Protocol for Ensuring the Continued Performance of Infiltration Practices in the City of Middleton, Wisconsin

Prepared for the City of Middleton

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1. Introduction

Infiltration practices mitigate increases in stormwater runoff volumes from developed areas and promote groundwater recharge. In recent years they have become an important element of stormwater management. The state of Wisconsin, Under NR 151, mandates the use of infiltration practices in new development and redevelopment.

While the use of infiltration practices has been required, implementation has proven to be challenging. Two years after the state of Maryland enacted a law requiring the use of infiltration practice, only 48% of the facilities were found to be functioning as designed; six years afterward, the percentage dropped to 38% (Lindsey, Roberts, and Page, 1992). In Dane County, Wisconsin, the Conservation Department found that about half of the recently completed, small-scale infiltration facilities had failed (Personal discussion with Jeremy Balousek, 2006).

Clearly, there is a need to improve the performance of infiltration practices. This project was intended to address this need. The objectives were to

- Develop and demonstrate methods for assessing the performance of infiltration practices.
- Use these methods to determine the most common causes of failure of a sample of infiltration practices in and near Middleton, WI
- Develop protocols for assessing infiltration practices during installation, immediately after installation, and over the life of the practice.
- Make recommendations for avoiding common causes of failure and for remediation.
- Make recommendations regarding regulatory requirements ensuring that infiltration practices function properly.

Many infiltration practices meet infiltration, groundwater recharge, and water quality objectives. This report strictly focuses on infiltration and groundwater recharge.

The report begins with background about various types of infiltration practices, factors that affect their performance, and indicators of a healthy practice. It then presents the case studies conducted in this investigation. The report concludes with a formal protocol for evaluating the actual performance of an infiltration practice. Development of this protocol was informed by case studies of existing practices. Appendices include a summary of state, county, and city infiltration regulations, details about the specific methods used in testing the practices and a user-defined precipitation text file for the RECARGA model.

2. Background

In this chapter, the types of infiltration practices addressed in this study, factors that affect the performance of these infiltration practices, and standard indicators of successful practices are discussed.

2.1 Types of Infiltration Practices Covered Here

While there are many types of infiltration practices, this research focused on three that are in common use in the Middleton area. They are, in order from largest to smallest, infiltration basins, bioretention facilities, and rain gardens.

Infiltration Basins

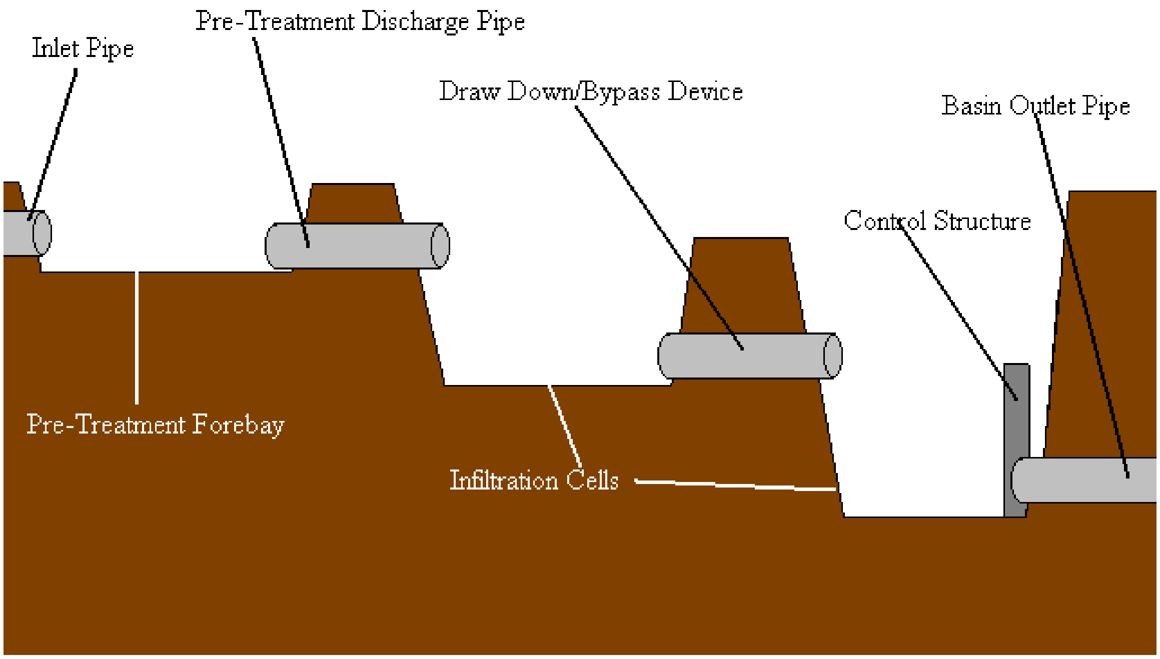

FIGURE 2.1: ELEMENTS OF AN INFILTRATION BASIN (NOT DRAWN TO SCALE)

The oldest type of infiltration practice is the infiltration basin. In the U.S. infiltration basins were first extensively used on Long Island (Aronson & Seaburn, 1974). Infiltration basins have developed as an extension of detention basins. While a detention basin holds onto runoff until it can be released downstream, an infiltration basin, located on naturally highly-permeable soil, allows the runoff to infiltrate into the ground and recharge the water table.

These basins typically have large tributary areas, between 5 and 50 acres. A pretreatment forebay allows sediment to drop out of the runoff before entering the infiltration basin proper. Multiple infiltration cells are sometimes used to prevent channelized flow. (*Infiltration Basin*, 2004)

Bioretention Facilities

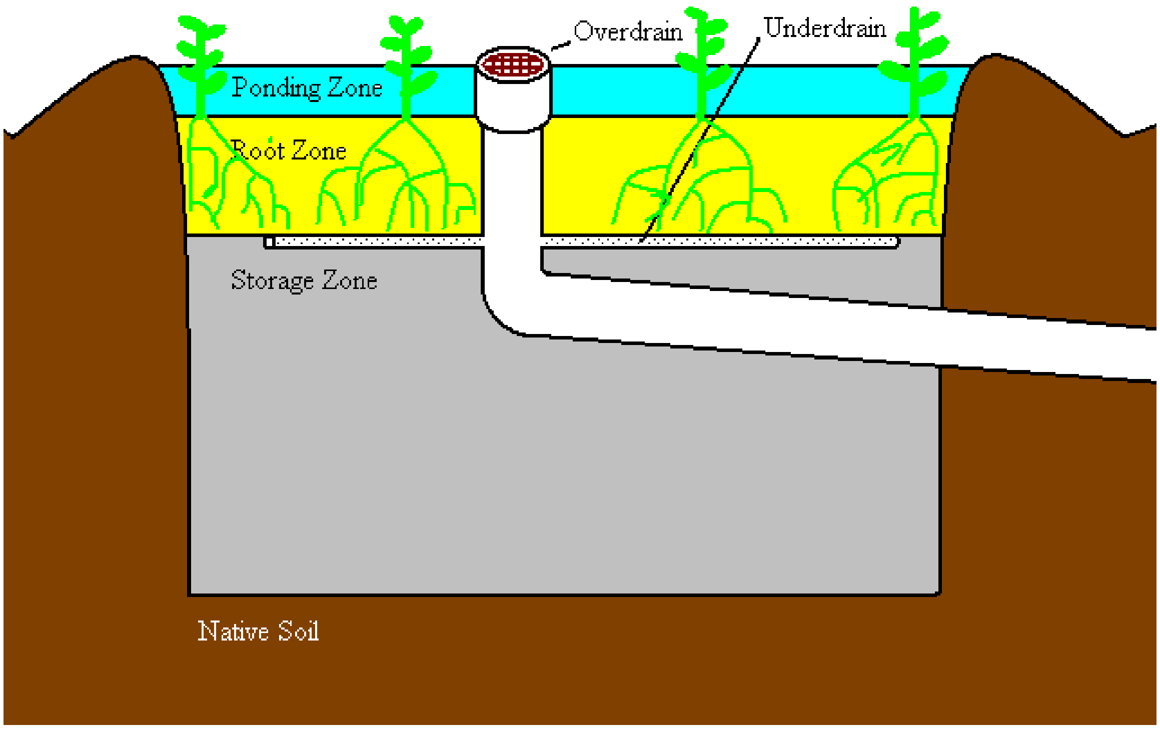

Figure 2.2: Elements of a bioretention facility (not drawn to scale)

A bioretention facility is a small, vegetated infiltration practice. All bioretention facilities include a **rooting zone**, consisting of **engineered soil**. The space above the rooting zone, where water collects until it is infiltrated into the practice is called the **ponding zone**. A **storage zone** may be constructed below the rooting zone. The **native soil,** on which the practice rests, while not constructed, is critical to the performance of the practice. A perforated pipe, called the **underdrain,** may be installed below the rooting zone. An **overdrain** may be installed to drain off water that exceeds the designed ponding depth in the ponding zone.

A key design parameter for the facility is the depth of water that is allowed to collect in the ponding zone before excess water escapes over the berm surrounding the facility or through the overdrain. By storing water, the ponding zone enhances the performance of a bioretention facility. However, as the ponding zone depth increases, so does the ponding time. Long ponding times increase the likelihood that the facility will not drain between storms, endangering the vegetation and diminishing overall performance. Also, excessively deep ponding zones can compact the engineered soil. Hence the ponding zone should never be deeper than 8 inches to a foot, depending on the permeability of the native soil.

The engineered soil is designed to provide a habitat for the vegetation in the facility, filter pollutants out of the water passing through it, and allow a rate of infiltration sufficient to accept the stormwater runoff.

The storage zone is made up of very permeable material (crushed rock, gravel, or sand) that will hold the water that has passed through the root zone until it can infiltrate into the (usually less permeable) native soil below.

The underdrain conveys water away from the facility when the storage zone fills up, preventing excessive saturation times in the rooting zone following large rain events. Water leaving the facility through the underdrain has been filtered by the root zone, unlike water leaving through the overdrain or spilling over the berm. The underdrain directs this escaping water to a storm sewer or surface water.

Below the facility is the **native soil.** The permeability of this layer is the most critical factor affecting the performance of a bioretention facility with respect to infiltration. Atchison, Potter, and Severson (2006) provide detailed information on the factors affecting the performance of bioretention facilities.

Rain Gardens

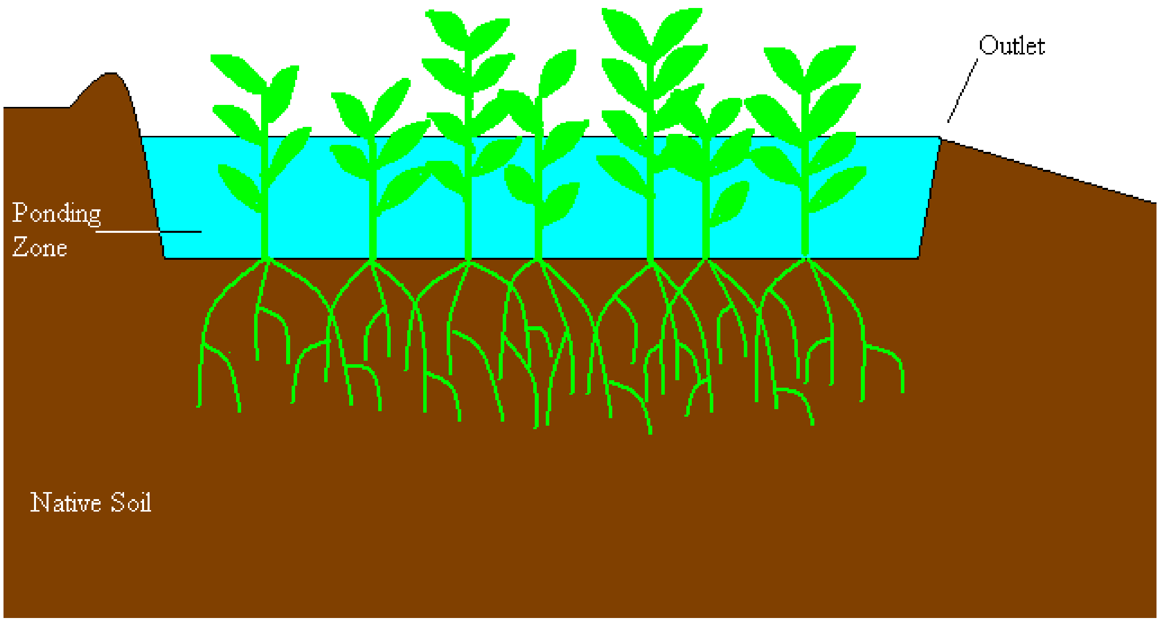

Figure 2.3: Elements of a Rain Garden (not drawn to scale)

For the purposes of this discussion, a rain garden is a relatively small, shallow, vegetated depression that collects stormwater runoff for the purpose of augmenting infiltration. Unlike a bioretention facility, the soil in a rain garden is native to the site, although it may be enhanced during construction. Hence a rain garden can be thought of as a miniature, vegetated infiltration basin. It is worth noting that some people use the terms “bioretention facility” and “rain garden” to mean the same thing, with the former used when communicating with professional colleagues and the latter for the general public.

2.2 Factors Affecting the Actual Performance of an Infiltration Practice

The primary factors affecting the performance of an infiltration practice are the flow rate through the limiting soil layer, the area of the practice relative to the source area, the storage capacity, the depth of the storage zone(s), and the hydraulic control structures (overdrains and underdrains). The limiting soil layer, the least permeable soil in or below the practice, is generally the native soil, and in most cases is not enhanced. The remaining factors are all designed, subject to DNR regulations. However, as discovered in the case studies reported in Chapter 4, actual practices often fail to perform as designed. Below common reasons for underperformance are discussed.

Flow rate

The most important factor affecting the performance of all infiltration practices is the flow rate through the practice. As long as the practice does not cause saturation of the soil from the bottom of the practice down to the water table, the primary factor affecting the flow rate is the permeability of the limiting soil layer. (In most cases the limiting soil layer is the native soil, although in some cases the engineered soil can become limiting.) NR-151 requires that the permeability of the native soil be tested prior to construction of an infiltration practice, and sets a standard of 0.6 inches/hour. But the ultimate permeability may differ from the design value because of incorrect design information, construction errors, or degradation of permeability during operation.

There are many reasons why soil permeability may be incorrectly estimated. The most common reasons have to do with the variation of permeability both vertically and horizontally. Soil permeability typically decreases with depth. Furthermore, the permeability of a subsoil layer may be much lower than that of the upper soil layers. If infiltration testing is not conducted for a sufficient duration, the test permeability may be much higher than that of the limiting layer. Soil permeability can also vary greatly in space. Hence for large practices, such as infiltration ponds, many measurements may be required to accurately estimate the average permeability for the practice (Asleson, et al).

Note that a practice may also fail because of incorrect assessment of the depth to the water table. Under some conditions, water table depths can vary significantly over time. Also, the introduction of the infiltration practice may cause a local increase in the water table (water table mounding).

Construction errors can result in substandard soil permeability. The engineered soil may be different from the design. Excessive clay can result in very low permeability, particularly if the runoff to the practice contains large concentrations of sodium chloride. The original WDNR specifications called for a mix of sand, compost, and topsoil, with no limitations on the clay content in the topsoil; the current specifications are 40% sand, 20-30% topsoil (USDA classified sandy loam, loamy sand, or loam), and the remainder compost. The use of immature compost can cause anaerobic conditions that promote the growth of bacteria that reduce soil permeability. Excavation of the practice made lead to smearing of clays in the native soil, reducing the permeability. Both the engineered and native soils may become compacted during construction.

Sediment from the tributary area may clog pores in the soil of the practice, decreasing its permeability over time. Effective pretreatment must be designed into any practice that receives sediment-laden runoff. Failing to trap the sediment before it gets into the engineered soil can dramatically decrease the working life of the engineered soil.

When a soil remains saturated for extended periods of time the soil becomes anaerobic and a breeding ground for bacteria that fill pore spaces, greatly reducing permeability. This is known as bioclogging and is seen most frequently in facilities designed to infiltrate treated wastewater, but it is a danger in stormwater infiltration practices as well. This process creates a vicious cycle, with extended ponding times leading to decreased infiltration rates, which leads to longer ponding times.

The impact of rainfall directly on unprotected soil can cause formation of a soil crust, which impedes water from infiltrating. The temporary application of mulch prevents soil crust formation until a permanent vegetative cover can be established.

In addition to providing aesthetic value, vegetation enhances the performance of an infiltration practice. The rooting action and the work of earthworms attracted by the plants lead to a structured soil, with plenty of macropores. This maintains or enhances soil permeability. A healthy vegetation cover also prevents the formation of soil crust. Further, thriving vegetation provides visual confirmation that the infiltration practice is functioning properly. Any factors that damage the vegetation in a practice will, in the long run, diminish the effectiveness of the practice.

Surface Area of Practice Relative to Source

The flow rate through a practice is measured as volume per unit area per time. The volume of water treated depends critically on the area of the practice. The area of a practice is designed to maximize performance. Too large an area may lead to diminished performance with respect to ground water recharge due to increased evapotranspiration. Too small an area will lead to underperformance with respect to both stay-on (water that reaches the practice and does not overflow or escape through an underdrain) and recharge (water that makes it through the bottom of the practice into the native soil), and may lead to failure due to overloading. Errors in the area of a practice can occur in design, construction, or long-term operation.

Depth of Storage Zone

An undersized storage zone will allow too much water to escape through the overdrain or underdrain when water is backed up, waiting to work into the native soil. This results in insufficient infiltration. If there is no underdrain, an oversized storage zone may allow saturated conditions to exist for too long at the storage zone-native soil boundary.

Hydraulic Control Structures

An overdrain or berm that allows water to exit the practice before it has reached the designed maximum ponding depth will result in diminished performance. The same is true of an underdrain that allows water to exit the practice before the storage zone is fully saturated. An overdrain or berm that does not allow water to escape the practice when it has reached the designed maximum ponding depth will result in too much water remaining in the practice, which can lead to excessive ponding times. An underdrain that does not allow water to escape the practice when the storage zone is fully saturated can lead to excessive saturation times for both the engineered soil and the storage zone. The cost of building field-adjustable overdrains may prove to be a good investment, as an adjustment of the ponding zone after observing as-built conditions would be less costly than rebuilding an overdrain.

2.3 Standard Indicators of Properly Functioning Practices

This report concentrates on four measurable properties of infiltration practices. Three of these properties are explicitly stated in applicable regulations, while the fourth is implicit. A practice that does not exhibit acceptable values for these properties is not functioning properly.

Duration of Ponding

DNR regulations require that a practice infiltrate all runoff within 24 hours of the cessation of runoff flowing into the practice. This is because extended saturation times can damage the vegetation and degrade the media. In addition, excessively long ponding times increase the likelihood that the facility will have reduced capacity during the next storm event. (*Bioretention for Infiltration, 2006*)

Media Above Limiting Layer is Free of Saturation 72 Hours After Event

A storage zone that is retaining saturation this long after a rain event will have reduced capacity for the next rain event. (*Bioretention for Infiltration, 2006*)

Sufficient Infiltration is Taking Place

NR 151 calls for 90% of pre-development infiltration volume to be infiltrated for residential developments and 60% of pre-development infiltration volume for non-residential developments (*Bioretention for Infiltration, 2006*). This volume is based on the 1981 rainfall record for Madison, 28.81 inches between March 12 and December 2. A practice that has infiltrated all of the ponded water after 24 hours and has allowed all of its collected runoff to pass through the limiting layer in 72 hours is not necessarily functioning as designed. If it is not collecting enough runoff in the first place, the fact that it is dry within three days does not alone indicate adequate performance. Where observing the other indicators is fairly simple, determining the amount of infiltration taking place in a practice will require measuring infiltration rates and modeling the practice. This will be discussed in Chapter 4.

Structural Elements are Functioning Properly

A practice that is free of ponding 24 hours after an event may have achieved that status by passing the water through leaking overdrains or permeable berms.

3. Case Studies

Twenty one practices distributed across sixteen locations were evaluated for this report. Descriptions, data, and analysis of these practices are grouped as follows:

- Clearly failed
- Repurposed or unconstructed practices
- Apparently functioning practices, difficult to test
- Testable practices

3.1 Clearly failed

A number of the practices showed clear signs of having failed. There were two classes of obvious failure -- extended ponding times and presence of dense wetland vegetation.

Extended ponding times

The Blue Chalk Club was observed to maintain ponded conditions for periods of weeks, rather than hours. It was clearly a failed practice and no further testing was needed to determine that it was underperforming. Two of the three CostCo practices exhibited dramatically extended ponding times. It was suspected that salt used to de-ice the parking lots feeding these two practices had dramatically reduced the permeability of the soils in these practices.

FIGURE 3.1: A PRACTICE THAT DISPLAYS EXCESSIVE PONDING TIMES AND HAS CLEARLY FAILED

The practice at Kelly-Williamson was filled with cattails. Clearly, this practice features saturated soil for much longer times than is healthy for an infiltration practice and no further testing is necessary to show that it has failed.

Figure 3.2: A practice that features excessive cattails to the exclusion of the intended vegetation and has clearly failed

Repurposed or unconstructed practices

The practices at Quaker Steak & Lube, Gaard Parc Condominiums, and Boston Pizza had been repurposed before testing could take place. In the first case, water was allowed to drain from the surface into the storm sewer to prevent ponding. In the latter two cases, the practices had been filled with rocks to above the elevation of the overdrain to prevent the ponding from being visible. No testing was possible in these cases.

FIGURE 3.3: A PRACTICE THAT HAS BEEN REPURPOSED

The practice that was planned for the Hart DeNoble site had not been constructed.

Apparently functioning practices, difficult to test

The practice at Sandhill Condominiums featured healthy, vigorous vegetation and did not demonstrate extended ponding times. The location of the practice made inundating it difficult, so other practices were chosen for inundation tests.

3.2 Testable practices
Practices with malfunctioning overdrains

At P.F. Chang's, UW Health – Transformations, and Ruth's Chris Steak House, the vegetation was clearly stressed, or completely dead, yet observation of the practice showed no ponding 24 hours after a significant rain event. Upon running an inundation test at each site, it was discovered that water flows through the walls of the overdrain before it reaches the inlet of the overdrain. Escape of water through the leaking overdrain gives the illusion of a well-performing practice. In fact, the soil is allowing little infiltration to take place. The water that does get into the rooting zone remains there long after a rain event, providing the wrong environment for the desired vegetation and infiltration. Any data collected from an inundation test would be useless, since the decreasing ponding level would be due to water escaping through the overdrain as well as into the soil. No modeling can be performed on a practice that features a leaking overdrain. Data for these practices is given in Table 3.1. Please note that CN is the NRCS Curve Number (curve numbers increase with impermeability of a soil) and K_{sat} is the saturated hydraulic conductivity of a soil. These two parameters are used by the RECARGA model.

Figure 3.4: A practice with a leaky overdrain

		Chang's		UW Health		Ruth's Chris	
Facility area	ft^2	125	Measured	1,000	Measured	60	Measured
Tributary area	ac	0.64	Submitted	0.25	Submitted	0.37	Measured
Facility-area ratio		0.4%	Calculated	9.2%	Calculated	0.4%	Calculated
% Impervious		89.6	Measured	100%		85.4	Measured
Pervious CN		80	Submitted	-	-	-	-
Depression depth	in	1	Measured	7	Measured	6	Measured
Root layer depth	in	6	Measured	24	Measured	32	Submitted
Storage layer depth	in	24	Submitted	40	Submitted	-	-

Table 3.1: Data for practices with leaky overdrains

Practices with functioning overdrains

In this study, pressure transducers were used to measure the depths of water in these practices. These devices measure the pressure at their sensors. When the air pressure is netted out, a simple calculation yields the depth of water over the device. Firemen's Park and Copps were tested before the best depth at which to place the pressure transducer had been determined. The rates gathered from the incorrectly-placed transducer showed generally favorable infiltration rates, but one is unable to determine saturated hydraulic conductivity from the data, making modeling impossible.

Spaight Street Residence

This practice, on the East side of Madison, consists of two simple rain gardens in the front yard of a house. In the inundation test, the pressure transducer was deployed too deep to yield meaningful numbers. However, manual measurements had been taken during the inundation of this practice, allowing rough calculations of permeability to be made. See Table 3.2 for data for this practice.

Facility area	96 ft^2	Measured
Tributary area	0.011 ac	Measured
Facility-area ratio	19.6%	Calculated
% Impervious	100%	Measured
Pervious CN	-	-
Depression depth	2 in	Measured
Root layer depth	10 in	Measured
Root layer K_{sat}	16.5 in/hr	Calculated
Storage layer depth	-	-
Storage layer K_{sat}	-	-
Native soil K_{sat}	5.5 in/hr	Calculated
Underdrain flowrate	-	-

TABLE 3.2: DATA FOR THE SPAIGHT STREET RESIDENCE

Modeling

RECARGA modeling with the above data gives a total stay-on of 28.2 inches, or 97.8%, for the 1981 Madison precipitation record of 28.81 inches and a Capacity Rain Event of 2.55 inches. The meaning and calculation of the Capacity Rain Event for a practice will be discussed in Chapter 4.

Analysis

A stay-on of 97.8% is a remarkable figure, especially when one considers the very shallow depression depth of 2 inches. However, the very permeable soils in this practice, along with the generous facility-area ratio of 19.6%, result in very good performance, along with very healthy vegetation. These calculations only consider the portion of the west roof that is directing water towards the practice. Taking into account the portions of the roof that do not direct runoff to the rain gardens, and the fact that the east rain garden is smaller, this house probably would not meet the requirements of NR 151. (As a homeowner-initiated practice, it of course is not subject to NR 151.) If meeting NR 151 were necessary, the eaves troughs could be altered to send all roof runoff to the rain gardens and the overflow weirs could be raised to create deeper ponding, yielding a property that meets the requirements.

Figure 3.5: A Fully-functioning practice

Oak Park Place

The practice at Oak Park Place (a.k.a. Harbor House) is a bioretention facility that receives runoff from the roof and parking lot of a residential facility. The stormwater is conveyed from the downspouts and parking lot to the practice through underground pipes, with riprap protecting the practice from force of the flow from the pipes. Some discrepancies exist between the practice specifications that were submitted to the city and the as-built practice. The practice, at 324 square feet, is smaller than the 1090 square feet design. This implies a facility area ratio of 1.0%, as opposed to the designed 3.3%. It was assumed that the tributary area of 0.75 acres is still accurate. The depth of the ponding zone was designed at 12 inches, but the as-built is 24 inches. The depth of the rooting zone is 24 inches, matching the design. It was assumed the depth of the storage zone matches the designed 45 inches. The data for this practice is shown in Table 3.3 and the depth gauge data is shown in Figure 3.3.

FIGURE 3.6: THE OAK PARK PLACE PRACTICE DURING INUNDATION TESTING

Facility area	324 ft^2	Measured
Tributary area	0.75 ac	Submitted
Facility-area ratio	1%	Calculated
% Impervious	60	Submitted
Pervious CN	68	Submitted
Depression depth	24 in	Measured
Root layer depth	24 in	Measured
Root layer K_{sat}	3.78 in/hr	Calculated
Storage layer depth	45 in	Submitted
Storage layer K_{sat}	5.91 in/hr	Default
Native soil K_{sat}	2.20 in/hr	Calculated
Underdrain flowrate	0.891 in/hr	Calculated

TABLE 3.3: DATA FOR OAK PARK PLACE

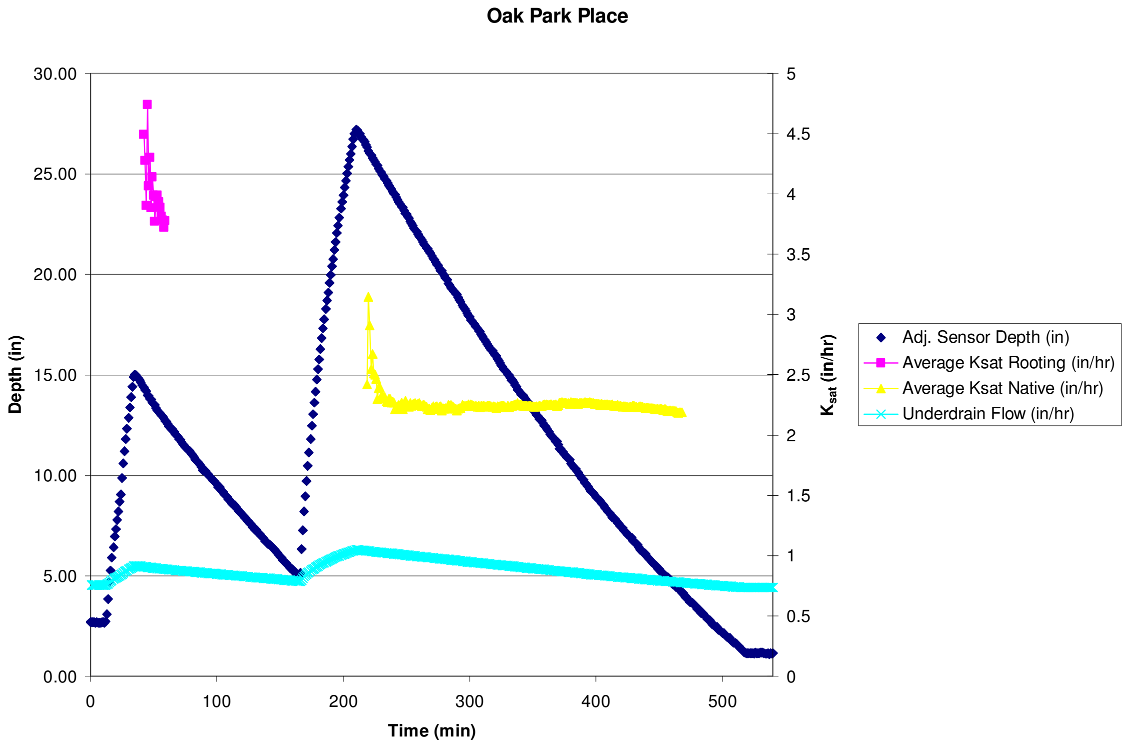

FIGURE 3.7: A DEPTH GAUGE DATA FOR OAK PARK PLACE

Modeling

RECARGA modeling with the above data gives a total stay-on of 23.1 inches, or 80.2% for the 1981 Madison precipitation record. Using the three-hour events precipitation file, it is determined that the maximum ponding time for a single, overflow event is 11.5 hours and that the Capacity Rain Event is a 0.45-in rainfall.

Analysis

A number of assumptions and estimations were made to complete this model. The facility area, ponding depth, and rooting zone depth were all different from the RECARGA model submitted by the designer. It was assumed that the as-built tributary area and storage layer depth matched the submitted values. Without being able to close off the underdrain, it was necessary to back estimated underdrain flows out of the measured rate of change in ponding before calculating K_{sat}s. The overdrain appeared to keep ponded water out until the ponding had reached the level of the grate. If the assumptions and estimations made are accurate, the data show a practice that is performing remarkably well for its very low facility-area ratio of 1%. The vigorous state of the vegetation in the practice corroborates the RECARGA modeling, at least as far as ponding times.

4. Protocol for Measuring the Performance of Infiltration Practices

This protocol has been developed after

- Discussing infiltration practices with engineering professionals, maintenance crews, and garden lovers;
- Researching what leaders in the field have written and said about infiltration practices; and
- Observing infiltration practices across the City of Middleton and elsewhere in Dane County before, during, and after they have been inundated.

This protocol is divided into four sections, representing four phases in the life of an infiltration practice – design, construction, certification, and recertification. Details on diagnosis and remediation for failed practices follow. It is hoped that the information provided here will contribute to proper construction and maintenance of infiltration practices across the city. Please note that soils are varied and complex physical, chemical, and biological systems. Infiltration failures can arise from a variety of mechanisms that may require specialized investigation.

4.1 Proper Design

The designer of any infiltration practice in Wisconsin should be thoroughly familiar with the most recent Department of Natural Resources Device standards. As of December, 2009, these standards are given in *Bioretention for Infiltration and Runoff Management*.

Some field results have shown that sodium chloride in runoff can react with even modest amounts of clay in a soil to cause a very low permeability in that soil. Since almost all runoff coming from anyplace visited by automobiles in Wisconsin will contain sodium chloride, it is best to clearly specify that no clay should be present in an engineered soil.

4.2 Construction

Three new requirements are proposed for the construction process: site inspections, installation of an observation well, and the capability of plugging the underdrain (if present) during an inundation test. Site inspections will ensure that the practice has been constructed as designed. An observation well will facilitate subsequent testing of the practice. Plugging the underdrain will allow accurate readings of infiltration rates to be made.

4.2.1 Site inspection

Multiple examples of infiltration practices that failed because they were not built as designed have been noted. Perhaps, with time and experience, this will no longer be a problem. Until that day arrives, a representative of the designer should visit the site at appropriate times to inspect the practice. The inspector should indicate that the practice meets the design specifications at the following stages of construction.

While the excavation is open, the following questions should be answered:

- Is the practice located at the design site? If not, has an infiltration test been conducted at the actual site?
- Does the depth of excavation match the design depth?
- Is there evidence of smearing of clay at base of excavation?
- Is there evidence of compaction in the native soil?

The following questions should be answered after installation of any drainage features and emplacement of storage zone material:

- Do the thickness and composition of the storage zone material conform to the design?
- Do the location and diameter of the underdrain match the design?
- Do the size and number of perforations in the underdrain match the design?
- Have appropriate precautions been taken to prevent clogging of underdrain?
- Is the overdrain watertight below the grate?
- Do the elevations of the berms and/or overdrain match the design?

The following questions must be answered after installation of the engineered soil and mulch but before installation of the vegetation:

- Do the volume and composition of the engineered soil match the design?
- Are there signs of compaction in the engineered soil?
- Do the depth and composition of the mulch match the design?

Correcting any faults discovered by the inspection will be much less costly before the practice is completed.

4.2.2 Installation of observation well

An observation well should be installed in each infiltration practice. The observation well should terminate just above the native soil and extend at least two feet clear of the highest expected ponding level. The two feet of dry well is to allow for those depth gauges that require connections outside of the well to keep that equipment dry when the practice is fully inundated. The well should be perforated over the bottom five or six inches to allow measurement of the head at the bottom of the practice during an inundation test or after a rain event. A watertight cap should be provided for the top of the well. The part of the well that extends above the mulch layer may be removable for aesthetic purposes, as long as a watertight seal is maintained when the top of the well is in place. This well will be used to evaluate the practice and will allow diagnostic measures without excavating the entire practice when the practice is underperforming or has failed.

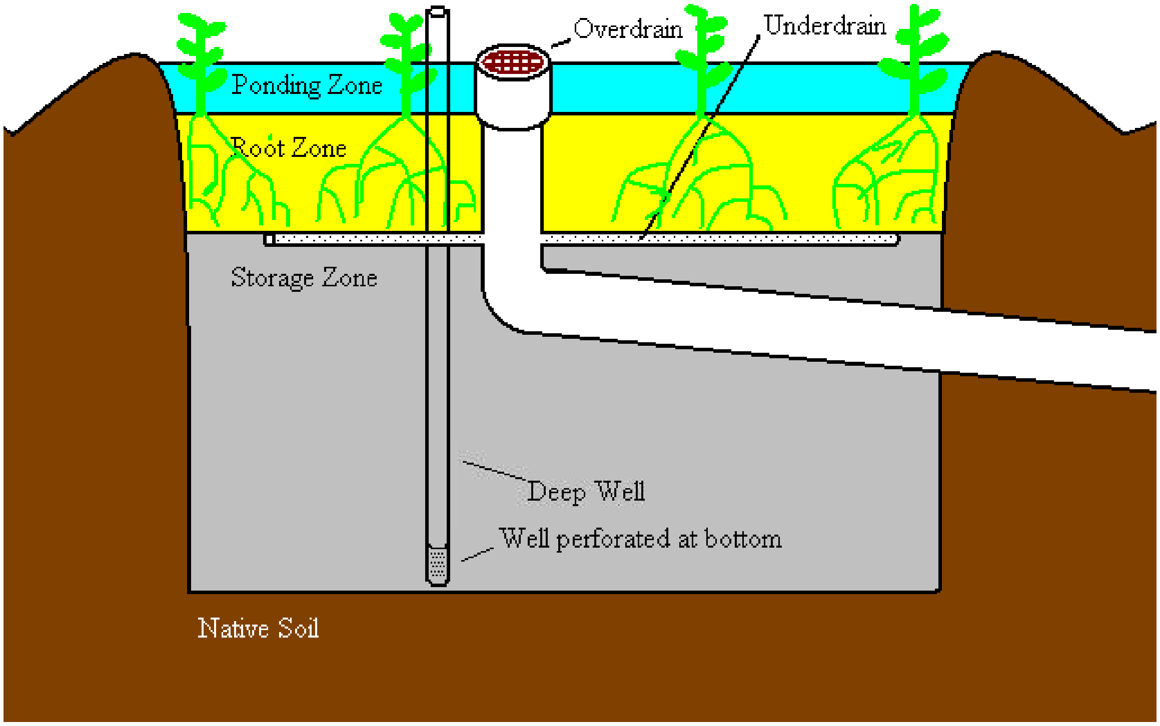

FIGURE 4.1: BIORETENTION FACILITY WITH OBSERVATION WELL INSTALLED

4.3 Post-construction

Soon after an infiltration practice is constructed, an inundation test should be conducted. The purpose of the test is two-fold.

First, the test will evaluate the key parameters of the practice. These parameters are depth of ponding, ponding area, and the effective saturated hydraulic conductivities (K_{sat}s) of the engineered and native soils. Until the storage zone fills up, the K_{sat} of the engineered soil is the factor that determines the rate of infiltration. After that point, the K_{sat} of the native soil determines the rate of infiltration. The measured parameters should be compared to the design parameters. If there are discrepancies, the performance of the practice should be re-evaluated.

The second purpose of the inundation test is to allow the observation of the practice while inundated. These observations can expose any of a number of potential structural problems. Such problems have been discovered in numerous sites throughout the City and, if disregarded, could greatly reduce the effectiveness of the practice and render meaningless the data collected during the inundation test.

4.3.1 Calculation of water requirements

An induced inundation test involves flooding a practice with water from a fire hydrant, water truck, or other source of water. A natural inundation test involves making measurements during and after a large runoff event. In either case, devices are used to measure and record the depth of ponding in the practice and the depth of water in the observation well at an appropriate time interval.

The induced inundation test is the preferred method, since observations as to the structural integrity of the practice can be more easily made during a scheduled, daytime procedure. One must determine if an induced inundation test is possible. A conservative estimate of the time it will take to fill the practice can be obtained by the steps given below.

1. Calculate the effective flow rate of water out of the practice into the native soil:

$$Q_{native} = K_{sat} A_{STO} \qquad [L^3/T]$$

where K_{sat} is the lesser of the design saturated hydraulic conductivities of the native and engineered soils and A_{STO} is the area of interface between the practice and the native soil. If Q_{native} is greater than Q_{source} (the flow from the water source) it will be impossible to fill the practice with the water source.

2. If Q_{native} is less than Q_{source}, calculate the void space in the entire practice:

$$V_{void} = V_{STO} n_{STO} + V_{ROOT} (n_{ROOT} - \theta) + V_{POND} \qquad [L^3]$$

where V_{STO}, V_{ROOT}, and V_{POND} are the volumes of the storage, rooting, and ponding zones, respectively and n_{STO} and n_{ROOT} are the porosity of the storage zone and rooting zones, respectively. Use the wilting point for the engineered soil for θ. The wilting point is the moisture content at which most plants can no longer draw water out of the soil. The wilting point for a fine sandy loam is about 5%.

3. Calculate the time to fill the practice with the water source:

$$T = \frac{V_{void}}{(Q_{source} - Q_{native})} \qquad [T]$$

This assumes that the maximum possible gravity drainage and evapotranspiration has occurred. The estimate assumes that the flow into the native soil begins at the same time as the flow into the practice from the water source.

The time to fill the practice can be reduced by inundating shortly after a rain event, when some of the practice will be saturated. One could create a RECARGA model of the practice and feed it user-generated rain data to estimate the amount of water in the practice at the start of the induced inundation.

Armed with an estimate of the time to fill the practice one can decide if an induced or natural inundation is the best option for this practice.

4.3.2 Performing the Inundation Test

The following steps describe the inundation test. The processes for three cases are given:

Case 1: Storage zone and observation well,
Case 2: Storage zone and no observation well,
Case 3: No storage zone.

4.3.2.1 Case 1: Storage Zone and Observation Well

1. Prime the observation well by pouring water into it and driving a plunger to the bottom of the well. This will remove any sediment that has blocked the openings in the well and ensure that water flows from the practice into the well easily. Remove the plunger. Deploy surface depth gauge and observation well depth gauge.
2. (Induced inundation method only) Protect areas around inlets from erosion.
3. Cap the underdrain, if present, to prevent water escaping the practice through the sewer system.
4. Begin logging data.
5. Begin induced inundation or wait for natural rain event. If inducing the inundation, one should direct the water to the tributary area of the practice, rather than into the practice directly.
6. Observe the structural elements as the practice begins to fill with water.
    - Can one hear water exiting the practice into the overdrain before the water has reached the level of the grate? If so, the test will overestimate the K_{sat} for the engineered soil, since the measured rate of receding ponding will be affected by water leaving the practice through the overdrain.
    - Is a berm allowing water to escape before it has reached the top of the berm? Water can pour over a low point in a berm or through an unsound berm. If water is escaping prematurely, the actual depth of the ponding zone may be different than designed.
    - Is loose mulch floating? If so, mulch may be lost during overflow events.
    - Do curb-cuts direct water into the practice as intended? If not, the practice will not receive or infiltrate the amount of water it was designed to.
    - Record the depth and area of the ponding zone that is actually ponded when water begins to overflow the berm or into the overdrain.
7. (Induced inundation method only) When water begins to overflow the berm or flow into the overdrain, check the depth of water in the observation well. If the water level in the observation well has neared the top of the storage zone, the inundation phase of the inundation test is complete; otherwise, stop the water source to allow the ponding to recede before restarting the water source. Depending on the volume of the storage zone, the saturated hydraulic conductivity of the engineered soil, and the flow rate of the water source, the water may need to be stopped and restarted several times to prevent overflowing. If the K_{sat} of the native soil is greater than that of the engineered soil, the storage zone will never fill up, since the native soil will accept water faster than the engineered soil can supply it. If this is the case, apply enough water to fill the practice (if no percolation into the native soil were taking place) to make sure that a minimal saturation depth is occurring at the bottom of the storage zone.
8. Once the inundation has been completed and all the ponded water has infiltrated into the engineered soil, the surface depth gauge may be removed. Record the time for ponding to recede into the engineered soil.
9. Continue to collect water level data in the observation well until it shows that the bottom of the storage zone is no longer saturated.
10. Record the time for ponding to recede into the native soil.

11. Uncap the underdrain (if present).

4.3.2.2 Case 2: Storage Zone and no Observation Well

1. (Induced inundation method only) Protect areas around inlets from erosion.
2. Cap the underdrain, if present, to prevent water escaping the practice through the sewer system.
3. Begin logging data.
4. Begin induced inundation or wait for natural rain event. If inducing the inundation, one should direct the water to the tributary area of the practice, rather than into the practice directly.
5. Observe the structural elements as the practice begins to fill with water.
    - Can one hear water exiting the practice into the overdrain before the water has reached the level of the grate? If so, the test will overestimate K_{sat} for the engineered soil, since the measured rate of receding ponding will be affected by water leaving the practice through the overdrain.
    - Is a berm allowing water to escape before it has reached the top of the berm? Water can pour over a low point in a berm or through an unsound berm. If water is escaping prematurely, the actual depth of the ponding zone may be different than designed.
    - Is loose mulch floating? If so, mulch may be lost during overflow events.
    - Do curb cuts direct water into the practice as intended? If not, the practice will not receive or infiltrate the amount of water it was designed to.
    - Record the depth and area of the ponding zone that is actually ponded when water begins to overflow the berm or into the overdrain.

7. (Induced inundation method only) When water begins to overflow the berm or flow into the overdrain, stop the water source to allow the ponding to recede before restarting the water source. Keep track of the time you have been applying water to the practice and the rate of infiltration demonstrated in the ponding zone. When you have applied at least the estimated amount of water to fill the practice and the infiltration rate has decreased, you may stop the water source for the rest of the inundation. Depending on the volume of the storage zone, the saturated hydraulic conductivity of the engineered soil, and the flow rate of the water source, the water may need to be stopped and restarted several times to prevent overflowing. If the K_{sat} of the native soil is greater than that of the engineered soil, the storage zone will never fill up, since the native soil will accept water faster than the engineered soil can supply it. If this is the case, apply enough water to fill the practice (if no percolation into the native soil were taking place) to make sure that the infiltration rate is not being limited by a lower than expected K_{sat}.
8. Once the inundation has been completed and all the ponded water has infiltrated into the engineered soil, the surface depth gauge may be removed and the underdrain (if present) may be uncapped.
9. Record the time for ponding to recede into the engineered soil from the moment the water source was shut off or the runoff from a natural event stopped flowing into the practice.

4.3.2.3 Case 3: No Storage Zone

1. Install a temporary well to the bottom of the engineered soil. Pack a handful of bentonite chips around the well at the surface. Dampen the bentonite chips to activate them. The bentonite will prevent ponded water from running down the outer edge of the well. Prime this well by pouring water into it and driving a plunger to the bottom of the well. Remove the plunger. Deploy surface depth gauge and observation well depth gauge.
2. (Induced inundation method only) Protect areas around inlets from erosion.
3. Cap the underdrain, if present, to prevent water escaping the practice through the sewer system.
4. Begin logging data.
5. Begin induced inundation or wait for natural rain event. If inducing the inundation, one should direct the water to the tributary area of the practice, rather than into the practice directly.
6. Observe the structural elements as the practice begins to fill with water.
   - Can one hear water exiting the practice into the overdrain before the water has reached the level of the grate? If so, the test will overestimate K_{sat} for the engineered soil, since the measured rate of receding ponding will be affected by water leaving the practice through the overdrain.
   - Is a berm allowing water to escape before it has reached the top of the berm? Water can pour over a low point in a berm or through an unsound berm. If water is escaping prematurely, the actual depth of the ponding zone may be different than designed.
   - Is loose mulch floating? If so, mulch may be lost during overflow events.
   - Do curb cuts direct water into the practice as intended? If not, the practice will not receive or infiltrate the amount of water it was designed to.
   - Record the depth and area of the ponding zone that is actually ponded when water begins to overflow the berm or into the overdrain.
7. (Induced inundation method only) When water begins to overflow the berm or flow into the overdrain, check the depth of water in the observation well. If the water level in the observation well is at a significant depth, the inundation phase of the inundation test is complete; otherwise, stop the water source to allow the ponding to recede before restarting the water source. Depending on the volume of the engineered soil, the saturated hydraulic conductivity of the engineered soil, and the flow rate of the water source, the water may need to be stopped and restarted several times to prevent overflowing.
8. Once the inundation has been completed and all the ponded water has infiltrated into the engineered soil, the surface depth gauge may be removed and the underdrain (if present) may be uncapped.

9, Record the time for ponding to recede into the engineered soil from the moment the water source was shut off or the runoff from a natural event stopped flowing into the practice.

10. Remove the observation well.

4.3.3 Using the Data Gathered During the Inundation Test

For this protocol, the term "failed practice" is applied to a practice that remains ponded for more than 24 hours after cessation of runoff flowing into the practice. The term "underperforming practice" is applied to a practice that does not meet the infiltration requirements of the Wisconsin Department of Natural Resources.

4.3.3.1 Checking for a Failed Practice

Simply look at the time from the moment the water source was turned off to that when the ponding receded into the engineered soil. If this time is greater than 24 hours, the practice has failed. Longer ponding times may lead to bioclogging, which in return results in even longer ponding times (see the discussion of bioclogging in section 2.2). Excess ponding times also reduce the performance of the practice during successive events. The calculations below should be performed for a failed practice to determine which parameters are different from the design.

4.3.3.2 Checking for an Underperforming Practice

1. Import the data from the field equipment into a computer spreadsheet.
2. At each time step, compute

$$K_{sat} = \frac{\Delta E / \Delta t}{D / L + 1}$$

where ΔE is the previous depth minus the current depth of ponding, Δt is the difference between the previous and current time, D is the average depth of ponding over the time step, and L is the depth of the engineered soil. This value should converge to K_{sat} as the engineered soil saturates.

3. Calculate the K_{sat} of the native soil. If the site has an observation well, the rate is expressed:

$$K_{sat} = \frac{\Delta E n / \Delta t}{D / L + 1}$$

where ΔE, Δt, and D are the same as in step 2, L is an estimate of the distance from the top of the native soil to the water table, and n is the porosity of the zone (ponding, rooting, or storage) that contains the top of the water column, using a value of 1 for the n of the ponding zone. If there is no observation well, this calculation will be based on recession in the ponding zone, so the same formula, with a value of 1 for the n, will be used.

4. With the two measured K_{sat}s, compare the as-built dimensions and the calculated K_{sat}s with the design. If there are significant differences a new RECARGA model should be created and run with the annual rainfall record required by NR 151 (Madison's 1981 rainfall record of 28.81 inches in Dane County) to determine if the practice meets this regulation. NR 151 requires that residential practices infiltrate at least 90% of the pre-development infiltration volume and that non-residential practices infiltrate at least 60% of the pre-development infiltration volume.
5. If the requirements of NR 151 are not met, move to the diagnosis and remediation section of this chapter.

6. If the parameters are unchanged from the design or the requirements of NR 151 are met, calculate the Capacity Rain Event (CRE) for the practice. This is the minimal rain that will saturate the practice from the native soil to the top of the ponding zone. This figure will be used in the recertification process. An easy way to determine this figure is to run a user-generated precipitation file through the RECARGA model. The precipitation file should feature three-hour rain events every two weeks, increasing from 0.025 inches/hour to 1.000 inch/hour. See Appendix for a sample of the precipitation file that can be used. Analysis of the detailed output from RECARGA using this precipitation file will show the first rain event to saturate the practice. A monitoring schedule should be initiated for the practice, with a record of its CRE.

4.4 Monitoring Existing Practices

The performance of an infiltration practice may degrade over time. There are three clear signs that the practice is no longer performing as designed: excessive ponding times, stressed or dead vegetation, and the presence of cattails or other wetland plants. The operation and maintenance plan for all infiltration practices should include provisions for observing these indicators.

Relying on community comment to trigger problem practices is impractical. The complaints made by neighbors normally relate to excessive weeds. To an untrained eye, native vegetation originally installed in the practice may look like weeds. So, a healthy infiltration practice could provoke more complaints than a failed one.

Observations of ponding times and state of vegetation do not require highly-trained personnel. Property management could assign someone regularly at the site to report on the state of vegetation and the ponding times. Alternatively, high school students interested in Earth Science or Botany could be given inexpensive digital cameras and turned loose on the city's infiltration practices after rain events. The most important ponding observations are the ones after a critical rain event, since the absence of ponding after a smaller rain is not necessarily a sign of a properly functioning practice. The ponding levels for a practice should be checked after a Capacity Rain Event (CRE) at least once per year. Photographs or depth readings taken in the morning and the afternoon for the 36 hours following a significant rain event would be an ample record for a practice.

An effective reporting structure needs to be designed to get these reports to a decision maker. For example, a computer record of practices in the city could be kept. This record would contain the location of each practice, its CRE, contact information for the monitor, and a flag if the practice has passed a CRE successfully in the current season. After a sizable rain event, it would take a simple query to find the practices that received a CRE that have not successfully passed a CRE this season. Messages to the monitors for those practices could go out, requesting observations of the practices. Alternatively, the monitors could be sent messages in the spring reminding them to start observing the practice and then follow-up messages when their practices have successfully passed a CRE and no longer require monitoring. When a practice shows signs of failure, the diagnosis process must be undertaken.

4.5 Diagnosis for failed practices

If the practice is underperforming or has failed, a troubleshooting process must be undertaken to determine the location of the problem, the cause, and appropriate corrections. The following investigative steps are sorted from least invasive to most invasive.

1. Check that the original design of the infiltration practice meets the requirements of NR 151, particularly regarding duration of ponding.
2. Compare the physical dimensions of the practice with the design.
   - The media may have settled, lowering the interface between engineered soil and ponding zone, creating a deeper ponding zone that designed. Berms that are too high or an overdrain that is too high will also increase the depth of the ponding zone. A deeper ponding zone may result in a longer ponding time and a failed practice.
   - A rooting zone surface that is too high, berms that are too low or an overdrain that is too low will increase the amount of water spilling out of the system, reducing the amount of infiltration taking place and possibly leading to underperformance.
   - A smaller ponding area than designed will result in less infiltration taking place, possibly leading to underperformance.
3. Examine the engineered soil. The following investigations can reveal problems without requiring an inundation test. (If an inundation test has been performed and the K_{sat} of the engineered soil is acceptable, this step may be skipped.)
   - Determine whether the engineered soil meets the specifications. If it does not, determine the reason. If sedimentation is the problem, it may be sufficient to replace the upper layer, unless clay particles have been transported throughout the facility.
   - Check for compaction in the engineered soil using a penetrometer. If compaction has taken place, the engineered soil needs to be tilled.
   - Check that the organic matter in the engineered soil is fully composted. Organic matter that has not been fully composted can create anaerobic conditions and form a seal to water. If the soil contains organic matter that is not fully composted, it will need to be replaced.
   - Check for evidence of bioclogging, which can occur when soils remain saturated for extended periods. (See the discussion of bioclogging in section 2.2.) Examination of a soil core will show a discolored region in the engineered soil. Replacing the affected soil will remove the bioclogging, but the original cause of excessive ponding times needs to be corrected, or else the microbes that case bioclogging will come back.
4. A water table that is too near the bottom of the practice will prevent infiltration from taking place. If this is a possibility, install an observation well near the practice to determine the depth of the water table. If the water table is less than three feet below the bottom of the practice, the practice should be redesigned to filter water and allow it to drain to the sewer system instead of infiltrating into the soil.

5. If the problem is not with the engineered soil, excavate to the underdrain and check it for clogging. Remember to take precautions to prevent sediment from entering the practice while the engineered soil is removed. The underdrain is designed to allow excess water to be filtered by the engineered soil before exiting the system at a rate limited by the relatively high K_{sat} of the engineered soil. If the underdrain is clogged the rate of excess water leaving the system is limited by the relatively low K_{sat} of the native soil.

6. If the problem does not lie in the engineered soil or the underdrain, excavate to the native soil. Remember to take precautions to prevent sediment from entering the practice while the engineered soil and storage zone are removed. Determine whether the problem is at the surface of the native soil. Causes of surface problems include:

- a layer of clay that was smeared across the top of the native soil during excavation,
- sediment from improperly washed storage zone material clogging the native soil,
- silting of geotech fabric,
- bioclogging.

Clogging due to sediment deposition or smeared clay will be clearly evident from visual inspection. Bioclogging will be evident upon examining a core sample of the native soil. If the problem exists at the surface remove the top three inches of native soil and re-prepare the native soil interface layer according to section B.9 of *Bioretention for Infiltration*.

Problems that extend deeper than the surface include

- compaction,
- a natural permeability that is simply lower than assumed during the design of the practice.

Use a penetrometer to check for compaction. If the problem is compaction, spading to a depth of three feet should be performed before reconstructing the practice. If compaction is not the problem, measure the K_{sat} of the native soil and redesign the practice with this accurate figure.

Appendix 1: Methods

There are several tools one could use to record the depth of ponded water in the practice. In this study, pressure transducers were used. Here are the steps used to secure a pressure transducer to measure surface depths:

1. Auger hole 6 inches deep, saving the soil that is removed.
2. Pour a bit of sand into the hole for the well to rest on.
3. Place a well, (PVC pipe, screened six inches above the bottom) into the hole.
4. Pack sand around the well. Pack a handful of bentonite chips around the well at the surface. Dampen the bentonite chips to activate them. The bentonite will prevent ponded water from running down the outer edge of the well.
5. Place a plastic sheet with a hole matching the diameter of the well over the well at ground level, to keep sediment from clogging the screen.
6. Place the pressure transducer into the well.
7. Perform the inundation test.
8. Remove the plastic sheet and the well, carefully disposing of the bentonite.
9. Replace the soil that had been removed to make the hole.
10. Remember to subtract 0.5 feet from any readings you get. When measuring depths at the bottom of the storage zone, you will use a well that had been installed when the practice was constructed. This well must be primed prior to deploying a depth gauge. Fill the well with water, and then run a plunger, matching the inner diameter of the well, to the bottom of the well.

Appendix 2: Regulations

Included here are key requirements of regulations from the State of Wisconsin, Dane County, and the City of Middleton. Please note that many important features of these regulations, including exclusions and exemptions are not included.

State of Wisconsin: NR-151.12

(c) *Infiltration.* BMPs shall be designed, installed and maintained to infiltrate runoff to the maximum extent practicable in accordance with the following, except as provided in subds. 5. to 8.:
1. For residential developments one of the following shall be met:
a. Infiltrate sufficient runoff volume so that the post–development infiltration volume shall be at least 90% of the pre–development infiltration volume, based on an average annual rainfall. However, when designing appropriate infiltration systems to meet
this requirement, no more than 1% of the project site is required as an effective infiltration area.
b. Infiltrate 25% of the post–development runoff volume from the 2–year, 24–hour design storm with a type II distribution. Separate curve numbers for pervious and impervious surfaces shall be used to calculate runoff volumes and not composite curve numbers as defined in TR–55. However, when designing appropriate infiltration systems to meet this requirement, no more than 1% of the project site is required as an effective infiltration area.
2. For non–residential development, including commercial, industrial and institutional development, one of the following shall be met:
a. For this subdivision only, the "project site" means the rooftop and parking lot areas.
b. Infiltrate sufficient runoff volume so that the post–development infiltration volume shall be at least 60% of the pre–development infiltration volume, based on an average annual rainfall. However, when designing appropriate infiltration systems to meet this requirement, no more than 2% of the project site is required as an effective infiltration area.
c. Infiltrate 10% of the post–development runoff volume from the 2–year, 24–hour design storm with a type II distribution. Separate curve numbers for pervious and impervious surfaces shall be used to calculate runoff volumes and not composite curve numbers as defined in TR–55. However, when designing appropriate infiltration systems to meet this requirement, no more than 2% of the project site is required as an effective infiltration area.

Parts 1.b. and 2.c. are soon to be removed from the regulation.

Dane County Ordinances, Chapter 14
14.51 Stormwater Management Plan Requirements

(2)(e) *Infiltration.*
1. *Residential development.* For residential developments, design practices to infiltrate sufficient runoff volume so that post-development infiltration volume shall be at least 90% of the pre-development infiltration volume, based upon average annual rainfall. If when designing appropriate infiltration systems, more than one percent (1%) of the site is required to be used as effective infiltration area, the applicant may alternately design infiltration systems and pervious surfaces to meet or exceed the estimated average annual recharge rate (7.6 inches per year). If this alternative design approach is taken, at least one percent (1%) of the site must be used for infiltration.
2. *Nonresidential development.* For nonresidential development, including commercial, industrial and institutional development, design practices to infiltrate sufficient runoff volume so that post-development infiltration volume shall be at least 60% of the pre-development infiltration volume, based on average annual rainfall. If when designing appropriate infiltration systems, more than two percent (2%) of the site is required to be used as effective infiltration area, the applicant may alternately design infiltration systems and pervious surfaces to meet or exceed the estimated average annual recharge rate (7.6 inches per year). If this alternative design approach is taken, at least two percent (2%) of the site must be used for infiltration.

City of Middleton Ordinances, Chapter 26 Storm Water Runoff Control
26.06 Storm Water Management Standards

(3) Infiltration.
(a) New Development. New residential and nonresidential developments must implement storm water management practices designed to meet the following standards:
1. Infiltration – Residential Development. For residential development, practices shall be designed so that the post-development infiltration volume is at least 90% of the average annual pre-development infiltration volume and/or the effective infiltration area comprise at least 1% of the site, whichever is less.
2. Infiltration – Nonresidential Development. For nonresidential development, practices shall be designed so that the post-development infiltration volume is at least 60% of the average annual pre-development infiltration volume and/or the effective infiltration area comprise at least 2% of the site, whichever is less.
3. Groundwater Recharge – All Development. In addition, infiltration systems and pervious surfaces for both residential and nonresidential development shall be designed to meet or exceed the estimated average annual groundwater recharge rate of at least 7.6 inches per year, regardless of the effective area of the infiltration system.

Appendix 3: 3HrEventsUS.txt

In this paper, a parameter called the Capacity Rain Event (CRE) has been introduced. This parameter represents the amount of rain to fall in a three-hour period that would completely fill up a particular infiltration practice, according to the RECARGA model. This is used in monitoring the performance of the practice over time. The following user-input file can be used with the RECARGA model to determine this parameter. An output file name should be entered and the "Record" checkbox in the Files box should be checked. Upon completion of the run, the output file should be examined for the first rain event in the user input file that generated runoff from the modeled practice.

time (hr)	rain (in.)	evap (in.)
0	0	0.003753051
1	0.025	0
2	0.025	0
3	0.025	0
4	0	0.003753051
…		
336	0	0.003753051
337	0.05	0
338	0.05	0
339	0.05	0
340	0	0.003753051
…		
672	0	0.003753051
673	0.075	0
674	0.075	0
675	0.075	0
676	0	0.003753051
…		
1008	0	0.003753051
1009	0.1	0
1010	0.1	0
1011	0.1	0
1012	0	0.003753051
…		
1344	0	0.003753051
1345	0.125	0
1346	0.125	0
1347	0.125	0
1348	0	0.003753051
…		
1680	0	0.003753051
1681	0.15	0
1682	0.15	0
1683	0.15	0
1684	0	0.003753051
…		
2016	0	0.003753051
2017	0.175	0
2018	0.175	0
2019	0.175	0
2020	0	0.003753051
…		
2352	0	0.003753051
2353	0.2	0
2354	0.2	0
2355	0.2	0
2356	0	0.003753051
…		
2688	0	0.003753051
2689	0.225	0
2690	0.225	0
2691	0.225	0
2692	0	0.003753051
…		
3024	0	0.003753051
3025	0.25	0
3026	0.25	0
3027	0.25	0
3028	0	0.003753051
…		
3360	0	0.003753051
3361	0.275	0
3362	0.275	0
3363	0.275	0
3364	0	0.003753051
…		
3696	0	0.003753051
3697	0.3	0
3698	0.3	0
3699	0.3	0
3700	0	0.003753051

…		
4032	0	0.003753051
4033	0.325	0
4034	0.325	0
4035	0.325	0
4036	0	0.003753051
…		
4368	0	0.003753051
4369	0.35	0
4370	0.35	0
4371	0.35	0
4372	0	0.003753051
…		
4704	0	0.003753051
4705	0.375	0
4706	0.375	0
4707	0.375	0
4708	0	0.003753051
…		
5040	0	0.003753051
5041	0.4	0
5042	0.4	0
5043	0.4	0
5044	0	0.003753051
…		
5376	0	0.003753051
5377	0.425	0
5378	0.425	0
5379	0.425	0
5380	0	0.003753051
…		
5712	0	0.003753051
5713	0.45	0
5714	0.45	0
5715	0.45	0
5716	0	0.003753051
…		
6048	0	0.003753051
6049	0.475	0
6050	0.475	0
6051	0.475	0
6052	0	0.003753051
…		
6384	0	0.003753051
6385	0.5	0
6386	0.5	0
6387	0.5	0
6388	0	0.003753051
…		
6720	0	0.003753051
6721	0.525	0
6722	0.525	0
6723	0.525	0
6724	0	0.003753051
…		
7056	0	0.003753051
7057	0.55	0
7058	0.55	0
7059	0.55	0
7060	0	0.003753051
…		
7392	0	0.003753051
7393	0.575	0
7394	0.575	0
7395	0.575	0
7396	0	0.003753051
…		
7728	0	0.003753051
7729	0.6	0
7730	0.6	0
7731	0.6	0
7732	0	0.003753051
…		
8064	0	0.003753051
8065	0.625	0
8066	0.625	0
8067	0.625	0
8068	0	0.003753051
…		
8400	0	0.003753051
8401	0.65	0
8402	0.65	0
8403	0.65	0
8404	0	0.003753051
…		
8736	0	0.003753051
8737	0.675	0
8738	0.675	0
8739	0.675	0
8740	0	0.003753051
…		
9072	0	0.003753051

9073	0.7	0
9074	0.7	0
9075	0.7	0
9076	0	0.003753051
…		
9408	0	0.003753051
9409	0.725	0
9410	0.725	0
9411	0.725	0
9412	0	0.003753051
…		
9744	0	0.003753051
9745	0.75	0
9746	0.75	0
9747	0.75	0
9748	0	0.003753051
…		
10080	0	0.003753051
10081	0.775	0
10082	0.775	0
10083	0.775	0
10084	0	0.003753051
…		
10416	0	0.003753051
10417	0.8	0
10418	0.8	0
10419	0.8	0
10420	0	0.003753051
…		
10752	0	0.003753051
10753	0.825	0
10754	0.825	0
10755	0.825	0
10756	0	0.003753051
…		
11088	0	0.003753051
11089	0.85	0
11090	0.85	0
11091	0.85	0
11092	0	0.003753051
…		
11424	0	0.003753051
11425	0.875	0
11426	0.875	0
11427	0.875	0
11428	0	0.003753051
…		
11760	0	0.003753051
11761	0.9	0
11762	0.9	0
11763	0.9	0
11764	0	0.003753051
…		
12096	0	0.003753051
12097	0.925	0
12098	0.925	0
12099	0.925	0
12100	0	0.003753051
…		
12432	0	0.003753051
12433	0.95	0
12434	0.95	0
12435	0.95	0
12436	0	0.003753051
…		
12768	0	0.003753051
12769	0.975	0
12770	0.975	0
12771	0.975	0
12772	0	0.003753051
…		
13104	0	0.003753051
13105	1	0
13106	1	0
13107	1	0
13108	0	0.003753051
…		
13440	0	0.003753051

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