building rooftop. Treating a portion of the rooftop would require a smaller storage area increase.

Table 3-20. BMP performance summary for the parking ramp and Meat Sciences building combined.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				243,972					1,510				
Native conditions				10,222	233,750	96%							
Option 1			--	**53,987**	**189,985**	**78%**		--	**-43**	**1,552**	**103%**		--
Street Sweeping	--	Parking & street	--		0	0%	0%	--		229	22%		--
Meat Sciences settling tank	--	Driveway east of Meat Sciences	--		0	0%	0%	--		189	13%	81%	--
Underground infiltration below parking ramp	0.2 acre pretreatment and 0.4 acre storage	Meat Sciences rooftop and parking ramp	$458,000		189,985	78%	100%	$2.41		1,134	75%	100%	$403.88

Notes

* Underground settling tank performance per calculations provided by Graef.

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3.13 Linden Drive

Description

The area considered in the Linden Drive analysis extends from the west side of the Veterinary Medicine building to the east side of the Meat Sciences building. It includes the Linden Drive pavement surface and terraces, courtyards and rooftop from the Veterinary Medicine building expansion, and parking to the west of the Veterinary Medicine building expansion. The analysis area was bounded to the east by the eastern edge of the Meat Sciences analysis area and to the west by Willow Creek (**Figure 3-15)**. Street sweeping, proprietary hydrodynamic devices and permeable pavement were among the BMPs considered in the analysis. **Tables 3-21** and **3-22** detail the land areas used in the analysis along with BMP performance, efficiency, and cost information for various BMP arrangements.

Figure 3-15. Linden Drive site boundary.

Table 3-21. Source areas for proposed conditions

Source type	Area (ac)
Roof	0.05
Parking	0.13
Sidewalks	0.27
Driveways	0.06
Street	0.45
Landscaped	0.11
Total	1.06

Observations

- Passing stormwater from Linden Drive to other analysis areas appears unfeasible due to shallow grades and utility conflicts.
- Permeable pavement offers modest stormwater treatment benefits due to limited coverage within the analysis area.

Table 3-22. BMP performance summary for Linden Drive.

Scenario	Control practices			Runoff					TSS				
	Size	Source areas treated	Capital cost	Total analysis area runoff volume (ft^3)	Runoff volume reduction (ft^3)	Runoff volume reduction (%)	Individual BMP efficiency for source area runoff (%)	BMP cost / ft^3	TSS load from analysis area (lb)	TSS load reduction (lb)	TSS load reduction (%)	Individual BMP efficiency for source area TSS (%)	BMP cost / lb TSS removed
No controls				78,369					993				
Native conditions				8,834	69,535	89%							
Option 1			--	**58,253**	**20,116**	**26%**		--	**717**	**276**	**28%**		--
Street sweeping	--	Driveway east of Meat Sciences	--		0	0%	0%			182	18%	24%	--
Permeable pavement	11,600 ft^2	Sidewalks	$116,000		20,116	26%	100%	$5.77		94	9%	100%	$1,232
Option 2			--	**78,369**	**0**	**0%**		--	**695**	**299**	**30%**		--
Street sweeping	--	Driveway east of Meat Sciences	--		0	0%	0%	--		182	18%	24%	--
Hydrodynamic devices	2 ea	Sidewalks	$40,000		0	0%	0%	--		117	12%	20%	$342

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3.14 Peak Discharge Performance

Peak discharges from the study area were analyzed for existing conditions, proposed conditions without controls, and proposed conditions with controls. The proposed condition with controls evaluated the peak discharge performance of biofiltration BMPs as described in the analysis above. The 24-inch underground storage layer for the Near East fields is also included in the analysis. The peak discharge rates are shown for the 1-, 2-, 10- and 100-year events in **Table 3-22**. The BMPs presented above provide significant peak flow attenuation and meet the Wisconsin Division of State Facilities' Sustainable Facilities Standards for peak discharge.

Table 3-22. Summary of peak flow rates.

Recurrence interval	Peak flows (cfs)		
	Existing	Proposed with no controls	Proposed with controls
1-year	33.88	42.76	11.74
2-year	41.08	50.21	20.35
10-year	67.18	76.07	44.64
100-year	125.31	131.07	95.94

4 Conclusions and Recommendations

We performed this analysis to evaluate the feasibility of regional stormwater management within the study area and to evaluate a range of BMPs to provide runoff reduction and sediment discharge reduction. The analysis describes the effectiveness of various BMPs on a functional level but does not go to the detail of a design-level analysis. The results and conclusions of this study could be applicable to other areas on campus. This is particularly true in areas with similar land use characteristics, soil properties, and groundwater environment. Increased soil permeability and/or increased depth to groundwater would provide performance increases for BMPs that rely on infiltration.

This conceptual stormwater plan analysis has the following general conclusions:

1. The native conditions runoff objective is very challenging to meet.
2. Nonetheless, even with the challenging soil and ground conditions, significant progress toward this objective is possible.
3. Due to utility conflicts and existing grades, there appears to be no feasible location for a regional stormwater management practice to treat runoff from the entire study area.
4. Biofilters are the most cost effective runoff volume and TSS control practice where there is available land. Where land is too valuable for buildings or other facilities, and in areas where grades and existing utilities do not allow convenient conveyance to treatment systems, practices such as green roofs and permeable pavement become more viable.
5. Infiltration performance may vary significantly within the study area due to differing soil conditions and may vary through time due to differing groundwater conditions.
6. BMPs presented in this report require proper construction and diligent maintenance to provide the anticipated stormwater management benefits.
7. All infiltration-based BMPs are very likely to require underdrains.

Considering the constraints of the study area, such as groundwater conditions, soil characteristics and existing grades, we have the following recommendations:

1. Consider the range of options presented when individual buildings are designed.
2. Design infiltration practices with underdrains and storage layers that are based on location-specific soils investigation.
3. Where space allows, install biofilters to treat stormwater runoff.
4. Consider water reuse due to its significant benefits for runoff reduction and reducing potable water supply groundwater pumping.
5. Continue to monitor water levels in the 8 monitoring wells in the neighborhood. Options include periodic manual measurements (e.g. quarterly) with an electronic water level indicator tape, or instrumenting the wells with continuously recording pressure transducers.

5 References

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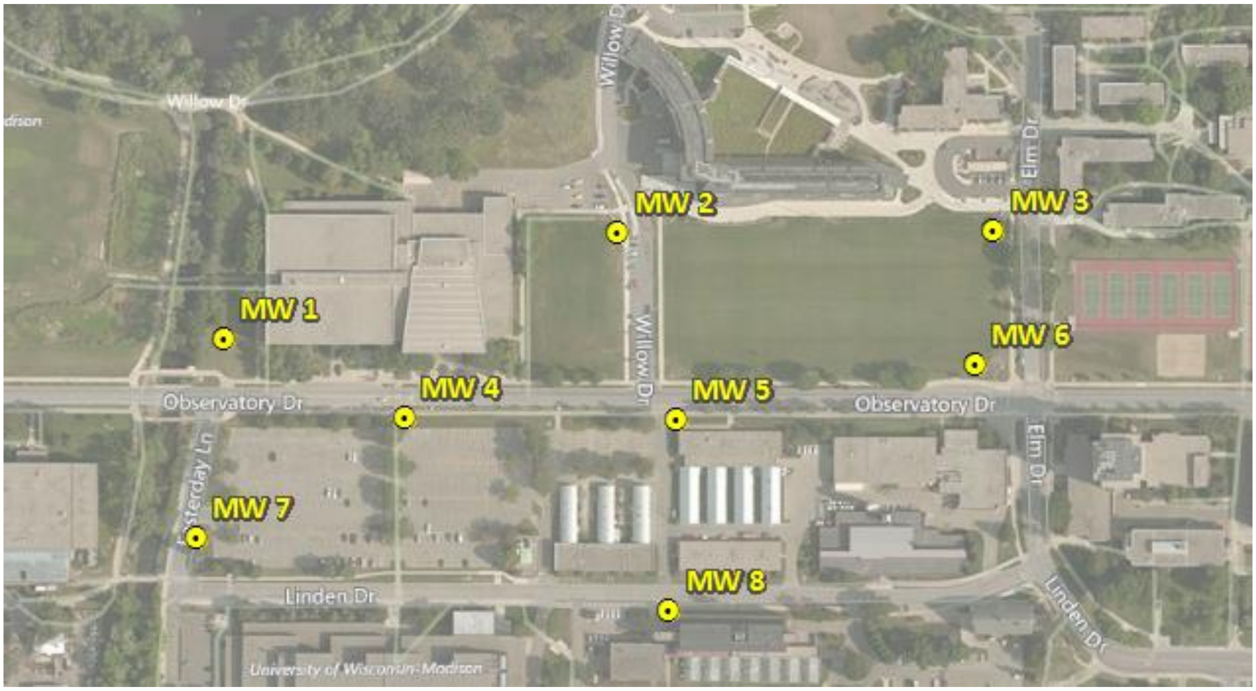
Appendix A – Soil Boring Logs



Soil boring locations. (Not to scale.)

SOIL BORING LOG: MW-1

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)		VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 855.3	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
		0-9" topsoil 9-12" brown fine to medium sand 12-40" brown clay; gravel inclusions at 30"; redox at 20" 40-52" tan sandy clay	1	5	4.3	0	5	
1	854.3							
2	853.3							
3	852.3							
4	851.3							
5	**850.3**	0-9" tan sandy clay w/ fine sand seam and gravel inclusions 9-13" grey to black clay 13-16" grey clay w/ organics, weathered sand, and gravel inclusions	2	5	1.3	5	10	
6	849.3							
7	848.3							
8	847.3							
9	846.3							
10	**845.3**	0-6" black clay; wet at 1" 6-11" grey clay 11-15" brown silty clay with fine sand and organics 15-19"brown clay 19-28" grey silt and fine sand with gravel inclusions 28-58" grey to brown silt with clay seams	3	5	4.8	10	15	
11	844.3							
12	843.3							
13	842.3							
14	841.3							
15	**840.3**	0-6" brown silt 6-28" brown silt with clay seams 28-48" brown clay 48-57" brown silty fine sand 57-58" brown clay	4	5	4.8	15	20	
16	839.3							
17	838.3							
18	837.3							
19	836.3							
20	**835.3**							

End of Boring: 20'

Notes:

Depth of well 19.49'
N: 43.07678 W: 89.42125
screened 5-20'

Water Level / Caving Observations:

Water Level During Drilling: 7.17 V
Water Level Upon Completion: ± ft (El. 855.27±) V
Caved at Upon Completion: ± ft (El. 855.27±)

Additional Comments:

Boring Location Offset:

*Lines of demarcation represent **approximate** boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

Montgomery Associates
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SOIL BORING LOG: MW-2

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)		VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 860.3	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
		0-15" topsoil w/ blended clays. Clay content increases with depth, angular materials in top 8" 15-23" brown fine to medium sand 23-27" tan medium sand 27-30" silty sand w/ coarse inclusions 30-33" greyish dark brown silty clay	1	5	2.8	0	5	
1	859.3							
2	858.3							
3	857.3							
4	856.3							
5	**855.3**							
		0-8" greyish brown silty clay w/ silt inclusions 8-12" tan fine to medium sand, perched water at 12" 12-20" brown silty fine sand w/ clay seams 20-29" reddish brown silty fine sand 29-30" brown fine to medium sand	2	5	2.5	5	10	
6	854.3							
7	853.3							
8	852.3							
9	851.3							
10	**850.3**							
		0-10" brown fine to medium sand w/ silty inclusions 10-15" dark brown clay 15-26" reddish fine to medium sand 26-48" light brown fine to medium sand, coarser w/ depth	3	5	4.0	10	15	
11	849.3							
12	848.3							
13	847.3							
14	846.3							
15	**845.3**							
		0-12" light brown fine sand 12-33" light brown fine to medium sand 33-45" reddish brown fine to medium sand 45-48" tan silty clay with coarse inclusions	4	5	4.8	15	20	
16	844.3							
17	843.3							
18	842.3							
19	841.3							
20	**840.3**							

End of Boring: 20'

Notes:

Depth of well 18.92'
N: 43.07728 W: 89.41864
screened 4.5-19.5'

Water Level / Caving Observations:

Water Level During Drilling: 12.62 ▽
Water Level Upon Completion: ± ft (El. 860.33±) ▽
Caved at Upon Completion: ± ft (El. 860.33±)

Additional Comments:

Boring Location Offset:

Lines of demarcation represent ***approximate*** *boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

SOIL BORING LOG: MW-3

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)		VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 859.8	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
1 2 3 4 **5**	858.8 857.8 856.8 855.8 **854.8**	0-2" red silty clay and fine sand 2-17" brown silty clay with fine sand seams and gravel inclusions 17-25" greyish brown silty fine sand 25-30" dark brown clay with silt and fine sand seams	1	5	2.5	0	5	
6 7 8 9 **10**	853.8 852.8 851.8 850.8 **849.8**	0-14" dark brown clay with silt and fine sand seams 14-24" greyish brown clay 24-45" light brown silty fine sand; redox features at 38-40" 45-48" grey silty fine sand 49-58" tan silt	2	5	4.8	5	10	
11 12 13 14 **15**	848.8 847.8 846.8 845.8 **844.8**	0-6" brown silty clay 6-24" tan silty fine sand; wet at 19" 15-26" reddish fine to medium sand 24-30" tan silty clay 30-31" red fine sand 31-33" grey medium sand 34-51" tan silty clay	3	5	4.3	10	15	
16 17 18 19 **20**	843.8 842.8 841.8 840.8 **839.8**	0-12" tan silty clay 12-22" tan silty fine sand 22-25" red fine to medium sand 25-58" grey tan silty clay 58-60" brown fine to medium sand	4	5	4.8	15	20	

End of Boring: 20'

Notes:

Depth of well 16.40'
N: 43.07728 W: 89.41616
screened 2.5-17.5'

Water Level / Caving Observations:

Water Level During Drilling: 14.22 v
Water Level Upon Completion: ± ft (El. 859.76±) v
Caved at Upon Completion: ± ft (El. 859.76±)

Additional Comments:

Boring Location Offset:

*Lines of demarcation represent **approximate** boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

SOIL BORING LOG: MW-4

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)	VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 856.7	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
1 855.7 2 854.7 3 853.7 4 852.7 **5 851.7**	0-16" brown medium sand with gravel inclusions 16-24" brown clay with fine sand and silt inclusions 24-28" dark brown clay 28-30" brown fine to medium sand 30-40" brown clay with fine snad seams and gravel inclusions 40-46" black clay	1	5	3.8	0	5	
6 850.7 7 849.7 8 848.7 9 847.7 **10 846.7**	0-7" light brown silty sand with gravel inclusions 7-12" brown silty clay 12-18" dark brown clay 18-24" grey clay 24-31" tan fine to medium sand; red stains 27-31"; wet at 27" 31-48" light brown silty fine sand 48-52" light brown silty fine sand with clay seams	2	5	4.3	5	10	
11 845.7 12 844.7 13 843.7 14 842.7 **15 841.7**	0-3" light brown silty sand 3-10" red fine to medium sand with gravel inclusions 10-38" light brown silty clay; clay content increase w/ depth 38-43" light brown silty fine sand 43-58" light brown silty fine sand with gravel inclusions	3	5	4.8	10	15	
16 840.7 17 839.7 18 838.7 19 837.7 **20 836.7**	0-10" light brown silty clay 10-56" light brown to grey silt w/ clay seams and gravel inclusions 56-58" brown fine to medium sand	4	5	4.8	15	20	

End of Boring: 20'

Notes:

Depth of well 19.66'
N: 43.07639 W: 89.42006
screened 3-18'

Water Level / Caving Observations:

Water Level During Drilling: 8.65 V
Water Level Upon Completion: ± ft (El. 856.66±) V
Caved at Upon Completion: ± ft (El. 856.66±)

Additional Comments:

Boring Location Offset:

*Lines of demarcation represent **approximate** boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

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SOIL BORING LOG: MW-5

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)	VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 859.8	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
1 858.8 2 857.8 3 856.8 4 855.8 5 854.8	0-18" brown silty loam 18-24" black to brown silt with red stains 24-29" brown silt with fine sand 29-35" dark brown clay 35-42" light brown clay	1	5	3.5	0	5	
6 853.8 7 852.8 8 851.8 9 850.8 10 849.8	0-4" light brown clay with gravel inclusions 4-16" dark to light brown silt w/ clay and fine sand 16-17" grey to light brown silty clay and fine sand 17-31" red to tan fine sand with coarser inclusions 31-50" tan silty fine sand; wet at 31"	2	5	4.8	5	10	
11 848.8 12 847.8 13 846.8 14 845.8 15 844.8	0-5" brown silty clay 5-13" light brown silty fine sand with clay seams 13-15" light brown clayey silt 21-30" tan silt with clay seams 30-36" tan silty fine to medium sand 36-39" tan silty clay	3	5	3.3	10	15	
16 843.8 17 842.8 18 841.8 19 840.8 20 839.8		4	5		15	20	

End of Boring: 13' due to auger refusal

Notes:

Depth of well 12.15'
N: 43.07637 W: 89.41827
screened 3-13'

Water Level / Caving Observations:

Water Level During Drilling: 11.42 V
Water Level Upon Completion: ± ft (El. 859.81±) V
Caved at Upon Completion: ± ft (El. 859.81±)

Additional Comments:

Boring Location Offset:

*Lines of demarcation represent **approximate** boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

Montgomery Associates
Resource Solutions, LLC

SOIL BORING LOG: MW-6

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)		VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 858.5	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
0–5	858.5–853.5	0-6" grey clay with loam inclusions 6-14" brown silty fine sand w/ gravel inclusions 14-21" tan fine sand 21-24" brown clay 24-29" light brown fine to medium sand	1	5	2.4	0	5	
5–10	853.5–848.5	0-10" light brown fine to medium sand 10-26" light brown silty fine sand 26-34" light brown sandy silt; wet at 29"	2	5	2.8	5	10	
10–15	848.5–843.5	0-42" light brown sandy silt; clay seams 24-42", wet at 21" 42-51" light brown fine to medium sand with silt seams 51-57" light brown silt w/ clay and fine sand seams	3	5	4.8	10	15	
15–20	843.5–838.5	0-15" light brown silty fine sand 15-54" red to brown fine to medium sand with gravel inclusions; bedrock suspected at 48"	4	5	4.5	15	20	

1	857.5
2	856.5
3	855.5
4	854.5
5	**853.5**
6	852.5
7	851.5
8	850.5
9	849.5
10	**848.5**
11	847.5
12	846.5
13	845.5
14	844.5
15	**843.5**
16	842.5
17	841.5
18	840.5
19	839.5
20	**838.5**

End of Boring: 20'

Notes:

Depth of well 18.89'

N: 43.07663 W: 89.41629

Water Level / Caving Observations:

Water Level $_{\text{During Drilling}}$: 10.51 ▽
Water Level $_{\text{Upon Completion}}$: ± ft (El. 858.47±) ▽
Caved at $_{\text{Upon Completion}}$: ± ft (El. 858.47±)

Additional Comments:

Boring Location Offset:

Lines of demarcation represent ***approximate*** *boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

Montgomery Associates
Resource Solutions, LLC

SOIL BORING LOG: MW-7

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)		VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 855.9	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
		0-9" dark brown topsoil 9-15" brown silt w/ sand seams 15-44" brown clay with fine sand seams 44-48" black clay with fine sand seams	1	5	4.0	0	5	
1	854.9							
2	853.9							
3	852.9							
4	851.9							
5	**850.9**	0-8" black clay w/ fine sand seams 8-40" light brown to black clay w/ silt and sand seams 40-48" brown clay w/ gravel inclusions and silt seams	2	5	4.0	5	10	
6	849.9							
7	848.9							
8	847.9							
9	846.9							
10	**845.9**	0-2" lbrown clay w/ gravel inclusions and silt seams 2-15" brown silt w/ grey clay seams 15-24" light brown fine sand 24-27" light brown clay 27-52" light brown fine to medium sand with silt seams	3	5	4.3	10	15	
11	844.9							
12	843.9							
13	842.9							
14	841.9							
15	**840.9**	0-14" light brown silty fine sand 14-28" brownclay with red sand seams 28-35" light brown fine sand w/ silt seams; red stains at 34" 35-58"tan clay	4	5	4.7	15	20	
16	839.9							
17	838.9							
18	837.9							
19	836.9							
20	**835.9**							

End of Boring: 20'

Notes:

Depth of well 19.60'
N: 43.07582 W: 89.42144
well screened 6-20'

Water Level / Caving Observations:

Water Level During Drilling: 6.33 v
Water Level Upon Completion: ± ft (El. 855.91±) v
Caved at Upon Completion: ± ft (El. 855.91±)

Additional Comments:

Boring Location Offset:

*Lines of demarcation represent **approximate** boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*

Montgomery Associates
Resource Solutions, LLC

SOIL BORING LOG: MW-8

Project: UW-Madison Near West Neighborhood Stormwater
Project No.: 1709
Location: Observatory Drive
Madison, WI

Drill Date: May 2, 2016
Drilled by: Onsite Environmental
Logged by: Dane Wudel
Sampling Method: Geoprobe 1" cores

Depth Below Surface (ft)		VISUAL SOIL CLASSIFICATION Ground Surface Elevation: 860.8	Sample No.	Feet Driven	Feet Recovered	Sample Top	Sample Bottom	Remarks
		0-12" light brown fine sand with silt seams 12-17" light brown silt w/ fine sand seams 17-18" black coarse sand, angular grains 18-22" light brown silty fine sand 22-25" dark brown silty clay	1	5	2.1	0	5	
1	859.8							
2	858.8							
3	857.8							
4	856.8							
5	**855.8**	0-8" brown silt w/ rounded gravel inclusions 8-21" brown fine sand 21-25" brown silty fine sand, some larger grains 25-33" reddish tan fine to medium sand 33-40" reddish tan fine sand with rounded gravel inclusions	2	5	2.5	5	10	
6	854.8							
7	853.8							
8	852.8							
9	851.8							
10	**850.8**	--	3	5	4.0	10	15	
11	849.8							
12	848.8							
13	847.8							
14	846.8							
15	**845.8**	--	4	5	4.8	15	20	
16	844.8							
17	843.8							
18	842.8							
19	841.8							
20	**840.8**							

End of Boring: 9.08' encountered bedrock

Notes:

Depth of well 9.08'

N: 43.07545 W: 89.41832

Water Level / Caving Observations:

Water Level $_{\text{During Drilling}}$: NONE ENCOUNTERED ∇
Water Level $_{\text{Upon Completion}}$: ± ft (El. 860.8±) ∇
Caved at $_{\text{Upon Completion}}$: ± ft (El. 860.8±)

Additional Comments:

Boring Location Offset:

Lines of demarcation represent ***approximate*** *boundaries between soil types. Variations may occur between sampling intervals and between boring locations, and the transition may be gradual.*