CITY OF BIRMINGHAM
STORM WATER UTILITY
APPEALS BOARD

CITY COMMISSION ROOM
151 MARTIN ST., BIRMINGHAM, MI
(248) 530-1850
REGULAR MEETING AGENDA
TUESDAY, MAY 16, 2017, 7:00 P.M

1. INTRODUCTIONS
2. RECOGNITION OF GUESTS
3. INTRODUCTION TO ORDINANCE
4. REVIEW OF SPECIAL CASES
5. HEARINGS

   A. 1452 BUCKINGHAM RD.

10. NEXT MEETING: NOVEMBER, 2017

Persons with disabilities that may require assistance for effective participation in this public meeting should contact the City Clerk's Office at the number (248) 530-1880, or (248) 644-5115 (for the hearing impaired) at least one day before the meeting to request help in mobility, visual, hearing, or other assistance.

Las personas con incapacidad que requieren algún tipo de ayuda para la participación en esta sesión pública deben ponerse en contacto con la oficina del escribano de la ciudad en el número (248) 530-1800 o al (248) 644-5115 (para las personas con incapacidad auditiva) por lo menos un dia antes de la reunión para solicitar ayuda a la movilidad, visual, auditiva, o de otras asistencias. (Title VI of the Civil Rights Act of 1964).

City of Birmingham
A Walkable Community

MEMORANDUM

Engineering Dept.

DATE: **May 10, 2017**

TO: **Storm Water Utility Appeals Board**

FROM: **Paul T. O'Meara, City Engineer**

SUBJECT: **Introduction to Ordinance**

Pursuant to a court order, the City of Birmingham has developed a new methodology for collecting fees needed to pay for storm water disposal costs. The court order essentially redesigned the method to apportion responsibility for these costs. As a part of the court order, the City was asked to form a board of volunteers that would be available to hear appeals to the charges being assessed. The Board must have at least three members, two of which are trained in civil engineering. On behalf of the City, I thank you for your willingness to help, and for volunteering your time.

The storm water ordinance was developed by local consulting firm Hubbell, Roth, & Clark, Inc. (HRC). The new ordinance was first introduced to the City Commission at their meeting of October 27, 2016. Since this was a big change that impacted thousands of land owners and residents, the City advertised the information, and scheduled a public hearing in December, 2016. Attached for your information is an introduction memo and detailed report from HRC. Also attached are the minutes from the two City Commission meetings when this topic was discussed. I encourage you to review the materials closely, as it will be the basis for appeals decisions you will be asked to consider.

I have invited Jim Surhigh of HRC to attend our first meeting. He was the key staffperson in charge of preparing the ordinance. He will give a brief presentation, and be available to discuss the ordinance in detail, if you have questions.

Also attached are the several pages prepared for the public to review that are now posted on the City's website for those that need more detail. It can be found at www.bhamgov.org/stormwater. We will go through the various pieces of information at the meeting as an introduction.

City of Birmingham
A Walkable Community

MEMORANDUM

Office of the City Manager

DATE: **October 20, 2016**

TO: **City Commission**

FROM: **Joseph A. Valentine, City Manager**

SUBJECT: **Storm Water Utility Fee**

Background

The City of Birmingham maintains a sewer system, which includes the disposal of storm water. When it rains, water that is not absorbed into the soil runs into the storm drains in the street. That storm water, once collected in the drains, travels through a vast system of sewer pipes, and is eventually disposed of and purified before being released into the Detroit River by the Detroit Water and Sewer Department (DWSD), currently known as the Great Lakes Water Authority (GLWA).

Residents of the City who are connected to the sewer system pay a fee for this service. In fact, even the City of Birmingham pays into this fund, because the City owns property that is connected into the sewer system. The City gets a bill from the Water Resource Commission for Oakland County (WRC) for the disposal of this storm water. In turn, the WRC gets a bill for this stormwater from the former DWSD, now the GLWA. When the City gets the bill from Oakland County, the City calculates how much each property owner is responsible for, and bills each household that uses the sewer system.

Currently, storm water costs are included in the overall sewer rate charged to all users of the water and sewer system. The amount a user of the system pays for storm water is based on the amount of water that is consumed based on a water meter. This system has been in place for a very long time and is the methodology that is used by many similar cities with combined sewer systems throughout the state. The City is separated into two sewage disposal districts: George W. Kuhn and the Evergreen-Farmington. For FY 2014-2015 the amount the City was charged for storm water was approximately $1,222,000 for the George W. Kuhn and $1,029,000 for the Evergreen-Farmington districts for a total of $2,251,000. This cost is then allocated to each user based on the above referenced method.

In 1998, the Michigan Supreme Court decided a case, *Bolt v City of Lansing,* which dealt with the City of Lansing using its water/sewer bills to raise revenue unrelated to the actual usage. *Bolt* held that raising revenue through the water/sewer bill was an unconstitutional tax. *Bolt* also held that cities may use water and sewer bills to pay for the disposal of storm and sanitary sewage, but the charge had to be proportional to the actual usage. The *Bolt* case has evolved to now stand as a challenge to municipalities in determining the appropriate methodology for a city to use when apportioning storm water disposal fees to its residents. The decision resulted in a change in the law as to how cities like Birmingham should divide that fee amongst its residents. One of the factors the Court in *Bolt* determined is that the storm water disposal fee must be in proportion to the amount of water that enters the sewer system from each parcel or lot in the city.

Bolt v City of Lansing

A property owner challenged Lansing's newly imposed storm water utility fee, arguing that the fee was a tax levied without voter approval in violation of the Headlee Amendment to the Michigan Constitution. Lansing imposed the storm water fee on virtually all properties in the city to pay for the city's storm water and sanitary sewer separation project costs as permitted under state statute.

The Michigan Supreme Court ruled that the storm water service charge imposed by Lansing was unconstitutional and void on the basis that it was a tax for which voter approval was required and not a valid use fee. The Court established three criteria for distinguishing between a fee and a tax: 1) a user fee must serve a regulatory purpose rather than a revenue-raising purpose; 2) a user fee must be proportionate to the necessary costs of the service; and 3) a user fee must be voluntary – property owners must be able to refuse or limit their use of the commodity or service. The Court found that the charge failed to satisfy the first and second criteria.

Over time, additional rulings from the Michigan Court of Appeals have helped further define the ruling in the *Bolt* case as to the specifics of how storm water charges are allocated. What these rulings from the Court have demonstrated is that the billing methodology used by so many communities in the State must be changed as the ability to divide the storm water disposal fee that the cities get charged from the County based on water consumption is no longer an acceptable practice. As a result, several cities, including Birmingham, have been served with class action lawsuits challenging this methodology resulting from a recent decision by the Michgian Supreme Court. Other class action lawsuits that have recently been filed on this issue include:

CLASS ACTION LAWSUITS	**DATE FILED**
Panzica v City of Jackson	2001
Wolf v City of Ferndale	2014
Wolf v Birmingham	2014
Schroeder v City of Royal Oak	2014
Kish and Bannon v City of Oak Park	2015
v Oakland Township	2015
v City of Dearborn	2016
v City of Detroit	2016
v City of Taylor	2016
v City of Canton	2016
v Westland	2016

City Actions

Going forward, the City is required to implement a new billing methodology beginning January 1, 2017 for storm water utility fees in accordance with a court order. This new method will be based on several factors such as storm/rainfall rates, topography of each parcel of land in the City, size of each parcel and how much pervious v impervious surface exists on each lot. To assist in this effort, the City engaged the services of the engineering firm Hubbell, Roth & Clark (HRC) to develop a storm water utility fee apportionment study to develop an acceptable methodology to charge storm water fees.

HRC has been involved in designing and maintaining the City's water, sewer and storm water systems for several decades and is very familiar with the City's infrastructure. The City has been working with HRC for the past several months in the development of this new method. HRC will present their *Storm Water Utility Fee Apportionment Report* at the City Commission meeting of October 27th to introduce the proposed change in billing methodology.

In conjunction with the development of the Apportionment Report, the City has also been working with the Michigan Municipal League (MML), as well as, State Representative Mike McCready, in the development of state legislation to address the creation of a storm water utility fee. Recently, House Bill 5991 was introduced by Representative McCready to the House and was referred to the committee on Local Government. The City has modeled its ordinance after this legislation. Consequently, we don't expect full adoption of this new statute prior to January 1, 2017, however, it is the intent for the City to adopt its ordinance under the timeframe established by the court order.

Implementation Plan

In order to meet January 1, 2017 requirement to establish a new billing methodology, the following implementation plan has been established.

A presentation to the City Commission will be conducted on October 27, 2016 to present the *Storm Water Utility Fee Apportionment Report* prepared by HRC and allow the City Commission to accept the plan. In addition, a draft storm water utility ordinance will be proposed that complies with the recommendations of the report. Further, a public hearing will be scheduled for December 5, 2016 for formal consideration of a storm water utility ordinance. The Apportionment Report, draft ordinance and additional information will be made available on the City's website at www.bhamgov.org/stormwater for review by the public prior to the public hearing.

The following suggested resolution has been prepared for consideration by the City Commission.

Suggested Resolution:

To accept the Storm Water Utility Fee Apportionment Report prepared by Hubbell, Roth & Clark, Inc. and further, to set a public hearing date of December 5, 2016 to consider adoption of a storm water utility ordinance for the City of Birmingham.

REPORT

FOR

Storm Water Utility Fee Apportionment

FOR

CITY OF BIRMINGHAM

OCTOBER 21, 2016

Prepared by:

HUBBELL, ROTH & CLARK, INC
CONSULTING ENGINEERS SINCE 1915

HUBBELL, ROTH & CLARK, INC.
Consulting Engineers
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Bloomfield Hills, MI 48303-0824

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Section 1 - Executive Summary

The City of Birmingham has a combined sewer system that collects and transports both sanitary waste and storm water that enters the sewers through building footing drains and drainage structures, such as catch basins and inlets located in the streets, parking lots and yards. The sanitary waste and storm water that enters the sewers can be referred to as "sewage", and is transported through County Interceptors or Drains owned by the Oakland County Water Resources Commissioner (WRC) to Interceptors owned by the Great Lakes Water Authority (formerly DWSD), and eventually treated at the GLWA wastewater treatment plant in Detroit.

The City of Birmingham is charged for the transportation and treatment of all the sewage generated from within the City. A component of these charges is listed as storm water to reflect the diluted nature of the sewage being treated after precipitation events occur in the region. In the past, the City has passed the storm water charges on to their sewer customers as function of water usage. Due to a recent legal challenge to that method, the City is changing the basis for billing for storm water charges to one that is proportional to the amount of storm water generated from all properties in the City that enters the sewer system, and not just sewer customers.

The Storm Water Utility Fee will be apportioned to all properties in the City that contribute storm water into the City's sewer system, from both surface runoff and underground footing drain inflow. Each properties share of the storm water utility fee will be proportional to the runoff potential of that property, which is based on the size of the property, and the amount of impervious surface area on the property. The runoff potential for a typical single family residential property is defined as a "standard unit", called an Equivalent Storm Water Unit (ESWU). Other types of properties are assigned a multiple of the "standard unit" by dividing their particular runoff potential by the "standard" runoff potential. The ESWU's are totaled for all the properties being assessed, and each property's share of the total is determined by dividing their particular ESWU by the total of the ESWU's.

Procedures will be implemented for property owners to appeal and adjust their ESWU assignments if it is found to be in error. The opportunity for property owners to receive certain credits to their storm water utility fee will be available when measures are taken by the property owner to reduce the amount of storm water that enters the City sewer system from their property.

Section 2 - Background

The sewage produced in the City is transported to the wastewater treatment plant in Detroit through sanitary interceptors owned by either the Oakland County Water Resources Commissioner (WRC) or the Great Lakes Water Authority (formerly Detroit Water and Sewerage Department). The Great Lakes Water Authority charges Oakland County WRC for sewage treatment at their plant, a portion of which is designated as storm water based on the increase in base flow during precipitation events. Oakland County WRC then passes the sewage treatment and storm water charges on to the individual municipalities that are connected to their interceptors. In addition, Oakland County WRC includes costs associated with operating and maintaining the combined sewer overflow retention treatment facilities that are used by the City. In the past, the City has passed these charges on to individual properties as a component of their water and sewer bills as a function of water usage.

In 2014, the water-usage basis for billing for the storm water charges from Oakland County WRC was challenged in Circuit Court as violating the "Bolt criteria". A synopsis of the Bolt criteria (Bolt v City of Lansing 459 Mich 152 – 1998) is as follows:

> *Background:*
> *A property owner challenged Lansing's newly imposed storm water utility fee, arguing that the fee was a tax levied without voter approval in violation of the Headlee Amendment to the Michigan Constitution (Mich Const 1963, art 9, sections 25 and 31). Lansing had imposed the storm water fee on virtually all properties in the city to pay for the city's storm water and sanitary sewer separation project costs as permitted under state statute.*
>
> *What was the outcome?*
> *The Michigan Supreme Court ruled that the storm water service charge imposed by Lansing was unconstitutional and void on the basis that it was a tax for which voter approval was required and not a valid use fee. The Court established three criteria for distinguishing between a fee and a tax: 1) a user fee must serve a regulatory purpose rather than a revenue-raising purpose; 2) a user fee must be proportionate to the necessary costs of the service; and 3) a user fee must be voluntary—property owners must be able to refuse or limit their use of the commodity or service. The Court found that the charge failed to satisfy the first and second criteria.*

The City is modifying the basis of billing for storm water charges by using a method that meets the three aspects of the Bolt criteria.

Section 3 - Purpose and Summary

The purpose of assessing a storm water utility fee to properties in the City is to apportion the sewage treatment charges incurred from Oakland County WRC attributable to storm water that enters the City's combined sewer system in a manner that is proportional to the runoff potential from each property. With this method of apportionment, all properties that contribute runoff to the sewer system will pay their share of the costs, regardless if the property consumes potable water or not, or the amount of water that is consumed.

In general, the amount of runoff generated from a particular property for a given amount of precipitation is largely based on the amount of impervious surface on that property - more impervious surface means more runoff. To a smaller degree, even pervious surfaces will contribute some runoff. Therefore, the runoff potential for a particular property is determined by both the amount of impervious area and pervious area. The runoff potential for a typical single-family residential property is used as a "standard" unit, called an Equivalent Storm Water Unit (ESWU). Other types of properties are assigned a multiple of the "standard unit" by dividing their particular runoff potential by the "standard" runoff potential. The ESWU's are totaled for all of the properties being assessed, and each property's share of the total is determined by dividing their particular ESWU by the total of the ESWU's.

Impervious Areas

An impervious area can be defined as a surface area that is resistant to permeation by surface water. Because precipitation cannot be absorbed by the impervious surface, runoff will be generated that must be managed by the sewer system. For the purpose of this apportionment, the following surfaces are considered to be impervious:

- Pavements – including sidewalks, private roads, parking lots, and patios made from concrete, asphalt, brick pavers and stone materials.
- Buildings
- Athletic courts and tracks
- Gravel (or dirt) driveways and parking areas used by vehicles
- Decks covered by a roof or having an impervious underlying surface (including plastic sheeting)

Pervious Areas

A pervious area will allow an amount of surface runoff to percolate into the soil naturally, to the extent possible based on the type of soil and degree of saturation. Note that large portions of the City have naturally occurring clayey (or loamy) soils near the surface that do not allow high rates of infiltration, so even undeveloped properties will generate some runoff for moderate amounts of rainfall. For the purpose of this apportionment, the following surfaces are considered to be pervious:

- Grass
- Gardens
- Landscape areas without impervious underlying membrane
- Open-slatted decks over an otherwise pervious surface
- Gravel (or dirt) paths used by pedestrians only
- Swimming pools (but not the paved surfaces around the pool)
- Pavers set in porous material specifically designed to be pervious
- Porous pavements specifically designed to be pervious

Section 4 - General Methodology

Properties in the City are considered to be part two general categories – single-family residential (SFR) or non-single-family residential. Non-single-family residential properties include two-family residential, multifamily residential, institutional (public properties, schools and churches), public recreational, commercial, business, office, and parking.

Due to the variability in lot sizes across the City, the single-family residential (SFR) category is divided into six classes based on the total area of the parcel in order to group similarly developed properties together:

SFR CLASS	LOT SIZE RANGE
Class A	0.125 acres or less
Class B	0.126 to 0.250 acres
Class C	0.251 to 0.500 acres
Class D	0.501 to 0.750 acres
Class E	0.751 to 1.000 acres
Class F	1.001 acres or larger

The most numerous type of property in the City is the Class B SFR, which is considered to be the "standard unit" for determining ESWU's. The following table illustrates the distribution of property types across the City:

PROPERTY TYPE	# PROPERTIES	% OF TOTAL
SFR Class A (0.125 acres or less)	1,375	17.3%
SFR Class B (0.126 to 0.250 acres)	3,949	49.6%
SFR Class C (0.251 to 0.500 acres)	1,716	21.6%
SFR Class D (0.501 to 0.750 acres)	115	1.4%
SFR Class E (0.751 to 1.000 acres)	43	0.5%
SFR Class F (1.001 acres or larger)	47	0.6%
Non-Single-Family Residential Properties	719	9.0%
Total # Parcels Part of Apportionment:	7,964	

Runoff Potential

The runoff potential from a property is based on hydrologic engineering principles for calculating runoff that use both the impervious surface area and pervious surface area. All surfaces will generate some amount of runoff during precipitation events, and can be assigned a runoff coefficient to represent the fraction of the precipitation that results in runoff. The runoff coefficients used in this study are based on widely accepted practices for calculating runoff (refer to *"Handbook of Applied Hydrology: A Compendium of Water-resources"* by Chow, 1964).

The runoff coefficient used for impervious surfaces is 0.9, which generally means that 90% of the precipitation on that surface will result in runoff. Every surface has some ability to absorb water or allow it to infiltrate into the earth to one degree or another. Impervious surfaces such as pavements will have pores or cracks in the surface that allow some water to be absorbed or pass through to the underlying soil materials, or have areas where water will pond and eventually evaporate.

The runoff coefficient used for pervious surfaces, which is considered to be the total area minus the impervious area of a given property, is 0.15. Pervious surfaces such as lawn or mulched landscaped areas can only allow a relatively large fraction of the precipitation that occurs to be absorbed and infiltrate into the earth based on the permeability of the soil and how saturated it may be when the precipitation occurs. The predominate near-surface soil types in the City are clayey (or loamy), and have relatively slow permeability rates. The runoff coefficient value of 0.15 generally means that 15% of the precipitation on that surface will result in runoff.

The remaining amount of precipitation that is not absorbed or infiltrated will become runoff that leaves the property and will ultimately be collected by the City's sewer system. Runoff potential is measured in square feet, using the following formula:

Runoff Potential = 0.15 x [Total Area - Impervious Area] + 0.9 x [Impervious Area]

Impervious Area Measurement

The area of a property or parcel of land that is covered by buildings, pavements, or other materials that substantially reduce the rate at which precipitation can infiltrate into the earth is considered to be impervious surface area. Common examples of impervious surfaces include roofs, driveways, parking areas, sidewalks, patios, tennis courts, and gravel surfaces used for vehicles. The Southeast Michigan Council of Governments (SEMCOG) conducted an aerial survey of the region in 2010 that was analyzed to determine the building footprints and impervious surface areas. The resulting data sets were provided to each community, and the building footprint and impervious surface area data sets were used for this study. The impervious surface area measurements made using the SEMCOG data were verified for many properties of different types by visually analyzing aerial photographs of the individual parcels.

Section 5 -
Single Family Residential Methodology

The ESWU for each of the six lot-area categories for single-family residential properties is based on the average runoff potential for that category. For each group, the total impervious surface and pervious surface areas were summed up, and then divided by the number of parcels. Those areas were entered into the runoff potential equation to determine the average runoff potential for each category. The single-family residential Class B category that was determined to the "standard unit" has lot sizes between 0.126 acres and 0.250 acres, and an average runoff potential of 4,317 square feet. The Equivalent Storm Water Unit (ESWU) for each category is calculated by dividing the average runoff potential for each by 4,317 square feet. All single family residential properties in each of the lot-size category are assigned the same ESWU for that category. The ESWU values for the single-family residential categories are summarized in the following table:

PROPERTY TYPE	AVE. RUNOFF POTENTIAL	ESWU
SFR Class A (0.125 acres or less)	3,166	0.7
SFR Class B (0.126 to 0.250 acres)	4,317	1.0
SFR Class C (0.251 to 0.500 acres)	6,714	1.6
SFR Class D (0.501 to 0.750 acres)	10,553	2.4
SFR Class E (0.751 to 1.000 acres)	13,904	3.2
SFR Class F (1.001 acres or larger)	19,744	4.6

Section 6 -
Non-Single Family Residential Methodology

The ESWU for all other, non-single-family residential properties is based on the runoff potential for each particular property. The impervious surface area and pervious surface area for each of these properties is measured, and the runoff potential is then calculated for each. Each runoff potential value is divided by the "standard unit" runoff potential value of 4,317 square feet to calculate the ESWU value for each.

Verifying Impervious Area Measurements

The impervious area measurements for certain properties were verified by analyzing the aerial imagery of the individual parcel instead of relying on the computer-analyzed impervious surface data. Parcels for verification included all City-owned properties and those with an ESWU over 4.4 as initially determined by the computer-analyzed impervious surface data.

Section 7 - Apportionment

Every parcel included in the apportionment roll will be assessed their share of the costs being apportioned based on the ESWU value for the particular property. To determine each individual property's share, the ESWU value for the particular property is divided by the sum of all the ESWU values.

Major Drainage Districts

The combined sewers in the City drain to two different major drainage districts, the Evergreen Farmington District (EF) and South Oakland County District (SO). In general, the east and south-central part of the City is in the SO District (George W. Kuhn Drainage District, formerly 12-Towns Drainage District), and the western part is in the EF District (includes the Birmingham CSO Drain, Acacia Park CSO Drain, and Bloomfield Village CSO Drain). The City receives separate storm water charges from Oakland County WRC for those districts, and will therefore apportion those costs separately to the particular parcels located within each major drainage district.

Storm Water Utility Fee Examples

To illustrate the storm water utility fees, the following examples are presented. First, the example annual fee for a single ESWU is derived. Afterward, the fees for several typical types of properties with various ESWU values are listed. These examples are for illustrative purposes only, and do not represent the actual fees any particular property. The City Commission will adopt the annual fee amount for a single ESWU in both the EF and SO districts every year. The actual storm water utility fees for each property will be the adopted single ESWU rate multiplied by the ESWU value for the particular property. For this example, based on an annual incurred charge for storm water of $1.17 million in the EF District and $1.24 million in the SO District (approximate 2016 actual charges), the resulting apportioned annual fee per single ESWU would be as follows:

MAJOR DRAINAGE DISTRICT	TOTAL # PARCELS	TOTAL # ESWU's	SHARE FOR ESWU = 1.0	APPROX. ANNUAL FEE PER ESWU = 1.0
Evergreen-Farmington (EF)	4,335	6,442.1	0.00016	$182
South Oakland (SO)	3,629	5,201.8	0.00019	$238

Note: Share for ESWU = 1.0 is equal to 1.0 divided by Total # ESWU's for each District

Using the annual storm water utility fee derived for this example, storm water utility fees for other typical types of properties in the City would be calculated by multiplying the single ESWU rate by the ESWU value for the particular property. For single family residential classes, the example amount of for the storm water fee would be as follows:

EXAMPLE SINGLE FAM. RESID. PROPERTY	ESWU	APPROX. ANNUAL FEE IN EF DISTRICT	APPROX. ANNUAL FEE IN SO DISTRICT
Single Family Residential Class A	0.7	$127	$167
Single Family Residential Class B	1.0	$182	$238
Single Family Residential Class C	1.6	$292	$381
Single Family Residential Class D	2.4	$437	$571
Single Family Residential Class E	3.2	$582	$762
Single Family Residential Class F	4.6	$837	$1,119

Every non-single family residential property will have its ESWU value determined based on the unique characteristics for that property, including the total area of the property and the amount of impervious area on that property. Following are some examples of the storm water utility fee for fictitious properties with the noted characteristics:

EXAMPLE PROPERTY (with size of parcel)	ESWU	APPROX. ANNUAL FEE IN EF DISTRICT	APPROX. ANNUAL FEE IN SO DISTRICT
Two-Family Resid., 0.200 acres, 62% Imperv.	1.2	$218	$286
Multi-Family Resid., 0.730 acres, 76% Imperv.	5.3	$967	$1,261
Multi-Family Resid., 1.750 acres, 72% Imperv.	12.2	$2,217	$2,904
Office/Commercial, 0.150 acres, 100% Imperv.	1.4	$254	$333
Office/Commercial, 1.000 acres, 88% Imperv.	8.2	$1,490	$1,952
School/Institutional, 3.500 acres, 55% Imperv.	19.9	$3,617	$4,736
Park, 3.500 acres, 10% Imperv.	7.9	$1,436	$1,880
Vacant Parcel, 1.000 acres, 0% Imperv.	1.5	$273	$357

Billing for Storm Water Utility Fees – Current Water & Sewer Customers

Under the current system of distributing the sewage treatment costs attributable to storm water, the cost was included in the sewer rate on customers water and sewer bills. Going forward, the sewer rate on their bill will no longer include these costs, but instead there will be a separate line item for the Storm Water Utility Fee. The net effect for the total amount being charged will vary for every customer, with some being less than they have experienced in the past, and others more, dependent upon the characteristics of their particular property and their water consumption habits. As an example of how the new method compares to the old, the following table provides an example for illustrative purposes:

COMPARSION OF QUARTERLY WATER AND SEWER BILLS
OLD METHOD VERSUS NEW METHOD

OLD METHOD		NEW METHOD	
WATER CONSUMPTION	20 UNITS	WATER CONSUMPTION	20 UNITS
WATER	$ 87.20	WATER	$ 87.20
SEWER	$ 193.60	SEWER	$ 134.80
METER CHARGE	$ 8.00	STORM WATER *	$ 45.75
		METER CHARGE	$ 8.00
TOTAL WATER AND SEWER BILL	$ 288.80	TOTAL WATER & SEWER BILL	$ 275.75
		* ASSUMES RESIDENTIAL CLASS B IN THE EVERGREEN-FARMINGTON DISTRICT $183 ANNUAL FEE/4	

Billing for Storm Water Utility Fees – Properties Not Current Water & Sewer Customers

All properties in the City that contribute runoff to the City's sewer system will be assessed a Storm Water Utility Fee, regardless if they had been water and sewer utility customers or not. For those properties that currently do not receive a water and sewer bill, they will expect to receive a bill from the City going forward. For those properties that do not directly consume water, they will find their water consumption listed as zero, and thereby will have zero charges under the water, sewer and meter charge line items. The total of the water and sewer bill will consist of the Storm Water Utility Fee only.

Properties with Multiple Units or Tenants

The storm water utility fee determination is on a parcel by parcel basis, and does not take into account the number of units or tenants that may occupy any particular property. For properties with multiple units or tenants that have a unique property owner, the storm water utility fee will be assessed to the owner of property, and not the individual units or tenants that may occupy the property. For condominium properties with a defined number of units, the storm water utility fee determined for the entire property will be divided by the number of units and assessed to the individual unit owners.

Properties or Land Area Not Included in Apportionment Roll

Certain properties or areas of land are not included in the storm water apportionment as follows:

- Road right-of-way areas under the jurisdiction of the City or other agencies are not included in the apportionment based on the premise that the road systems are part of the drainage system, and benefit the City as a whole.
- Private properties where the development included separated sanitary sewers and storm sewer systems (with footing drain/sump pumps connected to storm) that are not utilizing the City sewer system for storm water.
- Certain public properties that do not contribute any runoff to the sewer system, and are mainly those through which the Rouge River passes.

Section 8 - Administrative Recommendations

Whereas the previous sections of the report were specific to the methodology for determining the ESWU's for properties in the City and establishing the apportionment roll, this section presents some recommendations for administering the storm water utility program. All of these recommendations are general in nature, and for the City's consideration in developing related ordinances and procedures.

Costs Included in the Apportionment

The costs incurred by the City from Oakland County WRC for transportation and treatment of storm water that enters the City's sewer system will vary year-to-year. The City may also find that other costs are incurred as it administers the program going forward, which are necessary and therefore appropriate to be included in the apportionment. Provisions for stipulating the costs to be included in the apportionment on an annual basis should be established.

Public Education

Information should be developed to educate the public on the purpose of the storm water utility fee, how it was determined, how they can appeal or make corrections, and how they can take measures to reduce the runoff being generated from their property that enters the sewer system. Developing a "frequently asked questions" document would also be beneficial. This information can be disseminated on the City's website or through printed brochures.

Process for Appeals and Adjustment

A process should be established for property owners to request adjustments to the impervious area measurements made for their property. To be customer friendly, this process could allow receiving requests throughout the year and have approved changes applied to the next years' apportionment. With this method, a specific deadline for receiving requests should be established each year to allow time for review of the request and to update the apportionment roll before the next years' apportionment is implemented.

For single-family residential (SFR) properties, the average impervious area for each lot-size classification was used to determine the ESWU value for that classification, and therefore, variations from parcel to parcel within each class are expected. Any SFR property's specific deviation from the average is not considered an "error".

Credits and Methods for Reducing Fees

Property owners must have a means for having their storm water utility fee reduced when they employ methods for reducing the amount of runoff generated by their property that enters the sewer system. The means for reducing the storm water utility fee can be accomplished through generally defined credits, or site specific modifications. Due to the method for determining the ESWU for the SFR properties, only credits are appropriate means for reducing their fee. Because the ESWU for non-single-family residential properties is determined on a site specific basis, measures taken for reducing runoff can be more directly applied.

Credits for SFR Properties

Credits for SFR properties must be applied for by the property owner following the process determined by the City to be most appropriate. As part of all applications, it should be clearly stated that application for the credit grants the City access to the property at any reasonable time to inspect or verify the measures related to the credit being applied for. Certain credits by their nature can easily be removed or discontinued, and could require annual application to ensure their continued use. In addition, the City should also have the right to revoke any credits given if the information provided is discovered to be false or if use of the measures were discontinued. Credits are only considered for low impact development (LID) measures that can actually reduce the amount of storm water that enters the sewer system, which benefits the entire City by reducing the treatment costs for storm water. While these measures would also have a water-quality benefit, that is not the primary goal for incentivizing their implementation. SFR credits can include some of the following:

- **Installing rain barrels** would collect the runoff from rooftops and prevent a portion of it from entering the sewer system. To qualify for this credit, the minimum requirements should include that one or more rain barrels be installed to collect the runoff from at least 50% of the main home's roof area, and that the barrels be at least 35 gallons in size. The application for the rain barrel credit should include a plan of the roof area of the home, the location and number of barrels installed, and they manufacturer and model number of the rain barrel installed. Suggested credit amount on the order of $10 to $20 annually.

- **Installing Rain Gardens or Bio-Swales** to collect the runoff from roofs and paved surfaces and prevent a portion of it from entering the sewer system. Rain gardens provide some surface storage volume that allows more time for infiltration and evapotranspiration (adsorption through plant roots) to occur, and can be installed in most soil types (appropriate plant selection based on soil types). This feature is not appropriate for poorly draining soils where captured water would not infiltrate within 24 hours. To qualify for this credit, the minimum requirements should include that at least 50% of the roof area (or equivalent amount of paved area) drain to the feature, the surface area be no less than 130 square feet, and that the depth provided be at least 3 to 6 inches throughout. The application for the rain garden credit should include a plan showing the areas draining to the rain garden, and dimensions of the feature. Rain gardens should be located at least 15 feet away from building foundations, and the overflow path should not go directly to paved surfaces or adjacent properties. Suggested credit amount on the order of $15 to $25 annually.

- **Installing Dry-Wells or Infiltration Trenches** to collect the runoff from roofs and paved surfaces and prevent a portion of it from entering the sewer system by taking advantage of the infiltration capacity of the soils on the property. Dry-wells and infiltration trenches are buried perforated structures or pipes surrounded by high porosity stone encapsulated by filter fabric. These features rely solely on the infiltration capacity of the soil and may only be applied where soil conditions warrant. To test the potential site's capacity for infiltration, a simple percolation test can be conducted by filling 18 inch deep hole (or deeper for dry-wells) with water, let it drain completely, fill with water again and measure time to drain. If less than 24 hours, then the infiltration capacity is adequate. Because these features promote quick, unfiltered infiltration, they should not be used in areas that have the potential to collect large amounts of sediment or where there is a high risk for surface contamination to be present. To qualify for this credit, the minimum requirements should include that at least 50% of the roof area (or equivalent amount of paved area) drain to the feature, and that the volume of the structure(s) and pipes be at least 33 cubic feet (or 250 gallons). The application for the dry-well or infiltration trench credit should include a plan showing the areas draining to the feature, and dimensions of the feature. Dry-wells and infiltration trenches should be located at least 15 feet away from building foundations, and the overflow path should not go directly to paved surfaces or adjacent properties. Suggested credit amount on the order of $20 to $30 annually.

- **Installing a Cistern** to collect the runoff from rooftops and prevent a portion of it from entering the sewer system. Cisterns are larger than rain barrels, and may be located below grade or at above ground. To qualify for this credit, the minimum requirements should include that the cistern be installed to collect the runoff from at least 50% of the main home's roof area, and have a minimum capacity of 500 gallons (or 66 cubic feet). The application for the cistern credit should include a plan of the roof area of the home, the location of the cistern installed, and they details and specifications of the cistern installed. Suggested credit amount on the order of $20 to $30 annually.

- **Installing Porous Pavement or Pavers** to replace otherwise impervious pavements. Porous paving systems must be specifically designed to promote infiltration, and include a porous stone base encapsulated with filter fabric. To qualify for this credit, the minimum requirements should include that the minimum surface area of the porous pavements be at least 200 square feet, and that the porous stone base thickness be at least 6 inches. Porous pavements should not be located within 10 feet of building foundations. Suggested credit amounts are $10 annually for 200 to 300 square feet, $20 annually for 300 to 400 square feet, and $30 annually for over 400 square feet.

- **Disconnecting Footing Drains** with an internal sump pump and outlet to grade. Sump pump discharges must be to a stable, pervious location on the same property, and not outlet or overflow directly to public sidewalks or streets, or to adjacent properties. Sump pump discharges should be at least 15 feet from the building foundation and preferably be collected in a rain garden, bio-swale, dry-well or infiltration trench. Footing drain disconnections require a plumbing permit through the City Building Department. Suggested credit amount on the order of $35 to $50 annually.

Typical details for the low impact development (LID) features mentioned in this section are included in Appendix C. These are excerpts from the Low Impact Development Manual for Michigan, published by SEMCOG, and are included for easy reference. The entire document can be found at http://semcog.org/Reports/LID/index.html.

Credits and Methods for Reducing Fees for NSFR Properties

Credits and other methods for reducing storm water utility fees for non-single family residential properties (NSFR) must be applied for by the property owner following the process determined by the City to be most appropriate. As part of all applications, it should be clearly stated that application for the credit grants the City access to the property at any reasonable time to inspect or verify the measures related to the credit being applied for. Certain credits by their nature can easily be removed or discontinued, and could require annual application to ensure their continued use. In addition, the City should also have the right to revoke any credits given if the information provided is discovered to be false or if use of the measures were discontinued. Credits are only considered for measures that can actually reduce the amount of storm water that enters the sewer system, which benefits the entire City by reducing the treatment costs for storm water. While these measures would also have a water-quality benefit, that is not the primary goal for incentivizing their implementation. NSFR credits or methods for reducing fees can include some of the following:

- **Install LID Features** as described for SFR properties. Suggested credit amounts similar to those noted for SFR properties. However, NSFR property owner can elect to apply for a reduction in their storm water utility fee in excess of the specified credit amount by demonstrating that the calculated ESWU for the parcel considering implementation of properly designed LID features, with impervious areas draining to the features considered to be pervious, will have a greater cost reduction. To qualify for fee reductions in excess of specified credit amounts, plans, details, specifications and calculations for the proposed features must be prepared by a licensed Professional Engineer.

- **Install On-Site Detention Systems** designed to capture and infiltrate 0.5 inches of rainfall on the site. Systems that only detain flows, and slowly release to the sewer system benefit the sewer system by reducing the peak flow from the site during intense rain events, but do not reduce the volume of storm water that eventually enters the sewer system and has to be treated. To qualify for a fee reduction for a detention system, plans, details, specifications and calculations for the proposed features must be prepared by a licensed Professional Engineer.

- **Install Green Roofs or Other LID Building features** designed to capture 0.5 inches of rainfall on the site. To qualify for a fee reduction for other types of systems, plans, details, specifications and calculations for the proposed features must be prepared by a licensed Professional Engineer.

Typical details for the low impact development (LID) features mentioned in this section are included in Appendix C. These are excerpts from the Low Impact Development Manual for Michigan, published by SEMCOG, and are included for easy reference. The entire document can be found at http://semcog.org/Reports/LID/index.html.

<u>Process for Updating Apportionment Roll</u>

A process should be established for updating the apportionment roll on an annual basis. The updates would include property transactions (splits or combinations), developments, additions, modifications, adjustments, and corrections that had occurred in the previous year. After changes are made to the property data, ESWU values would be recalculated along with each parcel's share of the overall cost to be apportioned. In addition, when new impervious surface data is available from SEMCOG, we would recommend that the average impervious area measurements for the SFR classifications be updated, and new values be established for the "standard" ESWU.

Appendix A

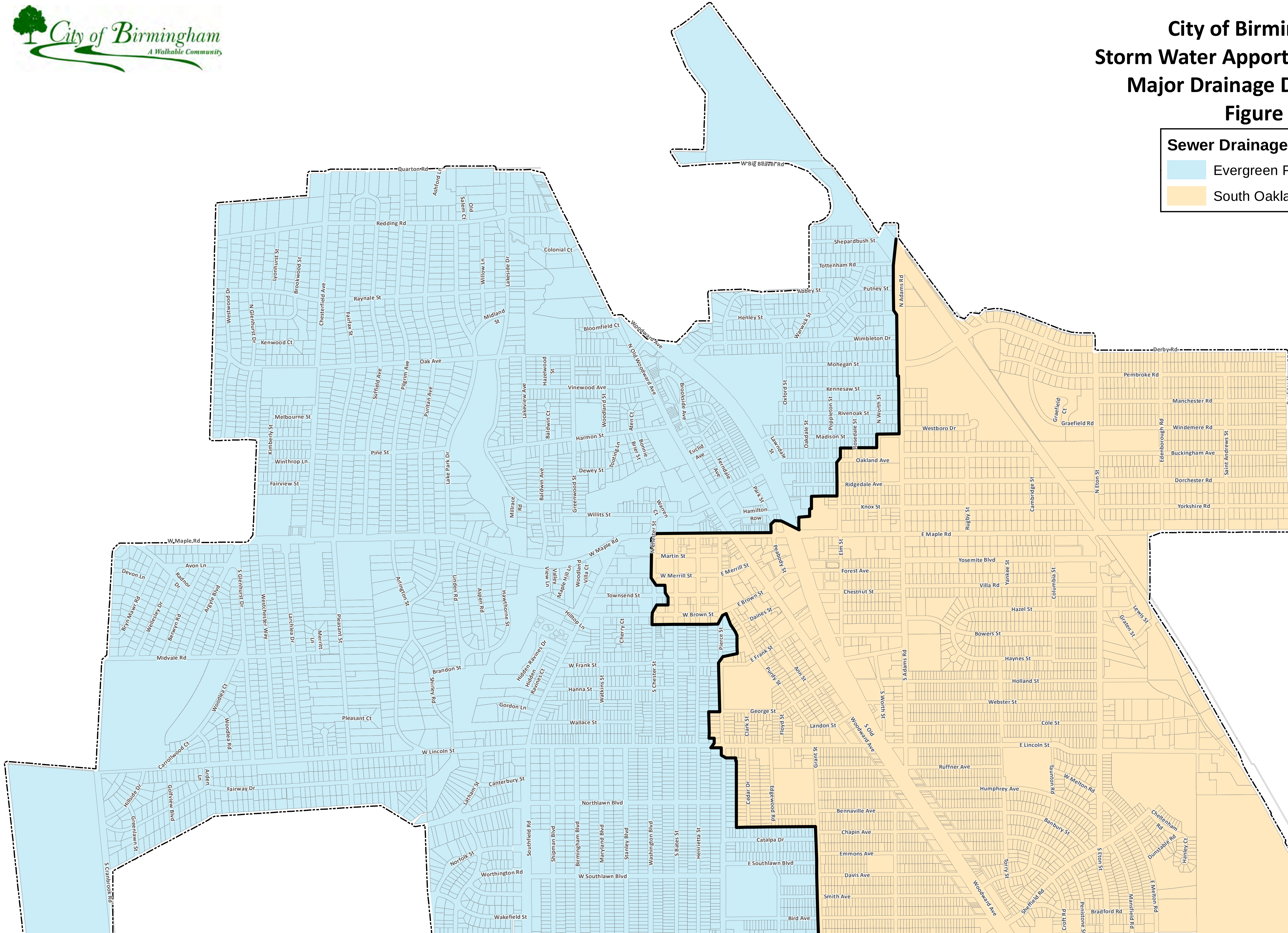
Figure 1 – Major Drainage District Map

Figure 2 – Single Family Residential Parcel Map

Figure 3 – Non-Single Family Residential Parcel Map

City of Birmingham
A Walkable Community

City of Birmingham
Storm Water Apportionment Study
Major Drainage District Map
Figure 1



Sewer Drainage Districts

- Evergreen Farmington
- South Oakland

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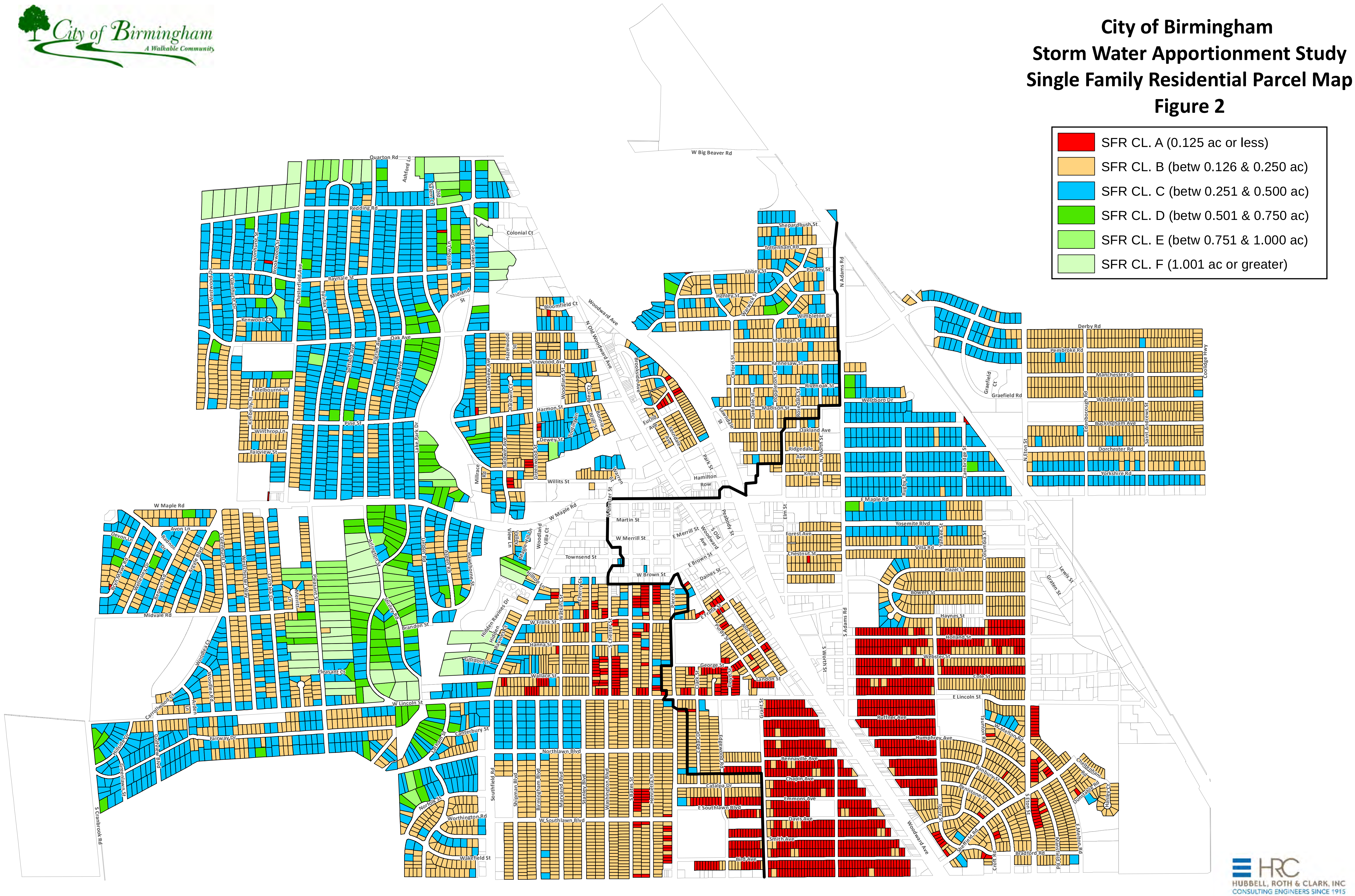
City of Birmingham
Storm Water Apportionment Study
Single Family Residential Parcel Map
Figure 2



HRC
HUBBELL, ROTH & CLARK, INC
CONSULTING ENGINEERS SINCE 1915

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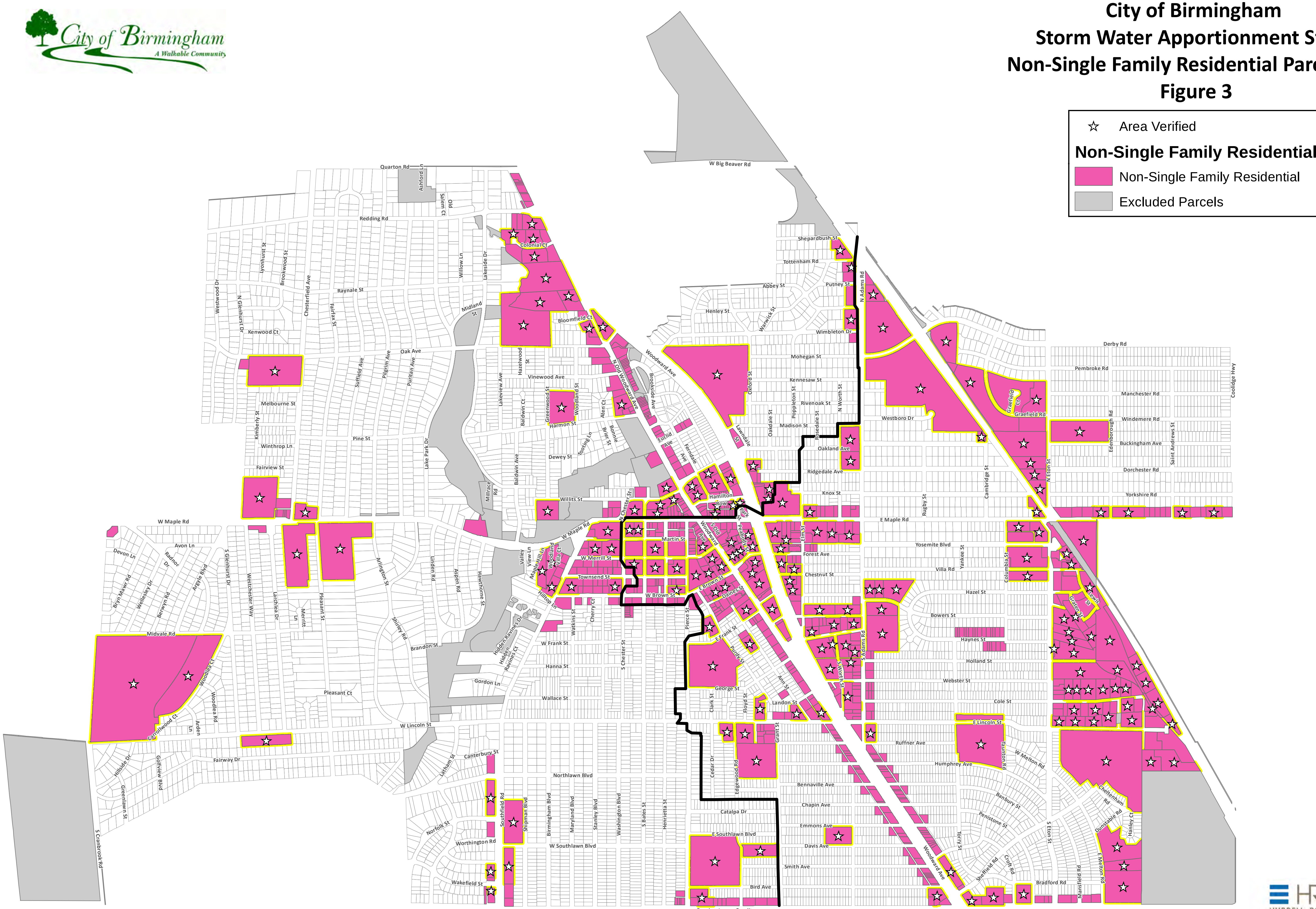
City of Birmingham
Storm Water Apportionment Study
Non-Single Family Residential Parcel Map
Figure 3



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Appendix C

Low Impact Development Guidelines & Details

(excerpts from Low Impact Development Manual for Michigan – published by SEMCOG http://semcog.org/Reports/LID/index.html)

Each fact sheet includes:

BMP Fact Sheet

Title

Short definition of BMP

Applications – Indicates in what type of land use BMP is applicable or feasible (**Yes, No,** or **Limited**).

Stormwater Quantity Functions – Indicates how well the BMP functions in mitigating stormwater management criteria (**High, Medium,** or **Low**).

Stormwater Quality Functions – Indicates how well the BMP performs in terms of pollutant removal (**High, Medium,** or **Low**).

Applications		Stormwater Quantity Functions	
Residential		**Volume**	
Commercial		**Groundwater Recharge**	
Ultra Urban		**Peak Rate**	
Industrial		**Stormwater Quality Functions**	
Retrofit		**TSS** – Total Suspended Solids	
Highway/Road		**TP** – Total Phosphorus	
Recreational		**TN** or **NO3** – Total Nitrogen/Nitrate	
		Temperature	

Additional Considerations

Cost – Indicate whether cost is high, medium or low by the following categories

- **High** – => adds more than 5% to total project cost
- **Medium** – adds 1–5% to total project cost
- **Low** – =< adds less than 1% to total project cost

Maintenance – Indicates level of maintenance required to maintain BMP (**High, Medium,** or **Low**).

- **High** – Maintenance intensive (i.e., year-round maintenance)
- **Medium** – Several times per year
- **Low** – One time per year

Winter Performance – Indicates if BMP provides equivalent performance throughout the winter (**High, Medium,** or **Low**)

- **High** – BMP performs very well in winter conditions
- **Medium** – BMP has reduced performance in winter conditions
- **Low** – BMP still performs in winter conditions, but performance is significantly reduced.

Variations (optional)

List of variations to the BMP if applicable

Key Design Features

Bulleted list of information that is key to the design of BMP

Site Factors (optional)

List of specific factors that relate to BMP performance:

- Water table/bedrock separation distance
- Soil type
- Feasibility on steeper slopes
- Applicability on potential hotspots (e.g., brownfields)

Benefits

List of benefits directly related to implementing the BMP

Limitations

List of site constraints associated with implementation

BMP Fact Sheet

Bioretention (Rain Gardens)

Bioretention areas (often called rain gardens) are shallow surface depressions planted with specially selected native vegetation to capture and treat stormwater runoff from rooftops, streets, and parking lots.

Formal Rain Garden, Traverse City, MI

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Med/High
Ultra Urban	Limited	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Yes	**TP**	Medium
Recreational	Yes	**TN**	Medium
		Temperature	High

Additional Considerations	
Cost	Medium
Maintenance	Medium
Winter Performance	Medium

Variations

- Subsurface storage/ infiltration bed
- Use of underdrain
- Use of impervious liner

Key Design Features

- Flexible in size and infiltration
- Ponding depths 6-18 inches for drawdown within 48 hours
- Native plants
- Amend soil as needed
- Provide positive overflow for extreme storm events

Site Factors

- Water table/bedrock separation: two-foot minimum, four foot recommended
- Soils: HSG A and B preferred; C & D may require an underdrain (see Infiltration BMP)
- Feasibility on steeper slopes: Medium
- Potential hotspots: Yes with pretreatment and/or impervious liner
- Max. drainage area: 5:1, not more than 1 acre to one area

Benefits

- Volume control and groundwater recharge, moderate peak rate control, filtration
- Versatile with broad applicability
- Enhance site aesthetics, habitat
- Potential air quality and climate benefits

Limitations

- Higher maintenance until vegetation is established
- Limited impervious drainage area
- Requires careful selection and establishment of plants

Case Study: Grayling Stormwater Project

The Grayling Stormwater Project is an example of a hybrid project that combines LID with end-of-pipe treatment. This project demonstrates that a small community is capable of making the fundamental shift in management towards LID and providing leadership for other communities to make similar changes.

The measures taken will eliminate approximately 80 percent of the water pollution from the city.

Typical Grayling Rain Garden, July 2007
Source: Huron Pines

This large-scale project includes 86 rain gardens along with installation of an "end-of-the-pipe" detention basin and seven underground Vortechnic oil-grit separator units. Several of the rain gardens that are smaller or that need to accommodate higher volumes of water were installed with underdrains, but most use the natural infiltration capacity of the area's sandy soils.

Currently, all major outfalls of stormwater from the City of Grayling are being treated by one or more of these measures. Future plans for the project include a maintenance program with incentives for landowners who water and weed their rain gardens, and an outreach program to educate the public and help other communities voluntarily integrate LID into their stormwater management.

Case Study Site Considerations	
Project Type	Protect sensitive/special value features, rain gardens/bioretention, detention/extended detention, filters (specifically oil-grease separators)
Soil Conditions	Sandy and extremely well drained
Estimated Total Project Cost	$1.2 million
Maintenance Responsibility	City of Grayling – maintenance of Vortechnic Units, Huron Pines – establishment of plants
Project Contact	Jennifer Muladore, 989-344-0753 ext 30, Jennifer@huronpines.org

Lessons Learned

The rain gardens were planted with seed and a few shrubs. The seed did not grow well, most likely due to the harsh cold winters and hot, dry summers in the Grayling area, where plants take a lot longer to establish in the extremely well-drained, sandy soils.

Plants that thrive in dry soils do need frequent watering to survive (project contracted out to a local landscaping company for watering).

In addition, many of the residents in the neighborhood are not happy with the "wild" seeded look and would rather have had more manicured gardens. In future phases, the City of Grayling will plant fewer gardens with larger plant stock and try to locate them where homeowners are more interested in helping to maintain them.

Description and Function

Bioretention is a method of managing stormwater by pooling water within a planting area and allowing the water to infiltrate the garden. In addition to managing runoff volume and reducing peak discharge rates, this process filters suspended solids and related pollutants from stormwater runoff. Bioretention can be implemented in small, residential applications (Figure 7.3) or as part of a management strategy in larger applications (Figure 7.4).

Figure 7.3
Residential Rain Garden

Source: Rain Gardens of West Michigan

Figure 7.4
Commercial Rain Garden

Source: Rain Gardens of West Michigan

Bioretention is designed into a landscape as a typical garden feature, to improve water quality while reducing runoff quantity. Rain gardens can be integrated into a site with a high degree of flexibility and can integrate nicely with other structural management systems including porous pavement parking lots, infiltration trenches, and other *non-structural* stormwater BMPs.

Bioretention vegetation serves to filter (water quality) and transpire (water quantity) runoff, and enhance infiltration. Plants absorb pollutants while microbes associated with the plant roots and soil break them down. The soil medium filters out pollutants and allows storage and infiltration of stormwater runoff, providing volume control. In addition, engineered soil media may serve as a bonding surface for nutrients to enhance pollutant removal.

Properly designed bioretention techniques provide a layer of compost that acts like a sponge to absorb and hold runoff. Vegetation in the rain garden can be diverse, through the use of many plant species and types, resulting in a system tolerant to insects, diseases, pollution, and climatic stresses.

The term "rain garden" is used to refer to smaller-scale bioretention facilities typically found on residential properties.

Bioretention can Accomplish the Following:

- Reduce runoff volume
- Filter pollutants, through both soil particles (which trap pollutants) and plant material (which take up pollutants)
- Provide habitat
- Recharge groundwater (if no underdrain is placed underneath)
- Reduce stormwater temperature impacts
- Enhance site aesthetics

Figure 7.5 illustrates a schematic of a relatively simple bioretention area (or rain garden). Figure 7.6 illustrates a schematic of a bioretention area that is a more technically engineered structure, designed to complete specific stormwater management goals. Pond depth, soil mixture, infiltration bed, perforated underdrains, domed risers, and positive overflow structures may be designed according to the specific, required stormwater management functions.

Figure 7.5
Schematic of a small residential rain garden

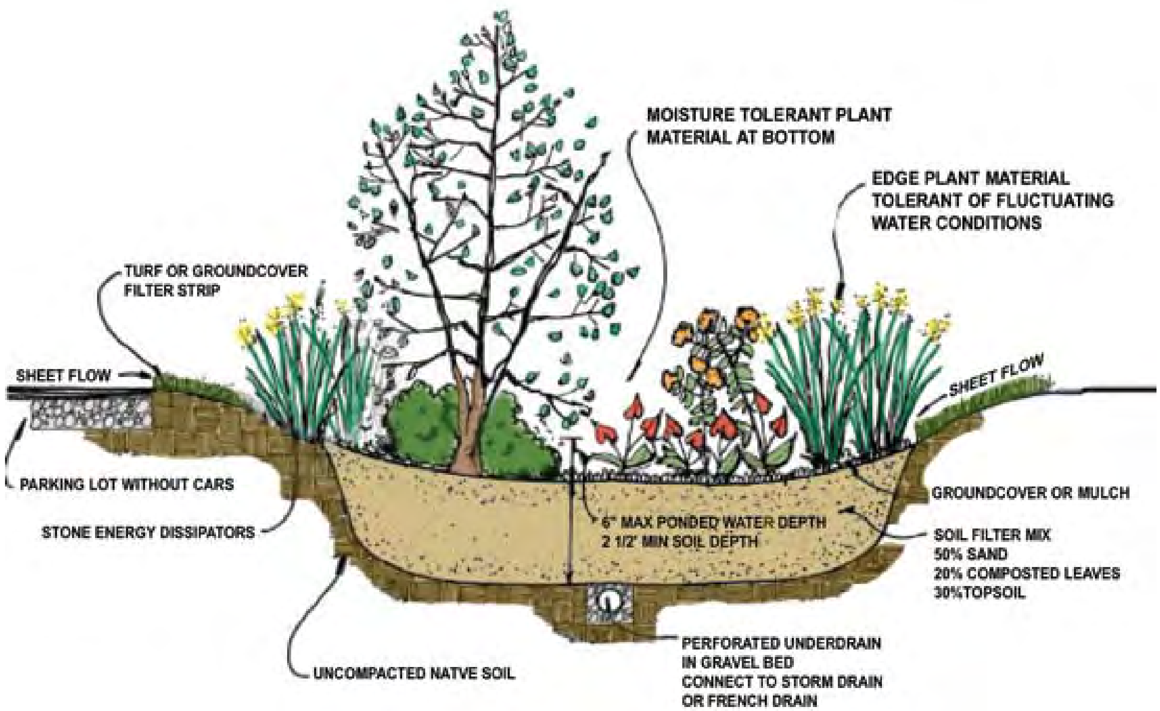
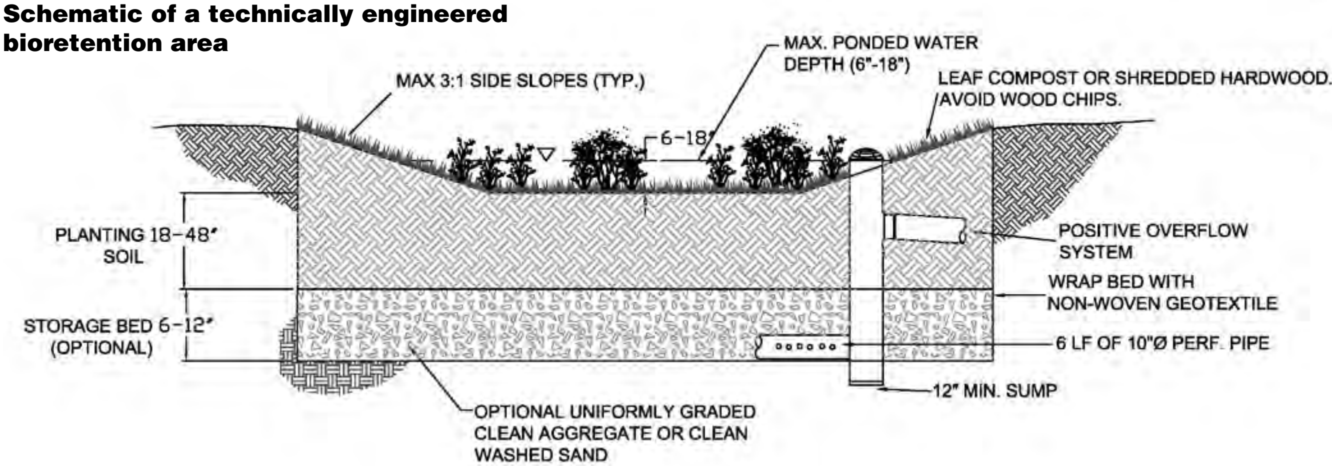


Figure 7.6
Schematic of a technically engineered bioretention area



Source: Prince George's County Bioretention Manual with modifications by Cahill Associates, 2004

Variations

A bioretention system is a depression in the ground planted like a garden that provides for the storage and infiltration of relatively small volumes of stormwater runoff, often managing stormwater on a lot-by-lot basis. This use of many small stormwater controls versus one large detention area promotes the low impact development goal of decentralized treatment of stormwater. But, if greater volumes of runoff must be managed or stored, a bioretention system can be designed with an expanded subsurface infiltration bed, or can be increased in size. Typically, the ratio of impervious area draining to the bioretention area should not exceed five-to-one, and the total impervious area draining to a single system should not be more than one acre. Variations noted relate to performance types, flow entrance, and positive overflow.

Performance types

Depending on varying site conditions, bioretention can be designed to allow for 1) complete infiltration, 2) infiltration/filtration, or 3) filtration. These variations will often determine the need for such design features as the gravel bed, underdrains, and impervious liners.

Bioretention using complete infiltration occurs in areas where groundwater recharge is beneficial and the soils have the permeability necessary to accommodate the inflow. This type of BMP is often less expensive to construct because there is no underdrain and the soils on site are often used.

The most common variation to this type of bioretention includes a gravel or sand bed underneath the planting bed and often accompanied by the use of an underdrain. This allows for additional storage or for areas with low permeability to use bioretention as infiltration, as well as, filtration (Figure 7.6). Some volume reduction will occur through infiltration, as well as evaporation and transpiration.

Signage at Rouge River rain garden

Another variation is to use bioretention primarily for filtration. This is often used in contaminated soils or hot spot locations using an impervious liner to prevent infiltration and groundwater contamination. The primary stormwater function then becomes filtration with some volume reduction through evaporation and transpiration.

For areas with low permeability, bioretention may achieve some infiltration while acting as detention with peak rate control for all storms up to the design storm.

Flow inlet

Pretreatment of runoff should be provided where sediment or pollutants entering the rain garden may cause concern or decreased BMP functionality. Soil erosion control mats, blankets, or rock must be used where runoff flows from impervious areas enter the rain garden.

Flow inlet: Trench drain

Trench drains can accept runoff from impervious surfaces and convey it to a rain garden (Figure 7.7). The trench drain may discharge to the surface of the rain garden or may connect directly to an aggregate infiltration bed beneath.

Figure 7.7
Trench drain and curb cut connected to bioretention area

Source: Macomb County Planning and Economic Development

Educational Signage

Once a bioretention area is established, installing signage will help the general public and maintenance crews recognize LID practices which can help promote sustainable stormwater management. Educational signs can incorporate LID goals, and maintenance objectives in addition to the type of LID project being employed.

Flow inlet: Curbs and curb cuts

Curbs can be used to direct runoff from an impervious surface along a gutter to a low point where it flows into the rain garden through a curb cut. Curb cuts may be depressed curbs (Figure 7.8), or may be full height curbs with openings cast or cut into them.

Figure 7.8
Curb cut into bioretention area/rain garden

Source: Huron Pines

Positive overflow

A positive overflow, via the surface or subsurface, is recommended to safely convey excessive runoff from extreme storm events.

Positive overflow: Domed riser

A domed riser may be installed to ensure positive, controlled overflow from the system (Figure 7.9). Once water ponds to a specified depth, it will begin to flow into the riser through a grate, which is typically domed to prevent clogging by debris.

Figure 7.9
Positive Overflow Device: Domed riser at Macomb County Public Works Office

Source: Macomb County Public Works Office

Positive overflow: Inlet structure

An inlet structure may also be installed to ensure positive, controlled overflow from the system. Once water ponds to a specified depth, it will begin to flow into the inlet.

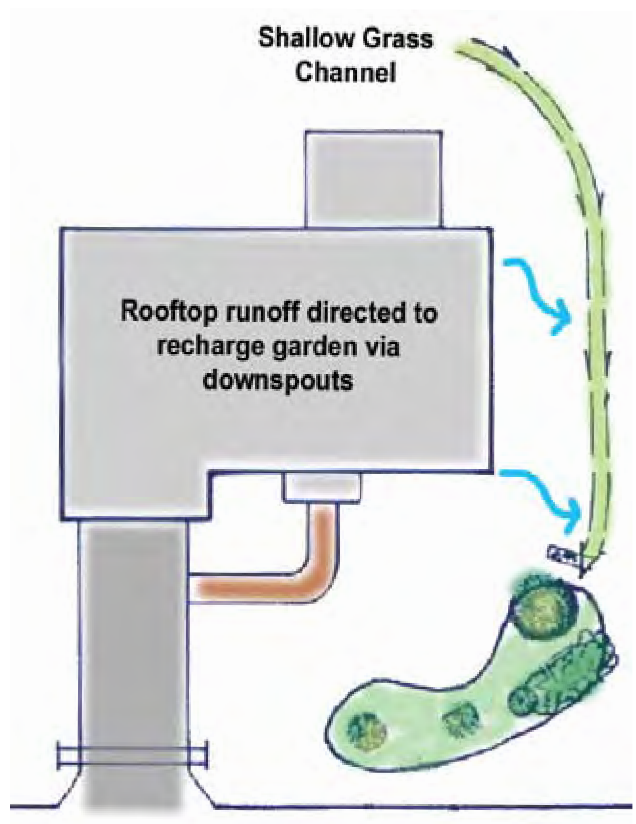
Applications

Bioretention areas can be used in a variety of applications, from small areas in residential lawns to extensive systems in commercial parking lots (incorporated into parking islands or perimeter areas). Industrial, retrofit, highway/road, and recreational areas can also readily incorporate bioretention. One key constraint in using bioretention in ultra-urban settings is space.

Residential

The residential property owner that wants to design and build a rain garden at home does not need to go through the engineering calculations listed under stormwater calculations and functions. Assistance with simple rain gardens is available from several sources listed under the Plant Selection portion of this BMP.

Figure 7.10
Single-family residential lot drainage schematic



Claytor and Schueler, 1995 with modifications by Cahill Associates

Figure 7.11
Residential rain garden

Source: Pokagon Band of Potawatomi Indians

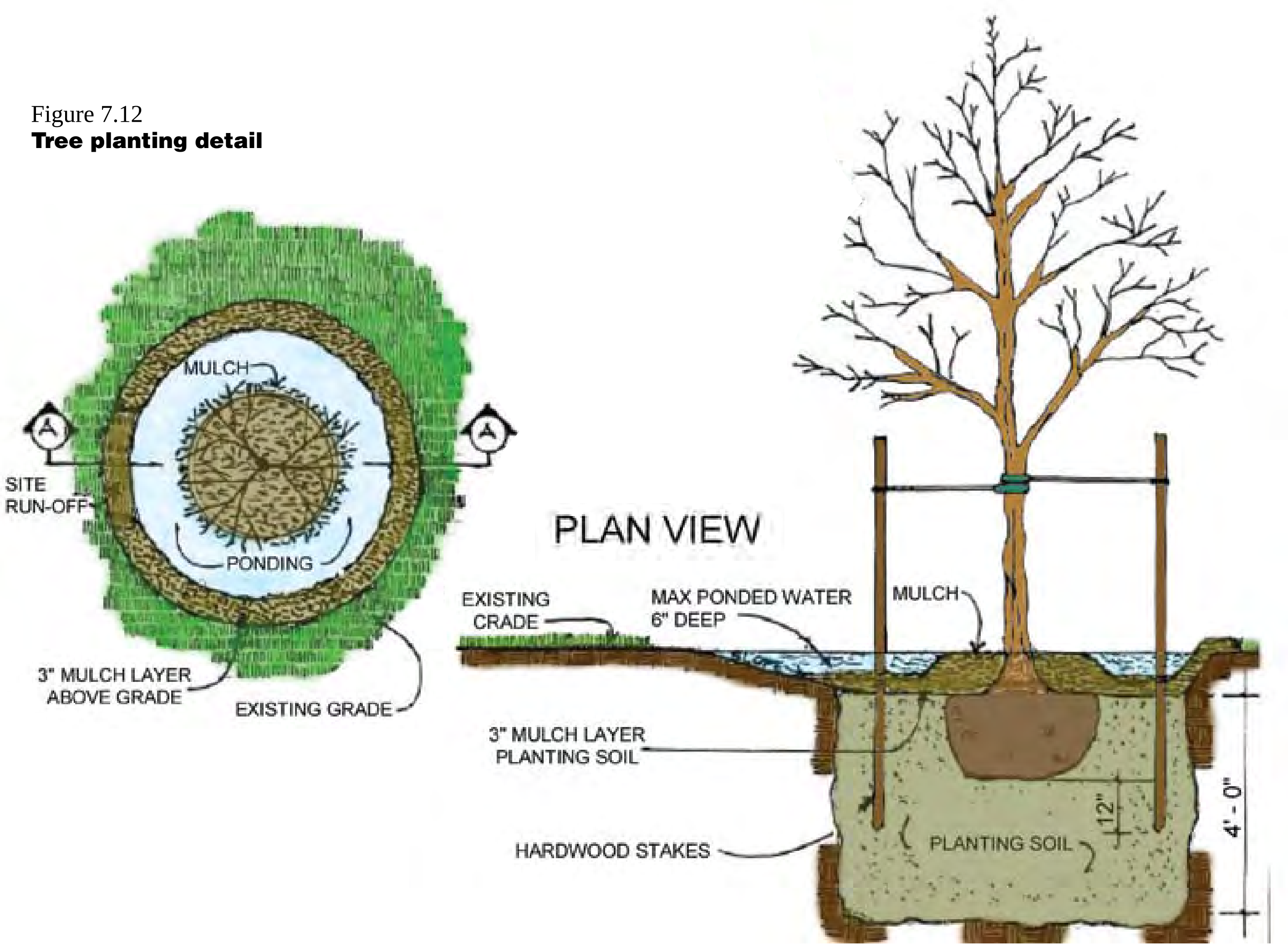
Figure 7.10 shows a typical rain garden configuration on a residential property. The rain garden shown in Figure 7.11 represents a simple design that incorporates a planting bed adjacent to an uncurbed road.

Another source of water for a small rain garden is connecting the roof leader from adjacent buildings. The stormwater may discharge to the surface of the bioretention area or may connect directly to an aggregate infiltration bed beneath.

Tree and shrub pits

Tree and shrub pits intercept runoff and provide shallow ponding in mulched areas around the tree or shrub (Figure 7.12). Mulched areas should typically extend to the tree's drip line.

Figure 7.12
Tree planting detail



Source: Prince George's County, Maryland, The Bioretention Manual with modifications by Cahill Associates, 2004

Roads and highways

Figure 7.13 shows a linear bioretention area feature along a highway. Runoff is conveyed along the concrete curb (bottom of photo) until it reaches the end of the gutter, where it spills into the vegetated area.

Figure 7.13
Linear Bioretention Area along Roadway

Source: Low Impact Development Center, Inc.

Parking lot island bioretention

In parking lots for commercial, industrial, institutional, and other uses, stormwater management and green space areas are limited. In these situations, bioretention areas for stormwater management and landscaping may provide multiple benefits (Figure 7.14).

A bioretention area in a parking lot can occur in parking lots with no curbs and with curbs. The no-curb alternative allows stormwater to sheet flow over the parking lot directly into the bioretention area.

In a curbed parking lot, runoff enters the bioretention area through a curb cut. If the runoff volume exceeds the ponding depth available, water overflows the bioretention area and enters a standard inlet (Figure 7.15).

A variation on this design is a direct underground connection to the standard inlet from the underground aggregate infiltration bed via an overflow pipe.

Figure 7.15
Standard inlet to allow for overflow from the bioretention area

Source: Low Impact Development Center, Inc.

Figure 7.14
Bioretention area within parking lot

Source: City of Rochester Hills

Primary Components of a Bioretention System

1. Pretreatment (may be necessary to help prevent clogging)

- Sediment removal through a vegetated buffer strip, cleanout, stabilized inlet, water quality inlet, or sediment trap prior to runoff entry into the bioretention area

2. Flow inlet

- Varies with site use (e.g., parking island versus residential lot applications – see Figures 7.11 through 7.14)
- Entering velocities must be non-erosive – use erosion control mats, blankets, or rock where concentrated runoff enters the bioretention area

3. Ponding area

- Provides temporary surface storage of runoff and allows sediment to settle
- Provides evaporation for a portion of runoff
- Depth no more than 6-18 inches for aesthetics, functionality, and safety

4. Plant material (see Appendix C for recommended plant lists)

- Absorbs stormwater through transpiration
- Root development creates pathways for infiltration
- Bacteria community resides within the root system creating healthy soil structure with water quality benefits
- Can improve aesthetics for site
- Provides habitat for animals and insects
- Reinforces long-term performance of subsurface infiltration
- Ensures plants are salt tolerant if in a location that would receive snowmelt chemicals
- Should be native plant species and placed according to drought and water tolerance

5. Organic layer or mulch

- Acts as a filter for pollutants in runoff
- Protects underlying soil from drying and eroding
- Simulates leaf litter by providing environment for microorganisms to degrade organic material
- Provides a medium for biological growth, decomposition of organic material, adsorption and bonding of heavy metals
- Wood mulch should be shredded – compost or leaf mulch is preferred

6. Planting soil/volume storage bed

- Provides water/nutrients to plants
- Enhances biological activity and encourages root growth
- Provides storage of stormwater by the voids within the soil particles
- Provides surface for adsorption of nutrients

7. Positive overflow

- Provides for the direct discharge of runoff during large storm events when the subsurface/surface storage capacity is exceeded
- Examples of outlet controls include domed risers, inlet structures, and weirs

Design Considerations

Bioretention is flexible in design and can vary in complexity according to site conditions and runoff volume requirements. Design and installation procedures may vary from very simple for “backyard” rain gardens to highly engineered bioretention areas in ultra-urban areas.

Infiltration BMPs should be sited so that they minimize risk to groundwater quality and present no threat to subsurface structures. Table 7.4 provides recommended setback distances of bioretetnion areas to various lot elements.

Table 7.4
Setback distances

Setback from	Minimum distance (feet)
Property line	10
Building foundation*	10
Private well	50
Public water supply well**	50
Septic system drainfield***	100

* minimum with slopes directed away from building

** At least 200 feet from Type I or IIa wells, 75 feet from Type IIb and III wells (MDEQ Safe Drinking Water Act, PA 399)

*** 50 feet for septic systems with a design flow of less than 1,000 gallons per day

The distance from the bottom of the infilration BMP to the seasonal high groundwater level or bedrock is recommended to be four feet. Two feet is allowable, but may reduce the performance of the BMP.

Bioretention is best suited for areas with at least moderate infiltration rates (more than 0.25 inches per hour) – see Infiltration BMP. In extreme situations where permeability is less than 0.25 inches per hour, special variations may apply, such as using amended subsoils or underdrains (or using constructed wetlands instead). The following procedures should be considered when designing bioretention areas:

1. The **flow entrance** must be designed to prevent erosion in the bioretention area. Some alternatives include flared end sections, erosion control mats, sheet flow into the facility over grassed areas, rock at entrance to bioretention area, curb cuts with grading for sheet flow, and roof leaders with direct surface connection.
2. **A positive overflow system** should be designed to safely convey away excess runoff. The overflow can be routed to the surface in a non-erosive manner or to another stormwater system. Some alternatives include domed risers, inlet structures, weirs, and berms.
3. Sizing criteria
   a. **Surface area** is dependent upon storage volume requirements, but should generally not exceed a maximum loading ratio of 5:1 impervious drainage area to bioretention area and no more than one acre drainage area to one bioretention cell. However, for design purposes, the total volume of water generated from the contributing drainage area must be used, not just the impervious portion. See Infiltration BMP for additional guidance on loading ratios.

      The required bioretention surface area is determined by taking the volume of runoff to be controlled according to LID criteria, maintaining the maximum ponding depth, the loading rate, and the emptying time. Infiltration and evapotranspiration are increased by increasing the surface area of the bioretention area. The total surface area needed may be divided into multiple cells. This configuration may be useful to collect runoff from both the front and back of a building.

   b. Surface side slopes should be gradual. For most areas, maximum 3:1 side slopes are recommended.
   c. The recommended surface ponding depth is six inches. Up to 18 inches may be used if plant selection is adjusted to tolerate water depth. Drain within 24-48 hours.
   d. **Ponding area** should provide sufficient surface area to meet required storage volume without exceeding the design ponding depth. The


Preparing bed with planting soil
Source: City of Troy

subsurface infiltration bed is used to supplement surface storage where appropriate.

4. **Planting soil depth** should generally be between 18 and 48 inches where only herbaceous plant species will be used. If trees and woody shrubs will be used, soil media depth may be increased, depending on plant species. Native soils can be used as planting soil or modified to be suitable on many sites. Small, backyard rain gardens can generally use existing soils without a specialized depth. Planting soil should be approximately four inches deeper than the bottom of the largest root ball.

5. **Planting soil** should be capable of supporting a healthy vegetative cover. Soils should be amended with a composted organic material. A recommended range of a soil mixture is 20-40 percent organic material (compost), 30-50 percent sand, and 20-30 percent topsoil, although any soil with sufficient drainage may be used for bioretention.

   Soils should also have a pH of between 5.5 and 6.5 (better pollutant adsorption and microbial activity), a clay content less than 10 percent (a small amount of clay is beneficial to adsorb pollutants and retain water although no clay is necessary if pollutant loadings are not an issue), be free of toxic substances and unwanted plant material, and have a 5-10 percent organic matter content. Additional organic matter can be added to the soil to increase water holding capacity.

   If brought from off site, **sand** should be clean, coarse, and conform to ASTM C-33 (Standard Specification for Concrete Aggregates).

   If the void space within an amended soil mix will be used in calculating runoff volume capacity in the system, tests should be conducted on the soil's porosity to determine the available storage capacity.

Selecting proper plants
Source: City of Troy

6. Proper **plant selection** is essential for bioretention areas to be effective. Typically, native floodplain or wet meadow plant species are best suited to the variable environmental conditions encountered in a bioretention area. Suggested species may include Cardinal Flower (*Lobelia cardinalis*), Blue Lobelia (*Lobelia siphilitica*), New England Aster (*Aster novae-angliae*), and Brown Fox Sedge (*Carex vulpinoidea*) (See recommended Plant List in Appendix C for a detailed list).

   In most cases, seed is not the preferred method for establishing plants in a bioretention area. The fluctuating water levels make it difficult for the seed to readily establish, while the random nature of seeding produces a look previous experience indicates is unacceptably "wild." Therefore, it is strongly recommended that live plant material in plug or gallon-potted form be used and installed on 1-2 foot centers for a more formal appearance. Shrubs and trees are also recommended to be included in a bioretention area.

   A landscape architect can be used to design a native planting layout. Additional resources for planting layouts are Rain Gardens for West Michigan (www.raingardens.org), Washtenaw County Free Designs, Wild Ones Natural Landscapers, and MDEQ Landscaping for Water Quality booklets.

7. **Planting periods** will vary but, in general, trees and shrubs should be planted from mid-April through early June, or mid-September through mid-November. Native seed should be installed between October 1 and June 1. Live plant material (plugs or gallon pots) should be installed between May 1 and June 15. Planting dates may be lengthened if a regular water source can be provided. Likewise, planting should be ceased at an earlier date in the event of a drought year.
8. A maximum of 2-3 inches of shredded hardwood **mulch** aged at least six months to one year or leaf compost (or other comparable product) should be uniformly applied immediately after shrubs and trees are planted to prevent erosion, enhance metal removals, and simulate leaf litter in a natural forest system. Wood chips should be avoided as they tend to float during inundation periods. Mulch or compost should not exceed three inches in depth or be placed directly against the stems or trunks of plants to maintain oxygen flow.
9. When working in areas with **steeper slopes**, bioretention areas should be terraced laterally along slope contours to minimize earthwork and provide level areas for infiltration.
10. A subsurface **storage/infiltration bed**, if used, should be at least six inches deep and constructed of clean gravel with a significant void space for runoff storage (typically 40 percent) and wrapped in geotextile fabric.
11. **Underdrains** are often not needed unless in-situ soils are expected to cause ponding lasting longer than 48 hours. If used, underdrains are typically small diameter (6-12-inches) perforated pipes in a clean gravel trench wrapped in geotextile fabric (or in the storage/infiltration bed). Underdrains should have a flow capacity greater than the total planting soil infiltration rate and should have at least 18 inches of soil/gravel cover. They can daylight to the surface or connect to another stormwater system. A method to inspect and clean underdrains should be provided (via cleanouts, inlet, overflow structure, etc.)

Underdrain in trench

Source: City of Rochester Hills

Recycled asphalt product (RAP) used throughout parking lot and left behind curb to give structural support.

Underdrain excavation, three feet wide, six inches deep. Peastone was placed in excavation.

Four-foot-diameter catch basins, used as overflows. Rim elevation set nine inches above mulch layer to allow nine inches of ponding before overflow occurs. Two catch basins used to ensure stormwater doesn't overflow to parking lot.

Source: City of Rochester Hills

Stormwater Functions and Calculations

When designing a bioretention area, it is recommended to follow a two-step process:

1. Initial sizing of the bioretention area based on the principles of Darcy's Law.
2. Verify that the loading ratio and the necessary volume reductions are being met.

Initial sizing of the bioretention area

Bioretention areas can be sized based on the principles of Darcy's Law, as follows:

With an underdrain:

$A_f = V \times d_f / [k \times (h_f + d_f) \times t_f]$

Without an underdrain:

$A_f = V \times d_f / [i \times (h_f + d_f) \times t_f]$

Where:

A_f = surface area of filter bed (ft^2)

V = required storage volume (ft^3)

d_f = filter bed depth (ft)

k = coefficient of permeability of filter media (ft/day)

i = infiltration rate of underlying soils (ft/day)

h_f = average height of water above filter bed (ft)

t_f = design filter bed drain time (days)

A "quick check" for sizing the bioretention area is to ignore the infiltration rate and calculate the storage volume capacity of the bioretention area as follows:

A_{inf} = (Area of bioretention area at ponding depth + Bottom area of bioretention area) divided by two = Infiltration area (average area)

The size of the infiltration area is determined by the volume of water necessary to remove as determined by LID criteria, depth of the ponded area (not to exceed 18 inches), infiltration rate of the soil, loading ratio, and, if applicable, any subsurface storage in the amended soil or gravel.

This volume can be considered removed if the bioretention is not underdrained. If the bioretention cell is underdrained, consider the bioretention cell as a detention device with the volume calculated above discharged to a surface water over time t_f.

Verification of meeting volume reduction requirements

The bioretention facility should be sized to accommodate the desired volume reductions (see Chapter 9 for Volume Control Criteria). This can be based on water quality volume (e.g., first inch of runoff from the site) or based on size storm event (e.g., no net increase based on presettlement conditions of the two-year, 24-hour event).

The volume of a bioretention area can have three components: surface storage volume, soil storage volume, and infiltration bed volume. These three components should be calculated separately and added together. The goal is that this total volume is larger than the required volume reduction that is often included in local ordinances. If the total volume is less than the required volume, another adjustment may be needed to the bioretention area (e.g., increased filter bed depth).

Total volume calculation:

1. Surface storage volume (ft^3) = Average bed area (ft^2) x Maximum design water depth (ft)
2. Soil storage volume (ft^3) = Infiltration area (ft^2) x Depth of amended soil (ft) x Void ratio of amended soil.
3. Subsurface storage/Infiltration bed volume (ft^3) = Infiltration area (ft^2) x Depth of underdrain material (ft) x Void ratio of storage material

Total bioretention volume = Surface storage volume + Soil storage volume (if applicable) + Infiltration bed volume (if applicable).

Peak rate mitigation

Chapter 9 provides information on peak rate mitigation methodology and addresses links between volume reduction and peak rate control. Underdrained bioretention acts as a detention practice with a discharge rate roughly equal to the infiltration rate of the soil x the average bed area.

Water Quality Improvement

The reported water quality benefits of bioretention can be expected to remove a high amount of total suspended solids (typically 70-90 percent), a medium amount of total phosphorus (approximately 60 percent), and a medium amount of total nitrogen (often 40-50 percent). In areas with high sediment loading, pretreatment of runoff can significantly reduce the amount of bioretention maintenance required (See Chapter 9 for water quality calculation procedures).

Construction Guidelines

The following is a typical construction sequence (Note for all construction steps: Erosion and sediment control methods need to adhere to the latest requirements of MDEQ's Soil Erosion and Sedimentation Control Program and local standards).

1. Complete site grading, minimizing compaction as much as possible. If applicable, construct curb cuts or other inflow entrance, but provide protection so that drainage is prohibited from entering the bioretention construction area. Construct pre-treatment devices (filter strips, swales, etc.) if applicable.
2. Subgrade preparation
   a Existing subgrade in rain gardens should not be compacted or subject to excessive construction equipment traffic. Loads on the subgrade should not exceed four pounds per square inch.
   b. Initial excavation can be performed during rough site grading, but should not be carried to within one foot of the final bottom elevation. Final excavation should not take place until all disturbed areas in the drainage area have been stabilized.
   c. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding in the graded bottom, this material should be removed with light equipment and the underlying soils scarified to a minimum depth of six inches with a york rake or equivalent by light tractor.
   d. Bring subgrade of bioretention area to line, grade, and elevations indicated. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All bioretention areas should be level grade on the bottom.
3. Stabilize grading except within the bioretention area. Bioretention areas may be used as temporary sediment traps provided the proposed finish elevation of the bed is at least 12 inches lower than the bottom elevation of the sediment trap (if used as such, all accumulated material and at least 12 inches of soil should be removed).
4. Excavate bioretention area to proposed invert depth and scarify the existing soil surfaces. Do not compact soils.
5. Backfill bioretention area with amended soil as shown on plans and specifications. Overfilling is recommended to account for settling. Light hand tamping is acceptable if necessary.
6. Complete final grading to achieve proposed design elevations, leaving space for upper layer of compost, mulch, or topsoil as specified on plans.
7. Bioretention area/rain garden installation
   a. Upon completing subgrade work, notify the engineer to inspect at his/her discretion before proceeding with bioretention installation.
   b. For the subsurface storage/infiltration bed installation, amended soils should be placed on the bottom to the specified depth.
   c. Planting soil should be placed immediately after approval of subgrade preparation/bed installation. Any accumulation of debris or sediment that takes place after approval of subgrade should be removed prior to installation of planting soil at no extra cost to the owner.
   d. If called for in the design, install approved planting soil in 18-inch maximum lifts and lightly compact (tamp with backhoe bucket or by hand). Keep equipment movement over planting soil to a minimum — **do not over-compact**. Install planting soil to grades indicated on the drawings. Loads on the soil should not exceed four pounds per square inch.
   e. Presoak the planting soil at least 24 hours prior to planting vegetation to aid in settlement.
   f. Plant trees and shrubs according to supplier's recommendations and only from mid-March through the end of June or from mid-September through mid-November.
   g. Install two or three inches of shredded hardwood mulch (minimum age six months) or compost mulch evenly as shown on plans. Do not apply mulch in areas where ground cover is to be grass or where cover will be established by seeding.
   h. Protect rain gardens from sediment at all times during construction. Compost socks, diversion berms, and/or other appropriate measures should be used at the toe of slopes that are adjacent to rain gardens to prevent sediment from washing into these areas during site development.
   i. When the site is fully vegetated and the soil mantle stabilized, notify the plan designer to inspect the rain garden drainage area at his/her discretion before the area is brought online and sediment control devices removed.
8. Mulch and install erosion protection at surface flow entrances where necessary.

Marking planting area
Source: City of Troy

Maintenance

Properly designed and installed bioretention areas require some regular maintenance, most within the first year or two of establishment. Less maintenance is required when the native perennial vegetation becomes established.

1. Water vegetation at the end of each day for two weeks after planting is completed. Newly established plants should continue to receive approximately one inch of water per week throughout the first season, or as determined by the landscape architect.
2. While vegetation is being established, pruning and weeding may be required. Weeds should be removed by hand.
3. Organic material may also need to be removed approximately twice per year (typically by hand).
4. Perennial plantings may be cut down at the end of the growing season to enhance root establishment.
5. Mulch should be re-spread when erosion is evident and replenished once every one to two years or until the plants begin to fill in the area and the space between plants is minimized.

Watering newly established vegetation
Source: City of Troy

Planting Tip

When planting your bioretention area, it is usually helpful to mark the different planting areas. An effective method is using spray paint and flags to mark designated areas. This is especially helpful when utilizing volunteers.

6. Bioretention area should be inspected at least two times per year for sediment buildup, erosion, and to evaluate the health of the vegetation. If sediment buildup reaches 25 percent of the ponding depth, it should be removed. If erosion is noticed within the bioretention area, additional soil stabilization measures should be applied. If vegetation appears to be in poor health with no obvious cause, a landscape specialist should be consulted.
7. Bioretention vegetation may require watering, especially during the first year of planting. Ensure the maintenance plan includes a watering schedule for the first year, and in times of extreme drought after plants have been established.
8. Bioretention areas should not be mowed on a regular basis. Trim vegetation as necessary to maintain healthy plant growth.

Winter Considerations

Use salt-tolerant vegetation where significant snowmelt containing deicing chemicals is expected. The use of sand, cinders, and other winter abrasives should be minimized. If abrasives are used, additional maintenance may be required to remove them in the spring. Bioretention soils can be expected to resist freezing and remain functioning for most of the year (although biological pollutant removal processes will be reduced during winter). Bioretention areas can even be used for snow storage assuming this will not harm the vegetation. Pipes, inlets, overflow devices, and other stormwater structures associated with bioretention should be designed according to general guidance on cold climate construction.

Cost

Bioretention areas often replace areas that were intensively landscaped and require high maintenance. In addition, bioretention areas can decrease the cost for stormwater conveyance systems on a site. Bioretention areas cost approximately $5-7 per cubic foot of storage to construct.

Designer/Reviewer Checklist for Rain Gardens/Bioretention

Item	Yes	No	N/A	Notes
Was Appendix E: *Soil infiltration Testing Protocol followed*?*				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Were the bioretention design guidelines followed?				
Minimum 2-foot separation between the bed bottom and bedrock/SHWT?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Natural, uncompacted soils?				
Level infiltration area (bed bottom)?				
Excavation in rain garden areas minimized?				
Hotspots/pretreatment considered?				
Loading ratio below 5:1 (described in infiltration BMP)?				
Ponding depth limited to 18 inches?				
Drawdown time less than 48 hours?				
Positive overflow from system?				
Erosion and Sedimentation control?				
Feasible construction process and sequence?				
Entering flow velocities non-erosive or erosion control devices?				
Acceptable planting soil specified?				
Appropriate native plants selected?				
Maintenance accounted for and plan provided? Review of treatment volume? Review of calculations?				

* In general, the protocol should be followed as much as possible.

References

Clar et al., *Rethinking Bioretention Design Concepts*. Pennsylvania Stormwater Management Symposium, October 2007.

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Minnesota Stormwater Manual, 2006. St. Paul, MN: Minnesota Pollution Control Agency, 2006.

Pennsylvania Stormwater Best Management Practices Manual, 2006. Pennsylvania Department of Environmental Protection. 2006.

Prince George's County Bioretention Manual, 2002. Prince George's County, MD: Department of Environmental Resources, 2002.

Rain Gardens of West Michigan: www.raingardens.org

Southeastern Oakland County Water Authority: www.socwa.org/lawn_and_garden.htm

Rain Gardens: A household way to improve water quality in your community. University of Wisconsin-Extension and Wisconsin Department of Natural Resources, 2002.

Wild Ones Natural Landscapers: www.for-wild.org/

BMP Fact Sheet

Capture Reuse

Structures designed to intercept and store runoff from rooftops allow for its reuse, reducing volume and overall water quality impairment. Stormwater is contained in the structures and typically reused for irrigation or other water needs.

Cistern at Fairlane Green shopping center, Allen Park, MI

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Yes	**Peak Rate**	Low*
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Med
Highway/Road	No	**TP**	Med
Recreational	Yes	**NO_3**	Med
		Temperature	Med

Additional Considerations	
Cost • Rain Barrel • Cistern • Manufactured porduct	 Low Med Varies
Maintenance	Med
Winter Performance	Med

Variations

- Rain barrels
- Cisterns, both underground and above ground
- Tanks
- Storage beneath a surface (using manufactured products)

Key Design Features

- Small storm events are captured with most structures
- Provide overflow for large storm events
- Discharge water before next storm event
- Consider site topography, placing structure up-gradient in order to eliminate pumping needs

Site Factors

- Water table to bedrock depth – N/A (although must be considered for subsurface systems)
- Soils – N/A
- Slope – N/A
- Potential hotspots – Yes with treatment
- Max. drainage area – N/A

Benefits

- Provides supplemental water supply
- Wide applicability
- Reduces potable water use
- Related cost savings and environmental benefits

Limitations

- Manages only relatively small storm events which requires additional management and use for the stored water.

* Depends on site design

Case Study: Stormwater Capture with an Underground Cistern

Fairmount Square, Grand Rapids, MI

All of the stormwater that falls onto Fairmount Square is handled onsite rather than at the municipal storm sewer. This four-acre site consists of a building, a new four-bay commercial building, and 37 town homes.

Several different LID techniques are used to manage all stormwater onsite, including rainwater capture, porous pavement, and rain gardens. The stormwater from the roofs of two buildings on Cherry Street in Fairmount Square is captured in an underground cistern and used to water the formal gardens and parking lot landscape. The cistern holds 30,000 gallons of water (up to two weeks of rainfall) and is 10' x 15' x 15'9" in size. A pump inside the cistern pumps rainwater to the formal garden area at the entrance to the Inner City Christian Federation building. The estimated savings using this cistern instead of standard irrigation is 1,340.3 cubic feet of water per year.

Maintenance activities and associated costs are minimal, as the cistern only requires periodic pump maintenance, which is contracted out as needed.

Underground cistern tank

Source: Fishbeck, Thompson, Carr, & Huber, Inc.

Case Study Site Considerations	
Project Type	Underground cistern
Estimated Total Project Cost	$40,269
Maintenance Responsibility	Contracted out as needed
Project Contact	Deb Sypien, Rockford Construction Company 616-285-8100 Rick Pulaski, Nederveld Inc. 616-575-5190

Description and Function

Capture reuse is the practice of collecting rainwater in a container and reusing it in the future. Other terms for this BMP include *storage/reuse, rainwater harvesting, and rainwater catchment system*.

This structural BMP reduces potable water needs while simultaneously reducing stormwater discharges. When rain barrels or cisterns are full, rooftop runoff should be directed to drywells, planters, or bioretention areas where it will be infiltrated.

Variations

Rain barrel

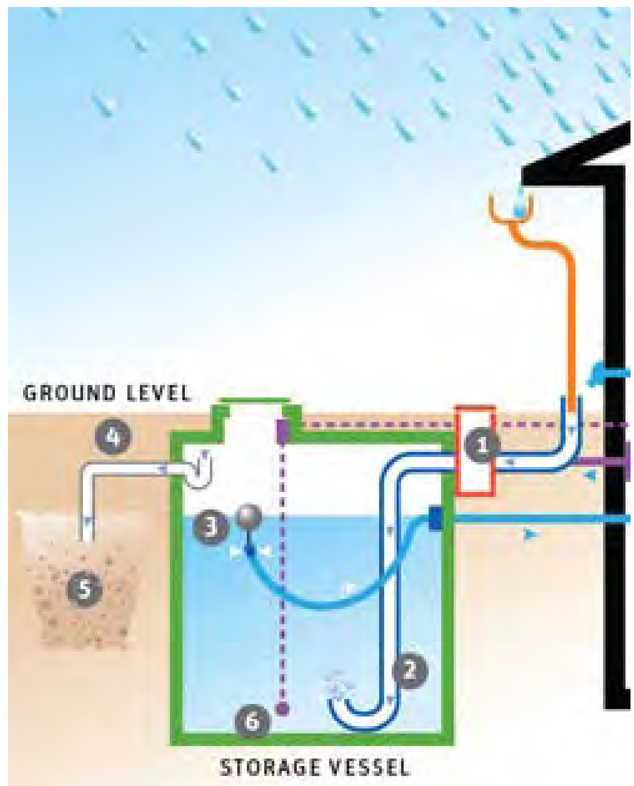
Commonly, rooftop downspouts are connected to a rain barrel that collects runoff and stores water until needed for a specific use. Rain barrels are often used at individual homes where water is reused for garden irrigation, including landscaped beds, trees, or other vegetated areas. Other uses include commercial and institutional facilities where the capacity of stormwater can be captured in smaller volume rain barrels.

Residential rain barrel
Source: Harley Ellis Devereaux

Cisterns

A cistern is a container or tank that has a greater storage capacity than a rain barrel. Typically, cisterns are used to supplement greywater needs (i.e., toilet flushing, or some other sanitary sewer use) though they can also be used for irrigation. Cisterns may be comprised of fiberglass, concrete, plastic, brick, or other materials and can be located either above or below ground. The storage capacity of cisterns can range from 200 gallons to 10,000 gallons. Very large cisterns, essentially constructed like an underground parking level, can also be used. Figure 7.16 highlights the typical components of a cistern.

Figure 7.16
Typical cistern components



Source: This image generously provided by www.rainkeeper.us

Figure Description:

1. Filter/screening mechanism to filter runoff
2. Inflow into cistern
3. Intake for water use
4. Cistern overflow
5. Subsequent stormwater system (infiltration system in this case) for cistern overflow
6. Optional level gauge

Ford Rouge Plant cistern

Vertical storage

A vertical storage container is a structure designed to hold a large volume of stormwater drained from a large impervious area and is the largest of the capture reuse containers. The use of these structures is a function of drainage area and water needs. Vertical structures are best used for intensive irrigation needs or even fire suppression requirements, and should be designed by a licensed professional. These storage systems can be integrated into commercial sites where water needs may be high.

Storage beneath structure

Stormwater runoff can be stored below ground under pavement and landscaped surfaces through the use of structural plastic storage units and can supplement onsite irrigation needs. These structures can provide large storage volumes without the need for additional structural support from the building.

Designing a capture reuse system in which the storage unit is underground is best used in institutional or commercial settings. This type of subsurface storage is larger, more elaborate, typically designed by a licensed professional, and requires pumps to connect to the irrigation system.

Applications

Capture reuse containers can be used in urbanized areas where the need for supplemental onsite irrigation or other high water use exists. Areas that would benefit from using a capture reuse container include:

- Parking garage,
- Office building,
- Residential home or building, and
- Other building use (commercial, light industrial, institutional, etc.).

Vertical storage units for vegetated roof plaza maintenance are common in Germany

Underground cistern at Lawrence Technological University
Source: Lawrence Technological University

Rainstore™ cistern beneath brick pavers on a vegetated roof-top plaza at University of North Carolina – Chapel Hill

Design Considerations

Design and installation procedures for capture reuse containers can vary from simple residential rain barrels to highly engineered underground systems in ultra-urban areas. Table 7.5 provides general information on cistern holding capacity. The following procedures should be considered when designing sites with capture reuse containers.

1. Identify opportunities where water can be reused for irrigation or indoor greywater reuse and then calculate the water need for the intended uses. For example, if a 2,000 square foot landscaped area requires irrigation for four months in the summer at a rate of one inch per week, the designer must determine how much water will be needed to achieve this goal (1,250 gallons per week, approximately 22,000 gallons for the season), and how often the storage unit will be refilled with precipitation. The usage requirements and the expected rainfall volume and frequency must be determined.

Table 7.5
Round cistern capacity (Gallons)

Height (feet)	6-foot Diameter	12-foot Diameter	18-foot Diameter
6	1,269	5,076	11,421
8	1,692	6,768	15,227
10	2,115	8,460	19,034
12	2,538	10,152	22,841
14	2,961	11,844	26,648
16	3,384	13,535	30,455
18	3,807	15,227	34,262
20	4,230	16,919	38,069

Source: The Texas Manual on Rainwater Harvesting

2. Rain barrels and cisterns should be positioned to receive rooftop runoff.
3. If cisterns are used to supplement greywater needs, a parallel conveyance system must be installed to separate greywater from other potable water piping systems. Do not connect to domestic or commercial potable water system.
4. Consider household water demands (Table 7.6) when sizing a system to supplementing residential greywater use.

Table 7.6.
Household water demand chart

Fixture	Use	Flow Rate
Toilet	# flushes per person per day	1.6 gallons per flush (new toilet)
Shower	# minutes per person per day (5 minutes suggested max.)	2.75 gallons per minute (restricted flow head)
Bath	# baths per person per day	50 gallons per bath (average)
Faucets	Bathroom and kitchen sinks	10 gallons per day
Washing Machine	# loads per day	50 gallons per load (average)
Dishwasher	# loads per day	9.5 gallons per load

Source: Philadelphia Stormwater Manual

5. Discharge points and storage units should be clearly marked “Caution: Untreated Rainwater, Do Not Drink.”
6. Screens should be used to filter debris from runoff flowing into the storage units. Screens should be made of a durable, non-corrodible material and be easily maintainable.
7. Protect storage elements from direct sunlight by positioning and landscaping. Limit light into devices to minimize algae growth.
8. The proximity to building foundations should be considered for overflow conditions. The minimum setback distance for capture and reuse systems is 10 feet.
9. If the capture and reuse system or any elements of the system are exposed to freezing temperatures, then it should be emptied during the winter months to prevent ice damage.
10. Cisterns should be watertight (joints sealed with nontoxic waterproof material) with a smooth interior surface.
11. Covers and lids should have a tight fit to keep out surface water, insects (mosquitoes), animals, dust, and light.

12. Release stored water between storm events for the necessary storage volume to be available.
13. Positive outlet for overflow should be provided a few inches from the top of the cistern and sized to safely discharge the appropriate design storms when the cistern is full.
14. Rain barrels require a release mechanism in order to drain empty between storm events. Connect a soaker hose to slowly release stored water to a landscaped area.
15. Observation risers should be at least six inches above grade for buried cisterns.
16. Reuse may require pressurization. Water stored has a pressure of 0.43 psi per foot of water elevation. A 10-foot tank when full would have a pressure of 4.3 psi (0.43*10). Most irrigation systems require at least 15 psi. To add pressure, a pump, pressure tank, and fine mesh filter can be used, while this adds to the cost of the system, it makes the system more versatile and therefore practical.
17. Capture/reuse can also be achieved using a subsurface storage reservoir which provides temporary storage of stormwater runoff for reuse. The stormwater storage reservoir may consist of clean uniformly graded aggregate and a waterproof liner or pre-manufactured structural stormwater storage units.

Stormwater Functions and Calculations

Volume reduction

In order to keep storage costs to a minimum, it makes sense to size the storage tank so that it does not greatly exceed the water need. Where this is done, especially where a high-volume demand greatly exceeds runoff (e.g., irrigation or industrial makeup water), then runoff volume reduction for a particular storm can be assumed to equal the total volume of storage.

Where the captured water is the sole source for a particular operation (e.g., flushing toilets) the user does not want the stored water to be depleted before the next runoff event that replenishes it. In that case, the appropriate volume to store will be relatively easy to calculate based on the daily water need. After water need is determined, use the table below to choose which structure will be large enough to contain the amount of water needed. The amount replenished by a particular storm is equal to the volume reduction.

Additional Volume Reduction Considerations

For storage vessels that are not drained down completely before the next runoff event, the volume available to be filled by a particular storm may be difficult to calculate. Typical LID sizing criteria is based on the volume that goes to storage during a particular storm. That volume can be subtracted from the runoff volume, and the designer/developer can size the storage unit to achieve the targeted volume reduction. But sizing criteria under these capture and reuse circumstances may become need based. The designer/builder may estimate the volume removal for a particular storm, but estimates should be realistic given the use rate and storm runoff frequency. The estimate can be based on an average available storage capacity or preferably on a water balance analysis based on actual rainfall statistics.

Available Volume for Capture (gallons) = Runoff Coefficient (unitless) x Precip (inches) x Area (SF) x 1 foot/12 inches x 7.4805 gallons/1 cubic foot

OR

$$V = 0.62 \times C \times P \times A$$

Where

V = available volume for capture (gallons)

0.62 = unit conversion (gal/in./square foot)

C = volumetric runoff coefficient (unitless), typically 0.9 to 0.95 for impervious areas

P = precipitation amount (inches)

A = drainage area to cistern (square feet)

Sizing the tank is a mathematical exercise that balances the available collection (roof) area, annual rainfall, intended use of rainwater and cost. In other words, balance what can be collected against how the rainwater will be used and the financial and spatial costs of storing it. In most areas of the country, it's possible to collect 80 percent of the rain that falls on the available roof area. (The 20 percent reduction accounts for loss due to mist and heavy storms that release more rain than the tank can accommodate.) (www.starkenvironmental.com/downloads/Interface_Engineering.pdf) That level of capture would yield approximately 500 gallons per inch of rain per 1000 SF of capture area. Table 7.7 includes available capture volumes based on drainage area and annual rainfall.

Peak rate mitigation

Overall, capture and reuse takes a volume of water out of site runoff and puts it back into the ground. This reduction in volume will translate to a lower overall peak rate for the site.

Water quality improvement

Pollutant removal takes place through filtration of recycled primary storage, and/or natural filtration through soil and vegetation for overflow discharge. Quantifying pollutant removal will depend on design. Sedimentation will depend on the area below the outlet that is designed for sediment accumulation, time in storage, and maintenance frequency. Filtration through soil will depend on flow draining to an area of soil, the type of soil (infiltration capacity), and design specifics (stone bed, etc.).

Maintenance

Rain barrels

- Inspect rain barrels four times per year, and after major storm events.
- Remove debris from screen as needed.
- Replace screens, spigots, downspouts, and leaders as needed.
- To avoid damage, drain container prior to winter, so that water is not allowed to freeze in devices.

Table 7.7
Annual rainfall yield (in gallons) for impervious surfaces

Annual Rainfall Yield in Gallons for Various Impervious Surface Sizes and Rainfall Amounts								
Impervious Surface Area (sf)	Rainfall (inches)							
	26	28	30	32	34	36	38	40
200	3,079	3,316	3,553	3,790	4,027	4,264	4,501	4,738
400	6,159	6,633	7,106	7,580	8,054	8,528	9,002	9,475
600	9,238	9,949	10,660	11,370	12,081	12,792	13,502	14,213
800	12,318	13,265	14,213	15,160	16,108	17,056	18,003	18,951
1,000	15,397	16,582	17,766	18,951	20,135	21,319	22,504	23,688
1,200	18,477	19,898	21,319	22,741	24,162	25,583	27,005	28,426
1,400	21,556	23,214	24,873	26,531	28,189	29,847	31,505	33,164
1,600	24,636	26,531	28,426	30,321	32,216	34,111	36,006	37,901
1,800	27,715	29,847	31,979	34,111	36,243	38,375	40,507	42,639
2,000	30,795	33,164	35,532	37,901	40,270	42,639	45,008	47,377
2,200	33,874	36,480	39,086	41,691	44,297	46,903	49,508	52,114
2,400	36,954	39,796	42,639	45,481	48,324	51,167	54,009	56,852
2,600	40,033	43,113	46,192	49,272	52,351	55,431	58,510	61,589
2,800	43,113	46,429	49,745	53,062	56,378	59,694	63,011	66,327
3,000	46,192	49,745	53,299	56,852	60,405	63,958	67,512	71,065
3,200	49,272	53,062	56,852	60,642	64,432	68,222	72,012	75,802
3,400	52,351	56,378	60,405	64,432	68,459	72,486	76,513	80,540
3,600	55,431	59,694	63,958	68,222	72,486	76,750	81,014	85,278
3,800	58,510	63,011	67,512	72,012	76,513	81,014	85,515	90,015

* Values represent the following percentage of precipitation (i.e., runoff coefficient) to account for losses: 95%

Cisterns

- Flush cisterns annually to remove sediment.
- Brush the inside surfaces and thoroughly disinfect twice per year.
- To avoid damage, drain container prior to winter, so that water is not allowed to freeze in devices.

Cost

Both rain barrels and cisterns are assumed to have a life span of 25 years.

	Capacity	Cost Range
Rain barrel	40-75 gal.	$100-$250
Cistern	200-10,000 gal.	Varies by manufacturer and material
Vertical storage	64-12,000 gal	$100-$11,000

Residential rain barrel with soaker hose

Source: http://www.urbangardencenter.com/products/rain-barrel/urb/index.html

Designer/Reviewer Checklist for Capture Reuse

Type and size (gallons) of storage system provided: ______________________________

ITEM*	YES	NO	N/A	NOTES
Capture area defined and calculations performed?				
Pretreatment provided to prevent debris/sediment from entering storage system?				
Water use identified and calculations performed?				
If the use is seasonal, has off-season operation been considered?				
Draw-down time considered?				
Is storage system located optimally for the use?				
Is a pump required?				
If so, has an adequate pump system been developed?				
Acceptable overflow provided?				
Winter operation (protection from freezing) considered?				
Observation/clean-out port provided?				
Maintenance accounted for and plan provided?				

* These items primarily relate to larger systems, not residential rain barrels.

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BMP Fact Sheet

Infiltration Practices

Infiltration practices are natural or constructed land areas located in permeable soils that capture, store, and infiltrate the volume of stormwater runoff into surrounding soil.

Infiltration Trench, City of Grayling, MI
Source: Huron Pines

Variations

- **Dry wells**, also referred to as seepage pits, French drains or Dutch drains, are a subsurface storage facility (structural chambers or excavated pits, backfilled with a coarse stone aggregate) that temporarily store and infiltrate stormwater runoff from rooftop structures. Due to their size, dry wells are typically designed to handle stormwater runoff from smaller drainage areas, less than one acre in size.
- **Infiltration basins** are shallow surface impoundments that temporarily store, capture, and infiltrate runoff over a period of several days on a level and uncompacted surface. Infiltration basins are typically used for drainage areas of 5 to 50 acres with land slopes that are less than 20 percent.
- **Infiltration berms** use a site's topography to manage stormwater and prevent erosion. Berms may function independently in grassy areas or may be incorporated into the design of other stormwater control facilities such as Bioretention and Constructed Wetlands. Berms may also serve various stormwater drainage functions including: creating a barrier to flow, retaining flow for volume control, and directing flows.
- **Infiltration trenches** are linear subsurface infiltration structures typically composed of a stone trench wrapped with geotextile which is designed for both stormwater infiltration and conveyance in drainage areas less than five acres in size.
- **Subsurface infiltration beds** generally consist of a rock storage (or alternative) bed below other surfaces such as parking lots, lawns, and playfields for temporary storage and infiltration of stormwater runoff with a maximum drainage area of 10 acres.
- **Bioretention** can be an infiltration practice and is discussed in the Bioretention BMP.
- **Level spreaders** can be an infiltration practice and is discussed in the Level Spreader BMP.

Key Design Features

- Depth to water table or bedrock
- Pretreatment is often needed to prevent clogging
- Often requires level infiltration surface
- Proximity to buildings, drinking water supplies, karst features, and other sensitive areas
- Soil types
- Provide positive overflow in most uses

Site Factors

- Maximum Site Slope: 20 percent
- Minimum depth to bedrock: Two feet
- Minimum depth to seasonally high water table: Two feet
- Potential Hotspots: Yes with pretreatment and/or impervious liner
- NRCS Soil type: A, B, C*, D*

*C & D soils have limited infiltration ability and may require an underdrain.

Infiltration BMP	Max. Drainage Area
Berming	5 acres
Dry Well	1 acre
Infiltration Basin	10 acres
Infiltration Trench	2 acres
Subsurface Infiltration Bed	5 acres

Benefits

- Reduces volume of stormwater runoff
- Reduces peak rate runoff
- Increases groundwater recharge
- Provides thermal benefits

Limitations

- Pretreatment requirements to prevent clogging
- Not recommended for areas with steep slopes

Erosion control matting and rock can be used at surface flow entrances

Bioretention is one variation of an infiltration BMP, such as this rain garden at the Macomb County Public Works Building

Applications

	Residential	Commercial	Ultra Urban	Industrial	Retrofit	Highway/Road	Recreational
Dry well	Yes	Yes	Yes	Limited	Yes	No	No
Infiltration basin	Yes	Yes	Limited	Yes	Limited	Limited	No
Infiltration berm	Yes	Yes	Limited	Yes	Yes	Yes	No
Infiltration trench	Yes	Yes	Yes	Yes	Yes	Yes	No
Subsurface infiltration bed	Yes	Yes	Yes	Yes	Yes	Limited	No

Stormwater Quantity Functions

	Volume	Groundwater Recharge	Peak Rate
Dry well	Medium	High	Medium
Infiltration basin	High	High	High
Infiltration berm	Low/Medium	Low/Medium	Medium
Infiltration trench	Medium	High	Low/Medium
Subsurface infiltration bed	High	High	High

Stormwater Quality Functions

	TSS	TP	NO3	Temperature
Dry well	High	High/Medium	Medium/Low	High
Infiltration basin	High	Medium/High	Medium	High
Infiltration berm	Medium/High	Medium	TN-Medium	Medium
Infiltration trench	High	High/Medium	Medium/Low	High
Subsurface infiltration bed	High	Medium/High	Low	High

Case Study: Saugatuck Center for the Arts

The Saugatuck Center for the Arts (SCA), in conjunction with the City of Saugatuck, Michigan Department of Environmental Quality, and private donors, constructed a public garden that treats rain water that falls on the SCA roof. The original design was modified to accommodate rain water that would otherwise have entered Kalamazoo Lake untreated. The resulting design for the garden absorbs and infiltrates 100 percent of the rain water from the SCA roof, resulting in zero discharge to the nearby lake.

Subsurface Infiltration
Source: JFNew

In addition to the garden at the Saugatuck Center for the Arts, the revised design incorporated a series of alternative stormwater Best Management Practices on City of Saugatuck property, including subsurface infiltration under porous pavers in the adjacent city parking lot and a rain garden/vegetated swale series at Coghlin Park to treat rain water from the city parking lot. The design incorporated native plants to address management in an urban setting while visually integrating with the contemporary social fabric of Saugatuck. The design also incorporated an innovative oil-and-grit separator to remove over 80 percent of sediment and nutrients draining from approximately nine acres of urban land surrounding the SCA and city parking lot. Through this series, or "treatment techniques," the SCA and City of Saugatuck are able to demonstrate a variety of innovative and unique alternatives for treatment and reduction of stormwater.

Case Study Site Considerations	
Project Type	Subsurface infiltration, rain gardens, porous pavers, native plants, water quality device
Estimated Total Project Cost	$200,000
Maintenance Responsibility	City of Saugatuck
Project Contact	Kirk Harrier, City Manager, 269-857-2603

Description and Function

Infiltration practices are designed to store, capture, and infiltrate stormwater runoff into the surrounding soils. During periods of rainfall, infiltration BMPs reduce the volume of runoff and help to mitigate potential flooding events, downstream erosion, and channel morphology changes. This recharged water serves to provide base-flow to streams and maintain stream water quality.

Infiltration BMPs provide excellent pollutant removal effectiveness because of the combination of a variety of natural functions occurring within the soil mantle, complemented by existing vegetation (where this vegetation is preserved). Soil functions include physical filtering, chemical interactions (e.g., ion exchange, adsorption), as well as a variety of forms of biological processing, conversion, and uptake. The inclusion of appropriate vegetation for some infiltration basins reinforces the work of the soil by reducing velocity and erosive forces, soil anchoring, and further uptake of nonpoint source pollutants. In many cases, even the more difficult-to-remove soluble nitrates can be reduced as well. It should be noted that infiltration BMPs tend to be excellent for removal of many pollutants, especially those that are in particulate form. However, there are limitations to the removal of highly soluble pollutants, such as nitrate, which can be transmitted through the soil.

Infiltration basin

In addition to the removal of chemical pollutants, infiltration can address thermal pollution. Maintaining natural temperatures in stream systems is recognized as an issue of increasing importance for protection of overall stream ecology. While detention facilities tend to discharge heated runoff flows, the return of runoff to the groundwater through use of infiltration BMPs guarantees that these waters will be returned at natural groundwater temperatures, considerably cooler than ambient air in summer and warmer in winter. As a result, seasonal extreme fluctuations in stream water temperature are minimized. Fish, macro-invertebrates, and a variety of other biota will benefit as the result.

Infiltration Limitations

The use of sediment pretreatment with infiltration BMPs is required for many infiltration BMPs to prevent clogging of the infiltration surface area. Sediment pretreatment can take the form of a water quality filtering device, a settling basin, filter strips, sediment trap, or a combination of these practices upstream of the infiltration practice. Pretreatment practices should be inspected and maintained at least once per year. Before entering an infiltration practice, stormwater should first enter a pretreatment practice sized to treat a minimum volume of 25% of the water quality volume (Vwq).

Sites that include hot spots, such as gasoline stations, vehicle maintenance areas, and high intensity commercial uses, may need additional pretreatment practices to prevent impairment of groundwater supplies. Infiltration may occur in areas of hot spots provided pretreatment is suitable to address concerns.

Pretreatment devices that operate effectively in conjunction with infiltration include grass swales, vegetated filter strips, bioretention, settling chambers, oil/grit separators, constructed wetlands, sediment sumps, and water quality inserts. Selection of pretreatment practices should be guided by the pollutants of greatest concern, and the extent of the land development under consideration.

Selection of pretreatment techniques will vary depending upon whether the pollutants are of a particulate (sediment, phosphorus, metals, etc.) versus a soluble (nitrogen and others) nature.

Applications

Infiltration systems can be used in a variety of applications, from small areas in residential properties to extensive systems under commercial parking lots or large basins in open space. Industrial, retrofit, highway/road, and recreational areas can also readily incorporate infiltration to varying degrees. The use of infiltration basins and berming in ultra urban and redevelopment settings is limited primarily due to space constraints.

Dry wells have limited applicability in industrial settings as they are designed for runoff from relatively small roof areas (therefore they are also not applicable to transportation corridors).

Infiltration basins, subsurface infiltration beds, and berming are also limited for transportation projects due to space constraints and grading requirements (however berming can be used to some degree — especially along the edge of the right of way — to capture runoff).

Variations

Subsurface infiltration

A subsurface infiltration bed generally consists of a rock storage (or alternative) bed below other surfaces such as parking lots, lawns and playfields for temporary storage and infiltration of stormwater runoff. Often subsurface storage is enhanced with perforated or open bottom piping. Subsurface infiltration beds can be stepped or terraced down sloping terrain provided that the base of the bed remains level. Stormwater runoff from nearby impervious areas is conveyed to the subsurface storage media, receives necessary pretreatment and is then distributed via a network of perforated piping.

The storage media for subsurface infiltration beds typically consists of clean-washed, uniformly graded aggregate. However, other storage media alternatives are available. These alternatives are generally variations on plastic cells that can more than double the storage capacity of aggregate beds. Storage media alternatives are ideally suited for sites where potential infiltration area is limited.

Subsurface infiltration at Saugatuck Performing Arts Center.
Source: JFNew

If designed, constructed, and maintained using the following guidelines, subsurface infiltration features can stand alone as significant stormwater runoff volume, rate, and quality control practices. These systems can also provide some aquifer recharge, while preserving or creating valuable open space and recreation areas. They have the added benefit of functioning year-round, because the infiltration surface is typically below the frost line.

Various methods can be utilized to connect to subsurface infiltration areas:

- **Connection of roof leaders**

  Runoff from nearby roofs can be directly conveyed to subsurface beds via roof leader connections to perforated piping. Roof runoff generally has relatively low sediment levels, making it ideally suited for connection to an infiltration bed.

- **Connection of inlets**

  Catch basins, inlets, and area drains may be connected to subsurface infiltration beds. However, sediment, oil and grease, and debris removal must be provided. Storm structures should include sediment trap areas below the inverts of discharge pipes to trap solids and debris. Parking lots and roadways must provide for the removal of oil and grease and other similar constituents through appropriate treatment. In areas of high traffic or excessive generation of sediment, litter, and other similar materials, a water quality insert or other pretreatment device may be required.

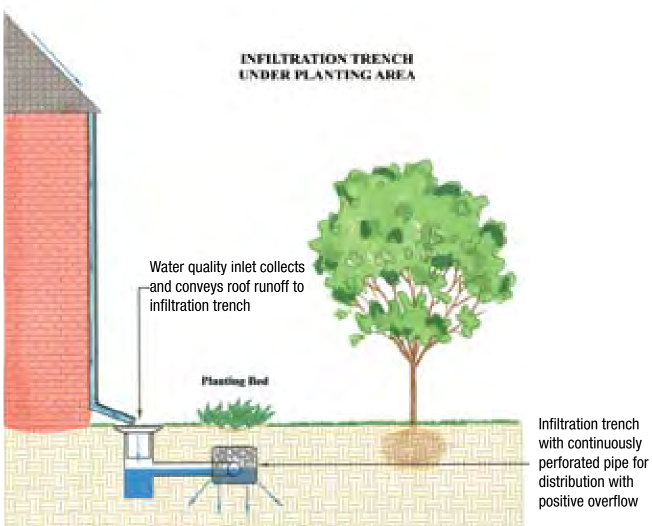
Infiltration trench

An infiltration trench is a linear stormwater BMP consisting of a continuously perforated pipe within a sub-surface stone-filled trench wrapped with geotextile. Usually, an infiltration trench is part of a conveyance system and is designed so that large storm events are conveyed through the pipe with some runoff volume reduction. During small storm events, volume reduction may be significant and there may be little or no discharge.

All infiltration trenches should be designed with a positive overflow. Sediment pretreatment of runoff from impervious areas should be considered to prevent clogging within the trench, particularly when conveying runoff from roadways and parking areas.

An infiltration trench differs from an infiltration bed in that it may be constructed in more confined areas. The designer must still consider the impervious area to infiltration area loading rate. It can be located beneath or within roadways or impervious areas (Figure 7.22) and can also be located down a mild slope by "stepping" the sections between control structures.

Figure 7.22
Residential rain garden with surface connection to subsurface infiltration bed under garden.



Infiltration basin

Infiltration basins (Figure 7.23) are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. The size and shape can vary from one large basin to multiple, smaller basins throughout a site.

Infiltration basins use the existing soil and native vegetation to reduce the volume of stormwater runoff by infiltration and evapotranspiration. Therefore, the use of sediment pretreatment is imperative to prevent clogging of the infiltration surface area within the basin. Sediment pretreatment can take the form of a water quality filtering device, vegetative filter strips, a settling basin, or a sediment trap. The key to promoting infiltration is to provide enough surface area for the volume of runoff to be absorbed within 72 hours.

An engineered overflow structure must be provided for the larger storms and can be designed for peak rate attenuation. With the use of a properly designed outlet structure, infiltration basins can be designed to mitigate volume and water quality for small frequent storms, while managing peak rates for large design storms.

Dry well

A dry well (Figure 7.24) is a subsurface storage facility that temporarily stores and infiltrates stormwater runoff from rooftops. Roof leaders usually connect directly into the dry well, which may be either an excavated pit filled with uniformly graded aggregate wrapped in geotextile or a prefabricated storage chamber or pipe segment. For structures without gutters or downspouts, runoff can be designed to sheet flow off a pitched roof surface and onto a stabilized ground cover that is then directed toward a dry well via stormwater pipes or swales.

Dry wells discharge the stored runoff via infiltration into the surrounding soils. In the event that the dry well is overwhelmed in an intense storm event, an overflow mechanism (e.g., surcharge pipe, connection to larger infiltration area, etc.) will ensure that additional runoff is safely conveyed downstream.

Figure 7.23
Schematic of infiltration basin

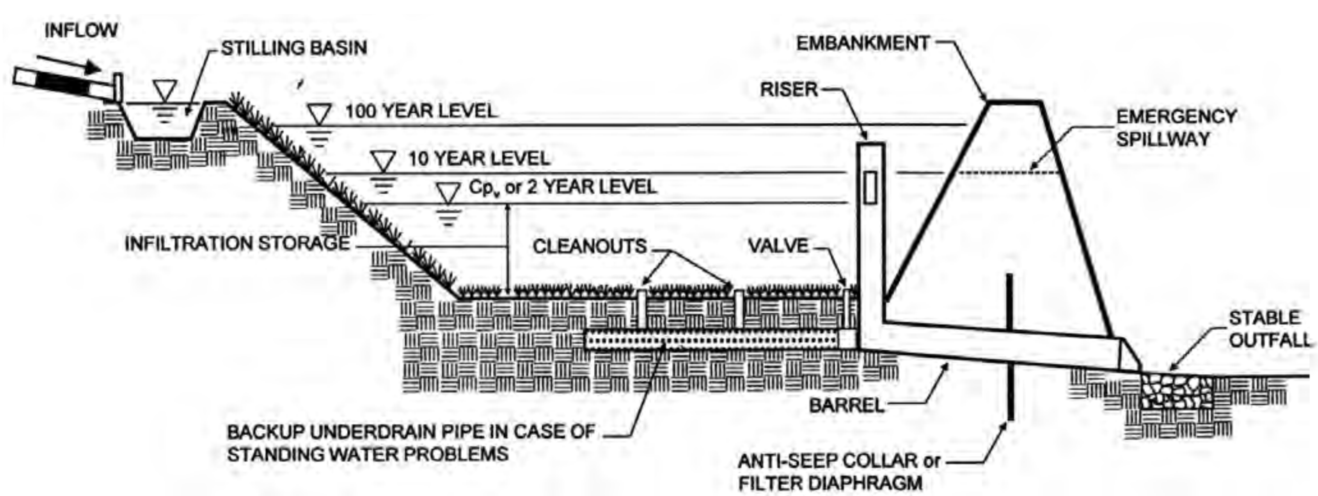
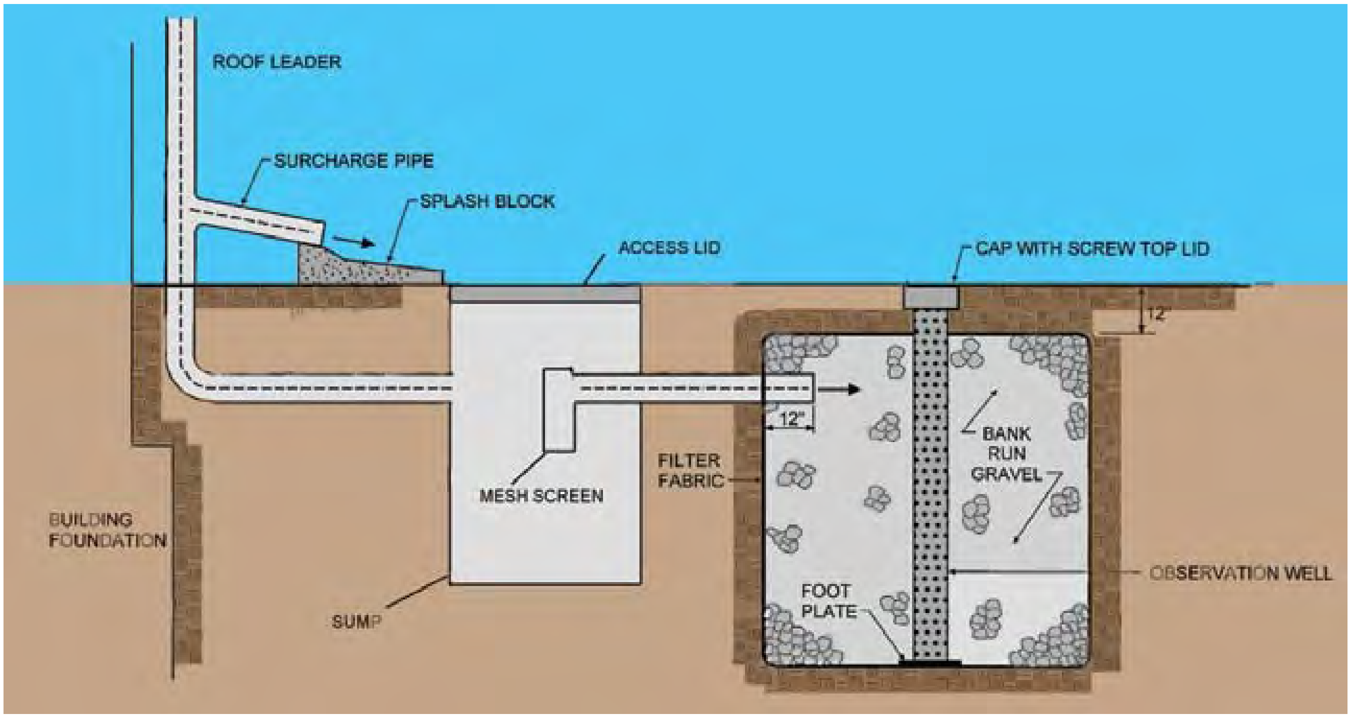


Figure 7.24
Cross-section of dry well with "sumped" catch basin for sediment pretreatment



Infiltration berm

Infiltration berms are linear vegetation features located along (i.e. parallel to) existing site contours in a moderately sloping area. They are built-up earthen embankments with sloping sides, which function to retain, slow down, or divert stormwater flows. Infiltration berms also have shallow depressions created by generally small earthen embankments that collect and temporarily store stormwater runoff allowing it to infiltrate into the ground and recharge groundwater.

Infiltration berms can be constructed in various areas on the site, including:

- **Diversion berms**

  Diversion berms can be used to protect slopes from erosion and to slow runoff rate. Like swales, berms may divert concentrated discharge from a developed area away from the sloped area. Additionally, berms may be installed in series down the slope to retain flow and spread it out along multiple, level berms to discourage concentrated flow.

- Diversion berms can also be used to direct stormwater flow in order to promote longer flow pathways, thus increasing the time of concentration. For example, berms can be installed such that vegetated stormwater flow pathways are allowed to "meander" so that stormwater travel time is increased.

Prefabricated dry wells

There are a variety of prefabricated, predominantly plastic subsurface storage chambers on the market today that can replace aggregate dry wells. Since these systems have significantly greater storage capacity than aggregate, space requirements are reduced and associated costs may be defrayed. If the following design guidelines are followed and infiltration is still encouraged, prefabricated chambers can prove just as effective as standard aggregate dry wells.

- **Meadow/woodland infiltration berms**

  Woodland infiltration berms can be installed within existing wooded areas for additional stormwater management. Berms in wooded areas can even improve the health of existing vegetation, through enhanced groundwater recharge. Care should be taken during construction to ensure minimum disturbance to existing vegetation, especially tree roots.

Berms are also utilized for a variety of reasons independent of stormwater management, such as to add aesthetic value to a flat landscape, create a noise or wind barrier, separate land uses, screen undesirable views or to enhance or emphasize landscape designs. Berms are often used in conjunction with recreational features, such as pathways through woodlands. In summary, even when used for stormwater management, berms can be designed to serve multifunctional purposes and are easily incorporated into the landscape.

Design Considerations

The following general design considerations are for all BMPs utilizing infiltration. These include: site conditions and constraints, as well as general design considerations. Specific design considerations for each BMP follow these same considerations.

Site conditions and constraints for all infiltration BMPs

- **Depth to seasonal high water table**. A four-foot clearance above the seasonally high water table is recommended. A two-foot clearance can be used, but may reduce the performance of the BMP. This reduces the likelihood that temporary groundwater mounding will affect the system, and allows sufficient distance of water movement through the soil to assure adequate pollutant removal. In special circumstances, filter media may be employed to remove pollutants if adequate soil layers do not exist.
- **Depth to bedrock**. A four-foot minimum depth to bedrock is recommended to assure adequate pollutant removal and infiltration. A two-foot depth can be used, but may reduce the performance of the BMP. In special circumstances, filter media may be employed to remove pollutants if adequate soil mantle does not exist.
- **Soil infiltration**. Soils underlying infiltration devices should have infiltration rates between 0.1 and 10 inches per hour, which in most development programs should result in reasonably sized infiltration systems. Where soil permeability is extremely low, infiltration may still be possible, but the surface area required could be large, and other volume reduction methods may be warranted. Undisturbed Hydrologic Soil Groups A, B, and C often fall within this range and cover most of the state. Type D soils may require the use of an underdrain.

  Soils with rates in excess of six inches per hour may require an additional soil buffer (such as an organic layer over the bed bottom) if the Cation Exchange Capacity (CEC) is less than 10 and pollutant loading is expected to be significant. In carbonate soils, excessively rapid drainage may increase the risk of sinkhole formation, and some compaction or additional measures may be appropriate.
- **Setbacks**. Infiltration BMPs should be sited so that any risk to groundwater quality is minimized and they present no threat to sub-surface structures such as foundations and septic systems. (Table 7.11)

Table 7.11
Setback Distances

Setback from	Minimum Distance (feet)
Property Line	10
Building Foundation*	10
Private Well	50
Public Water Supply Well**	50
Septic System Drainfield***	100

* minimum with slopes directed away from building. 100 feet upgradient from basement foundations.

** At least 200 feet from Type I or IIa wells, 75 feet from Type IIb and III wells (MDEQ Safe Drinking Water Act, PA 399)

*** 50 feet for septic systems with a design flow of less than 1,000 gallons per day

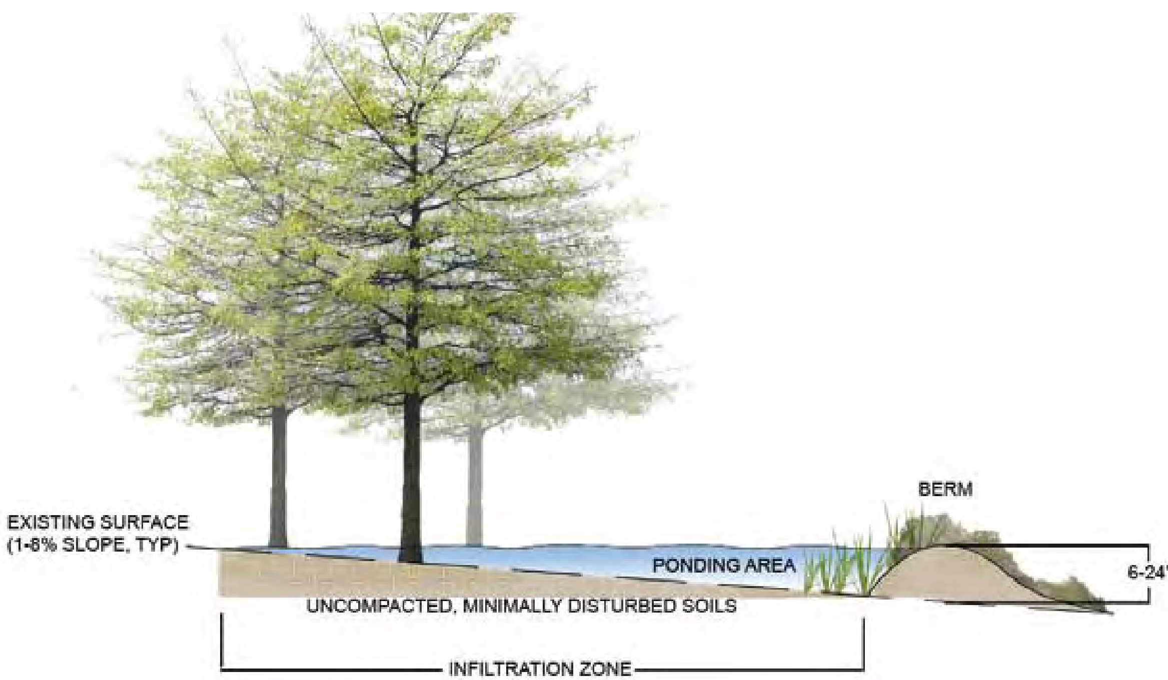
General design considerations for all infiltration BMPs

- **Do not infiltrate in compacted fill**. Infiltration in native soil without prior fill or disturbance is preferred but not always possible**.** Areas that have experienced historic disturbance or fill are suitable for infiltration provided sufficient time has elapsed and the soil testing indicates the infiltration is feasible. In disturbed areas it may be necessary to infiltrate at a depth that is beneath soils that have previously been compacted by construction methods or long periods of mowing, often 18 inches or more. If site grading requires placement of an infiltration BMP on fill, compaction should be minimal to prevent excess settlement and the infiltration capacity of the compacted fill should be measured in the field to ensure the design values used are valid.
- **A level infiltration area (one percent or less slope) is preferred**. Bed bottoms should always be graded into the existing soil mantle, with terracing as required to construct flat structures. Sloped bottoms tend to pool and concentrate water in small areas, reducing the overall rate of infiltration and longevity of the BMP. The longitudinal slope may range only from the preferred zero percent up to one percent, and that lateral slopes are held at zero percent. It is highly recommended that the maximum side slopes for an infiltration practice be 1:3 (V: H).

- **The soil mantle should be preserved for surface infiltration BMPs** and excavation should be minimized. Those soils that do not need to be disturbed for the building program should be left undisturbed. Macropores can provide a significant mechanism for water movement in surface infiltration systems, and the extent of macropores often decreases with depth. Maximizing the soil mantle also increases the pollutant removal capacity and reduces concerns about groundwater mounding. Therefore, excessive excavation for the construction of infiltration systems is strongly discouraged.
- **Isolate hot spot areas**. Site plans that include infiltration in hot spots need to be reviewed carefully. Hot spots are most often associated with some industrial uses and high traffic – gasoline stations, vehicle maintenance areas, and high intensity commercial uses (fast food restaurants, convenience stores, etc.). Infiltration may occur in areas of hot spots provided pretreatment is suitable to address concerns.
- **Utilize pretreatment**. Pretreatment should be utilized for most infiltration BMPs, especially for hot spots and areas that produce high sediment loading. Pretreatment devices that operate effectively in conjunction with infiltration include grass swales, vegetated filter strips, settling chambers, oil/grit separators, constructed wetlands, sediment sumps, and water quality inserts. Selection of pretreatment should be guided by the pollutants of greatest concern, site by site, depending upon the nature and extent of the land development under consideration. Selection of pretreatment techniques will vary depending upon whether the pollutants are of a particulate (sediment, phosphorus, metals, etc.) versus soluble (nitrogen and others) nature. Types of pretreatment (i.e., filters) should be matched with the nature of the pollutants expected to be generated.
- **The loading ratio of impervious area to bed bottom area must be considered**. One of the more common reasons for infiltration system failure is the design of a system that attempts to infiltrate a substantial volume of water in a very small area. Infiltration systems work best when the water is "spread out". The loading ratio describes the ratio of imperious drainage area to infiltration area, or the ratio of total drainage area to infiltration area. In general, the following loading ratios are recommended (some situations, such as highly permeable soils, may allow for higher loading ratios):
  - Maximum impervious loading ratio of 5:1 relating impervious drainage area to infiltration area.
  - Maximum total loading ratio of 8:1 relating total drainage area to infiltration area.
- **The hydraulic head or depth of water should be limited**. The total effective depth of water within the infiltration BMP should generally not be greater than two feet to avoid excessive pressure and potential sealing of the bed bottom. Typically the water depth is limited by the loading ratio and drawdown time and is not an issue.
- **Drawdown time must be considered**. In general, infiltration BMPs should be designed so that they completely empty within a 72-hour period in most situations (a 48-hour period is preferred).
- **All infiltration BMPs should be designed with a positive overflow** that discharges excess volume in a non-erosive manner, and allows for controlled discharge during extreme rainfall events or frozen bed conditions. Infiltration BMPs should never be closed systems dependent entirely upon infiltration in all storm frequency situations.
- **Geotextiles should be incorporated into the design as necessary**. Infiltration BMPs that are subject to soil movement into the stone medium or excessive sediment deposition must be constructed with suitably permeable non-woven geotextiles to prevent the movement of fines and sediment into the infiltration system. The designer is encouraged to err on the side of caution and use geotextiles as necessary within the BMP structure.
- **Aggregates used in construction should be washed**. In general, bank run material will contain fines that will wash off and clog the infiltration surface.
- **Infiltration utilizing vegetation**. Adequate soil cover (generally 12 to 18 inches) must be maintained above the infiltration bed to allow for a healthy vegetative cover. Vegetation over infiltration beds can be native grasses, meadow mix, or other low-growing, dense species (Appendix C). These plants have longer roots than traditional grass and will likely benefit from

Infiltration trench with geotextile

Figure 7.25
Typical components of a berm



the moisture in the infiltration bed, improving the growth of these plantings and, potentially increasing evapotranspiration.

- **Using underdrains in poor draining soils**. Underdrains can be used in infiltration BMPs where in-situ soils are expected to cause ponding lasting longer than 48 hours. If used, underdrains are typically small diameter (6 to 12 inches) perforated pipes in a clean gravel trench wrapped in geotextile fabric (or in the storage/infiltration bed). Underdrains should have a flow capacity greater than the total planting soil infiltration rate and should have at least 18 inches of soil/gravel cover. They can daylight to the surface or connect to another stormwater system. A method to inspect and clean underdrains should be provided (via cleanouts, inlet, overflow structure, etc.)
- **Freeboard**. It is recommended that two feet of freeboard be provided from the 100-year flood elevation of the infiltration practice to the lowest basement floor elevation of residential, commercial, industrial, and institutional buildings located adjacent to the BMP, unless local requirements recommend or stipulate otherwise.

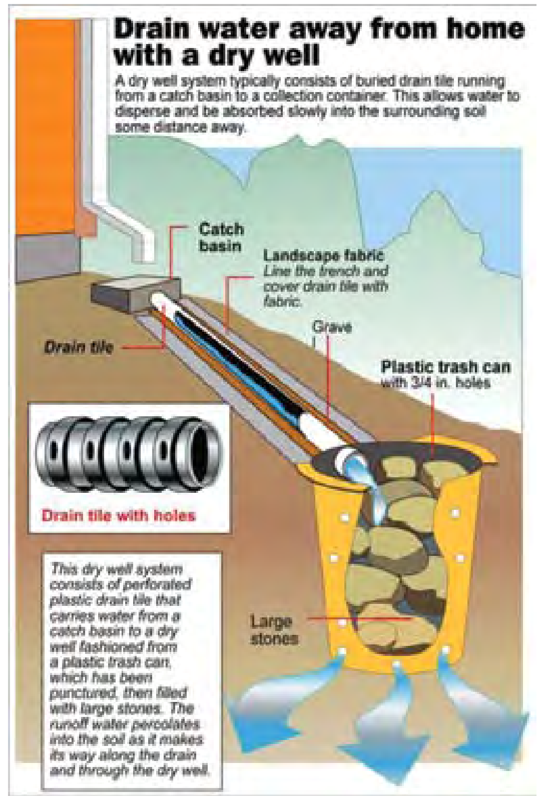
Additional design considerations for infiltration berms

- Sizing criteria (Figure 7.25) are dependent on berm function, location, and storage volume requirements.
  - Low **berm height** (less than or equal to 24 inches) is recommended to encourage maximum infiltration and to prevent excessive ponding behind the berm. Greater heights may be used where berms are being used to divert flow or to create "meandering" or lengthened flow pathways. In these cases, stormwater is designed to flow adjacent to (parallel to), rather than over the crest of the berm. Generally, more berms of smaller size are preferable to fewer berms of larger size.
  - **Berm length** is dependent on functional need and site size. Berms installed along the contours should be level and located across the slope. Maximum length will depend on width of the slope.
- Infiltration berms should be constructed along (parallel to) contours at a **constant level elevation**.
- **Soil**. The top one foot of a berm needs to consist of high quality topsoil, with well-drained, stable fill material making up the remainder of the berm. A berm may also consist entirely of high quality topsoil, but this the more expensive option.

  The use of gravel is not recommended in the layers directly underneath the topsoil because of the tendency of the soil to wash through the gravel. In some cases, the use of clay may be required due to its cohesive qualities (especially where the berm height is high or relatively steeply sloped). However, well-compacted soil is usually sufficient provided that the angle of repose, the angle at which the soil will rest and not be subject to slope failure (see #5 below), is adequate for the soil medium used.
- The **angle of repose of** any soil will vary with the texture, water content, compaction, and vegetative cover. Typical angles of repose are given below:
  - Non-compacted clay: 5 to 20 percent
  - Dry Sand: 33 percent
  - Loam: 35 to 40 percent
  - Compacted clay: 50 to 80 percent
- **Slope**. The angle of repose for the soil used in the berm should determine the maximum slope of the berm with additional consideration to aesthetic, drainage, and maintenance needs. If a berm is to be mowed, the slope should not exceed a 4:1 ratio (horizontal to vertical) in order to avoid "scalping" by mower blades. If trees are to be planted on berms, the slope should not exceed a 5:1 to 7:1 ratio. Other herbaceous plants, which do not require mowing, can tolerate slopes of 3:1, though this slope ratio may promote increased runoff rate and erosive conditions. Berm side slopes should never exceed a 2:1 ratio.
- **Plant materials**. It is important to consider the function and form of the berm when selecting plant materials. When using native trees and shrubs, plant them in a pattern that appears natural and accentuates the form of the berm. Consider native species from a rolling prairie or upland forest habitat. If turf will be combined with woody and herbaceous plants, the turf should be placed to allow for easy maneuverability while mowing. Low maintenance native plantings, such as trees and meadow plants, rather than turf and formal landscaping, are encouraged and can be found in Appendix C.
- **Infiltration trench option**. Soil testing is required for infiltration berms that will utilize a subsurface infiltration trench. Infiltration trenches are not recommended in existing woodland areas as excavation and installation of subsurface trenches could damage tree root systems. See the infiltration trench section for information on infiltration trench design.
- **Aesthetics**. To the extent possible, berms should reflect the surrounding landscape. Berms should be graded so that the top of the berm is smoothly convex and the toes of the berms are smoothly concave. Natural, asymmetrical berms are usually more effective and attractive than symmetrical berms, which tend to look more artificial. The crest of the berm should be located near one end of the berm rather than in the middle.
- Pretreatment. The small depression created by an infiltration berm can act as a sediment forebay prior to stormwater entering a down slope BMP, such as a bioretention basin, a subsurface infiltration bed, or another such facility.

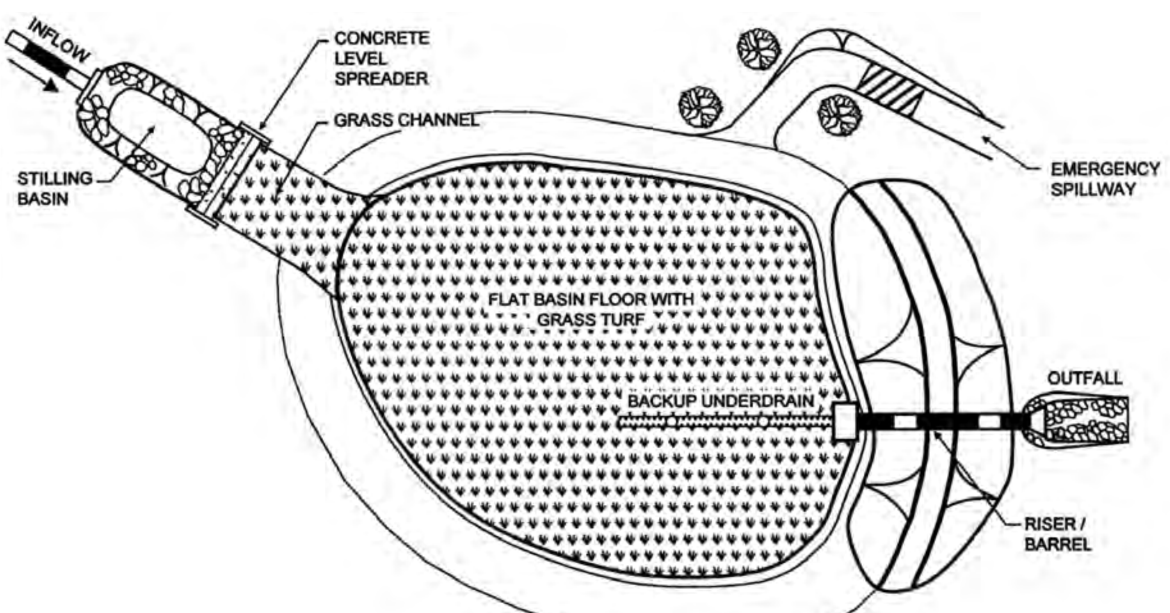
Additional design considerations for dry wells

- Dry wells typically consist of 18 to 48 inches of clean washed, uniformly graded aggregate with 40 percent void capacity (AASHTO No. 3, or similar). Dry well aggregate is wrapped in a nonwoven geotextile, which provides separation between the aggregate and the surrounding soil. Typically, dry wells will be covered in at least 12 inches of soil or six inches of gravel or riverstone. An alternative form of dry well is a subsurface, prefabricated chamber, a number of which are currently available on the market.
- All dry wells must be able to convey system overflows to downstream drainage systems. System overflows can be incorporated either as surcharge (or overflow) pipes extending from roof leaders or via connections from the dry well itself.
- The design depth of a dry well should take into account frost depth to prevent frost heave.
- A removable filter with a screened bottom should be installed in the roof leader below the surcharge pipe in order to screen out leaves and other debris.
- Inspection and maintenance access to the dry well should be provided. Observation wells not only provide the necessary access to the dry well, but they also provide a conduit through which pumping of stored runoff can be accomplished in case of slowed infiltration.



Residential dry well
Source - AP/Stan Kohler

Figure 7.26
Infiltration basin sketch



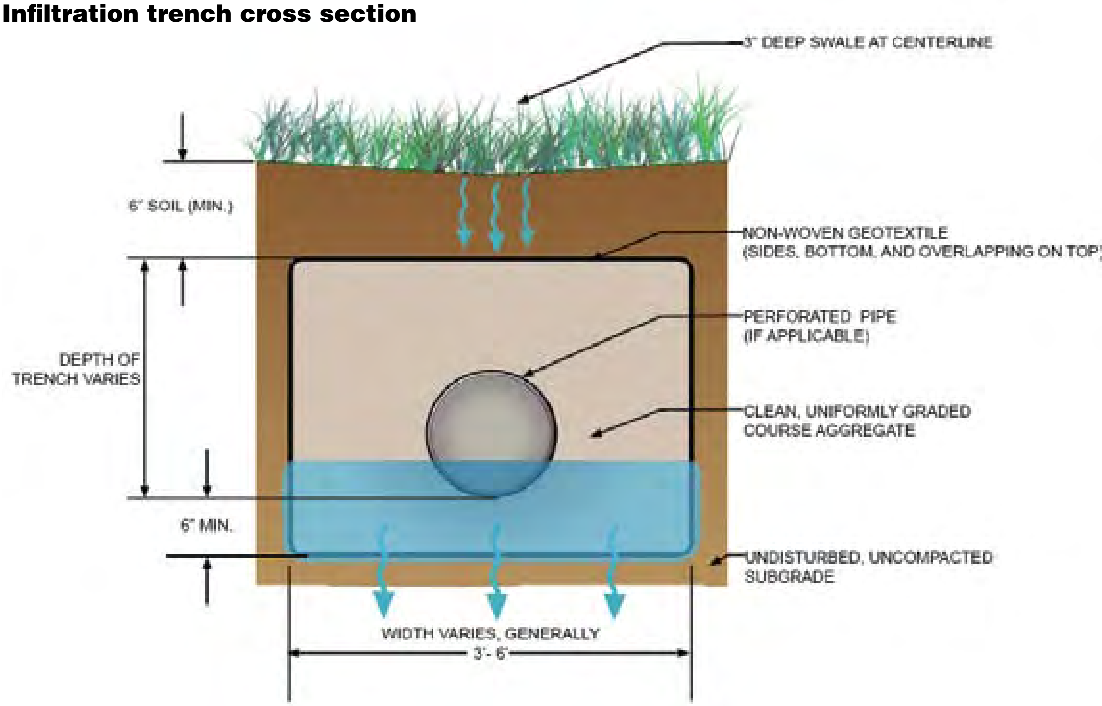
Source: Maryland Stormwater Design Manual

- Though roofs are generally not a significant source of runoff pollution, they can still be a source of particulates and organic matter, as well as sediment and debris during construction. Measures such as roof gutter guards, roof leader clean-outs with sump, or an intermediate sump box can provide pretreatment for dry wells by minimizing the amount of sediment and other particulates that enter it.

Additional Design Considerations for Infiltration Basins

- Infiltration basins are typically used for drainage areas of five to 50 acres with land slopes that are less than 20 percent.
- A six-inch layer of sand must be placed on the bottom of an infiltration basin (Figure 7.26). This sand layer can intercept silt, sediment, and debris that could otherwise clog the top layer of the soil below the basin.
- An infiltration basin does not normally have a structural outlet to discharge runoff from the stormwater quality design storm. Instead, outflow from an infiltration basin is through the surrounding soil. An infiltration basin may also be combined with an extended detention basin to provide additional runoff storage for both stormwater quality and quantity management. A structural outlet or emergency spillway is provided for storms that exceed the design of the infiltration basin.
- The berms surrounding the basin should be compacted earth with a slope of not less than 3:1, and a top width of at least two feet.
- The overflow from the infiltration basin must be properly designed for anticipated flows. Large infiltration basins may require multiple outlet control devices to effectively allow for overflow water during the larger storms. Emergency overflow systems can be constructed to direct large storm overflows.
- The sediment pre-treatment structure should be designed to provide for access and maintenance.
- In some cases, basins may be constructed where impermeable soils on the surface are removed and where more permeable underlying soils then are used for the basin bottom. Care should be taken in the excavation process to make sure that soil compaction does not occur.
- The inlets into the basin should have erosion protection.
- Use of a backup underdrain or low-flow orifice may be considered in the event that the water in the basin does not drain within 72 hours.

Figure 7.27
Infiltration trench cross section



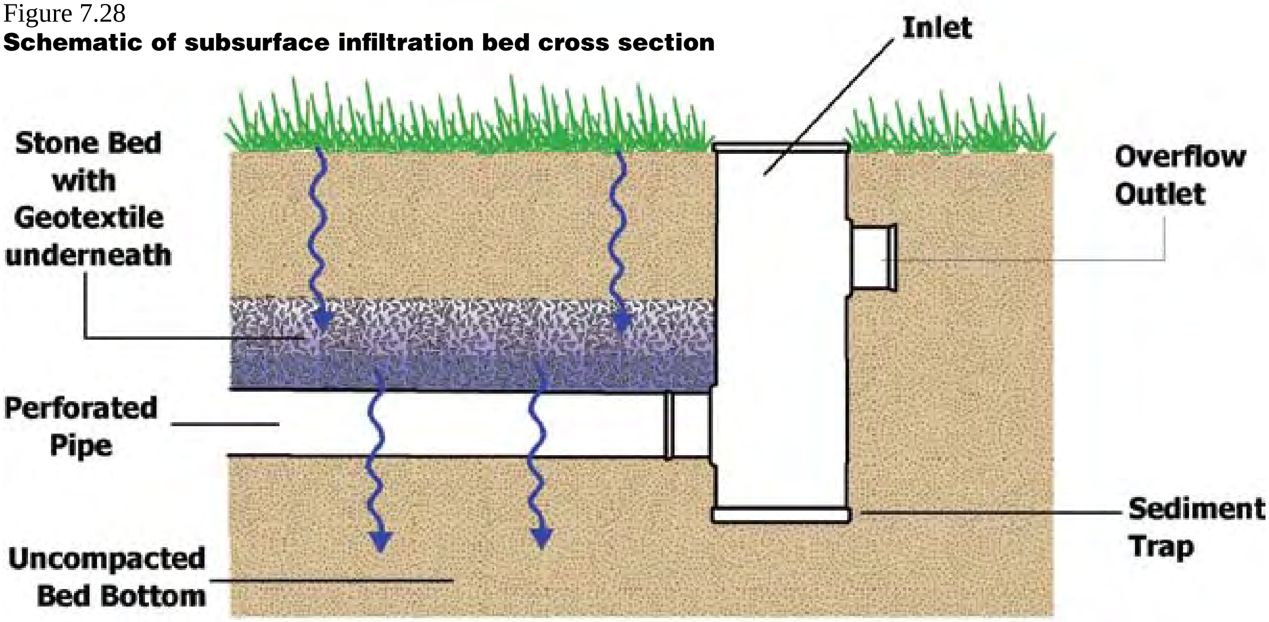
Additional design considerations for infiltration trenches

- The infiltration trench (Figure 7.27) is typically comprised of a section of uniformly graded aggregate, such as AASHTO No. 3, which ranges one to two inches in gradation. Depending on local aggregate availability, both larger and smaller size aggregate may be used. The critical requirements are that the aggregate be uniformly-graded, clean-washed, and contain at least 40 percent void space. The depth of the trench is a function of stormwater storage requirements, frost depth considerations, and site grading.
- Water quality inlets or catch basins with sumps are required for all surface inlets to prevent clogging of the infiltration trench with sediment and debris. Parking lot and street runoff must be treated by vegetated filter strips, bioretention, or water quality inlets capable of removing oil and grease and similar pollutants. Untreated parking lot and road runoff should never be directly discharged underground.
- Cleanouts, observation wells, or inlets must be installed at both ends of the infiltration trench and at appropriate intervals to allow access to the perforated pipe.
- When designed as part of a storm sewer system, a continuously perforated pipe that extends the length of the trench and has a positive flow connection may be include to allow high flows to be conveyed through the infiltration trench. Depending on size, these pipes may provide additional storage volume.
- Trees may be planted over the infiltration trench provided that adequate soil media is provided above the trench (a minimum of three feet).
- While most infiltration trenches areas consist of an aggregate storage bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate, at an increased cost.

Additional design considerations for subsurface infiltration beds

- The infiltration bed must be wrapped in nonwoven geotextile filter fabric to prevent migration of the subsoils into the stone voids. (Bottom, top, and sides).
- The subsurface infiltration bed (Figure 7.28) is typically comprised of a 12 to 36-inch section of aggregate, such as AASHTO No.3, which ranges from one to two inches in gradation. Depending on local aggregate availability, both larger and smaller size aggregate has been used. The critical requirements are that the aggregate be uniformly-graded, clean-washed, and contain at least 40 percent void space. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, and site grading. Infiltration beds are typically sized to mitigate the increased runoff volume from a two-year design storm.
- A water quality inlet or catch basin with sump is required for all surface inlets to avoid standing water for periods greater than 72 hours.

Figure 7.28
Schematic of subsurface infiltration bed cross section



Subsurface infiltration bed
Source: Driesenga & Associates, Inc.

- Perforated pipes along the bottom of the bed can be used to evenly distribute runoff over the entire bed bottom. Continuously perforated pipes should connect structures (such as cleanouts and inlet boxes). Pipes should lay flat along the bed bottom to provide for uniform distribution of water. Depending on size, these pipes may provide additional storage volume.
- Cleanouts or inlets should be installed at a few locations within the bed at appropriate intervals to allow access to the perforated piping network and storage media.
- Grading of adjacent contributing areas should be mildly sloped between one percent and three percent to facilitate drainage.
- In areas with poorly-draining soils, subsurface infiltration areas may be designed to slowly discharge to adjacent wetlands or bioretention areas.
- The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, detention basins may be eliminated or significantly reduced in size.
- During construction, the excavated bed may serve as a temporary sediment basin or trap, which can reduce overall site disturbance. The bed should be excavated to at least one foot above the final bed bottom elevation for use as a temporary sediment trap or basin. Following construction and site stabilization, sediment should be removed and final grades established.

Incorporating a Safety Factor into Infiltration BMP Design

For the purposes of site suitability, areas with tested soil infiltration rates as low as 0.1 inches per hour may be used for infiltration BMPs. However, in the design of these BMPs and the sizing of the BMP, the designer should incorporate a safety factor. Safety factors between 1 (no adjustment) and 10 have been used in the design of stormwater infiltration systems, with a factor of two being used in most cases. Therefore a measured infiltration rate of 0.5 inches per hour should generally be considered as a rate of 0.25 inches per hour in design. See the Soil Infiltration Testing Protocol in Appendix E for guidance on performing infiltration tests.

Modeling Infiltration Systems

As discussed in Chapter 9 of this manual, infiltration systems can be modeled similarly to traditional detention basins. The marked difference with modeling infiltration systems is the inclusion of the infiltration rate, which can be considered as another outlet. For modeling purposes, it is sometimes useful to develop infiltration rates that vary (based on the infiltration area provided as the system fills with runoff) for inclusion in the stage-storage-discharge table.

Table 7.12
Stormwater Functions by Infiltration BMP Type

	Volume	Peak Rate	Water Quality
Infiltration Berms	Can be used to reduce the volume of runoff and provide infiltration in accordance with LID stormwater goals. The volume reduction potential of berms is a function of the storage provided (surface and subsurface, if applicable) and the infiltration that will occur.	Can be used at mitigating peak rates for larger storms through two mechanisms: providing storage for detention (and on-going infiltration) behind them and, in some cases, elongating the flow path through a site, thereby extending the time of concentration.	Can be expected to achieve pollutant removals between 30% - 70% and in the upper ranges especially for smaller storms.
Infiltration Basins	Provides an excellent means of capturing and infiltrating runoff. Provides runoff volume storage during storm events, while the undisturbed vegetated surface allows infiltration of runoff into the underlying soil mantle. Can be sized to meet the entire channel protection volume recommended by LID criteria or sized smaller and used in conjunction with other LID practices.	Provides effective management of peak rates to meet the LID design criteria. The basin acts as a storage reservoir during large storm events, even while runoff infiltrates. Outlet structures can be designed to manage peak rates with the use of weir and orifice controls and systems can be designed to manage peak rates for storms up to and including the 100-year storm.	Effective in reducing total suspended solids, nutrients, metals, and oil and grease. Both the vegetative surface and the underlying soils allow pollutant filtration. When designed to capture and infiltrate runoff volumes from small storm events, they provide very high pollutant reductions.
Infiltration Trenches	Provides an excellent means of capturing and infiltrating runoff from small storms. The trench provides runoff volume storage and infiltration during small storm events, while the perforated pipe allows runoff conveyance during large design storms or more extreme events.	Provides limited management of peak rates. The trench may provide more peak rate benefit for small frequent storms, rather than large design storms. Because infiltration trenches help to provide a decentralized approach to stormwater management, they may benefit peak rate mitigation by contributing to increased stormwater travel time.	Effective in reducing total suspended solids, metals, and oil and grease. They provide very high pollutant reductions when designed to capture the volume from small storms because there is little if any discharge of runoff carrying the highest pollutant loads. Provide limited treatment of dissolved pollutants, such as nitrates.
Dry Wells	Dry wells are typically designed to capture and infiltrate runoff volumes from small storm events from roof area.	Provides limited management of peak rates. Provides some peak rate benefit by reducing direct connections of impervious area to storm sewer collection systems, and by contributing to increased stormwater travel time.	Effective at capturing and infiltrating the water quality volume or "first flush". Provides very high pollutant reductions because there is little if any discharge of "first flush" runoff which carries the highest pollutant loads.
Subsurface Infiltration	Provides effective management of volume. A well-designed system is capable of infiltrating the majority of small frequent storms on an annual basis.	Can be designed to manage peak rates by utilizing the stormwater storage bed, including simple rate controls such as weirs and orifices in the overflow control structure. Capable of infiltrating the majority of small frequent storms, while managing peak rates for designs storms up to the 100-year frequency storm.	Very effective at reducing total suspended solids, phosphorus, metals, and oil and grease. Because many systems are designed to capture and infiltrate small, frequent storms, they provide effective water quality control by reducing pollutants associated with the "first-flush".

Stormwater Functions and Calculations

Infiltration practices can provide excellent benefits for managing volume and water quality protection. While some BMPs are better than others in managing peak rates, all infiltration BMPs provide some peak rate benefit by removing direct connections from impervious surfaces and increasing time of travel. Table 7.12 provides a summary of the stormwater functions by BMP type.

Calculations for Infiltration BMPs

Infiltration area

The minimum infiltration area should be based on the following (according to the loading ratio):

> Minimum Surface Infiltration Area = [Contributing impervious area] / 5*
>
> *May be increased depending on soil infiltration capacity (e.g., where soils are Type A or rapidly draining). For carbonate, geologic areas may be decreased to three.

This actual infiltration area (Table 7.13) should be greater than the minimum infiltration area.

Protecting Groundwater Quality

The protection of groundwater quality is of utmost importance in any Michigan watershed. The potential to contaminate groundwater by infiltrating stormwater in properly designed and constructed BMPs with proper pretreatment is low.

Numerous studies have shown that stormwater infiltration BMPs have a minor risk of contaminating either groundwater or soil. The U.S. Environmental Protection Agency summarized in "Potential Groundwater Contamination from Intentional and Non-intentional Stormwater Infiltration" (Pitt et al., 1994) the potential of pollutants to contaminate groundwater as either low, low/moderate, moderate, or high. Of the 25 physical pollutants listed, one has a "high" potential (chloride), and two have "moderate" potential (fluoranthene and pyrene) for polluting groundwater through the use of shallow infiltration systems with some sediment pretreatment.

While chloride can be found in significant quantities due to winter salting, relatively high concentrations are generally safe for both humans and aquatic biota). Pentachlorophenol, cadmium, zinc, chromium, lead, and all the pesticides listed are classified as having a "low" contamination potential. Even nitrate which is soluble and mobile is only given a "low/moderate" potential.

Table 7.13
Definition of Infiltration Area for Infiltration BMPs

BMP	Infiltration Area Definition
Infiltration Berms	Total Infiltration Area (Ponding Area) = Length of Berm x Average Width of ponding behind berm.
Infiltration Basin	The Infiltration Area is the bottom area of the basin. This is the area to be considered when evaluating the Loading Ratio to the Infiltration basin.
Infiltration Trench	The Infiltration Area* is the bottom area of the trench. This is the area to be considered when evaluating the Loading Rate to the Infiltration basin. [Length of Trench] x [Width of Trench] = Infiltration Area (Bottom Area) * Some credit can be taken for the side area that is frequently inundated as appropriate.
Dry Well	A dry well may consider both bottom and side (lateral) infiltration according to design.
Subsurface Infiltration	The Infiltration Area is the bottom area of the bed. Some credit can be taken for the side area that is frequently inundated as appropriate.

Volume reduction

Infiltration BMPs can be used to reduce the volume of runoff and provide infiltration in accordance with LID stormwater goals. The volume reduction potential is a function of the storage provided (surface and subsurface, if applicable) and the infiltration that will occur. If a perforated pipe or underdrain is used in the design that discharges directly to surface water, the volume of water discharged must be subtracted from the volume reduction calculation.

Total Volume Reduced = Surface Storage Volume (if applicable) + Subsurface Volume (if applicable) + Infiltration Volume

Where,

Surface storage volume (ft^3) = Average bed area* (ft^2) x maximum design water depth (ft)

Subsurface storage/Infiltration bed volume (ft^3) = Infiltration area (ft^2) x Depth of underdrain material (ft) x Void ratio of storage material

*Depth is the depth of the water stored during a storm event, depending on the drainage area, conveyance to the bed, and outlet control.

Estimated Infiltration Volume (CF) = [Bed bottom area (SF)] x [Infiltration design rate (in/hr)] x [Infiltration period* (hr)] / 12 inches/ft.

*Infiltration Period is the time during the storm event when bed is receiving runoff and capable of infiltration at the design rate (typically 6 to 12 hours). See worksheet 5 in chapter 9.

Peak rate mitigation

The amount of peak rate control provided by infiltration practices is dependent on the cumulative runoff volume removed by all the infiltration practices applied to a site. Where sufficient infiltration is provided to control the runoff volume from any size storm, the corresponding peak runoff rate will also be restored and the peak runoff rate from larger, less frequent storms will be reduced. Where possible, reducing peak rate of runoff through volume control is generally more effective than fixed rate controls.

Some infiltration BMPs (e.g., infiltration basins) can manage peak rates better than others (e.g., infiltration berms). However, all infiltration BMPs provide some peak rate benefit (e.g., by removing direct connections from impervious surfaces and increasing time of travel). See Chapter 9 for more information.

Water quality improvement

Infiltration practices are effective in reducing pollutants such as total suspended solids, nutrients, metals, oil and grease. The vegetative surface and the underlying soils allow pollutant filtration and studies have shown that pollutants typically are bound to the soils and do not migrate deeply below the surface (i.e. greater than 30-inches). Infiltration practices should be used as part

Subsurface infiltration at Mid Towne Village at the City of Grand Rapids, MI

Source: Driesenga & Associates, Inc.

of a treatment train when capturing runoff from stormwater hot spots, such as industrial parking lots, due to the increased level of pollutants. Typical ranges of pollutant reduction efficiencies for infiltration practices are based on available literature data and listed below:

- TSS – 75 to 90 percent
- TP – 60 to 75 percent
- TN – 55 to 70 percent
- NO_3 – 30 percent

Construction Guidelines

The following guidelines apply for all infiltration BMPs.

- **Do not compact soil infiltration beds during construction**. Prohibit all heavy equipment from the infiltration area and absolutely minimize all other traffic. Equipment should be limited to vehicles that will cause the least compaction, such as low ground pressure (maximum four pounds per square inch) tracked vehicles. Areas for Infiltration areas should be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.

- **Protect the infiltration area from sediment by ensuring erosion and sediment control practices are implemented until the surrounding site is completely stabilized**. Methods to prevent sediment from washing into BMPs should be clearly shown on plans. Where geo-textile is used as a bed bottom liner, this should be extended several feet beyond the bed and folded over the edge to protect from sediment wash into the bed during construction, and then trimmed.

  Runoff from construction areas should never be allowed to drain to infiltration BMPs. This can usually be accomplished by diversion berms and immediate vegetative stabilization. The infiltration area may be used as a temporary sediment trap or basin during earlier stages of construction. However, if an infiltration area is also to be utilized as a temporary sediment basin, excavation should be limited to within one foot of the final bottom invert of the infiltration BMP to prevent clogging and compacting the soil horizon, and final grade removed when the contributing site is fully stabilized.

  All infiltration BMPs should be finalized at the end of the construction process, when upstream soil areas have a dense vegetative cover. In addition, do not remove inlet protection or other erosion and sediment control measures until site is fully stabilized. Any sediment which enters inlets during construction is to be removed within 24 hours.

- **Provide thorough construction oversight**. Long-term performance of infiltration BMPs is dependent on the care taken during construction. Plans and specifications must generally be followed precisely. The designer is encouraged to meet with the contractor to review the plans and construction sequence prior to construction, and to inspect the construction at regular intervals and prior to final acceptance of the BMP.

- **Provide quality control of materials**. As with all BMPs, the final product is only as good as the materials and workmanship that went into it. The designer is encouraged to review and approve materials and workmanship, especially as related to aggregates, geotextiles, soil and topsoil, and vegetative materials.

Additional Construction Guidelines for Infiltration Berms

The following is a typical construction sequence for an infiltration berm without a subsurface infiltration trench, though alterations will be necessary depending on design variations.

- Lightly scarify (by hand) the soil in the area of the proposed berm before delivering soil to site (if required). Heavy equipment should not be used within the berm area.
- Bring in fill material to make up the major portion of the berm (as necessary) as soon as subgrade preparation is complete in order to avoid accumulation of debris. Soil should be added in eight-inch lifts and compacted after each addition according to design specifications. The slope and shape of the berm should graded out as soil is added.
- Protect the surface ponding area at the base of the berm from compaction. If compaction of this area does occur, scarify soil to a depth of at least 8 inches.
- After allowing for settlement, complete final grading within two inches of proposed design elevations. Tamp soil down lightly and smooth sides of the berm. The crest and base of the berm should be level along the contour.
- Seed and plant berm with turf, meadow plants, shrubs or trees, as desired. Water vegetation at the end of each day for two weeks after planting is completed. (Appendix C).
- Mulch planted and disturbed areas with compost to prevent erosion while plants become established.

Additional Construction Guidelines for Subsurface Infiltration

- Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material should be removed with light equipment and the underlying soils scarified to a minimum depth of six inches with a York rake (or equivalent) and light tractor. All fine grading should be done by hand. All bed bottoms are to be at level grade.
- Earthen berms (if used) between infiltration beds should be left in place during excavation.
- Geotextile and bed aggregate should be placed immediately after approval of subgrade preparation

and installation of structures. Adjacent strips of geotextile should overlap a minimum of 18 inches, and should also be secured at least four feet outside of the bed to prevent any runoff or sediment from entering the storage bed. This edge strip should remain in place until storage media is placed in the bed.

- Clean-washed, uniformly-graded aggregate should be placed in the bed in maximum eight-inch lifts. Each layer should be lightly compacted, with construction equipment kept off the bed bottom as much as possible.
- Once bed aggregate has been installed, geotextile can be folded over the top of the aggregate bed. Additional geotextile should be placed as needed to provide a minimum overlap of 18 inches between adjacent geotextile strips.
- Place approved engineered soil media over infiltration bed in maximum six-inch lifts.
- Seed and stabilize topsoil.

Additional Construction Guidelines for Infiltration Trenches

- Excavate infiltration trench bottom to a uniform, level uncompacted subgrade free from rocks and debris. Do NOT compact subgrade.
- Place nonwoven geotextile along bottom and sides of trench. Nonwoven geotextile rolls should overlap by a minimum of 16 inches within the trench. Fold back and secure excess geotextile during stone placement.
- Install upstream and downstream control structures, cleanouts, observation wells, etc.
- Place uniformly graded, clean-washed aggregate in 8-inch lifts, lightly compacting between lifts.
- Install continuously perforated pipe as indicated on plans. Backfill with uniformly graded, clean-washed aggregate in 8-inch lifts, lightly compacting between lifts.
- Fold and secure nonwoven geotextile over infiltration trench, with minimum overlap of 16-inches.
- If vegetated, place a minimum six-inch lift of approved topsoil over infiltration trench, as indicated on plans.
- Seed and stabilize topsoil.

Causes of Infiltration BMP Failure

With respect to stormwater infiltration BMPs, the result of "failure" is a reduction in the volume of runoff anticipated or the discharge of stormwater with excessive levels of some pollutants. Where the system includes built structures, such as porous pavements, failure may include loss of structural integrity for the wearing surface, whereas the infiltration function may continue uncompromised. For infiltration systems with vegetated surfaces, such as play fields or rain gardens, failure may include the inability to support surface vegetation, caused by too much or too little water.

The primary causes of reduced performance are:

- Poor construction techniques, especially soil compaction/smearing, which results in significantly reduced infiltration rates.
- A lack of site soil stabilization prior to the BMP receiving runoff, which greatly increases the potential for sediment clogging from contiguous land surfaces.
- Inadequate pretreatment, especially of sediment-laden runoff, which can cause a gradual reduction of infiltration rates.
- Lack of proper maintenance (erosion repair, re-vegetation, removal of detritus, catch basin cleaning, vacuuming of pervious pavement, etc.), which can reduce the longevity of infiltration BMPs.
- Inadequate design.
- Inappropriate use of geotextile.

Infiltration systems should always be designed such that failure of the infiltration component does not completely eliminate the peak rate attenuation capability of the BMP. Because infiltration BMPs are designed to infiltrate small, frequent storms, the loss or reduction of this capability may not significantly impact the storage and peak rate mitigation of the BMP during extreme events.

Additional Construction Guidelines for Infiltration Basins

- If necessary, excavate infiltration basin bottom to provide a level and uncompacted subgrade free from rocks and debris. Never compact subgrade.
- Install outlet control structures.
- Seed and stabilize topsoil (Planting with native species is preferred).

Additional Construction Guidelines for Dry Wells

- Excavate dry well bottom to a uniform, level uncompacted subgrade, free from rocks and debris. Do NOT compact subgrade. To the greatest extent possible, excavation should be performed with the lightest practical equipment. Excavation equipment should be placed outside the limits of the dry well.
- Completely wrap dry well with nonwoven geotextile. If sediment and/or debris have accumulated in dry well bottom, remove prior to geotextile placement. Geotextile rolls should overlap by a minimum of 18-24 inches within the trench. Fold back and secure excess geotextile during stone placement.
- Install continuously perforated pipe, observation wells, and all other dry well structures. Connect roof leaders to structures as indicated on plans.
- Place uniformly graded, clean-washed aggregate in 6-inch lifts, between lifts.
- Fold and secure nonwoven geotextile over trench, with minimum overlap of 12-inches.
- Place 12-inch lift of approved topsoil over trench, as indicated on plans.
- Seed and stabilize topsoil.
- Connect surcharge pipe to roof leader and position over splashboard.

Maintenance

There are a few general maintenance practices that should be followed for all infiltration BMPs. These include:

- All catch basins and inlets should be inspected and cleaned at least twice per year.
- The overlying vegetation of subsurface infiltration features should be maintained in good condition, and any bare spots revegetated as soon as possible.
- Vehicular access on subsurface infiltration areas should be prohibited (unless designed to allow vehicles), and care should be taken to avoid excessive compaction by mowers.

Additional Maintenance Information for Infiltration Berms

Infiltration berms have low to moderate maintenance requirements, depending on the design. Unless otherwise noted, the following maintenance actions are recommended on an as-needed basis.

Infiltration berms

- Regularly inspect to ensure they are infiltrating; monitor drawdown time after major storm events (total drawdown of the system should not exceed 72 hours; surface drawdown should not exceed 48 hours).
- Inspect any structural components, such as inlet structures to ensure proper functionality
- If planted in turf grass, maintain by mowing (maintain two to four-inch height); other vegetation will require less maintenance; trees and shrubs may require annual mulching, while meadow planting requires annual mowing and clippings removal
- Avoid running heavy equipment over the infiltration area at the base of the berms; the crest of the berm may be used as access for heavy equipment when necessary to limit disturbance.
- Do not apply pesticides or fertilizers in and around infiltration structures
- Routinely remove accumulated trash and debris
- Remove invasive plants as needed
- Inspect for signs of flow channelization and/or erosion; restore level spreading immediately after deficiencies are observed (monthly)

Diversion berms

- Regularly inspect for erosion or other failures (monthly)
- Regularly inspect structural components to ensure functionality
- Maintain turf grass and other vegetation by mowing and re-mulching
- Do not apply pesticides or fertilizers where stormwater will be conveyed
- Remove invasive plants as needed
- Routinely remove accumulated trash and debris

Additional Maintenance Information for Infiltration Basins

- Inspect the basin after major storm events and make sure that runoff drains down within 72 hours. Mosquito's should not be a problem if the water drains in 72 hours. Mosquitoes require a considerably long breeding period with relatively static water levels.
- Inspect for accumulation of sediment, damage to outlet control structures, erosion control measures, signs of water contamination/spills, and slope stability in the berms.
- Mow only as appropriate for vegetative cover species.
- Remove accumulated sediment from the sediment pretreatment device/forebay as needed. Inspect pretreatment forebay at least one time per year.
- If Infiltration basin bottom becomes clogged, scrape bottom and remove sediment and restore original cross section. Properly dispose of sediment.

Additional Maintenance Information for Dry Wells

- Inspect dry wells at least four times a year, as well as after every storm exceeding one inch.
- Remove sediment, debris/trash, and any other waste material from the dry well and dispose of at a suitable disposal/recycling site and in compliance with local, state, and federal waste regulations.
- Evaluate the drain-down time of the dry well to ensure the maximum time of 72 hours is not being exceeded. If drain down time exceeds the maximum, drain the dry well via pumping and clean out perforated piping, if included. If slow drainage persists, the system may need replacing.
- Regularly clean out gutters and ensure proper connections to facilitate the effectiveness of the dry well.
- Replace filter screen that intercepts roof runoff as necessary.
- If an intermediate sump box exists, clean it out at least once per year.

Winter Considerations

Most infiltration practices are typically located below the frost line and continue to function effectively throughout the winter. It is imperative to prevent salt, sand, cinder, and any other deicers from clogging the surface area of infiltration practices by avoiding piling snow in these areas. Sand and cinder deicers could clog infiltration devices and soluble deicers such as salt can damage the health of vegetation.

Cost

The construction cost of many infiltration BMPs can vary greatly depending on the configuration, location, site conditions, etc. Following is a summary of both construction and maintenance costs. This information should be strictly as guidance. More detailed cost information should be discerned for the specific site before assessing the applicability of the BMP.

	Construction Costs	Maintenance Costs
Dry well*	$4-9/ft3	5-10% of capital costs
Infiltration basin	Varies depending on excavation, plantings, and pipe configuration.	Disposal costs
Infiltration trench**	$20-30/ ft3	5-10% of capital costs
Subsurface infiltration bed	$13/ ft3	

*2003 dollars.
**City of Portland. 2006 dollars.

Designer/Reviewer Checklist for Infiltration Berms

ITEM	YES	NO	N/A	NOTES
Was the Soil Infiltration Testing Protocol followed?*				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Was the Infiltration BMP followed?				
Two-foot separation from bedrock/SHWT?				
Soil permeability acceptable?				
Natural, uncompacted soils?				
Excavation in berm areas minimized?				
Loading ratio considered?				
Drawdown time less than 72 hours?				
Erosion and Sedimentation control?				
Feasible construction process and sequence?				
Entering flow velocities non-erosive?				
Berm height 6 to 24 inches?				
Berm designed for stability (temporary and permanent)?				
Acceptable berm side slopes?				
Are berm materials resistant to erosion?				
Located level, along contour?				
Acceptable soil for plants specified?				
Appropriate plants selected?				
Maintenance accounted for and plan provided?				

** In general, the protocol should be followed as much as possible (although there is more flexibility for berms than for other BMPs such as pervious pavement and subsurface infiltration that rely almost entirely on infiltration).*

Designer/Reviewer Checklist for Infiltration Trenches, Infiltration Basins, Dry Wells, and Subsurface Infiltration Beds

ITEM	YES	NO	N/A	NOTES
Was the Soil Infiltration Testing Protocol followed?				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Was the Infiltration BMP followed?				
Two-foot separation between the bed bottom and bedrock/ SHWT?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Adequate separations from wells, structures, etc.?				
Natural, uncompacted soils?				
Level infiltration area (e.g., trench bottom, bed bottom)?				
Excavation in infiltration area minimized?				
Hotspots/pretreatment considered?				
Loading ratio below 5:1?				
Storage depth limited to two feet?				
Drawdown time less than 72 hours?				
Positive overflow from system?				
Erosion and sedimentation control?				
Feasible construction process and sequence?				
Geotextile specified?				
Pretreatment provided?				
Clean, washed, open-graded aggregate specified?				
Stable inflows provided (infiltration basin)?				
Appropriate perforated pipe, if applicable?				
Appropriate plants selected, if applicable?				
Observation well/clean out provided, if applicable?				
Maintenance accounted for and plan provided?				

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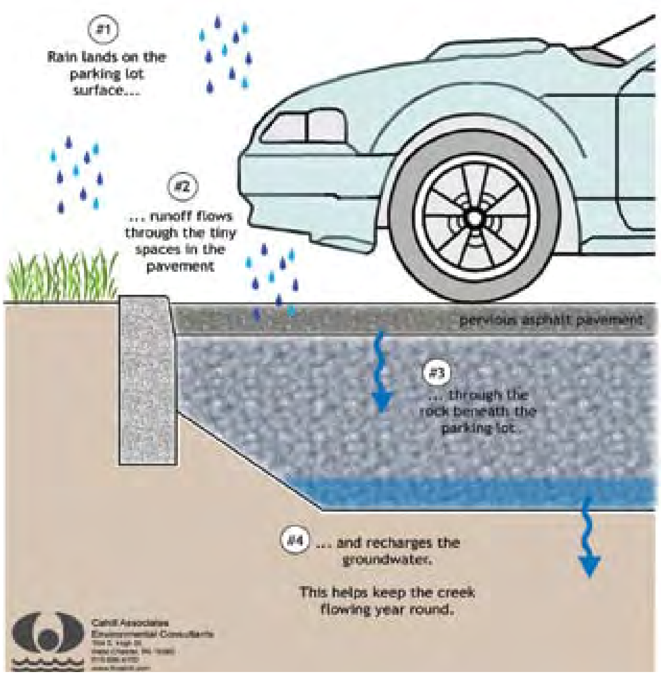
BMP Fact Sheet

Pervious Pavement with Infiltration

Pervious pavement is an infiltration technique that combines stormwater infiltration, storage, and structural pavement consisting of a permeable surface underlain by a storage reservoir. Pervious pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses.



Pervious pavement with infiltration schematic

Applications		Stormwater Quantity Functions	
Residential	Yes**	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Yes	**Peak Rate**	Med/High
Industrial	Yes**	**Stormwater Quality Functions**	
Retrofit	Yes**	**TSS**	High***
Highway/Road	Limited	**TP**	Med/High
Recreational	Yes	**TN**	Medium
		Temperature	High

Additional Considerations	
Cost	Medium
Maintenance	High
Winter Performance	Medium

Variations
- Porous asphalt
- Pervious concrete
- Permeable paver blocks
- Reinforced turf/gravel

Key Design Features
- Follow soil infiltration testing protocol (Appendix E) and infiltration BMP guidelines
- Do not infiltrate on compacted soil
- Level storage bed bottoms
- Provide positive stormwater overflow from bed
- Surface permeability >20”/hr

Site Factors
- Water table/Bedrock separation: two-foot min*.
- Feasibility on steeper slopes: Low
- Potential hot spots: Not without design of pretreatment system

Benefits
- Volume control and groundwater recharge, moderate peak rate control
- Dual use for pavement structure and stormwater management

Limitations
- Pervious pavement not suitable for all uses
- High maintenance needs

* Four feet recommended, if possible

**Applicable with special design considerations.

***Pretreatment for TSS is recommended.

Case Study: Grand Valley State University Porous Pavement Parking Lots

A crucial project for Grand Valley State University (GVSU) to prevent the accelerated degradation of steep ravines, which had historically been used as a receptacle for untreated stormwater, was to construct two 180-car parking lots using porous asphalt pavement for student parking on the Allendale Campus. The site consists of heavy clay soils and, instead of using limited space for a detention basin, porous pavement was chosen to make the best use of available space. It is also one of the first best management practices adopted for campus use to move the university towards its goal of sustainable site design.

GVSU's clay soils don't allow for much infiltration so the goal of the porous pavement was primarily filtration and storage in the stone bed. Underdrains exist in the beds for just over half of one lot which outlet into a swale that has been planted with grasses. All other underdrains outlet directly to a storm sewer.

Project Highlights

The porous pavement has performed well, and there are no maintenance issues to date.

Since the project was completed in 2004, GVSU faculty has used the porous asphalt lots as an educational tool to demonstrate sustainable stormwater management concepts with students.

The pavement section consisted of 12 inches of MDOT 6A course aggregate over a nonwoven geotextile fabric, a four-inch underdrain, and three inches of porous asphalt.

Grand Valley State University Parking Lot
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Water on Porous Asphalt
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Case Study Site Considerations	
Project Type	Pervious pavement
Soil Conditions	Heavy clay soils
Estimated Total Project Cost	$240,000 per lot
Maintenance Responsibility	Grand Valley State University
Project Contact	Bob Brown, brownbo@gvsu.edu 616-331-3582, Kerri Miller, P.E., kamiller@ftch.com 616-464-3933

Description and Function

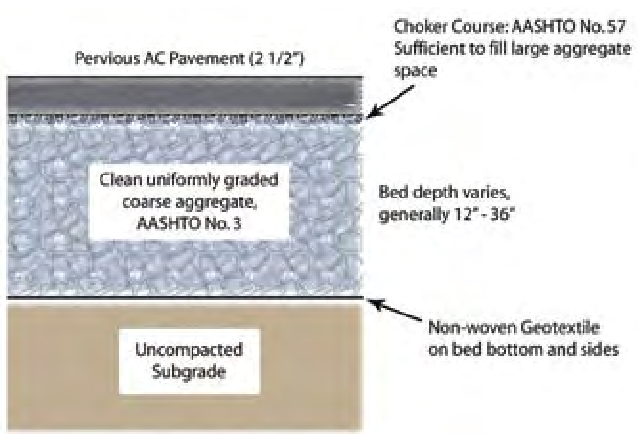
A pervious pavement system consists of a porous surface course underlain by a storage reservoir placed on uncompacted subgrade to facilitate stormwater infiltration (Figure 7.32). The storage reservoir may consist of a stone bed of uniformly graded, clean, and washed course aggregate with a void space of approximately 40 percent or other pre-manufactured structural storage units (see Infiltration BMP for detailed information on the use of structural storage units). The pervious pavement may consist of porous asphalt, pervious concrete, permeable paver blocks, or reinforced turf/gravel.

Stormwater drains through the surface course where it is temporarily held in the voids of the stone bed, and then slowly infiltrates into the underlying, uncompacted soil mantle (in some extreme cases, minimal compaction of the soil may be required). The stone bed can be designed with an overflow control structure so that during large storm events peak rates are controlled. At no time does the water level rise to the pavement level.

A layer of nonwoven geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The bed bottoms should be level and uncompacted to allow for even and distributed stormwater infiltration.

If new fill is required, it should consist of additional stone and not compacted soil. It is recommended that a fail safe be built into the system in the event that the pervious surface is adversely affected and suffers reduced performance. Many designs incorporate a riverstone/rock edge treatment (Figure 7.33) or inlets which are directly tied to the bed so that the stormwater system will continue to function despite the performance of the pervious pavement surface.

Figure 7.32
Example cross-section of porous asphalt system



Pervious pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater functions of the pavement. Pervious pavement roadways have seen wider application in Europe and Japan than in the U.S., although at least one U.S. system has been constructed successfully. (In Japan and the U.S., applying an open-graded asphalt pavement of one inch or less on roadways has been used to provide lateral surface drainage and prevent hydroplaning, but these are applied over impervious pavement on compacted subgrade. This application is not considered a stormwater BMP.)

Properly installed and maintained pervious pavement has a significant life span. For example, existing systems that are more than 20 years old continue to function successfully. Because water drains through the surface course and into the subsurface bed, freeze-thaw cycles do not tend to adversely affect pervious pavement.

Pervious pavement is most susceptible to failure difficulties during construction and, therefore, it is important that construction be undertaken in such a way as to prevent:

- Compacted underlying soil (except in certain limited conditions),
- Contaminated stone subbase with sediment and fines,
- Tracking of sediment or any temporary storage of soil on the pavement surface, and
- Drainage of sediment-laden waters onto pervious surface or into constructed bed.

Figure 7.33
Riverstone edge serves as a backup inlet into the infiltration bed under the porous asphalt

Staging, construction practices, and erosion and sediment control must all be considered when using pervious pavements.

When properly designed, pervious pavement systems provide effective management of stormwater volume and peak rates. The storage reservoir below the pavement surface can be sized to manage both direct runoff and runoff generated by adjacent areas, such as rooftops. Because the stone bed provides storage, outlet structures can be designed to manage peak rates with the use of weir and orifice controls. A well-designed system can infiltrate the majority of frequent small storms on an annual basis while providing peak rate control for storms up to and including the 100-year frequency storm event.

Studies have shown that pervious systems have been very effective in reducing contaminants such as total suspended solids, metals, and oil and grease. Because pervious pavement systems often have zero net discharge of stormwater for small frequent storms, they provide effective water quality control. The pervious surface and underlying soils below the storage bed allow filtration of most pollutants.

However, care must be taken to prevent infiltration in areas where toxic/contaminated materials are present in the underlying soils or within the stormwater itself (see Infiltration Systems Guidelines for more information). When designed, constructed, and maintained according to the following guidelines, pervious pavement with underlying infiltration systems can dramatically reduce both the rate and volume of runoff, recharge the groundwater, and improve water quality.

In northern climates, pervious pavements have less of a tendency to form black ice and often require less plowing. Sand and other abrasives should never be used on pervious pavements, although salt may be used on pervious asphalt as long as it does not contain significant non-soluble particles. Commercial deicers may be used on pervious concrete. Pervious pavement surfaces often provide better traction for walking paths in rain or snow conditions.

Variations

Porous asphalt

Early work on porous asphalt pavement was conducted in the early 1970s by the Franklin Institute in Philadelphia. It consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through small voids. Pervious asphalt is typically placed directly on the stone subbase in a single 3½ to four-inch lift that is lightly rolled to a finished thickness of 2½ to three inches (Figures 7.34 and 7.35).

Because porous asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt. Newer open-graded mixes for highway application give improved performance through the use of additives and higher-grade binders. Porous asphalt is suitable for use in any climate where standard asphalt is appropriate.

Figure 7.34
Porous asphalt being placed at the University of Michigan in Ann Arbor

Figure 7.35
Porous asphalt on open-graded stone subbase

Pervious concrete

Pervious Portland Cement Concrete, or pervious concrete, was developed by the Florida Concrete Association. Like pervious asphalt, pervious concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. In northern and mid-Atlantic climates such as Michigan, pervious concrete should always be underlain by a stone subbase designed for stormwater management and should never be placed directly onto a soil subbase.

While porous asphalt is very similar in appearance to standard asphalt, pervious concrete has a coarser appearance than conventional concrete. A clean, swept finish cannot be achieved. Care must be taken during placement to avoid working the surface and creating an impervious layer. Placement should be done by a contractor experienced with pervious concrete. Appropriately installed pervious concrete has proven to be an effective stormwater management BMP. Additional information pertaining to pervious concrete, including specifications, is available from the Michigan Concrete Association (www.miconcrete.org/).

Pervious and impervious concrete
Source: Michigan Department of Environmental Quality

Colored pervious concrete

Permeable paver blocks

Permeable paver blocks consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, parking areas, and low-speed streets. As new products are always being developed, the designer is encouraged to evaluate the benefits of various products with respect to the specific application.

Permeable paver lot at Grand Rapids Environmental Services Building

Permeable paver blocks at Fairlane Green shopping center, Allen Park, MI

Reinforced turf/gravel

Reinforced turf consists of interlocking structural units that contain voids or areas for turf grass growth or gravel and suitable for traffic loads and parking. Reinforced turf units may consist of concrete or plastic and are underlain by a stone and/or sand drainage system for stormwater management.

Reinforced turf/gravel applications are excellent for fire access lanes, overflow parking (Figure 7.36), and occasional-use parking (such as at religious and athletic facilities). Reinforced turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

Figure 7.36
Reinforced turf used as overflow parking

Other

There are other proprietary products similar to pervious asphalt and concrete, but they use clear binders so that the beauty of the natural stone is visible. Material strength varies, so some of these products are not suitable for vehicular traffic Typical applications include tree pits, walkways, plazas, and playgrounds. There are also pervious pavements made using recycled tires.

Highly permeable paver
Source: Permapave

Applications

Pervious pavements have been widely applied in retrofit situations when existing standard pavements are being replaced. Care must be taken when using pervious pavements in industrial and commercial applications where pavement areas are used for material storage or the potential for surface clogging is high due to pavement use (see Infiltration BMP).

Parking areas

Porous asphalt lot with slow discharge to vegetated swale at Ford Motor Co., Dearborn, MI

Walkways

Pervious pavement, both asphalt and concrete, has been used in walkways and sidewalks. These installations typically consist of a shallow (eight-inch minimum) aggregate trench that is angled to follow the surface slope of the path. In the case of relatively mild surface slopes, the aggregate infiltration trench may be "terraced" into level reaches in order to maximize the infiltration capacity, at the expense of additional aggregate.

Porous asphalt pathway at Grey Towers National Historic Site, Milford, PA

Playgrounds/basketball/tennis

Porous asphalt street in Portland, OR

Streets and alleys

Permeable paver street in Dowagiac, MI
Source: Pokagon Band of Potawatomi Indians

Rooftop/impervious area connections

Pervious pavement systems are often used to provide total site stormwater management where rooftops and other impervious surfaces are tied into the infiltration bed below the pavement surface. This can be an effective means to manage stormwater for a development site, while reducing land disturbance for stormwater BMPs.

If pervious pavement systems receive runoff from adjacent areas, proper sediment pretreatment for that runoff must be considered to prevent clogging of the storage bed. Typical pretreatment can be achieved by the use of properly maintained cleanouts, inlet sediment traps, and water quality inserts or filter devices.

It is recommended that direct surface sheet flow conveyance of large impervious areas to the pervious pavement surface be avoided. High sheet flow loading to pervious pavement surfaces can lead to premature clogging of the pavement surface. To avoid this, it is recommended that adjacent impervious areas be drained and conveyed to the infiltration bed via inlets and trench drains with proper sediment pretreatment.

Design Considerations

While evaluating the following design considerations, there are also several additional resources to consider when implementing pervious pavement. These include the Site Design Process for LID (Chapter 5), Soil Infiltration Testing Protocol (Appendix E), the Recommendations for Materials are specific to porous asphalt and porous concrete (Appendix D), and additional steps set forth in the introduction to this chapter.

Siting

1. The overall site should be evaluated for potential pervious pavement/infiltration areas *early* in the design process because effective pervious pavement design requires consideration of grading.
2. A four foot clearance above the seasonally high water table and bedrock is recommended. A two foot clearance can be used but may reduce the performance of the infiltration BMP used.
3. Orientation of the parking bays along the existing contours will significantly reduce the need for cut and fill.

4. Pervious pavement and infiltration beds **should not be placed on areas of recent fill** or compacted fill. If fill is unavoidable, permeable stone subbase material should be used wherever possible (and applicable infiltration rates should be used in the design). Areas of historical fill (>5 years) may also be considered for pervious pavement.
5. In those areas where the threat of spills and groundwater contamination is likely, pretreatment systems, such as filters and wetlands, may be required before any infiltration occurs. In hot spot areas, such as truck stops and fueling stations, the appropriateness of pervious pavement must be carefully considered. A stone infiltration bed located beneath standard pavement, preceded by spill control and water quality treatment, may be more appropriate.
6. The use of pervious pavement must be carefully considered in areas where the pavement may be seal coated or paved over due to lack of awareness, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. An example would include an infiltration system constructed under a conventional driveway. Educational signage at pervious pavement installations can encourage proper maintenance and is recommended (Figure 7.34).
7. In areas with poorly draining soils, infiltration beds below pervious pavement may be designed to slowly discharge to adjacent swales, wetlands, or bioretention areas. Only in extreme cases (e.g., industrial sites with contaminated soils) will the aggregate bed need to be lined to prevent infiltration.

Design

1. Bed bottoms must be level (0 percent slope) or nearly level. Sloping bed bottoms will lead to areas of ponding and reduced stormwater distribution within the bed. However, beds may be placed on a slope by benching or terracing parking bays (Figure 7.37). Orienting parking bays along existing contours will reduce site disturbance and cut/fill requirements.
2. All systems should be designed with an overflow system. Water within the subsurface stone bed should typically never rise to the level of the pavement surface. Inlet boxes can be used for cost-effective overflow structures. All beds should empty within 72 hours, preferably within 48 hours.
3. While infiltration beds are typically sized to handle the increased volume from a two-year design storm, they must also be able to convey and mitigate the peak of the less-frequent, more-intense storms, such as the 100-year storm. Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal weir and low-flow orifice is a common type of control structure (Figure 7.38). The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always must include positive overflow from the system to prevent surface ponding.
4. A weir plate or weir within an inlet or overflow control structure may be used to maximize the water level in the stone bed while providing sufficient cover for overflow pipes (Figure 7.38).
5. The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, the need for a detention basin may be eliminated or significantly reduced in size.
6. Pervious pavement installations should have a backup method for water to enter the stone storage bed in the event that the pavement fails or is altered. In uncurbed lots, this backup drainage may consist of an unpaved one-to-two foot wide stone edge drain connected directly to the bed (Figure 7.33). In curbed lots, inlets with sediment traps may be used at low spots. Backup drainage elements will ensure the functionality of the infiltration system if the pervious pavement is compromised.
7. Perforated pipes along the bottom of the bed may be used to evenly distribute runoff over the entire bed bottom (especially if runoff from adjacent areas is being brought into the bed). Continuously perforated pipes should connect structures (such as cleanouts and inlet boxes). Pipes may lay flat along the bed bottom and connect to the overflow structure (Figure 7.38). Depending on size, these pipes may provide additional storage volume.

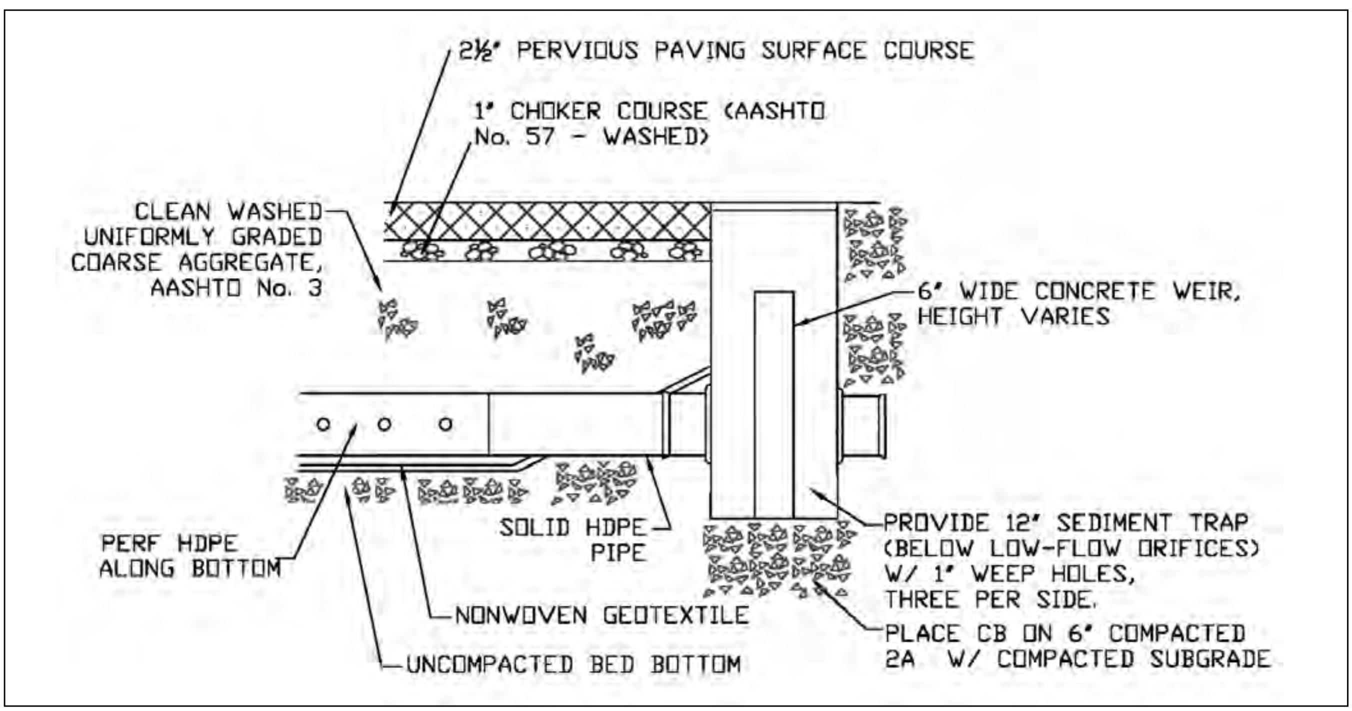
8. Perforated pipes can also be used as underdrains where necessary. Underdrains can ultimately discharge to daylight or to another stormwater system. They should be accessible for inspection and maintenance via cleanouts, overflow devices (Figure 7.38), or other structures.
9. Sediment transport to pervious systems should be minimized as much as possible to reduce maintenance requirements and extend the life of these systems. If roof leaders and area inlets convey water from adjacent areas to the bed, then native vegetation, water quality inserts, and/or sumped inlets should be used to prevent the conveyance of sediment and debris into the bed. Areas of impervious pavement draining directly onto pervious pavements should also be minimized as they can lead to clogging near the impervious-pervious boundary.
10. Infiltration areas should be located within the immediate project area in order to control runoff at its source. Expected use and traffic demands should also be considered in pervious pavement placement. An impervious water stop should be placed along infiltration bed edges where pervious pavement meets standard impervious pavements.

Figure 7.37
Slope stepping with berms

Source: Andropogon

11. The underlying infiltration bed is typically eight to 36 inches deep and comprised of clean, uniformly graded aggregate with approximately 40 percent void space. Local aggregate availability typically dictates the size of the aggregate used. The critical requirements are that the aggregate be uniformly graded, clean washed, and contain a significant void content. See the Specifications section for commonly used aggregates. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, site grading, and structural needs.

Figure 7.38
Example detail of an overflow device from a pervious asphalt system



12. Proper pervious pavement applications are resistant to freeze-thaw problems because of their permeable and open-graded components (the pavement surface should not be saturated and the base has a high void content which allows for expansion). In somewhat frost susceptible soils, it may be necessary to increase the minimum bed depth to 14-22 inches (depending on loading and specific soil conditions). In extremely susceptible soils, the bed and/or improved soils can be placed down to the full frost depth (Smith, 2006).

13. While most pervious pavement installations are underlain by an aggregate bed, alternative subsurface storage products may also be used. These include a variety of proprietary plastic units that contain much greater storage capacity than aggregate, at an increased cost.

Stormwater Functions and Calculations

Infiltration area

The infiltration area is defined as the plan area of the storage reservoir under the pervious pavement. The minimum infiltration area should be based on the following equation:

Minimum infiltration area = Contributing impervious area (including pervious pavement) / 5*

*May be increased depending on soil infiltration capacity (where soils are Type A or rapidly draining).

Volume reduction

Pervious pavements with infiltration provide an excellent means of capturing and infiltrating runoff. The storage bed below the pavement provides runoff volume storage during storm events, while the undisturbed subgrade allows infiltration of runoff into the underlying soil mantle. The total volume reduction can be estimated by summing the storage and infiltration volumes described below.

Storage volume = Depth* (FT) x Area (SF) x Void space (i.e., 0.40 for aggregate)

*Depth is the depth of the water stored during a storm event, depending on the drainage area, conveyance to the bed, and outlet control.

Infiltration volume = Bed bottom area (SF) x Infiltration design rate (in/hr) x Infiltration period* (hr) x (1/12)

*Infiltration period is the time when bed is receiving runoff and capable of infiltrating at the design rate. Not to exceed 72 hours.

Peak rate mitigation

Properly designed pervious pavement systems provide effective management of peak rates. The infiltration bed below the pavement acts as a storage reservoir during large storm events, even while runoff exfiltrates through the soil mantle through the process of infiltration. Outlet structures can be designed to manage peak rates with the use of weir and orifice controls and carefully designed systems may be able to manage peak rates for storms up to and including the 100-year storm. For additional information relating to peak rate modeling and routing, refer to Chapter 9, LID Stormwater Calculations and Methodology.

Water quality improvement

Pervious pavement systems are effective in reducing pollutants such as total suspended solids, metals, and oil and grease. Both the pervious pavement surface and the underlying soils below the infiltration bed allow pollutant filtration.

When pervious pavement systems are designed to capture and infiltrate runoff volumes from small storm events, they provide very high pollutant reductions because there is little if any discharge of runoff carrying the highest pollutant loads. Pervious pavement systems require pretreatment of TSS when adjacent areas drain to them, resulting in a high reduction of TSS and other particulates. However, pervious pavement systems will provide limited treatment of dissolved pollutants, such as nitrates. Typical ranges of pollutant reduction efficiencies for pervious pavements are listed as follows:

- TSS* – 65-100%
- TP – 30-90%
- NO_3 – 30%

*Pretreatment for TSS is recommended if adjacent areas drain to pervious pavement

Construction Guidelines

1. Follow the Recommendations for Materials that are specific to porous asphalt and porous concrete in Appendix D.
2. Due to the nature of construction sites, pervious pavement and other infiltration measures should be installed toward the end of the construction

period, if possible. Infiltration beds under pervious pavement may be used as temporary sediment basins or traps provided that they are not excavated to within 12 inches of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to its final grade and the pervious pavement system is installed.

3. The existing subgrade under the bed areas should **not** be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement. (Minor areas of unavoidable compaction can be partially remediated by scarifying the soil; see below.)

   Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material should be removed with light equipment and the underlying soils scarified to a minimum depth of six inches with a York rake (or equivalent) and light tractor. All fine grading should be done by hand. All bed bottoms are level grade.

4. Earthen berms (if used) between infiltration beds (Figure 7.39) may be left in place during excavation. These berms do not require compaction if proven stable during construction.

5. Geotextile and bed aggregate should be placed immediately after approval of subgrade preparation. Geotextile is to be placed in accordance with manufacturer's standards and recommendations.

   Adjacent strips of geotextile should overlap a minimum of 18 inches. It should also be secured at least four feet outside of bed in order to prevent any runoff or sediment from entering the storage bed. This edge strip should remain in place until all bare soils contiguous to beds are stabilized and vegetated. As the site is fully stabilized, excess geotextile along bed edges can be cut back to bed edge.

6. Clean (washed) uniformly graded aggregate (Figure 7.40) is placed in the bed in eight-inch lifts. Each layer should be lightly compacted, with construction equipment kept off the bed bottom. Once bed aggregate is installed to the desired grade, approximately one inch of choker base course crushed aggregate should be installed uniformly over the surface in order to provide an even surface for paving (if required).

Figure 7.39
Earthen berms separating terraced infiltration beds

7. Cement mix time: Mixtures should be produced in central mixers or in truck mixers. When concrete is delivered in agitating or non-agitating units, the concrete should be mixed in the central mixer for a minimum of 1.5 minutes or until a homogenous mix is achieved. Concrete mixed in truck mixers should be mixed at the speed designated as mixing speed by the manufacturer for 75-100 revolutions.

8. The Portland Cement aggregate mixture may be transported or mixed onsite and should be used within one hour of the introduction of mix water, unless otherwise approved by an engineer. This time can be increased to 90 minutes when using the specified hydration stabilizer. Each truck should not haul more than two loads before being cycled to another type concrete. Prior to placing concrete, the subbase should be moistened and in a wet condition. Failure to provide a moist subbase will result in reduced strength of the pavement.

9. A minimum of 30 revolutions at the manufacturer's designated mixing speed is required following any water added to the mix. Discharge should be a continuous operation and completed as quickly as possible. Concrete should be deposited as close to its final position as practicable and such that fresh concrete enters the mass of previously placed concrete.

10. Placing and finishing concrete equipment: The contractor should provide mechanical equipment of either slipform or form riding with a following compactive unit that will provide a minimum of 10 psi vertical force. The pervious concrete pavement will be placed to the required cross section and should not deviate more than +/- 3/8 inch in 10 feet from profile grade.

Figure 7.40
Open-graded, clean, coarse aggregate for infiltration beds

Placement should be continuous and spreading and strikeoff should be rapid. It is recommended to strike off about ½ to ¾ inch above the forms to allow for compaction. This can be accomplished by attaching a temporary wood strip above the top of the form to bring it to the desired height. After strikeoff, the strips are removed and the concrete is consolidated to the height of the forms.

11. Consolidation should be accomplished by rolling over the concrete with a steel roller, compacting the concrete to the height of the forms. Consolidation should be completed within 10 minutes of placement to prevent problems associated with rapid hardening and evaporation. After mechanical or other approved strike-off and compaction operation, no other finishing operation is needed. The contractor will be restricted to pavement placement widths of a maximum of 15 feet.
12. Jointing: Control (contraction) joints should be installed at maximum 20-foot intervals. They should be installed at a depth of ¼ the thickness of the pavement. These joints can be installed in the plastic concrete or saw cut. However, installing in the plastic concrete is recommended. Joints installed in the plastic concrete should be constructed using a small roller (salt or joint roller) to which a beveled fin with a minimum depth of ¼ the thickness of the slab has been welded around the circumference of a steel roller. When this option is used it should be performed immediately after roller compaction and prior to curing. If saw cut, the procedure should begin as soon as the pavement has hardened sufficiently to prevent raveling and uncontrolled cracking (normally just after curing).

    Transverse construction joints should be installed whenever placing is suspended a sufficient length of time that concrete may begin to harden. In order to assure aggregate bond at construction joints, a bonding agent suitable for bonding fresh concrete should be brushed, tolled, or sprayed on the existing pavement surface edge. Isolation (expansion) joints will not be used except when pavement is abutting slabs or other adjoining structures.
13. Curing procedures should begin within 15 minutes after placement. The pavement surface should be covered with a minimum six millimeter thick polyethylene sheet or other approved covering material. Prior to covering, a fog or light mist should be sprayed on the surface. The cover should overlap all exposed edges and should be completely secured (without using dirt) to prevent dislocation due to winds or adjacent traffic conditions.
14. Porous asphalt should not be installed on wet surfaces or when the ambient air temperature is below 50 degrees Fahrenheit. The temperature of the bituminous mix should be determined by the results of the Draindown test (ASTM D6390) but typically ranges between 275 degrees Fahrenheit and 325 degrees Fahrenheit (as determined by the testing and recommendations of the asphalt supplier).

    Pervious pavement should be laid in one lift directly over the storage bed and stone base course to a 2.5- to 3-inch finished thickness. Compaction of the surface course should take place when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction. More rolling could cause a reduction in the surface course porosity.
15. Do not place Portland Cement pervious pavement mixtures when the ambient temperature is 40 degrees Fahrenheit or lower, unless otherwise permitted in writing by the engineer.
16. Mixing, placement, jointing, finishing, and curing doesn’t apply to permeable paver systems. A manual on Permeable Interlocking Concrete Pavements from the Interlocking Concrete Pavement Institute (Smith, 2006) offers detailed guidance on the design and construction of permeable paver systems.
17. After final pervious asphalt or concrete installation, no vehicular traffic of any kind should be permitted on the pavement surface until cooling and

hardening or curing has taken place, and not within the first 72 hours (many permeable paver systems can be used right away). The full permeability of the pavement surface should be tested by applying clean water at the rate of at least five gallons per minute over the surface using a hose or other distribution devise (Figure 7.41). All water should infiltrate directly without puddle formation or surface runoff.

Maintenance

The primary goal of pervious pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from being clogged with fine sediments. To keep the system clean and prolong its life span, the pavement surface should be vacuumed twice per year with a commercial cleaning unit. Pavement washing systems or compressed air units are generally not recommended but may be acceptable for certain types of pavement. All inlet structures within or draining to the infiltration beds should also be cleaned out twice a year.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement. If any washout does occur, immediately clean it off the pavement to prevent further clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected twice a year. All trash and other litter should be removed during these inspections.

Superficial dirt does not necessarily clog the pavement voids. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking or spilling dirt onto the pavement. Furthermore, all construction or hazardous materials carriers should be prohibited from entering a pervious pavement lot.

Potholes in pervious pavement are unlikely, though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a depression could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The depression can also be filled with pervious mix.

If an area greater than 50 sq. ft. is in need of repair, approval of patch type must be sought from either the engineer or owner. If feasible, permeable pavers can be taken up and then simply re-installed (replacing damaged pavers if necessary). **Under no circumstance should the pavement surface ever be seal coated**. Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

Figure 7.41
Testing permeability with a high capacity hose

Pervious pavement maintenance considerations are summarized below:

Prevent clogging of pavement surface with sediment

- Vacuum pavement twice a year,
- Maintain planted areas adjacent to pavement,
- Immediately clean any soil deposited on pavement,
- Do not allow construction staging, soil/mulch storage, etc., on unprotected pavement surface, and
- Clean inlets draining to the subsurface bed twice a year.

Snow/Ice removal

- Pervious pavement systems generally perform better and require less treatment than standard pavements,
- Do not apply abrasives such as sand or cinders on or adjacent to pervious pavement,
- Snow plowing is fine but should be done carefully (i.e., set the blade slightly higher than usual), and
- Salt application is acceptable, although alternative deicers are preferable.

Repairs

- Surface should never be seal-coated,
- Damaged areas less than 50 sq. ft. can be patched with pervious or standard pavement,
- Larger areas should be patched with an approved pervious pavement,
- Permeable pavers should be repaired/replaced with similar permeable paver block material, and
- Permeable pavers and gravel pavers may require the addition of aggregate on an annual basis or as needed, in order to replenish material used to fill in the open areas of the pavers. Turf pavers may require reseeding if bare areas appear.

Winter Considerations

Pervious pavement systems should perform equally well in the winter, provided that infiltration bed design considers the soil frost line, and proper snow removal and deicing procedures are followed. Winter maintenance for pervious pavement may be necessary but is sometimes less intensive than that required for a standard pavement (especially for pervious asphalt). The underlying stone bed tends to absorb and retain heat so that freezing rain and snow melt faster on pervious pavement. Therefore, ice and light snow accumulation are generally not as problematic. However, snow will accumulate during heavier storms.

Abrasives such as sand or cinders should not be applied on or adjacent to the pervious pavement. Snow plowing is fine, provided it is done carefully (i.e., by setting the blade slightly higher than usual, about an inch). Salt with low non-soluble solids content is acceptable for use as a deicer on the pervious pavement. Non-toxic, organic deicers applied either as blended, magnesium chloride-based liquid products or as pretreated salt, are preferred.

Cost

The majority of added cost of a pervious pavement/infiltration system lies in the underlying stone bed, which is generally deeper than a conventional subbase and wrapped in geotextile. Costs may also be higher in areas where experienced contractors are not readily available. However, these additional costs are often offset by the significant reduction in the required number of inlets and pipes. Also, since pervious pavement areas are often incorporated into the natural topography of a site, there is generally less earthwork and/or deep excavations involved. Furthermore, pervious pavement areas with subsurface infiltration beds often eliminate the need (and associated costs, space, etc.) for detention basins. When all of these factors are considered, pervious pavement with infiltration has often proven itself less expensive than impervious pavement with associated stormwater management.

- Porous asphalt, with additives, is generally 15 percent to 25 percent higher in cost than standard asphalt on a unit area basis. Unit costs for pervious asphalt (without infiltration bed) range from about \$4/SF to \$5/SF.
- Pervious concrete as a material is generally more expensive than asphalt and requires more labor and expertise to install. Unit cost of a six-inch-thick pervious concrete (without infiltration bed) section is about \$4/SF to \$6/SF.
- Permeable paver blocks vary in cost depending on type and manufacturer.

NOTE: The data provided are based on average market costs. For greater accuracy, a site- and market-specific cost estimate should be developed.

Designer/Reviewer Checklist for Pervious Pavement with Infiltration Bed

Type of pervious pavement(s) proposed: ______________________________

Source of mix design or material source: ______________________________

ITEM		YES	NO	N/A	NOTES
Appropriate application of pervious pavement (e.g., use, traffic loading, slopes)?					
Was the Soil Infiltration Testing Protocol followed?					
	Appropriate areas of the site evaluated?				
	Infiltration rates measured?				
Was the Infiltration BMP followed?					
	Two-foot minimum separation between the bed bottom and bedrock/SHWT?				
	Soil permeability acceptable?				
	If not, appropriate underdrain provided?				
	Adequate separations from wells, structures, etc.?				
	Natural, uncompacted soils?				
	Level infiltration area (bed bottom)?				
	Excavation in pervious pavement areas minimized?				
	Hotspots/pretreatment considered?				
	Loading ratio below 5:1?				
	Storage depth limited to two feet?				
	Drawdown time less than 48 hours?				
	Positive overflow from system?				
	Erosion and Sedimentation control?				
	Feasible construction process and sequence?				
	Geotextile specified?				
Clean, washed, open-graded aggregate specified?					
Properly designed/specified pervious pavement surface?					
Maintenance accounted for and plan provided?					
Signage provided?					

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BMP Fact Sheet

Vegetated Roof

Vegetated roofs, or green roofs, are conventional rooftops that include a thin covering of vegetation allowing the roof to function more like a vegetated surface. The overall thickness of the vegetated roof may range from 2 to 6 inches, typically containing multiple layers consisting of waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, synthetic components, and foliage.

Green roof with sedum at Lawrence Technological University's Taubman Student Services Center

Source: Lawrence Technological University

Applications		Stormwater Quantity Functions	
Residential	Limited	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Low*
Ultra Urban	Yes	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Medium
Highway/Road	N/A	**TP**	Medium
Recreational	Yes	**TN**	Medium
		Temperature	High

Additional Considerations	
Cost	High
Maintenance	Medium
Winter Performance	Medium

Variations

- Intensive
- Semi-intensive
- Extensive

Key Design Features

- Extensive roofs are most commonly used for rainfall runoff mitigation
- Roofs with pitches steeper than 2:12 (9.5 degrees) must incorporate supplemental measures

Benefits

- Good stormwater volume control
- Heating and cooling energy benefits
- Increased lifespan of roof
- Heat island reduction
- Enhance habitat value

Limitations

- Cost (intensive systems)
- Careful design and construction required
- Maintenance requirements until plants established
- Can't store or treat stormwater from other parts of the property

* Although vegetated roofs can be used very successfully in combination with infiltration systems.

Case Study: City of Battle Creek City Hall Runoff Project

City of Battle Creek, MI

The City of Battle Creek City Hall Runoff Project was designed to treat stormwater runoff from a municipal complex adjacent to the Battle Creek River, a tributary of the Kalamazoo River. The goal of the project was to treat one-half inch of rainstorm runoff by incorporating several best management techniques (BMPs) that promote infiltration and low impact development. The BMPs included a vegetated roof system on the Police Department roof; infiltration of runoff water from the impervious walkway in front of the Police Department building; and infiltration from the parking lots behind and adjacent to City Hall and the Police Department buildings.

Green roof on City of Battle Creek Police Department building
Source: City of Battle Creek

The green roof is primarily an extensive system with the exception of a band around the perimeter of the roof which is intensive. The load reductions on the roof have been revised to accommodate the additional system. The City of Battle Creek is responsible for the light maintenance needed for the vegetated roof. Keeping the native plants, mainly sedum, properly watered during establishment did pose a challenge. Replanting was required in some areas.

Case Study Site Considerations	
Project Type	Extensive Green Roof
Estimated Total Project Cost	$520,252 for roof reconstruction plus green roof; green roof materials alone were $121,635
Maintenance Responsibility	City of Battle Creek
Project Contact	Christine Kosmowski, 269-966-0712

Estimated Annual Pollutant Load Reductions:

- Sediment – 3.8 tons
- Nitrogen – 101 lbs.
- Phosphorous – 16 lbs.
- Volume – 68 percent

Another goal of the City of Battle Creek City Hall Runoff Project was to increase community awareness of low impact development techniques and their water quality protection benefits. The City is promoting the area as a demonstration site for local builders and homeowners.

Description and Function

Vegetated roofs involve growing plants on rooftops, thus replacing the vegetated footprint that was removed when the building was constructed. Vegetated roof covers are an "at source" measure for reducing the rate and volume of runoff released during rainfall events. The water retention and detention properties of vegetated roof covers can be enhanced through selection of the engineered media and plants. Depending on the plant material and planned usage for the roof area, modern vegetated roofs can be categorized as systems that are intensive, semi-intensive, or extensive (Table 7.16).

Intensive vegetated roofs utilize a wide variety of plant species that may include trees and shrubs, require deeper substrate layers (usually > four inches), are generally limited to flat roofs, require 'intense' maintenance, and are often park-like areas accessible to the general public.

Extensive vegetated roofs are limited to herbs, grasses, mosses, and drought tolerant succulents such as sedum, can be sustained in a shallow substrate layer (<four inches), require minimal maintenance once established, and are generally not designed for access by the public. These vegetated roofs are typically intended to achieve a specific environmental benefit, such as rainfall runoff mitigation. Extensive roofs are well suited to rooftops with little load bearing capacity and sites which are not meant to be used as roof gardens. The mineral substrate layer, containing little nutrients, is not very deep but suitable for less demanding and low-growing plant communities.

Semi-intensive vegetated roofs fall between intensive and extensive vegetated roof systems. More maintenance, higher costs and more weight are the characteristics for this intermediate system compared to that of the extensive vegetated roof.

Vegetated system layers

A proprietary system provides a growing environment on the roof which adequately compensates for the plant's natural environment. It ensures reliable technical and ecological functionality for decades. Vegetated roof systems contain the following functional layers (from bottom to top):

Root barrier: The root barrier protects the roof construction from being damaged by roots. If the waterproofing is not root resistant a separate root barrier has to be installed.

Extensive vegetated roof at Kresge Foundation Headquarters in Troy, MI

Source: Conservation Design Forum

Waterproof membrane: This layer protects the roof structure from moisture and can include a unique root-resistant compound to prevent roots from penetrating.

Protection layer: A specially designed perforation resistant protection mat prevents mechanical damage of the root barrier and roof construction during the installation phase. Depending on the thickness and the material the protection layer can also retain water and nutrients.

Drainage Layer: The drainage layer allows for excess water to run-off into the water outlets. Depending on the design and the material the drainage layer has additional functions such as water storage, enlargement of the root zone, space for aeration of the system and protection for the layers below it. Due to the weight constraints of the roof, the drainage layer is made of light-weight materials. Molded drainage elements made of rubber or plastic are used quite often. Other drainage layers are made of gravel, lava, expanded clay or clay tiles.

Filter layer: The filter layer separates the plant and substrate layers from the drainage layer below. Especially small particles, humic and organic materials, are retained by the filter sheet and are therefore available for the plants. In addition, the filter sheet ensures that the drainage layer and the water outlet are not clogged with silt. Filter layers are preferably made of geo-textiles such as fleece or other woven materials.

Table 7.16
Vegetated roof types

	Extensive Vegetated Roof	Semi-Intensive Vegetated Roof	Intensive Vegetated Roof
Maintenance	Low	Periodically	High
Irrigation (after plants are established)*	No	Periodically	Regularly
Plant Communities	Moss, Sedum, Herbs, and Grasses	Grass, Herbs, and Shrubs	Perennials, Shrubs, and Trees
System build-up height	60-200 mm	120-250 mm	150-400 mm Underground garages = > 1000 mm
Weight	60 - 150 kg/m2 13-30 lbs/sqft	120 - 200 kg/m2 25-40 lbs/sqft	180 - 500 kg/m2 35-100 lbs/sqft
Construction costs	Low	Medium	High
Desired use	Ecological protection layer	Designed vegetated roof	Park-like garden

*Irrigation is required regularly to establish plant communities, especially during the first season.

Source: Adapted from International Green Roof Association

Growing medium: The growing medium is the basis of the vegetated roof. A sufficient depth for the root zone has to be ensured as well as an adequate nutrient supply and a well balanced water-air relation. Depending on the type of vegetated roof and the construction requirements, a variety of different system substrates are available.

Light-weight mineral materials, with high water retention capacity and good water permeability, such as lava, pumice, expanded clay, expanded schist, and clay tiles, have proven to be reliable for many years. Untreated organic material and top soil have disadvantages in terms of weight and drainage function; they are only used as additions to mineral substrates.

Plant level: The plant selection depends on the growing medium as well as local conditions, available maintenance and the desired appearance. Low maintenance, durable and drought resistant plants are used for extensive vegetated roofs, versus, a nearly limitless plant selection for intensive vegetated roofs.

Variations

Some specialized vegetated roof companies offer installation using vegetated blankets/mats or trays. Pre-vegetated blankets/mats are grown off-site and brought to the site for installation (similar to the concept of sod for grass). They can provide an immediate vegetative coverage which can prevent erosion, reduce installation times, and reduce maintenance during what would otherwise be the establishment period for vegetation.

Frasier School District is testing both the tray system (foreground) and mat system (background} on their operations and maintenance building.

Modular systems are manufactured trays filled with various vegetated roof layers (often pre-vegetated as well) that are delivered to the site and installed on a prepared roof. Manufacturers of these systems claim that benefits include faster installation and easier access to the roof if maintenance or leak repairs are necessary (in addition to the potential benefits of a pre-vegetated system). Others argue that these benefits are not significant and that trays can have drawbacks such as increased cost, poor aesthetics (module edges being visible), and reduced performance (wet and dry spots resulting from the barriers between modules in the system).

Installation of green roof at the Ford Rouge Plant in Dearborn, MI

Source: Rouge River National Wet Weather Demonstration Project

Extensive vegetated roofs

Extensive vegetated roofs are the most commonly used systems due to their higher mitigation of stormwater runoff as well as their lower cost compared to the other systems. Extensive systems have three variations of assemblies that can be considered in design.

Single media assemblies

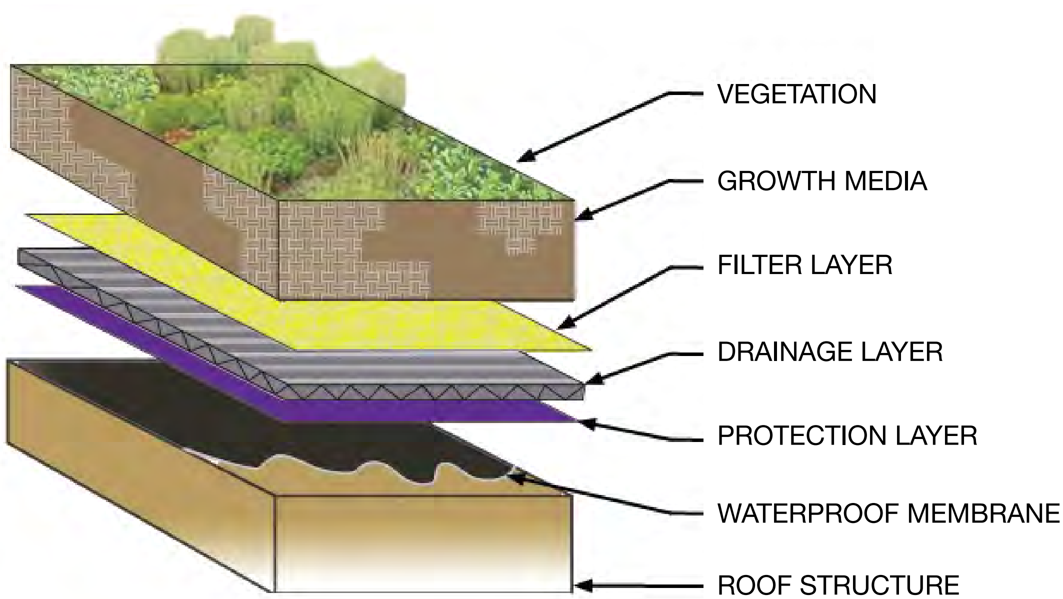
Single media assemblies (Figure 7.57) are commonly used for pitched roof applications and for thin and lightweight installations. These systems typically incorporate very drought tolerant plants and utilize coarse engineered media with high permeability. A typical profile would include the following layers:

1. Waterproofing membrane
2. Protection layer
3. Root barrier (optional, depending on the rootfastness of the waterproofing)
4. Drainage layer
5. Filter layer
6. Growth media
7. Vegetation

Pitched roof applications may require the addition of slope bars, rigid slope stabilization panels, cribbing, reinforcing mesh, or similar method of preventing sliding instability.

Flat roof applications with mats as foundations typically require a network of perforated internal drainage conduit to enhance drainage of percolated rainfall to the deck drains or scuppers.

Figure 7.57
Single media assembly



Dual media assemblies

Dual media (Figure 7.58) assemblies utilize two types of non-soil growth media. In this case a finer-grained media with some organic content is placed over a base layer of coarse lightweight mineral aggregate. They do not include a geocomposite drain.

The objective is to improve drought resistance by replicating a natural alpine growing environment in which sandy topsoil overlies gravelly subsoil. These assemblies are typically 4 to 6 inches thick and include the following layers:

1. Waterproofing membrane
2. Root barrier/ protection layer
3. Coarse-grained drainage media
4. Filter layer
5. Growth media
6. Vegetation

These assemblies are suitable for roofs with pitches less than, or equal to about 1.5:12 (7.1 degrees). Large vegetated covers will generally incorporate a network of perforated internal drainage conduit located within the coarse grained drainage layer.

Dual media with synthetic retention/detention layer

These assemblies introduce impervious plastic panels with cup-like receptacles on their upper surface (i.e., a modified geocomposite drain sheet). The panels are in-filled with coarse lightweight mineral aggregate. The cups trap and retain water. They also introduce an air layer at the bottom of the assembly. A typical profile would include:

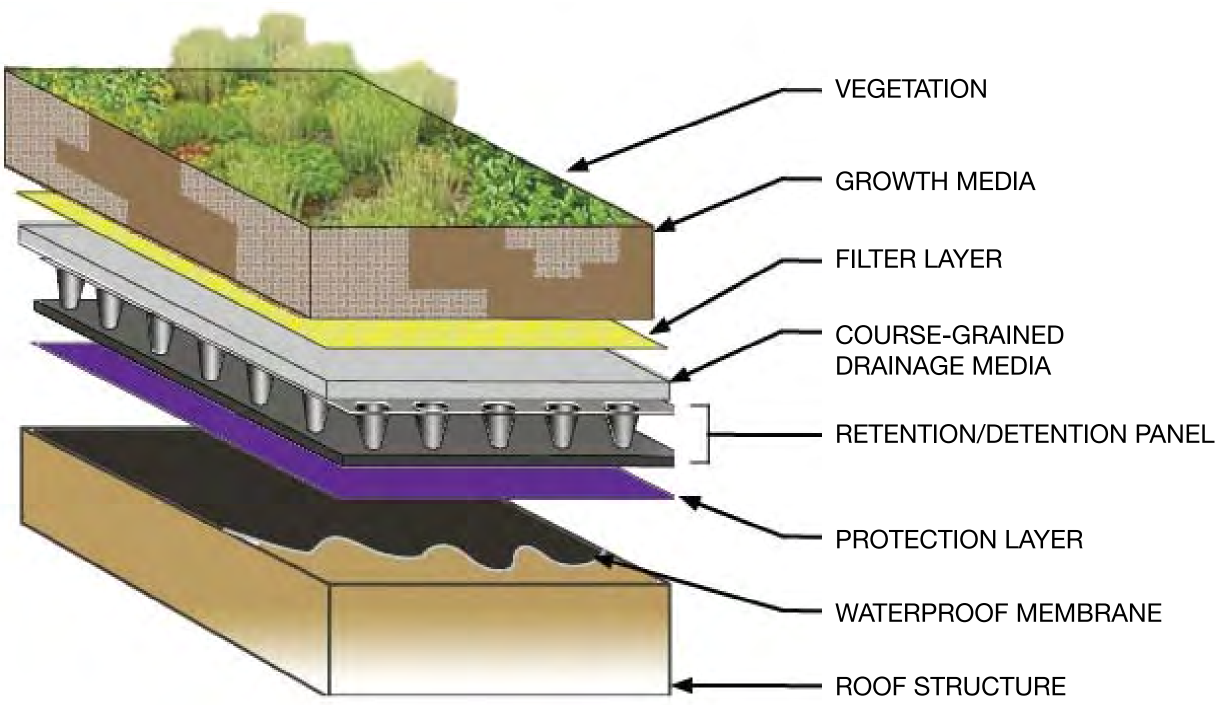
1. Waterproof membrane
2. Protection layer
3. Retention/detention panel
4. Coarse-grained drainage media
5. Filter layer
6. Growth media
7. Vegetation

These assemblies are suitable on roof with pitches less than or equal to 1:12 (4.8 degrees). Due to their complexity, these systems are usually a minimum of five inches deep. If required, irrigation can be provided via surface spray or mid-level drip.

Treatment Train

Vegetated roof covers are frequently combined with ground infiltration measures. This combination can be extremely effective for stormwater management and is one of the best ways to replicate the natural hydrologic cycle. Vegetated roofs evapotranspirate a significant fraction of annual rainfall and typically discharge larger

Figure 7.58
Dual media assembly



storm events relatively slowly. If overflow is directed to an infiltration system, the discharge can be infiltrated efficiently as the system has more time to absorb water as it is slowly released from the roof. Vegetated roof covers improve the efficiency of infiltration devices by:

- Reducing the peak runoff rate,
- Prolonging the runoff, and
- Filtering runoff to produce a cleaner effluent.

Benefits

Establishing plant material on rooftops provides numerous ecological and economic benefits including stormwater management, energy conservation, mitigation of the urban heat island effect, increased longevity of roofing membranes, as well as providing a more aesthetically pleasing environment to work and live. A major benefit of green roofs is their ability to absorb stormwater and release it slowly over a period of several hours, retaining 60-100 percent of the stormwater they receive, depending on the duration and the intensity of the storm.

In addition, green roofs have a longer life-span than standard roofs because they are protected from ultraviolet radiation and the extreme fluctuations in temperature that cause roof membranes to deteriorate. A vegetated roof has a life expectancy of 60 years — three times as long as a traditional roof.

As pervious surfaces are replaced with impervious surfaces due to urban development, the need to recover green space is becoming increasingly critical for the health of our environment. Vegetated roof covers have been used to create functional meadows and wetlands to mitigate the development of open space. This can be accomplished with assemblies as thin as six inches.

Design Considerations

Roof substructure

Wooden constructions, metal sheeting as well as reinforced concrete decks can be considered as appropriate roof substructures. The base for the vegetated roof is a waterproof roof construction with appropriate load bearing capacity.

Root barrier

Root barriers should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended.

Green roof at the Ford Rouge Plant in Dearborn, MI

Recognized in 2004 by Guinness World Records as the largest green roof in the world, this green roof covers 454,000 square feet atop Ford's truck assembly plant in Dearborn, MI. The green roof is part of a comprehensive effort to revitalize the historic Ford Rouge complex as a model for 21st Century sustainable manufacturing and is a significant component of a site-wide 600-acre stormwater management system.

Over a period of time roots can damage the waterproofing and roof construction if there have been no corresponding protection measures taken. The root resistance of the waterproofing is determined from the "Procedure for investigating resistance to root penetration at green-roof sites" by the FLL (The Landscaping and Landscape Development Research Society). Over 70 different waterproofing products meet the requirements of this test. If the waterproofing is not root resistant, an additional root barrier has to be installed. Aside from the roof surface, the upstands, perimeters, joints and roof edges also have to be protected against root penetration.

Growth media

Growth media should be a soil-like mixture containing not more than 15 percent organic content. The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and 'soil' structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Blowing media onto Mallet's Creek Library Roof, Ann Arbor, MI

Source: Mallet's Creek Library, Ann Arbor, MI

Separation fabric

Separation fabric should be readily penetrated by roots, but provide a durable separation between the drainage and growth media layers. (Only lightweight nonwoven geotextiles are recommended for this function.)

Roof penetrations

For vegetated roofs, the following upstand and perimeter heights have to be considered:

- Upstand height for adjacent building parts and penetrations: minimum of six inches.
- Upstand height for roof edges: minimum of four inches.

> Even though it is possible to build pitched green roofs with a slope of 45° it is not recommended to exceed 10° due to significant limited accessibility for upkeep and maintenance.

Important: The upstand height is always measured from the upper surface of the vegetated roof system build up or gravel strip. Clamping profiles guarantee reliable protection and a tight connection of the upstand areas. Roof penetrations (e.g. water connections, building parts for the usage of the roof area, etc.), when possible, should be grouped in order to keep roof penetration to a minimum.

Roof slope

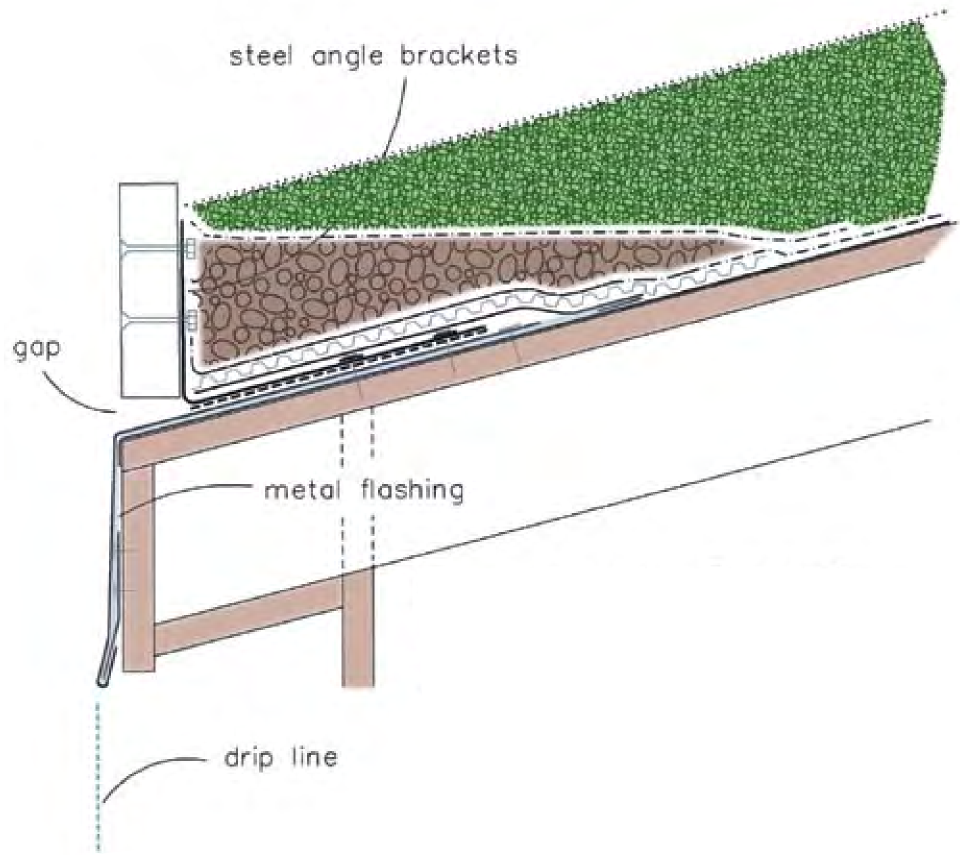
Using modern technologies it is possible to install a reliable vegetated roof system not only on conventional flat roofs, but also on saddle roofs, shed roofs and barrel roofs. Special technical precautions for the mitigation of existing shear forces and erosion are only necessary for a roof slope over 10°.

Roofs with a slope of more than 45° are normally not suitable for a vegetated roof system. Roofs with a slope of less than two percent are special roof constructions on which puddles often develop.

In order to avoid damage to extensive vegetated roofs by water retention, specific arrangements for the roof drainage are necessary. In contrast, it can be beneficial for intensive vegetated roofs to design the roof construction without slope to allow for dam up irrigation.

Load calculations

The maximum load bearing capacity of the roof construction must be considered when installing vegetated roofs. Therefore, the water saturated weight of



Example eave detail for sloped roof
Source: Roofscapes, Inc.

the green roof system, including vegetation must be calculated as permanent load. Extensive vegetated roofs weigh between 60-150 kg/m2 (13.0-30.0 lb/sq.ft.) depending on the thickness of the vegetated roof system build-up. Trees, shrubs, and construction elements such as pergolas and walkways cause high point loads and, therefore, have to be calculated accordingly.

Wind uplift

A vegetated roof must be tight to the roof, especially in cases of strong wind. When designing and installing the vegetated roof, safety measures against wind uplift are to be considered.

This is especially important when the vegetated roof provides the load for a loose laid waterproofing and root barrier. The actual influence from the wind depends on the local wind zone, height of the building, roof type, slope, and area (whether corner, middle or edge) and the substructure.

Roof drainage

Vegetated roof systems store a major part of the annual precipitation and release it to the atmosphere by transpiration. Depending on the thickness of the vegetated roof system build-up and rain intensity, surplus water may accumulate at certain times and must be drained off the roof area. The number of roof outlets and the penetrability factor, or more precisely, the water retaining capacity of the vegetated roof system build-up, has to be adjusted to the average local precipitation.

Roof outlets are to be kept free of substrate and vegetation and have to be controllable at all times. For this purpose “inspection chambers” are installed over the roof outlets. Due to safety precautions, roof areas with inlayed drainage must always have two drainage outlets or one outlet and one safety overflow. For facades and roof areas, gravel strips, gullies and grids provide fast drainage of rainwater into the drainage system.

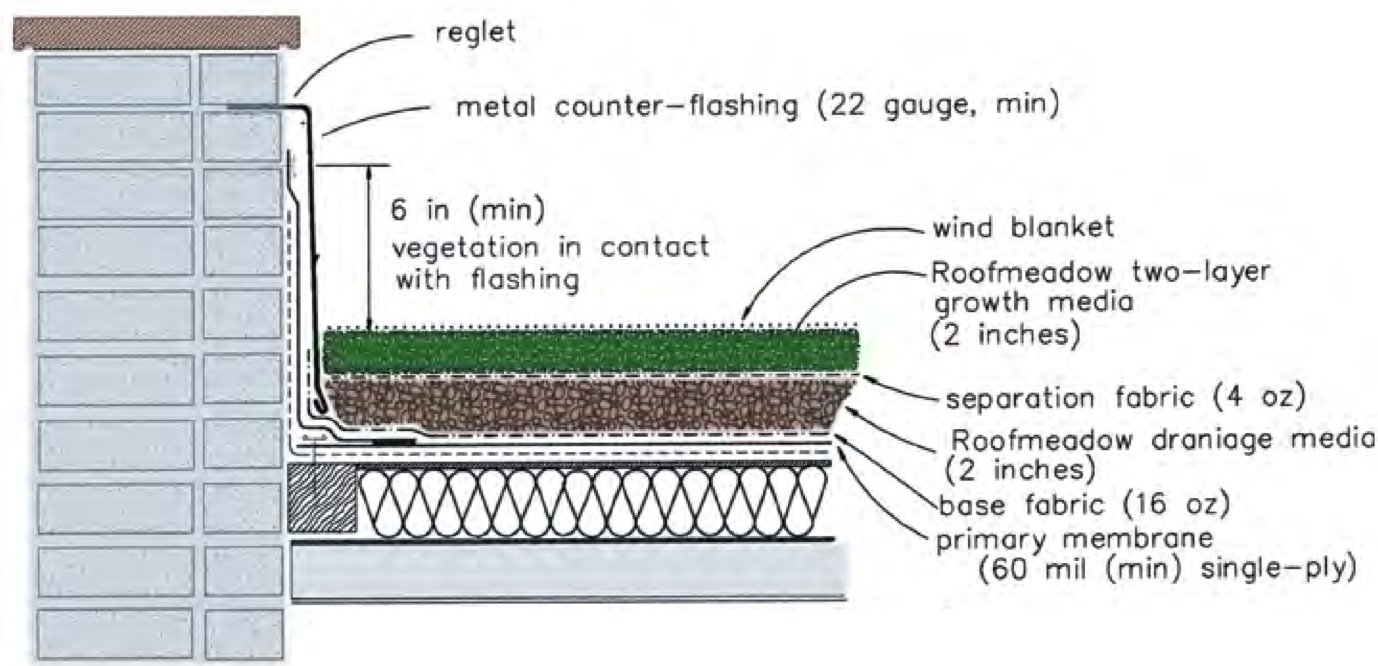
Pitched Vegetated Roofs

Technical requirements

Root resistant waterproofing is necessary for pitched vegetated roofs; installing an additional root barrier, requires much effort and increases the risk of slippage. Stable abutments have to be installed on the eaves edges to transfer shear forces from the vegetated roof system build-up and the additional snow load into the roof construction. Additional shear barriers may be necessary to transfer the shear forces depending on the roof slope and the roof length. It is recommended the design for the shear barriers and the eaves profiles be done by a structural engineer. With increasing slope, the vegetated roof system build-up is more complicated and the substrate has to be protected from erosion; plastic grid elements can be used for this purpose.

Plant selection

The success of the landscaping on pitched roofs depends on the plants. Fast surface coverage is the highest priority. A dense planting of root ball plants or pre-cultivated vegetation mats are used in cases of steep slopes and allow for rapid coverage. It is also important to consider the exposure of the roof area, the slope and the location of the building when selecting plants. Perennials and grasses can be used whereas Sedum is the most suitable for pitched roofs, due to the species' high water retention capacity and erosion protection. The water run-off is much faster on pitched roofs compared to a flat roof. It is advisable to plan for an additional irrigation system to provide water during dry periods. The irrigation can be provided either by drip irrigation or by sprinkler systems.



Example parapet flashing detail for a flat roof
Source: Roofscapes, Inc.

Irrigation

Extensive vegetated roofs with drought resistant plant species have to be irrigated only during planting and installation maintenance over the first two years. After its establishment, the annual rainfall is sufficient to sustain the vegetation. In contrast, the requirements are more involved for intensive vegetated roofs with lawn, shrubs, or trees. An adequate number of precisely dimensioned hoses with automatic irrigation units make plant maintenance during drought periods more manageable. The water supply for roof gardens with no slope can be increased through additional dam-up irrigation. Vegetated roofs can also be irrigated with cistern water.

Fire prevention

As a part of the "hard roof" classification, intensive vegetated roofs provide preventative fire protection in the case of sparks and radiating heat. The criteria that extensive vegetated roofs must meet in order to be considered fire resistant, are already met by most vegetated roof systems that are offered by suppliers. Openings within the vegetated roof (e.g. skylights) need to be installed with a vegetation free zone (approx. 20 in). On larger roof areas a vegetation free zone (e.g. gravel strip or concrete slabs) are to be installed at least every 130 feet.

Vegetation Considerations

Extensive vegetated roofs

Plants for extensive vegetated roofs have to survive intense solar radiation, wind exposure, drought, low nutrient supply, freezing temperatures and limited root area. Suitable plant varieties are those growing in severe locations with little moisture and nutrient supply, such as dry meadows. The main varieties are sedum, and delosperma. The plants are able to store high amounts of water in the leaves, are stress resistant and recover easily from periods of drought. Other varieties such as dianthus species, asteraceae and ornamental grasses are also suitable for these conditions.

Plugs prior to planting extensive vegetated roof

Source: Mallet's Creek Library, Ann Arbor, MI

Intensive green roofs

Having an appropriate vegetated roof system and sufficient growing medium (with higher root penetration volume, nutrients and water supply) growth of sophisticated plant varieties on the roof is possible. The selected plants need to be resistant to intense solar radiation and strong winds. Vegetation with various plant varieties such as perennials, herbs, grasses and trees allow for a natural character on the roof. Having a broader plant community increases the amount of maintenance required.

Conventional roof prior to retrofit

Extensive vegetated roof cover retrofit incorporating a patio for viewing

Stormwater Functions and Calculations

The performance of vegetated roof covers as stormwater best management practices cannot be represented by simple algebraic expressions used for surface runoff. In the analysis of vegetated roof covers, the water that is discharged from the roof is not surface runoff, but rather underflow, i.e., percolated water. The rate and quantity of water released during a particular storm can be predicted based on knowledge of key physical properties, including:

- Maximum media water retention
- Field capacity
- Plant cover type
- Saturated hydraulic conductivity
- Non-capillary porosity

The maximum media water retention is the maximum quantity of water that can be held against gravity under drained conditions. Standards that have been developed specifically for measuring this quantity in roof media are available from FLL and ASTM (E2399).

Conventional runoff coefficients, such as the NRCS **runoff curve number**, CN, can be back-calculated from computer simulation or measurements of vegetated roof cover assemblies. However, these coefficients will only apply for the specific design storm for which they have been determined.

Volume reduction

All vegetated roof covers have both a retention and a detention volume component. Benchmarks for these volumes can be developed from the physical properties described above.

Peak rate mitigation

Vegetated roof covers can exert a large influence on peak rate, especially in less extreme storms such as the 1-, 2-, and 5-year storms. Because volume is reduced, there is some peak rate reduction achieved for all storms. An evaluation of peak runoff rates requires either computer simulation or measurements made using prototype assemblies.

A general rule for vegetated roof covers is that rate of runoff from the covered roof surface will be less than or equal to that of open space (i.e., NRCS curve number of about 65) for storm events with total rainfall volumes up to three times the maximum media water retention of the assembly. For example, a representative vegetated roof cover with maximum moisture retention of one inch will react like open space for storms up to and including the three-inch magnitude storm.

Using computer simulations, municipalities could generate a table of CN values for specific design storms and green roof types. The table would relate maximum moisture capacity to the CN coefficients

Water quality improvement

Direct runoff from roofs is a contributor to pollutants in stormwater runoff. Vegetated roof covers can significantly reduce this source of pollution. Assemblies intended to produce water quality benefits will employ engineered media with almost 100 percent mineral content. Furthermore, following the plant establishment period (usually about 18 months), on-going fertilization of the cover is no longer needed. Experience indicates that it may take five or more years for a water quality vegetated cover to attain its maximum pollutant removal efficiency.

Dam-up Irrigation in Vegetated Roof

Intensive Vegetated Roofs depend mainly on additional irrigation. To install an irrigation system which does not use fresh water, a water dam-up irrigation unit is recommended.

Requirements of a dam-up irrigation unit:

- flat roof
- dam-up elements above roof outlets
- an appropriate drainage layer with the necessary height

In case of heavy rain the reservoir is filled primarily and any excess water is collected in the cistern. During dry periods the water on the roof is used first, then water is pumped from the cistern onto the roof and supplied to the plants.

This process can be carried out either manually or electronically. The water in the cistern can also be used for other purposes, provided the reservoir is big enough.

Maintenance

- Irrigation will be required as necessary during the plant establishment period and in times of drought.
- During the plant establishment period, three to four visits to conduct basic weeding, fertilization, and infill planting is recommended.
- The soluble nitrogen content (nitrate plus ammonium ion) of the soil should be adjusted to between one and five parts per million, based on soil test.
- Once plants are established, it is crucial to maintain the roof once or twice a year. Weeds and other unwanted plants on the entire roof, at the perimeters and at the upstands need to be removed. For grass and herb vegetation the organic buildup has to be removed once a year. Intensive vegetated roofs require higher maintenance and service throughout the year.

Winter Considerations

Applicable snow load must be considered in the design of the roof structure.

Cost

The construction cost of vegetated roof covers varies greatly, depending on factors such as:

- Height of the building
- Accessibility to the structure by large equipment such as cranes and trailers
- Depth and complexity of the assembly
- Remoteness of the project from sources of material supply
- Size of the project

Active growth on Fraser public school maintenance green roof during winter in Fraser, MI

However, under 2007 market conditions, extensive vegetated covers for roof will typically range between $8 and $16 per square foot, including design, installation, and warranty service (not including waterproofing). Basic maintenance for extensive vegetated covers typically requires about 2-3 person-hours per 1,000 square feet, annually.

Although vegetated roofs are relatively expensive compared to other BMPs in terms of stormwater management, they can have other significant benefits which serve to reduce their life-cycle costs. For example, the longevity of the roof system may be greatly increased. In addition, heating and cooling costs can be significantly reduced.

Designer/Reviewer Checklist for Vegetated Roofs

Type of vegetated roof(s) proposed: ____

ITEM	YES	NO	N/A	NOTES
Load and structural capacity analyzed?				
Waterproofing layer and protection adequate?				
Leak protection system provided?				
Internal drainage capacity for large storms?				
Appropriate growing medium?				
Appropriate drainage media and/or layer?				
Geotextile/filter fabric specified?				
Good detailing (flashings, penetrations, drains, gravel edges, etc.)?				
Slope stability provided, if necessary?				
Appropriate vegetation selected?				
Plant establishment (temporary irrigation/fertilization) procedures provided?				
Erosion control / wind protection provided?				
Maintenance accounted for and plan provided?				

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Southern Illinois University. *Green Roof Environmental Evaluation Network.* www.green-siue.com.

Appendix C

Recommended Plant Lists for Best Management Practices

This appendix contains recommended native and non-native (when appropriate) plant species for the Best Management Practices detailed throughout the manual. Species have been recommended based on hardiness, aesthetics, functionality, and commercial availability. It is certain that species exist outside the confines of this list that will perform in a comparable way to those listed; however, commercial availability is often a limiting factor in obtaining material for native plantings. Over time, and in certain locales, additional species will become available to supplement those listed below.

An array of planting zones is provided based on normal water levels (Figure C.1). Using these zones will provide the best chances for long-term success of native planting in the context of LID. While plants may naturally occur outside of the given ranges, these ranges are intended to be guidelines for plant installation. Whenever possible and practical in standing water conditions, native plants should be installed in live plant form (rather than seed). Seed or a combination of seed and live plants may be used in upland situations.

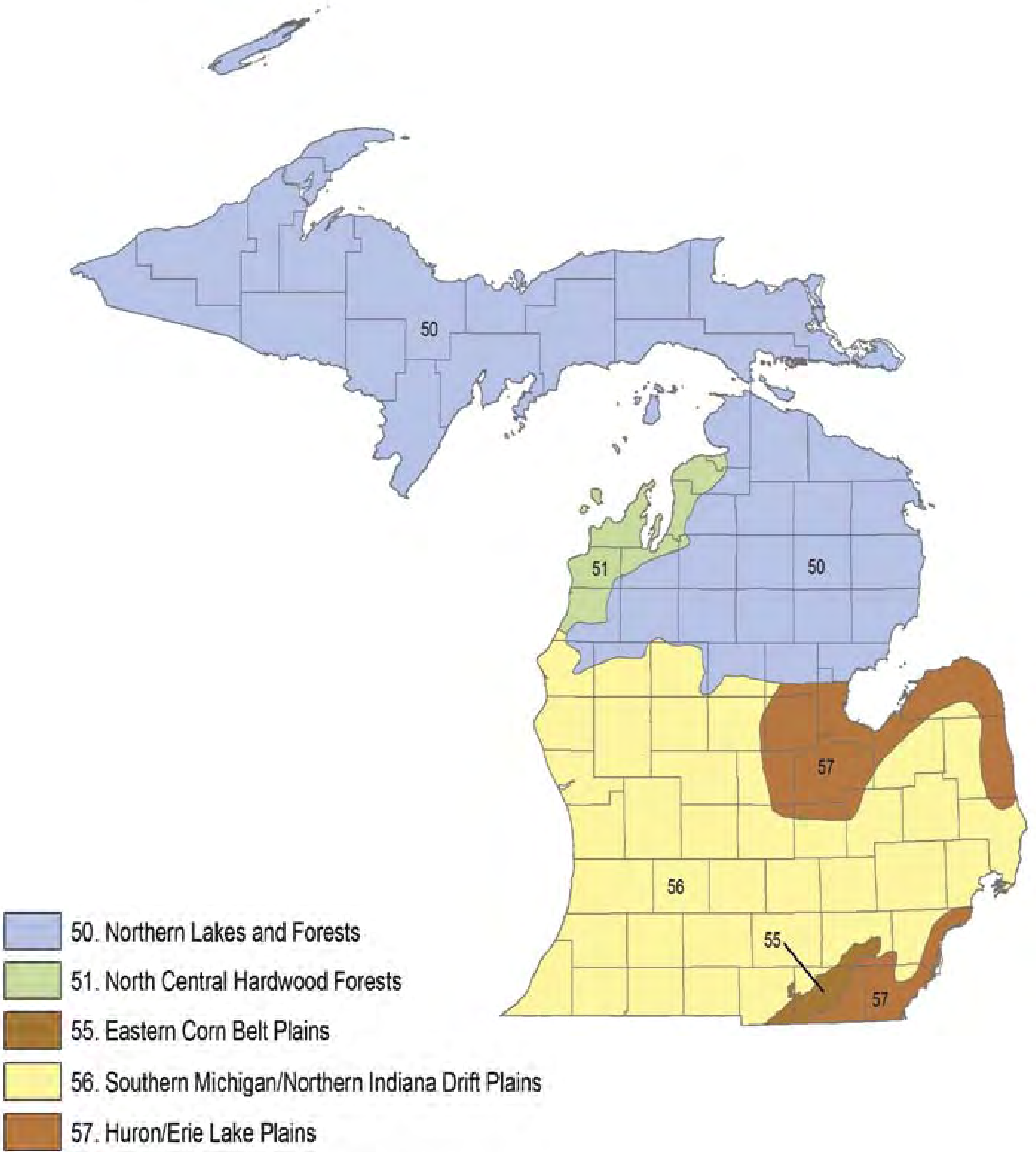
Recommendations are given for height, bloom color, bloom time, sun requirements, salt tolerance, and ecoregion. Please note that these are recommendations based on a range of situations, and a specific plant or population may vary from site-to-site. For sun requirements, F = Full sun required, P = Partial sun tolerated, and S = Shade tolerated. Salt tolerance is classified as Yes (Y) or No (N). This was determined through literature reviews and anecdotal evidence. If there is no information confirming tolerance, a “No” was listed.

Figure C.1
Planting Zone/BMP Matrix

	Zone A — 2”-4” Below Water Level	Zone B — 0”-2” Below Water Level	Zone C — 0”-2” Above Water Level	Zone D — 2”-4” Above Water Level	Zone E — 4”-18” Above Water Level	Zone F — 18”+ Above Water Level	Zone G — Planter Boxes	Zone H — Vegetated Roofs
Rain gardens/Bioretention	✤	✤	✤	✤	✤	✤		
Vegetated Filter Strips			✤	✤	✤	✤		
Vegetated Swales		✤	✤	✤				
Infiltration Basin		✤	✤					
Subsurface Infiltration Basins				✤	✤	✤		
Infiltration Trenches				✤	✤	✤		
Infiltration Berns	✤	✤	✤	✤	✤	✤		
Planter Boxes							✤	
Vegetated Roofs								✤
Constructed Wetlands	✤	✤	✤	✤				
Wet Ponds	✤	✤	✤					
Dry Extended Detention Basins			✤	✤	✤	✤		
Riparian Corridor Restoration			✤	✤				
Native Revegetation	✤	✤	✤	✤	✤	✤	✤	✤

Ecoregion recommendations are also provided for each species (Figure C.2). Whenever possible, the designer/installer should seek to use species that historically occurred in the same ecoregion as the project. When necessary, species occurring in an adjacent ecoregion may be used.

Figure C.2
EPA Level III Ecoregions for Michigan



Source: USEPA

Plant Installation

Native Seeding

Seasonal consideration: October 1-June 15 (note: seeds should not be planted on frozen ground).

Native seeding is generally recommended for areas above the water line or 1-2” below the water line. Live plant material should be used to establish vegetation at deeper water levels.

Broadcast seeding
Broadcast seeding is preferred over drill seeding on graded, bare soil sites. Apply the seed uniformly over the surface using a combination seeder/cultipacker unit such as a Brillion or Truax Trillion seeder. The Trillion seeder is preferred as it is designed to handle native seeds.

A cone seeder or other similar broadcasting equipment may also be used if the seed mix does not contain fluffy seeds in amounts sufficient to prevent free flowing without plugging. Seed should then be pressed into the surface using a cultipacker or roller.

Drill seeding
A rangeland-type no-till drill designed to plant native grasses and forbs may be used in bare soils although this equipment is specifically designed to plant through existing vegetation which is killed with an herbicide. Cultipacking or rolling before seeding may be required to prevent seed placement depths exceeding .25 inch, but cultipacking or rolling after seeding is not required.

All seeding equipment, whether broadcast or drill, should be calibrated to deliver the seed at the rates and proportions specified in the plans. Equipment should be operated to ensure complete coverage of the entire area to be seeded, and seed must be placed no deeper than .25 inch in the soil. No fertilizers or soil conditioners will be required or allowed.

Native Planting

Seasonal considerations: May 1-July 1

Plant plugs should be installed in holes drilled with an auger the same diameter and depth as the plug within +0.75 inch/- 0.25 inch. In wetland plantings where soil is soft and moist enough, a dibble bar or trowel may also be used. The planting layout should consider the requirements of the individual species regarding soil type, moisture, slope, shading, and other factors for the particular plant species.

Planting densities vary according to budget and project goals and can range from three-to-five foot spacing for plug supplements of seeded areas to six inches to two foot spacing for high visibility landscaping projects with large budgets. Groups of five-to-seven plugs of the same species planted approximately one foot apart is usually preferable to planting all species intermixed randomly across the site at a uniform density.

In wetland or shoreline areas with potential for high wave action or wildlife predation that may dislodge newly planted plugs, plugs should be secured with six inch or eight inch U-shaped wire erosion control blanket staples. Staple length is determined by the density of the planting substrate; softer substrates require longer length to hold plugs adequately.

In areas where potential for wildlife predation exists, such as retention basins or other planting areas adjacent to open water, waterfowl barriers should be installed around a minimum of 50 percent of the plugs. All plugs not protected by barriers should be stapled into the substrate as described above. Barriers may consist of plastic or wire mesh enclosures supported with wooden stakes, adequately constructed to inhibit access by waterfowl for one growing season. Enclosures should extend at least two feet above the plant tops. Methodology should be approved by the project designer with input from a restoration ecologist if necessary. Barriers may be removed after one growing season.

Maintenance and Management

Maintaining vegetated BMPs is typically most important during the first few years following installation. Supplemental irrigation may be needed to help establish plants in drought conditions. Plants may need to be replaced due to predation or other unseen factors. Most commonly, management includes removing invasive species via mowing, hand-pulling, or spot herbicide applications. In larger areas, broadcast herbicide applications may be appropriate. Over time in upland areas, controlled burning may be used as a way to invigorate the plantings and control certain invasive species. If not feasible for social or cultural reasons, an annual or biennial mowing may be used instead of fire.

Long-term management may be necessary, but is typically significantly less intensive. The site should be periodically checked for invasive species infestations. Any prairie or open area may need occasional (every three to five years) burning or mowing to remove woody vegetation that may encroach.

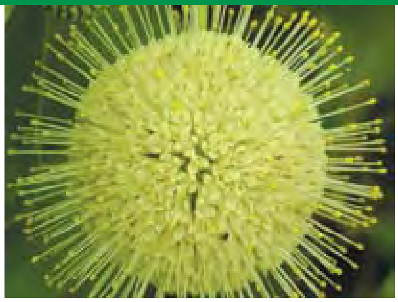
Zone A

Planting Zone = two-to-four inches below water level

These species require continual inundation within the given water depths in order to thrive. Although slight, short-term variances may be tolerated (+/-five inches for a period of 48 hours or less), water levels must remain in this range for a majority of the growing season for maximum plant growth and survival.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Cephalanthus occidentalis	Buttonbush	15’	White	Jun-Aug	F/P/S	N	51,55,56,57
Grasses/Sedges/Rushes:							
Acorus calamus	Sweet flag	1’-4’	Green	May-Jun	F/P	N	50,51,55,56,57
Scirpus acutus	Hard-stemmed bulrush	4’-6’	Brown	Apr-Aug	F	Y	50,51,55,56,57
Scirpus validus	Great bulrush	4’-8’	Brown	May-Aug	F	Y	50,51,55,56,57
Sparganium americanum	American bur reed	2’-5’	Green	Jun-Aug	F/P	N	50,51,55,56,57
Sparganium eurycarpum	Common bur reed	2’-6’	Green	May-Aug	F	N	50,51,55,56,57
Forbs:							
Asclepias incarnata	Swamp milkweed	3’-5’	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Decodon verticillatus	Swamp loosestrife	2’-4’	Purple	Jul-Sep	F/P	N	51,55,56,57
Iris virginica	Blue flag iris	2’-3’	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Peltandra virginica	Arrow arum	2’-5’	Green	Jun-Jul	F/P/S	N	55,56,57
Pontedaria cordata	Pickerelweed	1’-3’	Violet	Jun-Sep	F/P	N	50,51,55,56,57
Sagittaria latifolia	Arrowhead	1’-4’	White	Jun-Sep	F/P	N	50,51,55,56,57

Representative Zone A Species



Buttonbush

Swamp Milkweed

Pickerel Weed

Arrowhead

Blue Flag Iris

Source: JFNew

Zone B

Planting Zone = zero-to-two inches below water level

These species tolerate fluctuating water levels within this range. Although slight, short-term variances may be tolerated (+/-five inches for a period of 48 hours or less), water levels must remain in this range for most of the growing season for maximum plant growth and survival.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Cephalanthus occidentalis	Buttonbush	15’	White	Jun-Aug	F/P/S	N	51,55,56,57
Grasses/Sedges/Rushes:							
Acorus calamus	Sweet flag	1’-4’	Green	May-Jun	F/P	N	50,51,55,56,57
Carex comosa	Bristly sedge	2’-3’	Green	May-Jun	F	N	50,51,55,56,57
Carex lacustris	Lake sedge	2’-4’	Brown	May-Jun	F/P/S	N	50,51,55,56,57
Carex stricta	Tussock sedge	2’-3’	Brown	Apr-Jun	F/P	N	50,51,55,56,57
Eleocharis acicularis	Needle spike rush	6”	Green	May-Oct	F	N	50,51,55,56,57
Eleocharis obtusa	Blunt spike rush	1’-2’	Green	May-Sep	F/P	N	50,51,55,56,57
Glyceria striata	Fowl manna grass	1’-5’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Juncus effusus	Soft rush	1’-4’	Brown	July	F/P	N	50,51,55,56,57
Scirpus acutus	Hard-stemmed bulrush	4’-6’	Brown	Apr-Aug	F	Y	50,51,55,56,57
Scirpus cyperinus	Wool grass	3’-5’	Tan	Jun-Sep	F	Y	50,51,55,56,57
Scirpus pendulus	Red bulrush	2’-4’	Brown	May-Jun	F	N	51,55,56,57
Scirpus validus	Great bulrush	4’-8’	Brown	May-Aug	F	Y	50,51,55,56,57
Sparganium americanum	American bur reed	2’-5’	Green	Jun-Aug	F/P	N	50,51,55,56,57
Sparganium eurycarpum	Common bur reed	2’-6’	Green	May-Aug	F	N	50,51,55,56,57
Forbs:							
Alisma plantago-aquatica	Water plantain	2’-4’	White	Jul-Sep	F	N	50,51,55,56,57
Asclepias incarnata	Swamp milkweed	3’-5’	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Decodon verticillatus	Swamp loosestrife	2’-4’	Purple	Jul-Sep	F/P	N	51,55,56,57
Iris virginica	Blue flag iris	2’-3’	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Peltandra virginica	Arrow arum	2’-5’	Green	Jun-Jul	F/P/S	N	55,56,57
Pontedaria cordata	Pickerelweed	1’-3’	Violet	Jun-Sep	F/P	N	50,51,55,56,57
Sagittaria latifolia	Arrowhead	1’-4’	White	Jun-Sep	F/P	N	50,51,55,56,57
Saururus cernuus	Lizard’s tail	2’-4’	White	Jun-Aug	P/S	N	55,56,57

Representative Zone B Species

Blue Flag Iris

Arrowhead

Bristly Sedge

Pickerel Weed

Swamp Milkweed

Source: JFNew

Zone C

Planting Zone = zero-to-two inches above water level

These plants are tolerant of fluctuating water levels within this range. They will also tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for BMP settings.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90’	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Alnus rugosa	Speckled alder	25’	Brown	Mar-May	F/P	N	50,51,55,56,57
Amelanchier arborea	Downy serviceberry	40’	White	April	F/P/S	N	50,51,55,56,57
Aronia prunifolia	Purple chokeberry	10’	White	Apr-Jul	F/P	N	50,51,55,56,57
Betula alleghaniensis	Yellow birch	100’	Purple/ Yellow	Apr-May	P/S	N	50,51,55,56,57
Betula papyrifera	Paper birch	70’	Brown	Apr-May	F/P	N	50,51,55,56,57
Cephalanthus occidentalis	Buttonbush	15’	White	Jun/Aug	F/P/S	N	51,55,56,57
Cornus amomum	Silky dogwood	10’	White	May-Jul	F/P	N	51,55,56,57
Cornus sericea	Red-osier dogwood	10’	White	May-Sep	F/P	N	50,51,55,56,57
Ilex verticillata	Winterberry	10’	White	June	F/P/S	Y	50,51,55,56,57
Larix laricina	American larch	75’	Brown	May	F/P	N	50,51,55,56,57
Lindera benzoin	Spicebush	15’	Yellow	Apr-May	P/S	N	51,55,56,57
Morus rubra	Red mulberry	50’	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100’	Green	May-Jul	F/P/S	Y	51,55,56,57
Physocarpus opulifolius	Ninebark	10’	White	May-Jun	F/P	N	50,51,55,56,57
Picea mariana	Black spruce	60’	Brown	May-Jun	F/P/S	N	50,51,57
Quercus bicolor	Swamp white oak	70’	Green/ yellow	May	F/P/S	Y	55,56,57
Quercus palustris	Pin oak	90’	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Ribes americanum	Wild black currant	5’	Yellow	Apr-Jun	F/P/S	N	50,51,55,56,57
Rosa palustris	Swamp rose	2’-7’	Pink	Jun-Aug	F/P/S	N	50,51,55,56,57
Thuja occidentalis	White cedar	50’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Ulmus americana	American elm	100’	Brown	Mar-Apr	F/P/S	N	50,51,55,56,57
Ulmus rubra	Slippery elm	80’	Green	Mar-Apr	F/P/S	N	51,55,56,57
Viburnum lentago	Nannyberry	20’	White	Apr-Jun	P/S	Y	50,51,55,56,57
Grasses/Sedges/Rushes:							
Calamagrostis canadensis	Blue joint grass	2’-4’	Brown	June	F/P	N	50,51,55,56,57
Carex comosa	Bristly sedge	2’-3’	Green	May-June	F/P	N	50,51,55,56,57
Carex crinita	Fringed sedge	2’-5’	Green	May	F/P/S	N	50,51,55,56,57
Carex hystericina	Porcupine sedge	2’-3’	Green	May-June	F/P/S	N	50,51,55,56,57
Carex lupulina	Common hop sedge	2’-3’	Green/ Brown	May-June	F/P/S	N	50,51,55,56,57
Carex muskingumensis	Palm sedge	1’-2’	Brown	May-June	S	N	55,56,57
Carex stipata	Common fox sedge	1’-3’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Carex stricta	Tussock sedge	2’-3’	Brown	Apr-Jun	F/P	N	50,51,55,56,57
Carex vulpinoidea	Brown fox sedge	2’-3’	Brown	May-Jun	F/P	N	50,51,55,56,57
Cinna arundinacea	Common wood reed	3’-4’	Green	Aug-Sep	P/S	N	55,56,57
Eleocharis acicularis	Needle spike rush	6”	Green	May-Oct	F	N	50,51,55,56,57
Eleocharis obtusa	Blunt spike rush	1’-2’	Green	May-Sep	F/P	N	50,51,55,56,57
Glyceria striata	Fowl manna grass	1’-5’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Juncus effusus	Soft rush	1’-4’	Brown	July	F/P	N	50,51,55,56,57
Juncus tenuis	Path rush	6”-2’	Brown	June	F/P/S	N	50,51,55,56,57
Juncus torreyi	Torrey’s rush	1’-2’	Brown	Jun-Sep	F	Y	51,55,56,57
Scirpus acutus	Hard-stemmed bulrush	4’-6’	Brown	Apr-Aug	F	Y	50,51,55,56,57
Scirpus atrovirens	Dark green rush	3’-5’	Brown	Jun-Aug	F	N	50,51,55,56,57
Scirpus cyperinus	Wool grass	3’-5’	Tan	Jun-Sep	F	Y	50,51,55,56,57
Scirpus pendulus	Red bulrush	2’-4’	Brown	May-Jun	F	N	51,55,56,57
Scirpus validus	Great bulrush	4’-8’	Brown	May-Aug	F	Y	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Forbs:							
Alisma plantago-aquatica	Water plantain	2'-4'	White	Jul-Sep	F	N	50,51,55,56,57
Anemone canadensis	Canada anemone	1'-2'	White	May-Sep	F/P	N	50,51,55,56,57
Angelica atropurpurea	Great angelica	6'-9'	White	May-Jun	F/P	N	55,56,57
Asclepias incarnata	Swamp milkweed	3'-5'	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Aster novae-angliae	New England aster	3'-6'	Violet	Jul-Oct	F/P	N	50,51,55,56,57
Aster puniceus	Swamp aster	3'-6'	Lav/ White	Aug-Oct	F	Y	50,51,55,56,57
Aster umbellatus	Flat-topped aster	1'-4'	White	Jul-Oct	F/P	N	50,51,55,56,57
Cassia hebecarpa	Wild senna	3'-5'	Yellow	Jul-Aug	F/P	N	55,56
Chelone glabra	Turtlehead	2'-4'	Cream	Aug-Sep	F/P/S	N	50,51,55,56,57
Eupatorium maculatum	Spotted Joe-pye weed	4'-7'	Pink	Jun-Oct	F/P	N	50,51,55,56,57
Eupatorium perfoliatum	Boneset	3'-5'	White	Jul-Oct	F/P	Y	50,51,55,56,57
Euthamia graminifolia	Grass-leaved goldenrod	1'-4'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Gentiana andrewsii	Bottle gentian	1'-3'	Blue	Aug-Oct	F/P	N	50,51,55,56,57
Helenium autumnale	Sneezeweed	3'-5'	Yellow	Jul-Nov	F/P	Y	50,51,55,56,57
Helianthus giganteus	Tall sunflower	5'-12'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Iris virginica	Blue flag iris	2'-3'	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Liatris spicata	Marsh blazing star	3'-5'	Pink	Jul-Sep	F/P	N	55,56,57
Lilium michiganense	Michigan lily	3'-8'	Orange	Jul-Aug	P/S	N	55,56,57
Lobelia cardinalis	Cardinal flower	2'-5'	Red	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia siphilitica	Great blue lobelia	1'-4'	Blue	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia spicata	Pale spiked lobelia	1'-3'	Lavender	May-Aug	F/P	N	50,51,55,56,57
Mimulus ringens	Monkeyflower	2'-4'	Lavender	Jun-Sep	F/P	N	50,51,55,56,57
Physostegia virginiana	Obedient plant	2'-5'	Pink	Aug-Oct	F	Y	50,51,55,56,57
Pycnanthemum virginianum	Mountain mint	1'-3'	White	Jun-Oct	F/P	N	55,56,57
Rudbeckia laciniata	Cutleaf coneflower	3'-10'	Yellow	Jul-Nov	F/P/S	N	50,51,55,56,57
Sagittaria latifolila	Arrowhead	1'-4'	White	Jun-Sep	F/P	N	50,51,55,56,57
Saururus cernuus	Lizard's tail	2'-4'	White	Jun-Aug	P/S	N	55,56,57
Sisyrinchium angustifolium	Stout blue-eyed grass	1'	Blue	May-Aug	F/P	N	55,56,57
Solidago ohiensis	Ohio goldenrod	2'-3'	Yellow	Jul-Oct	F/P	N	50,51,55,56,57
Solidago patula	Swamp goldenrod	3'-6'	Yellow	Aug-Oct	F/P/S	N	50,51,55,56,57
Solidago riddellii	Riddell's goldenrod	2'-5'	Yellow	Sep-Nov	F	N	55,56,57
Spiraea alba	Meadowsweet	3'-6'	White	June-Sep	F/P	Y	50,51,55,56,57
Spiraea tomentosa	Steeplebush	2'-5'	Pink	Jul-Sep	F/P	Y	55,56,57
Thalictrum dasycarpum	Purple meadow-rue	3'-6'	Cream	May-Jul	F/P	N	50,51,55,56,57
Verbena hastata	Blue vervain	3'-6'	Violet	Jun-Sep	F	N	50,51,55,56,57
Vernonia missurica	Missouri ironweed	3'-5'	Purple	Jul-Sep	F	N	55,56,57
Zizia aurea	Golden Alexanders	1'-3'	Yellow	Apr-Jun	F/P/S	Y	55,56,57

Representative Zone C Species

Cardinal Flower

Swamp Milkweed

Blue-Eyed Grass

Obedient Plant

Joe-Pye Weed

Path Rush

Red-Osier Dogwood

Monkey Flower

Source: JFNew

Zone D

Planting Zone = two-to-four inches above water level

These plants tolerate fluctuating water levels within this range. They will also tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for BMP settings.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90’	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Acer saccharinum	Silver Maple	100’	Yellow	Mar-Apr	F/P	N	50,51,55,56,57
Amelanchier arborea	Downy serviceberry	40’	White	April	F/P/S	N	50,51,55,56,57
Aronia prunifolia	Purple chokeberry	10’	White	Apr-Jul	F/P	N	50,51,55,56,57
Betula alleghaniensis	Yellow birch	100’	Purple/ Yellow	Apr-May	P/S	N	50,51,55,56,57
Betula papyrifera	Paper birch	70’	Brown	Apr-May	F/P	N	50,51,55,56,57
Celtis occidentalis	Hackberry	60’	Green	May	F/P/S	N	55,56,57
Cercis canadensis	Redbud	25’	Red	Apr-May	F/P/S	N	55,56,57
Cornus amomum	Silky dogwood	10’	White	May-Jul	F/P	N	51,55,56,57
Cornus sericea	Red-osier dogwood	10’	White	May-Sep	F/P	N	50,51,55,56,57
Corylus americana	American hazelnut	10’	Yellow	Apr-May	F/P	N	55,56,57
Ilex verticillata	Winterberry	10’	White	June	F/P/S	Y	50,51,55,56,57
Juglans nigra	Black walnut	90’	Green	May	F/P	N	51,55,56,57
Juniperus virginiana	Red-cedar	50’	Brown	Apr-May	F/P	N	55,56,57
Larix laricina	American larch	75’	Brown	May	F/P	N	50,51,55,56,57
Lindera benzoin	Spicebush	15’	Yellow	Apr-May	P/S	N	51,55,56,57
Liriodendron tulipifera	Tulip tree	110’	Green	May-Jun	F/P	N	55,56,57
Morus rubra	Red mulberry	50’	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100’	Green	May-Jul	F/P/S	Y	51,55,56,57
Physocarpus opulifolius	Ninebark	10’	White	May-Jun	F/P	N	50,51,55,56,57
Picea mariana	Black spruce	60’	Brown	May-Jun	F/P/S	N	50,51,57
Platanus occidentalis	Sycamore	100’	Green	May	F/P	N	55,56,57
Quercus bicolor	Swamp white oak	70’	Green/ yellow	May	F/P/S	N	55,56,57
Quercus macrocarpa	Bur oak	85’	Yellow	May-Jun	F/P/S	N	50,51,55,56,57
Quercus palustris	Pin oak	90’	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Ribes americanum	Wild black currant	5’	Yellow	Apr-Jun	F/P/S	N	50,51,55,56,57
Rosa carolina	Pasture rose	3’	Pink	Jun-Sep	F/P	N	55,56,57
Rosa palustris	Swamp rose	2’-7’	Pink	Jun-Aug	F/P/S	N	50,51,55,56,57
Thuja occidentalis	White cedar	50’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Tilia americana	Basswood	100’	White	Jun-Jul	F/P/S	N	50,51,55,56,57
Tsuga canadensis	Hemlock	100’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Ulmus americana	American elm	100’	Brown	Mar-Apr	F/P/S	N	50,51,55,56,57
Ulmus rubra	Slippery elm	80’	Green	Mar-Apr	F/P/S	N	51,55,56,57
Viburnum dentatum	Arrowwood	10’	White	May-Jun	F/P/S	N	51,55,56,57
Viburnum lentago	Nannyberry	20’	White	Apr-Jun	P/S	Y	50,51,55,56,57
Viburnum prunifolium	Black haw	10’	White	Apr-May	F/P	N	55
Viburnum trilobum	Cranberry Viburnum	10’	White	Apr-May	F/P/S	N	50,51,55,56,57
Grasses/Sedges/Rushes:							
Andropogon gerardii	Big bluestem	4’-8’	Purple	Jul-Sep	F	N	50,51,55,56,57
Calamagrostis canadensis	Blue joint grass	2’-4’	Brown	June	F/P	N	50,51,55,56,57
Carex comosa	Bristly sedge	2’-3’	Green	May-June	F/P	N	50,51,55,56,57
Carex crinita	Fringed sedge	2’-5’	Green	May	F/P/S	N	50,51,55,56,57
Carex hystericina	Porcupine sedge	2’-3’	Green	May-June	F/P/S	N	50,51,55,56,57
Carex lupulina	Common hop sedge	2’-3’	Green/ Brown	May-June	F/P/S	N	50,51,55,56,57
Carex muskingumensis	Palm sedge	1’-2’	Brown	May-June	S	N	55,56,57
Carex stipata	Common fox sedge	1’-3’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Carex stricta	Tussock sedge	2’-3’	Brown	Apr-Jun	F/P	N	50,51,55,56,57
Carex vulpinoidea	Brown fox sedge	2’-3’	Brown	May-Jun	F/P	N	50,51,55,56,57
Cinna arundinacea	Common wood reed	3’-4’	Green	Aug-Sep	P/S	N	55,56,57
Elymus canadensis	Canada wild rye	3’-6’	Green	Jun-Sep	F/P	N	50,51,55,56,57
Elymus hystrix	Bottlebrush Grass	3’-5’	Green	Jun-Jul	P/S	N	
Elymus virginicus	Virginia wild rye	2’-4’	Green	Jun	F/P/S	N	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Glyceria striata	Fowl manna grass	1’-5’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Juncus tenuis	Path rush	6”-2’	Brown	June	F/P/S	N	50,51,55,56,57
Juncus torreyi	Torrey’s rush	1’-2’	Brown	Jun-Sep	F	Y	51,55,56,57
Panicum virgatum	Switch grass	3‘-5’	Green/ Purple	Jun-Oct	F/P	Y	51,55,56,57
Scirpus atrovirens	Dark green rush	3’-5’	Brown	Jun-Aug	F	N	50,51,55,56,57
Scirpus cyperinus	Wool grass	3’-5’	Tan	Jun-Sep	F	Y	50,51,55,56,57
Scirpus pendulus	Red bulrush	2’-4’	Brown	May-Jun	F	N	51,55,56,57
Spartina pectinata	Prairie cordgrass	6’-7’	Green	Jul-Aug	F	Y	50,51,55,56,57
Forbs:							
Anemone canadensis	Canada anemone	1’-2’	White	May-Sep	F/P	N	50,51,55,56,57
Angelica atropurpurea	Great angelica	6’-9’	White	May-Jun	F/P	N	55,56,57
Asclepias incarnata	Swamp milkweed	3’-5’	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Aster novae-angliae	New England aster	3’-6’	Violet	Jul-Oct	F/P	N	50,51,55,56,57
Aster puniceus	Swamp aster	3’-6’	Lav/ White	Aug-Oct	F	Y	50,51,55,56,57
Aster umbellatus	Flat-topped aster	1’-4’	White	Jul-Oct	F/P	N	50,51,55,56,57
Cacalia atriplicifolia	Pale Indian plantain	3’-8’	White	Jun-Oct	F/P/S	N	55,56
Cassia hebecarpa	Wild senna	3’-5’	Yellow	Jul-Aug	F/P	N	55,56
Chelone glabra	Turtlehead	2’-4’	Cream	Aug-Sep	F/P/S	N	50,51,55,56,57
Coreopsis tripteris	Tall coreopsis	4’-8’	Yellow	Aug-Sep	F/P	N	55,56,57
Desmodium canadense	Showy tick-trefoil	2’-5’	Purple	Jun-Sep	F/P	N	51,55,56,57
Eryngium yuccifolium	Rattlesnake master	3’-5’	White	Jul-Sep	F	N	55
Eupatorium maculatum	Spotted Joe-pye weed	4’-7’	Pink	Jun-Oct	F/P	N	50,51,55,56,57
Eupatorium perfoliatum	Boneset	3’-5’	White	Jul-Oct	F/P	Y	50,51,55,56,57
Euthamia graminifolia	Grass-leaved gold-enrod	1’-4’	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Gentiana andrewsii	Bottle gentian	1’-3’	Blue	Aug-Oct	F/P	N	50,51,55,56,57
Helenium autumnale	Sneezeweed	3’-5’	Yellow	Jul-Nov	F/P	Y	50,51,55,56,57
Helianthus giganteus	Tall sunflower	5’-12’	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Heliopsis helianthoides	False sunflower	4’-6’	Yellow	Jun-Oct	F/P	N	50,51,55,56,57
Iris virginica	Blue flag iris	2’-3’	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Liatris spicata	Marsh blazing star	3’-5’	Pink	Jul-Sep	F/P	N	55,56,57
Lilium michiganense	Michigan lily	3’-8’	Orange	Jul-Aug	P/S	N	55,56,57
Lobelia cardinalis	Cardinal flower	2’-5’	Red	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia siphilitica	Great blue lobelia	1’-4’	Blue	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia spicata	Pale spiked lobelia	1’-3’	Lavender	May-Aug	F/P	N	50,51,55,56,57
Mimulus ringens	Monkeyflower	2’-4’	Lavender	Jun-Sep	F/P	N	50,51,55,56,57
Monarda fistulosa	Wild bergamot	2’-5’	Lavender	Jul-Sep	F/P	N	50,51,55,56,57
Physostegia virginiana	Obedient plant	2’-5’	Pink	Aug-Oct	F	Y	50,51,55,56,57
Polygonatum biflorum	Solomon seal	1’-4’	Green/ White	May/Jul	P/S	N	55,56,57
Pycnanthemum virginianum	Mountain mint	1’-3’	White	Jun-Oct	F/P	N	55,56,57
Rudbeckia laciniata	Cutleaf coneflower	3’-10’	Yellow	Jul-Nov	F/P/S	N	50,51,55,56,57
Rudbeckia triloba	Three-lobed cone-flower	2‘-5’	Yellow	Aug-Oct	F/P	N	55,56,57
Solidago caesia	Bluestem goldenrod	1’-2’	Yellow	Sep-Oct	P/S	N	51,55,56,57
Solidago flexicaulis	Zigzag goldenrod	1’-3’	Yellow	Aug/Oct	P/S	N	50,51,55,56,57
Solidago ohiensis	Ohio goldenrod	2’-3’	Yellow	Jul-Oct	F/P	N	50,51,55,56,57
Solidago patula	Swamp goldenrod	3’-6’	Yellow	Aug-Oct	F/P/S	N	50,51,55,56,57
Solidago riddellii	Riddell’s goldenrod	2’-5’	Yellow	Sep-Nov	F	N	55,56,57
Spiraea alba	Meadowsweet	3’-6’	White	June-Sep	F/P	Y	50,51,55,56,57
Spiraea tomentosa	Steeplebush	2’-5’	Pink	Jul-Sep	F/P	Y	55,56,57
Thalictrum dasycarpum	Purple meadow-rue	3’-6’	Cream	May-Jul	F/P	N	50,51,55,56,57
Verbena hastata	Blue vervain	3’-6’	Violet	Jun-Sep	F	N	50,51,55,56,57
Vernonia missurica	Missouri ironweed	3’-5’	Purple	Jul-Sep	F	N	55,56,57
Veronicastrum virginicum	Culver’s root	3’-6’	White	Jun-Aug	F/P	N	55,56,57
Zizia aurea	Golden Alexanders	1’-3’	Yellow	Apr-Jun	F/P/S	Y	55,56,57

Representative Zone D Species


Big Bluestem


Marsh Blazing Star


Wild Columbine


Great Blue Lobelia


Michigan Lily


Virginia Mountain Mint


Blue Vervain


Meadowsweet

Source: JFNew

Zone E

Planting Zone = four-to-18 inches above water level

These plants tolerate fluctuating water levels within this range. They will also tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for BMP settings.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90’	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Acer saccharum	Sugar maple	100’	Green	Apr-May	F/P/S	N	50,51,55,56,57
Acer saccharinum	Silver Maple	100’	Yellow	Mar-Apr	F/P	N	50,51,55,56,57
Amelanchier arborea	Downy serviceberry	40’	White	April	F/P/S	N	N
Aronia prunifolia	Purple chokeberry	10’	White	Apr-Jul	F/P	N	50,51,55,56,57
Betula papyrifera	Paper birch	70’	Brown	Apr-May	F/P	N	50,51,55,56,57
Carya ovata	Shagbark hickory	80’	Green	May-Jun	F/P/S	N	55,56,57
Ceanothus americanus	New Jersey tea	1’-3’	White	Jun-Oct	F/P	N	50,51,55,56,57
Celtis occidentalis	Hackberry	60’	Green	May	F/P/S	N	55,56,57
Cercis canadensis	Redbud	25’	Red	Apr-May	F/P/S	N	55,56,57
Cornus amomum	Silky dogwood	10’	White	May-Jul	F/P	N	51,55,56,57
Cornus florida	Flowering dogwood	30’	White	May-Jun	F/P/S	N	55,56,57
Cornus sericea	Red-osier dogwood	10’	White	May-Sep	F/P	N	50,51,55,56,57
Corylus americana	American hazelnut	10’	Yellow	Apr-May	F/P	N	55,56,57
Gymnocladus dioicus	Kentucky coffee tree	85’	White	Jun	F/P	N	55,56,57
Juglans nigra	Black walnut	90’	Green	May	F/P	N	51,55,56,57
Juniperus virginiana	Red-cedar	50’	Brown	Apr-May	F/P	N	55,56,57
Larix laricina	American larch	75’	Brown	May	F/P	N	50,51,55,56,57
Lindera benzoin	Spicebush	15’	Yellow	Apr-May	P/S	N	51,55,56,57
Liriodendron tulipifera	Tulip tree	110’	Green	May-Jun	F/P	N	55,56,57
Morus rubra	Red mulberry	50’	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100’	Green	May-Jul	F/P/S	Y	51,55,56,57
Physocarpus opulifolius	Ninebark	10’	White	May-Jun	F/P	N	50,51,55,56,57
Picea mariana	Black spruce	60’	Brown	May-Jun	F/P/S	N	50,51,57
Pinus banksiana	Jack pine	60’	Brown	May-Jun	F/P	N	50,51,55,57
Pinus resinosa	Red pine	100’	Brown	Apr-May	F/P	N	50,51,55,57
Pinus strobus	White pine	100’	Brown	Jun	F/P/S	N	50,51,55,56,57
Platanus occidentalis	Sycamore	100’	Green	May	F/P	N	55,56,57
Prunus americana	American plum	30’	Red	Apr-May	F/P	N	55,56,57
Prunus virginiana	Choke cherry	30’	White	May-Jun	F/P/S	N	50,51,55,56,57
Quercus bicolor	Swamp white oak	70’	Green/ yellow	May	F/P/S	N	55,56,57
Quercus macrocarpa	Bur oak	85’	Yellow	May-Jun	F/P/S	N	50,51,55,56,57
Quercus palustris	Pin oak	90’	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Quercus rubra	Red Oak	90’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Ribes americanum	Wild black currant	5’	Yellow	Apr-Jun	F/P/S	N	50,51,55,56,57
Rosa carolina	Pasture rose	3’	Pink	Jun-Sep	F/P	N	55,56,57
Tilia americana	Basswood	100’	White	Jun-Jul	F/P/S	N	50,51,55,56,57
Thuja occidentalis	White cedar	50’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Tsuga canadensis	Hemlock	100’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Ulmus americana	American elm	100’	Brown	Mar-Apr	F/P/S	N	50,51,55,56,57
Ulmus rubra	Slippery elm	80’	Green	Mar-Apr	F/P/S	N	51,55,56,57
Viburnum acerifolium	Maple-leaved Viburnum	7’	White	May-Aug	F/P	N	50,51,55,56,57
Viburnum dentatum	Arrowwood	10’	White	May-Jun	F/P/S	N	51,55,56,57
Viburnum prunifolium	Black haw	10’	White	Apr-May	F/P	N	55
Grasses/Sedges/Rushes:							
Andropogon gerardii	Big bluestem	4’-8’	Purple	Jul-Sep	F	N	50,51,55,56,57
Carex bicknellii	Copper-shouldered oval sedge	1’-2’	Brown	May-Jun	F	N	55,56
Carex muhlenbergii	Sand bracted sedge	1’-3’	Brown	May-Jun	F/P/S	N	51,55,56,57
Elymus canadensis	Canada wild rye	3’-6’	Green	Jun-Sep	F/P	N	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Elymus hystrix	Bottlebrush Grass	3'-5'	Green	Jun-Jul	P/S	N	
Elymus virginicus	Virginia wild rye	2'-4'	Green	Jun	F/P/S	N	50,51,55,56,57
Eragrostis spectabilis	Purple love grass	1'-2'	Purple	Aug-Oct	F	N	51,55,56,57
Juncus tenuis	Path rush	6"-2'	Brown	June	F/P/S	N	50,51,55,56,57
Panicum virgatum	Switch grass	3'-6'	Green/ Purple	Jun-Oct	F/P	Y	51,55,56,57
Schizachyrium scoparium	Little bluestem	2'-4'	Brown	Aug-Sep	F/P	Y	50,51,55,56,57
Sorghastrum nutans	Indian grass	4'-9'	Green	Aug-Sep	F	N	51,55,56,57
Spartina pectinata	Prairie cordgrass	6'-7'	Green	Jul-Aug	F	Y	50,51,55,56,57
Stipa spartea	Porcupine grass	2'-4'	Green	Aug-Sep	F	Y	55,56,57
Forbs:							
Allium cernuum	Nodding wild onion	1'-2'	Lavender	Jun-Oct	F/P	N	55,56
Aquilegia canadensis	Wild columbine	1'-3'	Red/ Yellow	Apr-Jun	F/P/S	Y	50,51,55,56,57
Asclepias syriaca	Common milkweed	2'-4'	Pink	Jun-Aug	F/P	N	50,51,55,56,57
Asclepias tuberosa	Butterflyweed	1'-3'	Orange	Jun-Sep	F/P	Y	51,55,56,57
Asclepias verticillata	Whorled milkweed	1'-2'	White	Jun-Sep	F/P	N	51,55,56,57
Aster cordifolius	Heart-leaved aster	2'-4'	Blue/ White	Sep-Oct	P/S	N	55,56,57
Aster laevis	Smooth aster	3'-5'	Blue	Aug-Oct	F	Y	50,51,55,56,57
Aster lateriflorus	Calico aster	1'-3'	White	Jul-Oct	F/P/S	N	50,51,55,56,57
Aster macrophyllus	Big-leaved aster	6"-2'	Lav/ White	Jul-Oct	P/S	N	50,51,55,56,57
Aster novae-angliae	New England aster	3'-6'	Violet	Jul-Oct	F/P	N	50,51,55,56,57
Aster oolentangiensis	Sky-blue aster	1'-4'	Blue	Jul-Nov	F/P	Y	55,56,57
Aster shortii	Short's aster	1'-4'	Blue	Aug-Oct	P/S	N	55,56
Cacalia atriplicifolia	Pale Indian plantain	3'-8'	White	Jun-Oct	F/P/S	N	55,56
Campanula americana	Tall bellflower	2'-6'	Blue	Jul-Nov	P/S	N	55,56,57
Cassia hebecarpa	Wild senna	3'-5'	Yellow	Jul-Aug	F/P	N	55,56
Clematis virginiana	Virgin's bower	9' long	White	Jul-Aug	F/P	N	50,51,55,56,57
Coreopsis tripteris	Tall coreopsis	4'-8'	Yellow	Aug-Sep	F/P	N	55,56,57
Desmodium canadense	Showy tick-trefoil	2'-5'	Purple	Jun-Sep	F/P	N	55,56,57
Echinacea pallida	Purple coneflower	2'-5'	Lavender	May-Aug	F	N	55,56,57
Eryngium yuccifolium	Rattlesnake master	3'-5'	White	Jul-Sep	F	N	55
Eupatorium purpureum	Purple Joe-pye weed	3'-6'	Pink	Jul-Sep	P	N	55,56,57
Euphorbia corollata	Flowering spurge	2'-4'	White	May-Oct	F/P	N	51,55,56,57
Geranium maculatum	Wild geranium	1'-2'	Pink	Apr-Jul	F/P/S	N	55,56,57
Helianthus divaricatus	Woodland sunflower	2'-6'	Yellow	Jun-Sep	P/S	N	50,51,55,56,57
Helianthus giganteus	Tall sunflower	5'-12'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
elianthus pauciflorus	Prairie sunflower	3'-5'	Yellow	Jul-Oct	F	N	50,55,56,57
Heliopsis helianthoides	False sunflower	4'-6'	Yellow	Jun-Oct	F/P	N	50,51,55,56,57
Lespedeza capitata	Round-headed bush clover	2'-4'	Green	Jul-Sep	F/P	N	55,56,57
Liatris aspera	Rough blazing star	2'-3'	Violet	Jul-Nov	F/P	Y	50,55,56,57
Liatris spicata	Marsh blazing star	3'-5'	Pink	Jul-Sep	F/P/S	N	55,56,57
Liatris scariosa	Savanna blazing star	3'-5'	Violet	Aug-Oct	F/P	N	50,51,55,56,57
Monarda fistulosa	Wild bergamot	2'-5'	Lavender	Jul-Sep	F/P	N	50,51,55,56,57
Penstemon digitalis	Foxglove beardtongue	2'-4'	White	May-Jul	F/P	N	50,51,55,56,57
Penstemon hirsutus	Hairy beardtongue	1'-2'	Purple	May-Jul	F/P	N	55,56,57
Phlox divaricata	Wild blue phlox	1'-2'	Blue	Apr-Jun	P/S	N	51,55,56,57
Phlox pilosa	Sand prairie phlox	1'-2'	Pink	May-Aug	F/P	N	56
Physostegia virginiana	Obedient plant	2'-5'	Pink	Aug-Oct	F	Y	50,51,55,56,57
Polygonatum biflorum	Solomon seal	1'-4'	Green/ White	May/Jul	P/S	N	55,56,57
Polygonatum pubescens	Downy Solomon seal	1'-3'	White	May-Jul	P/S	N	50,51,55,56,57
Pycnanthemum virginianum	Mountain mint	1'-3'	White	Jun-Oct	F/P	N	55,56,57
Ratibida pinnata	Yellow coneflower	3'-6'	Yellow	Jul-Oct	F	N	55,56
Rudbeckia hirta	Black-eyed Susan	1'-3'	Yellow	May-Oct	F/P	Y	50,51,55,56,57
Rudbeckia triloba	Three-lobed cone-flower	2'-5'	Yellow	Aug-Oct	F/P	N	55,56,57
Silphium terebinthinaceum	Prairie-dock	3'-8'	Yellow	Jun-Sep	F	N	55,56,57
Smilacina racemosa	Feathery false Solo-mon's seal	1'-3'	White	Apr-Jun	P/S	N	50,51,55,56,57
Smilacina stellata	Starry false Solomon's seal	1'-2'	White	Apr-Jun	F/P	N	50,51,55,56,57
Solidago caesia	Bluestem goldenrod	1'-2'	Yellow	Sep-Oct	P/S	N	51,55,56,57
Solidago flexicaulis	Zigzag goldenrod	1'-3'	Yellow	Aug/Oct	P/S	N	50,51,55,56,57
Solidago juncea	Early goldenrod	2'-4'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Solidago speciosa	Showy goldenrod	1'-3'	Yellow	Jul-Oct	F/P	Y	50,51,55,56,57
Thalictrum dioicum	Early meadow-rue	1'-3'	Green	Apr-May	P/S	N	50,51,55,56,57
Tradescantia ohiensis	Spiderwort	2'-4'	Blue	May-Oct	F/P	N	55,56,57
Vernonia missurica	Missouri ironweed	3'-5'	Purple	Jul-Sep	F	N	55,56,57

Representative Zone E Species

New England Aster

Wild Bergamot

Showy Goldenrod

Tall Bellflower

Wild Geranium

Tall Coreopsis

Redbud

Indian Grass

Source: JFNew

Zone F

Planting Zone = 18+inches above water level

These plants tolerate fluctuating water levels within this range, although they are generally less tolerant than most wetter species. They may tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for upland BMP settings.

Veronicastrum virginicum	Culver's root	3'-6'	White	Jun-Aug	F/P	N	55,56,57

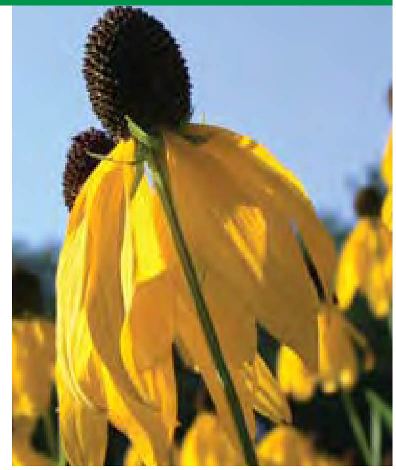
Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90'	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Acer saccharum	Sugar maple	100'	Green	Apr-May	F/P/S	N	50,51,55,56,57
Acer saccharinum	Silver Maple	100'	Yellow	Mar-Apr	F/P	N	50,51,55,56,57
Betula papyrifera	Paper birch	70'	Brown	Apr-May	F/P	N	50,51,55,56,57
Carya ovata	Shagbark hickory	80'	Green	May-Jun	F/P/S	N	55,56,57
Ceanothus americanus	New Jersey tea	1'-3'	White	Jun-Oct	F/P	N	50,51,55,56,57
Celtis occidentalis	Hackberry	60'	Green	May	F/P/S	N	55,56,57
Cercis canadensis	Redbud	25'	Red	Apr-May	F/P/S	N	55,56,57
Cornus florida	Flowering dogwood	30'	White	May-Jun	F/P/S	N	55,56,57
Corylus americana	American hazelnut	10'	Yellow	Apr-May	F/P	N	55,56,57
Gymnocladus dioicus	Kentucky coffee tree	85'	White	Jun	F/P	N	55,56,57
Hamamelis virginiana	Witch hazel	30'	Yellow	Oct-Nov	F/P/S	N	50,51,55,56,57
Juglans nigra	Black walnut	90'	Green	May	F/P	N	51,55,56,57
Juniperus virginiana	Red-cedar	50'	Brown	Apr-May	F/P	N	55,56,57
Liriodendron tulipifera	Tulip tree	110'	Green	May-Jun	F/P	N	55,56,57
Morus rubra	Red mulberry	50'	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100'	Green	May-Jul	F/P/S	Y	51,55,56,57
Pinus banksiana	Jack pine	60'	Brown	May-Jun	F/P	N	50,51,55,57
Pinus resinosa	Red pine	100'	Brown	Apr-May	F/P	N	50,51,55,57
Pinus strobus	White pine	100'	Brown	Jun	F/P/S	N	50,51,55,56,57
Prunus americana	American plum	30'	Red	Apr-May	F/P	N	55,56,57
Prunus virginiana	Choke cherry	30'	White	May-Jun	F/P/S	N	50,51,55,56,57
Quercus macrocarpa	Bur oak	85'	Yellow	May-Jun	F/P/S	N	50,51,55,56,57
Quercus palustris	Pin oak	90'	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Quercus rubra	Red Oak	90'	Green	May-Jun	F/P/S	N	50,51,55,56,57
Rosa carolina	Pasture rose	3'	Pink	Jun-Sep	F/P	N	55,56,57
Tilia americana	Basswood	100'	Yellow	Jun-Jul	F/P/S	N	50,51,55,56,57
Tsuga canadensis	Hemlock	100'	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Viburnum acerifolium	Maple-leaved Viburnum	7'	White	May-Aug	F/P	N	50,51,55,56,57
Viburnum dentatum	Arrowwood	10'	White	May-Jun	F/P/S	N	51,55,56,57
Grasses/Sedges/Rushes:							
Andropogon gerardii	Big bluestem	4'-8'	Purple	Jul-Sep	F	N	50,51,55,56,57
Carex bicknellii	Copper-shouldered oval sedge	1'-2'	Brown	May-Jun	F	N	55,56
Carex muhlenbergii	Sand bracted sedge	1'-3'	Brown	May-Jun	F/P/S	N	51,55,56,57
Elymus canadensis	Canada wild rye	3'-6'	Green	Jun-Sep	F/P	N	50,51,55,56,57
Elymus hystrix	Bottlebrush Grass	3'-5'	Green	Jun-Jul	P/S	N	50,51,55,56,57
Eragrostis spectabilis	Purple love grass	1'-2'	Purple	Aug-Oct	F	N	51,55,56,57
Koeleria macrantha	June grass	1'-2'	White	May-Jul	F/P	N	50,51,55,56,57
Panicum virgatum	Switch grass	3'-6'	Green/ Purple	Jun-Oct	F/P	Y	51,55,56,57
Schizachyrium scoparium	Little bluestem	2'-4'	Brown	Aug-Sep	F/P	Y	50,51,55,56,57
Sorghastrum nutans	Indian grass	4'-9'	Green	Aug-Sep	F	N	51,55,56,57
Spartina pectinata	Prairie cordgrass	6'-7'	Green	Jul-Aug	F	Y	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Stipa spartea	Porcupine grass	2'-4'	Green	Aug-Sep	F	Y	55,56,57
Forbs:							
Allium cernuum	Nodding wild onion	1'-2'	Lavender	Jun-Oct	F/P	N	55,56
Asclepias syriaca	Common milkweed	2'-4'	Pink	Jun-Aug	F/P	N	50,51,55,56,57
Asclepias tuberosa	Butterflyweed	1'-3'	Orange	Jun-Sep	F/P	Y	51,55,56,57
Asclepias verticillata	Whorled milkweed	1'-2'	White	Jun-Sep	F/P	N	51,55,56,57
Aster cordifolius	Heart-leaved aster	2'-4'	Blue/ White	Sep-Oct	P/S	N	55,56,57
Aster laevis	Smooth aster	3'-5'	Blue	Aug-Oct	F	Y	50,51,55,56,57
Aster oolentangiensis	Sky-blue aster	1'-4'	Blue	Jul-Nov	F/P	Y	55,56,57
Aster shortii	Short's aster	1'-4'	Blue	Aug-Oct	P/S	N	55,56
Cacalia atriplicifolia	Pale Indian plantain	3'-8'	White	Jun-Oct	F/P/S	N	55,56
Campanulaa americana	Tall bellflower	2'-6'	Blue	Jul-Nov	P/S	N	55,56,57
Clematis virginiana	Virgin's bower	9' long	White	Jul-Aug	F/P	N	50,51,55,56,57
Coreopsis lanceolata	Sand coreopsis	1'-2'	Yellow	May-Aug	F/P	N	50,51,55
Coreopsis palmata	Prairie coreopsis	1'-2'	Yellow	Jun-Aug	F/P	N	55
Coreopsis tripteris	Tall coreopsis	4'-8'	Yellow	Aug-Sep	F/P	N	55,56,57
Echinacea pallida	Purple coneflower	2'-5'	Lavender	May-Aug	F	N	55,56,57
Eryngium yuccifolium	Rattlesnake master	3'-5'	White	Jul-Sep	F	N	55
Eupatorium purpureum	Purple Joe-pye weed	3'-6'	Pink	Jul-Sep	P	N	55,56,57
Euphorbia corollata	Flowering spurge	2'-4'	White	May-Oct	F/P	N	51,55,56,57
Geranium maculatum	Wild geranium	1'-2'	Pink	Apr-Jul	F/P/S	N	55,56,57
Helianthus divaricatus	Woodland sunflower	2'-6'	Yellow	Jun-Sep	P/S	N	50,51,55,56,57
Helianthus occidentalis	Western sunflower	2'-4'	Yellow	Aug-Sep	F/P	N	50,51,55,56,57
Helianthus pauciflorus	Prairie sunflower	3'-5'	Yellow	Jul-Oct	F	N	50,55,56,57
Heliopsis helianthoides	False sunflower	4'-6'	Yellow	Jun-Oct	F/P	N	50,51,55,56,57
Lespedeza capitata	Round-headed bush clover	2'-4'	Green	Jul-Sep	F/P	N	55,56,57
Liatris aspera	Rough blazing star	2'-3'	Violet	Jul-Nov	F/P	Y	50,55,56,57
Liatris cylindracea	Cylindrical blazing star	1'-2'	Violet	Jul-Oct	F/P	N	51,55,56,57
Liatris scariosa	Savanna blazing star	3'-5'	Violet	Aug-Oct	F/P	N	50,51,55,56,57
Lupinus perennis	Wild lupine	1'-2'	Purple	Apr-Jun	F/P	N	55,56,57
Monarda fistulosa	Wild bergamot	2'-5'	Lavender	Jul-Sep	F/P	N	50,51,55,56,57
Penstemon digitalis	Foxglove beardtongue	2'-4'	White	May-Jul	F/P	N	50,51,55,56,57
Penstemon hirsutus	Hairy beardtongue	1'-2'	Purple	May-Jul	F/P	N	55,56,57
Phlox pilosa	Sand prairie phlox	1'-2'	Pink	May-Aug	F/P	N	56
Polygonatum biflorum	Solomon seal	1'-4'	Green/ White	May/Jul	P/S	N	55,56,57
Polygonatum pubescens	Downy Solomon seal	1'-3'	White	May-Jul	P/S	N	50,51,55,56,57
Ratibida pinnata	Yellow coneflower	3'-6'	Yellow	Jul-Oct	F	N	55,56
Rudbeckia hirta	Black-eyed Susan	1'-3'	Yellow	May-Oct	F/P	Y	50,51,55,56,57
Silphium terebinthinaceum	Prairie-dock	3'-8'	Yellow	Jun-Sep	F	N	55,56,57
Smilacina racemosa	Feathery false Solomon's seal	1'-3'	White	Apr-Jun	P/S	N	50,51,55,56,57
Smilacina stellata	Starry false Solomon's seal	1'-2'	White	Apr-Jun	F/P	N	50,51,55,56,57
Solidago caesia	Bluestem goldenrod	1'-2'	Yellow	Sep-Oct	P/S	N	51,55,56,57
Solidago juncea	Early goldenrod	2'-4'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Solidago speciosa	Showy goldenrod	1'-3'	Yellow	Jul-Oct	F/P	Y	50,51,55,56,57
Tradescantia ohiensis	Spiderwort	2'-4'	Blue	May-Oct	F/P	N	55,56,57
Veronicastrum virginicum	Culver's root	3'-6'	White	Jun-Aug	F/P	N	55,56,57

Representative Zone F Species

Spiderwort

Butterfly Weed



Yellow Coneflower

Little Bluestem

Foxglove Beardtongue

Wild Lupine

Pale Purple Coneflower

Rattlesnake Master

Sand Coreopsis

Source: JFNew

Zone G

Planter Box Plantings

Although this manual typically recommends using native plants wherever possible, certain situations call for non-native plants due to particular site conditions. Because planter boxes traditionally have a short soil column and are exposed to drier conditions, non-native plants should be considered as long as they are considered non-invasive. Therefore, the list below contains both native and non-native species. Many planter boxes have traditionally used annual flowers. However, we recommend using perennial plants for establishing root systems and lowering maintenance in the long term. Many more species are available for planter boxes than are listed.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun
Ajuga reptans 'Bronze Beauty'	Bronze Beauty Ajuga	6"	Blue	May-Jun	F
Allium maximowiczii 'Alba'	White Flowered Ornamental Chive	6"-1'	White	May-Jun	F
Allium schoenoprasum 'Glaucum'	Blue Flowered Ornamental Chive	6"-1'	Blue	Jun-Jul	F
Allium senescens montanum	Mountain Garlic	6"-1'	Pink/Purple	Jun-Aug	F
Allium senescens glaucum	Curly Onion	6"-1'	Pink	Jul-Sep	F
Allium tanguticum 'Summer Beauty'	Summer Beauty Ornamental Chive	6"-1'	Pink	Jul-Aug	F
Aster 'Wood's Light Blue'	Wood's Light Blue Aster	1'-3'	Blue	Aug-Sep	F
Athryium filix-femina	Lady Fern	1'-3'	Green	NA	F/P/S
Blechnum spicant	Deer Fern	1'-2'	Green	NA	F/P/S
Dryopteris erythrosora	Autumn Fern	1'-2'	Green	NA	F/P/S
Euphorbia myrsinites	Mytle Spurge	6"-1'	Yellow	May-Jun	F
Dryopteris intermedia	Fancy Fern	1'-3'	Green	NA	F/P/S
Dyropteris marginalis	Leatherleaf Fern	1'-2'	Green	NA	F/P/S
Geranium x 'Rozanne'	Rozanne Gernaium	1'-2'	Violet	Jun-Sep	F/P
Hemerocallis 'Barbara Mitchell'	Barbara Mitchell Daylily	2'-3'	Pink	Jun-Aug	F/P
Hemerocallis 'Bill Norris'	Bill Norris Daylily	2'-3'	Yellow	Jun-Aug	F/P
Hemerocallis 'Chicago Apache'	Chicago Apache Daylily	2'-3'	Red	Jul-Sep	F/P
Hosta 'Francee'	Francee Hosta	1'-2'	Lavender	Jul-Aug	F/P/S
Hosta 'Guacamole'	Guacamole Hosta	1'-2'	Pink	Aug-Sep	F/P/S
Hosta 'Summer Fragrance'	Summer Fragrance Hosta	1'-2'	Lavender	Aug-Sep	F/P/S
Hosta sieboldiana 'Elegans'	Elegans Hosta	1'-2'	White	Jul-Aug	F/P/S
Sedum 'Autumn Charm'	Autumn Charm Sedum	6"-1'	Pink	Jun-Jul	F
Sedum 'Joyce Henderson'	Joyce Henderson Sedum	6"-1'	Pink	May-Jun	F
Sedum 'Mini Me'	Mini Me Sedum	6"-1'	Green	NA	F
Sedum acre 'Oktoberfest'	Oktoberfest Sedum	6"-1'	Yellow	Jul-Sep	F
Sedum album 'Athoum'	Jelly Bean Sedum	6"-1'	Pink	Aug-Sep	F
Sedum album 'Coral Carpet'	Coral Carpet Sedum	6"-1'	White	Jun-Aug	F
Sedum album 'Faro Island'	Faro Island Sedum	6"-1'	White	Jun-Aug	F
Sedum album 'Green Ice'	Green Ice Sedum	6"-1'	White	Jun-Jul	F
Sedum album 'Murale'	Wall Sedum	6"-1'	White	Jun-Jul	F
Sedum cauticola 'Sunset Cloud'	Sunset Cloud Sedum	6"-1'	Pink	Jul-Aug	F
Sedum divergens	Cascade Sedum	6"-1'	Yellow	Jun-Jul	F
Sedum ellacombianum	Ellacombe's Sedum	6"-1'	Yellow	May-Jun	F
Sedum ellacombianum 'Variegatum'	Variegated Ellacombe's Sedum	6"-1'	Yelow	May-Jun	F
Sedum floriferum 'Weihenstephaner Gold'	Weihenstephaner Gold Sedum	6"-1'	Yellow	Jun-Jul	F
Sedum grisbachii	Griseback Sedum	6"-1'	Yellow	Jul-Aug	F
Sedum hybridum 'Tekaridake'	Tekaridake Kamtschatka Sedum	6"-1'	Yellow	Jun	F
Sedum kamtschaticum 'Variegatum'	Variegated Kamtschatka Sedum	6"-1'	Orange	Jul-Aug	F
Sedum middendorfianum var. diffusum	Diffuse Middendorf's Sedum	6"-1'	Yellow	May-Jun	F

Representative Zone G Species

Guacamole Hosta

Mountain Garlic

Wall Sedum

Lady Fern

Source: JFNew

Zone H

Vegetated Roof Plantings

Research to-date shows that native plants do not typically thrive in vegetated roofs. Therefore, the list below reflects species that are known to thrive in green roof situations. All species listed below will generally grow to a height of six-to-18 inches.

Botanical Name	Common Name	Color	Bloom Time
Allium maximowiczii 'Alba'	White Flowered Ornamental Chive	White	May-Jun
Allium schoenoprasum 'Dwarf'	Dwarf Ornamental Chive	Pink	May-Jun
Allium schoenoprasum 'Glaucum'	Blue Flowered Ornamental Chive	Blue	Jun-Jul
Allium senescens montanum	Mountain Garlic	Pink/Purple	Jun-Aug
Allium senescens glaucum	Curly Onion	Pink	Jul-Sep
Allium tanguticum 'Summer Beauty'	Summer Beauty Ornamental Chive	Pink	Jul-Aug
Euphorbia myrsinites	Mytle Spurge	Yellow	May-Jun
Sedum 'Autumn Charm'	Autumn Charm Sedum	Pink	Jun-Jul
Sedum 'Joyce Henderson'	Joyce Henderson Sedum	Pink	May-Jun
Sedum 'Mini Me'	Mini Me Sedum	Green	NA
Sedum acre 'Aureum'	Gold Leaved Goldmoss Sedum	Yellow	May-Jun
Sedum acre 'Oktoberfest'	Oktoberfest Sedum	Yellow	Jul-Sep
Sedum album 'Athoum'	Jelly Bean Sedum	Pink	Aug-Sep
Sedum album 'Coral Carpet'	Coral Carpet Sedum	White	Jun-Aug
Sedum album 'Faro Island'	Faro Island Sedum	White	Jun-Aug
Sedum album 'Green Ice'	Green Ice Sedum	White	Jun-Jul
Sedum album 'Murale'	Wall Sedum	White	Jun-Jul
Sedum album 'Red Ice'	Red Ice Sedum	White	Jun-Jul
Sedum cautacola 'Bertram Anderson'	Bertram Anderson Sedum	Pink	Jul-Aug
Sedum cauticola 'Sunset Cloud'	Sunset Cloud Sedum	Pink	Jul-Aug
Sedum divergens	Cascade Sedum	Yellow	Jun-Jul
Sedum ellacombianum	Ellacombe's Sedum	Yellow	May-Jun
Sedum ellacombianum 'Variegatum'	Variegated Ellacombe's Sedum	Yelow	May-Jun
Sedum floriferum 'Weihenstephaner Gold'	Weihenstephaner Gold Sedum	Yellow	Jun-Jul
Sedum grisbachii	Griseback Sedum	Yellow	Jul-Aug
Sedum hispanicum 'Pinkie'	Pinkie Sedum	Pink	Jun-Jul
Sedum hybridum 'Immergunchen'	Evergreen Sedum	Yellow	Jun, Sep
Sedum hybridum 'Tekaridake'	Tekaridake Kamtschatka Sedum	Yellow	Jun
Sedum kamtschaticum 'Variegatum'	Variegated Kamtschatka Sedum	Orange	Jul-Aug
Sedum middendorfianum var. diffusum	Diffuse Middendorf's Sedum	Yellow	May-Jun

*List provided by Hortech, Inc.

Representative Zone H Species

Mountain Garlic

Cascade Sedum

Ellacombe's Sedum

Wall Sedum

Source: JFNew

Appendix D

Recommended Materials

Numerous BMPs in this manual have similar material needs. These BMPs are listed in the table below. Detailed information on each material requirement follows. In addition, Porous Pavement and Vegetated Roofs have significant material requirements that are listed according to their individual needs.

	Constructed Filters	Dry Well	Infiltration Trench	Planter Boxes	Porous Pavement	Subsurface Infiltration	Vegetated Filter Strip	Vegetated Swale
Check dams							X	X
Non-Woven Geotextile	X	X	X	X	X	X	X	
Pea Gravel							X	
Peat	X			X				
Pervious Berms							X	
Pipe – 8”	X	X	X	X	X	X	X	
Sand	X			X				X
Stone/Gravel	X			X				
Stone – 30%							X	
Stone – 40%			X		X			

Check dams (Vegetated Filter Strip, Vegetated Swale)

An earthen check dam shall be constructed of sand, gravel, and sandy loam to encourage grass cover. (Sand: ASTM C-33 fine aggregate concrete sand 0.02 in to 0.04 in, Gravel: AASHTO M-43 0.5 in to 1.0 in). A stone check dam shall be constructed of R-4 rip rap, or equivalent.

Non-Woven Geotextile (Constructed Filter, Dry Well, Infiltration Trench, Planter Boxes, Vegetated Filter Strip)

Should consist of needled nonwoven polypropylene fibers and meet the following properties:

a. Grab Tensile Strength (ASTM-D4632)	120 lbs min.
b. Mullen Burst Strength (ASTM-D3786)	225 psi min.
c. Flow Rate (ASTM-D4491)	110 gal/min/ft2 min.
d. UV Resistance after 500 hrs (ASTM-D4355)	70% min.
e. Puncture strength (ASTM D-4833-00)	90 lb. min.
f. Apparent opening size (ASTM D-4751-99A)	60-70 US Sieve

Heat-set or heat-calendared fabrics are not permitted. Acceptable types include Mirafi 140N, Amoco 4547, Geotex 451, or approved others.

Pea Gravel (Vegetated Filter Strip)

Clean bank-run gravel may also be used and should meet ASTM D 448 and be sized as per No.6 or 1/8” to 3/8”.

Peat (Constructed Filter, Planter Boxes)

Should have ash content <15%, pH range 3.3-5.2, loose bulk density range 0.12-0.14 g/cc.

Pervious Berms (Vegetated Filter Strip)

The berm shall have a height of 6-12 in and be constructed of sand, gravel, and sandy loam to encourage grass cover. (Sand: ASTM C-33 fine aggregate concrete sand 0.02”-0.04”, Gravel: AASHTO M-43 ½” to 1”)

Pipe - (Dry Well, Porous Pavement, Subsurface Infiltration, Constructed Filter, Infiltration Trench, Planter Boxes, Vegetated Filter Strip)

Should be continuously perforated, smooth interior, with a minimum inside diameter as required. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or M294, Type S (12 gauge aluminum or pipe may also be used in seepage pits).

Sand (Constructed Filter, Planter Boxes, Vegetated Swale)

Should be ASTM-C-33 (or AASHTO M-6) size (0.02” – 0.04”), concrete sand, clean, medium to fine sand.

Stone/Gravel (Constructed Filter, Planter Boxes):

Should be uniformly graded coarse aggregate, 1 inch to ½ inch with a wash loss of no more than 0.5%, AASHTO size number 5 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and have voids of 40% as measured by ASTM-C29.

Stone – 40% voids (Infiltration Trench, Porous Pavement, Subsurface Infiltration Bed,)

Infiltration trenches should have stone 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29.

Porous Pavement

General

Choker base course aggregate for beds shall be 3/8 inch to 3/4 inch clean, uniformly-graded, coarse, crushed aggregate AASHTO size number 57 per Table 4, AASHTO Specifications, Part I, 19th Ed., 1998 (p. 47).

Porous Asphalt

Bituminous surface course for porous paving shall be 2.5 to 3 inches thick with a bituminous mix of 5.75% to 6.75% by total weight as determined by testing below. Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22P (in northern Michigan, use PG 76-28P as appropriate) as specified in AASHTO MP-1. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.

Determination of optimal asphalt content should be determined according the following tests:

- Draindown Test (ASTM Method D6390)
- Moisture Susceptibility Test using the Modifed Lottman Method (AASHTO T283) with the following:
    - Compact using 50 gyrations of Superpave gyratory compactor
    - Apply partial vacuum of 26 inches of Hg for 10 minutes to whatever saturation is achieved.
    - Keep specimens submerged in water during freeze cycle.
    - Required retained tensile strength (TSR) >= 80%
- Air Voids Test (AASHTO T269/ASTM D3203)

Hydrated lime, if required, shall meet the requirements of AASHTO M 303 Type 1 and shall be blended with the damp aggregate at a rate of 1.0% by weight of the total dry aggregate. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix.

Fibers, if used, shall consist of either cellulose fibers or mineral fibers which are to be treated with a cationic sizing agent to enhance dispersement of the fiber as well as increase cohesion of the fiber to the bitumen. Fiber is to be added at a dosage rate between 0.2% and 0.4% by weight of total mix.

- Mineral fibers shall be from virgin, basalt, diabase, or slag with a maximum average fiber length of 6.35 mm and a maximum average fiber thickness of 0.005 mm.
- Cellulose fiber – Fiber length shall be 6.4 mm (max), Ash Content 18% non-volatiles (±5%), pH 7.5 (± 1), Oil absorption (times fiber weight) 5.0 (± 1), Moisture Content 5.0 (max).

Porous Concrete

The use of Installers or Craftsmen who have been certified by the NRMCA's Pervious Concrete Contractor Certification Program is strongly recommended. Contractor shall furnish a proposed mix design with all applicable information to the Engineer prior to commencement of work. Critical mix characteristics typically include the following:

- Cement Content: 550 to 650 lb/cy
- Fine aggregate, if used: maximum 3 cu. ft. per cu. yd.
- Admixtures: use in accordance with the manufacturer's instructions and recommendations
- An aggregate/cement (A/C) ratio: 4:1 to 4.5:1
- Water/cement (W/C) ratio: 0.27 to 0.34
- Curing: shall begin within 15 minutes after placement and continue for 7 days

The data shall include unit weights determined in accordance with ASTM C29 paragraph 11, jigging procedure.

Cement: Portland Cement Type II or V conforming to ASTM C150 or Portland Cement Type IP or IS conforming to ASTM C595. The total cementitious material shall be between 550 and 650 lb./cy.

Aggregate: Use No 8 coarse aggregate (3/8 to No. 16) per ASTM C33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448. If other gradation of aggregate is to be used, submit data on proposed material to owner for approval. The volume of aggregate per cu. yd. shall be equal to 27 cu.ft. when calculated as a function of the unit weight determined in accordance with ASTM C 29 jigging procedure. Fine aggregate, if used, should not exceed 3 cu. ft. and shall be included in the total aggregate volume.

Air Entraining Agent: Shall comply with ASTM C 260 and shall be used to improve workability and resistance to freeze/thaw cycles.

Admixtures: The following admixtures shall be used:

- Type D Water Reducing/Retarding – ASTM C 494.
- A hydration stabilizer that also meets the requirements of ASTM C 494 Type B Retarding or Type D Water Reducing/Retarding admixtures may be used. This stabilizer suspends cement hydration by forming a protective barrier around the cementitious particles, which delays the particles from achieving initial set.

Water: Potable shall be used and shall comply with ASTM C1602. Mix water shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (Mix water yielding a cement paste with a dull-dry appearance has insufficient water for hydration).

- Insufficient water results in inconsistency in the mix and poor bond strength.
- High water content results in the paste sealing the void system primarily at the bottom and poor surface bond.

An aggregate/cement (A/C) ratio range of 4:1 to 4.5:1 and a water/cement (W/C) ratio range of 0.27 to 0.34 should produce pervious pavement of satisfactory properties in regard to permeability, load carrying capacity, and durability characteristics.

Vegetated roofs

Some key components and associated performance-related properties are as follows:

Root-barriers should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended. At present only FLL offers a recognized test for root-barriers. Several FLL-certified materials are available in the United States. Interested American manufactures can submit products for testing to FLL-certified labs.

Granular drainage media should be a non-carbonate mineral aggregate conforming to the following specifications:

• Saturated Hydraulic Conductivity	>= 25 in/min
• Total Organic Matter, by Wet Combustion (MSA)	<= 1%
• Abrasion Resistance (ASTM-C131-96)	<= 25% loss
• Soundness (ASTM-C88 or T103 or T103-91)	<= 5% loss
• Porosity (ASTM-C29)	>= 25%
• Alkalinity, CaCO3 equivalents (MSA)	<= 1 %
• Grain-Size Distribution (ASTM-C136)	
Pct. Passing US#18 sieve	<= 1%
Pct. Passing ¼-inch sieve	<= 30%
Pct. Passing 3/8-inch sieve	>= 80%

Growth media should be a soil-like mixture containing not more than 15% organic content (wet combustion or loss on ignition methods). The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and 'soil' structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Non-capillary Pore Space at Field Capacity, 0.333 bar (TMECC 03.01, A)	>= 15% (vol)
Moisture Content at Field Capacity (TMECC 03.01, A)	>= 12% (vol)
Maximum Media Water Retention (FLL)	>= 30% (vol)
Alkalinity, Ca CO3 equivalents (MSA)	<= 2.5%
Total Organic Matter by Wet Combustion (MSA)	3-15% (dry wt.)
pH (RCSTP)	6.5-8.0
Soluble Salts (DTPA saturated media extraction)"(RCSTP)	<= 6 mmhos/cm
Cation exchange capacity (MSA)	>= 10 meq/100g
Saturated Hydraulic Conductivity for Single Media Assemblies (FLL)	>= 0.05 in/min
Saturated Hydraulic Conductivity for Dual Media Assemblies (FLL)	>= 0.30 in/min

Grain-size Distribution of the Mineral Fraction (ASTM-D422)

Single Media Assemblies:

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	<= 5%
Pct. Passing US#60 sieve	<= 10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	0 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

Dual Media Assemblies:

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	5-15%
Pct. Passing US#60 sieve	10-25%
Pct. Passing US#18 sieve	20 - 50%
Pct. Passing 1/8-inch sieve	55 - 95%
Pct. Passing 3/8-inch sieve	90 -100%

Macro- and micro-nutrients shall be incorporated in the formulation in initial proportions suitable for support the specified planting.

Separation fabric should be readily penetrated by roots, but provide a durable separation between the drainage and growth media layers (Only lightweight nonwoven geotextiles are recommended for this function.

• Unit Weight (ASTM-D3776)	<= 4.25 oz/yd2
• Grab tensile (ASTM-D4632)	<= 90 lb
• Mullen Burst Strength (ASTM-D4632)	>= 135 lb/in
• Permittivity (ASTM-D4491)	>= 2 per second

Appendix E

Soil Infiltration Testing Protocol

Purpose of this Protocol

The soil infiltration testing protocol describes evaluation and field testing procedures to determine if infiltration BMPs are suitable at a site, as well as to obtain the required data for infiltration BMP design.

When to Conduct Testing

The Site Design Process for LID, outlined in Chapter 5 of this manual, describes a process for site development and application of nonstructural and structural BMPs. It is recommended that soil evaluation and investigation be conducted following development of a concept plan or early in the development of a preliminary plan.

Who Should Conduct Testing

Soil evaluation and investigation may be conducted by soil scientists, local health department sanitarians, design engineers, professional geologists, and other qualified professionals and technicians. The stormwater designer is *strongly* encouraged to directly observe the testing process to obtain a first-hand understanding of site conditions.

Importance of Stormwater BMP Areas

Sites are often defined as unsuitable for infiltration BMPs and soil-based BMPs due to proposed grade changes (excessive cut or fill) or lack of suitable areas. Many sites will be constrained and unsuitable for infiltration BMPs. However, if suitable areas exist, these areas should be identified early in the design process and should *not* be subject to a building program that precludes infiltration BMPs. Full build-out of site areas otherwise deemed to be suitable for infiltration should not provide an exemption or waiver for adequate stormwater volume control or groundwater recharge.

Safety

As with all field work and testing, attention to all applicable Occupational Safety and Health Administration (OSHA) regulations and local guidelines related to earthwork and excavation is required. Digging and excavation should never be conducted without adequate notification through the Michigan One Call system (Miss Dig www.missdig.net or 1-800-482-7171). Excavations should never be left unsecured and unmarked, and all applicable authorities should be notified prior to any work.

Infiltration Testing: A Multi-Step Process

Infiltration testing is a four-step process to obtain the necessary data for the design of the stormwater management plan. The four steps include:

1. Background evaluation
   - Based on available published and site specific data
   - Includes consideration of proposed development plan
   - Used to identify potential BMP locations and testing locations
   - Prior to field work (desktop)
2. Test pit (deep hole) observations
   - Includes multiple testing locations
   - Provides an understanding of sub-surface conditions
   - Identifies limiting conditions
3. Infiltration testing
   - Must be conducted onsite
   - Different testing methods available
4. Design considerations
   - Determine suitable infiltration rate for design calculations
   - Consider BMP drawdown
   - Consider peak rate attenuation

Step 1. Background evaluation

Prior to performing testing and developing a detailed site plan, existing conditions at the site should be inventoried and mapped including, but not limited to:

- Existing mapped soils and USDA Hydrologic Soil Group classifications.
- Existing geology, including depth to bedrock, karst conditions, or other features of note.
- Existing streams (perennial and intermittent, including intermittent swales), water bodies, wetlands, hydric soils, floodplains, alluvial soils, stream classifications, headwaters, and first order streams.
- Existing topography, slope, drainage patterns, and watershed boundaries.
- Existing land use conditions.
- Other natural or man-made features or conditions that may impact design, such as past uses of site, existing nearby structures (buildings, walls), abandoned wells, etc.
- A concept plan or preliminary layout plan for development should be evaluated, including:
  - Preliminary grading plan and areas of cut and fill,
  - Location of all existing and proposed water supply sources and wells,
  - Location of all former, existing, and proposed onsite wastewater systems,
  - Location of other features of note such as utility rights-of-way, water and sewer lines, etc.,
  - Existing data such as structural borings, and
  - Proposed location of development features (buildings, roads, utilities, walls, etc.).

In Step 1, the designer should determine the potential location of infiltration BMPs. The approximate location of these BMPs should be on the proposed development plan and serve as the basis for the location and number of tests to be performed onsite.

Important: If the proposed development is located on areas that may otherwise be a suitable BMP location, or if the proposed grading plan is such that potential BMP locations are eliminated, the designer is ***strongly*** encouraged to revisit the proposed layout and grading plan and adjust the development plan as necessary. Full build-out of areas suitable for infiltration BMPs should ***not*** preclude the use of BMPs for runoff volume reduction and groundwater recharge.

Step 2. Test pits (deep holes)

A test pit (deep hole) allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion of the site. An extensive number of test pit observations can be made across a site at a relatively low cost and in a short time period. The use of soil borings as a substitute for test pits is strongly discouraged, as visual observation is narrowly limited in a soil boring and the soil horizons cannot be observed in-situ, but must be observed from the extracted borings.

A test pit (deep hole) consists of a backhoe-excavated trench, 2½-3 feet wide, to a depth of 6-7½ feet, or until bedrock or fully saturated conditions are encountered. The trench should be benched at a depth of 2-3 feet for access and/or infiltration testing.

At each test pit, the following conditions are to be noted and described. Depth measurements should be described as depth below the ground surface:

- Soil horizons (upper and lower boundary),
- Soil texture, structure, and color for each horizon,
- Color patterns (mottling) and observed depth,
- Depth to water table,
- Depth to bedrock,
- Observance of pores or roots (size, depth),
- Estimated type and percent coarse fragments,
- Hardpan or limiting layers,
- Strike and dip of horizons (especially lateral direction of flow at limiting layers), and
- Additional comments or observations.

The Sample Soil Log Form at the end of this protocol may be used for documenting each test pit.

At the designer's discretion, soil samples may be collected at various horizons for additional analysis. Following testing, the test pits should be refilled with the original soil and the topsoil replaced. A test pit should ***never*** be accessed if soil conditions are unsuitable or unstable for safe entry, or if site constraints preclude entry. OSHA regulations should always be observed.

It is important that the test pit provide information related to conditions at the bottom of the proposed infiltration BMP. If the BMP depth will be greater than 90 inches below existing grade, deeper excavation of the test pit will be required. The designer is cautioned regarding the proposal of systems that are significantly deeper than the existing topography, as the suitability for infiltration is likely to decrease. The design engineer is encouraged to consider reducing grading and earthwork as needed to reduce site disturbance and provide greater opportunity for stormwater management.

The number of test pits varies depending on site conditions and the proposed development plan. General guidelines are as follows:

- For single-family residential subdivisions with on-lot infiltration BMPs, one test pit per lot is recommended, preferably within 100 feet of the proposed BMP area.
- For multi-family and high-density residential developments, one test pit per BMP area or acre is recommended.
- For large infiltration areas (basins, commercial, institutional, industrial, and other proposed land uses), multiple test pits should be evenly distributed at the rate of four to six pits per acre of BMP area.

The recommendations above are guidelines. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table levels, depth and type of bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required. Excessive testing and disturbance of the site prior to construction is not recommended.

Step 3. Infiltration tests

A variety of field tests exists for determining the infiltration capacity of a soil. Laboratory tests are not recommended, as a homogeneous laboratory sample does not represent field conditions. Infiltration tests should be conducted in the field. Infiltration tests should not be conducted in the rain, within 24 hours of significant rainfall events (>0.5 inches), or when the temperature is below freezing.

At least one test should be conducted at the proposed bottom elevation of an infiltration BMP, and a minimum of two tests per test pit are recommended. Based on observed field conditions, the designer may elect to modify the proposed bottom elevation of a BMP. Personnel conducting infiltration tests should be prepared to adjust test locations and depths depending on observed conditions.

Methodologies discussed in this protocol include:

- Double-ring infiltrometer tests.
- Percolation tests (such as for onsite wastewater systems).

There are differences between the two methods. A double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil from the inner ring. A percolation test allows water movement through both the bottom and sides of the test area. For this reason, the measured rate of water level drop in a percolation test must be adjusted to represent the discharge that is occurring on both the bottom and sides of the percolation test hole.

Other testing methodologies and standards that are available but not discussed in detail in this protocol include (but are not limited to):

- Constant head double-ring infiltrometer.
- Testing as described in the *Maryland Stormwater Manual*, Appendix D.1, using five-inch diameter casing.
- ASTM 2003 Volume 4.08, Soil and Rock (I): Designation D 3385-03, Standard Test Method for Infiltration Rate of Soils in Field Using a Double-Ring Infiltrometer.
- ASTM 2002 Volume 4.09, Soil and Rock (II): Designation D 5093-90, Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.
- Guelph permeameter.
- Constant head permeameter (Amoozemeter).

Methodology for double-ring infiltrometer field test

A double-ring infiltrometer consists of two concentric metal rings. The rings are driven into the ground and filled with water. The outer ring helps to prevent divergent flow. The drop-in water level or volume in the inner ring is used to calculate an infiltration rate. The infiltration rate is the amount of water per surface area and time unit which penetrates the soils. The diameter of the inner ring should be approximately 50-70 percent of the diameter of the outer ring, with a minimum inner ring size of four inches. Double-ring infiltrometer testing equipment designed specifically for that purpose may be purchased. However, field testing for stormwater BMP design may also be conducted with readily available materials.

Equipment for double-ring infiltrometer test:
Two concentric cylinder rings six inches or greater in height. Inner ring diameter equal to 50-70 percent of outer ring diameter (i.e., an eight-inch ring and a 12-inch ring). Material typically available at a hardware store may be acceptable.

- Water supply,
- Stopwatch or timer,
- Ruler or metal measuring tape,
- Flat wooden board for driving cylinders uniformly into soil,
- Rubber mallet, and
- Log sheets for recording data.

Procedure for double-ring infiltrometer test

- Prepare level testing area.
- Place outer ring in place; place flat board on ring and drive ring into soil to a minimum depth of two inches.
- Place inner ring in center of outer ring; place flat board on ring and drive ring into soil a minimum of two inches. The bottom rim of both rings should be at the same level.
- The test area should be presoaked immediately prior to testing. Fill both rings with water to water level indicator mark or rim at 30-minute intervals for one hour. The minimum water depth should be four inches. The drop in the water level during the last 30 minutes of the presoaking period should be applied to the following standard to determine the time interval between readings:
  - If water level drop is two inches or more, use 10-minute measurement intervals.
  - If water level drop is less than two inches, use 30-minute measurement intervals.
- Obtain a reading of the drop in water level in the center ring at appropriate time intervals. After each reading, refill both rings to water level indicator mark or rim. Measurement to the water level in the center ring should be made from a fixed reference point and should continue at the interval determined until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.
- The drop that occurs in the center ring during the final period or the average stabilized rate, expressed as inches per hour, should represent the infiltration rate for that test location.

Methodology for percolation test
Equipment for percolation test

- Post hole digger or auger,
- Water supply,
- Stopwatch or timer,
- Ruler or metal measuring tape,
- Log sheets for recording data,
- Knife blade or sharp-pointed instrument (for soil scarification),
- Course sand or fine gravel, and
- Object for fixed-reference point during measurement (nail, toothpick, etc.).

Procedure for percolation test

This percolation test methodology is based largely on the criteria for onsite sewage investigation of soils. A 24-hour pre-soak is generally not required as infiltration systems, unlike wastewater systems, will not be continuously saturated.

- Prepare level testing area.
- Prepare hole having a uniform diameter of 6-10 inches and a depth of 8-12 inches. The bottom and sides of the hole should be scarified with a knife blade or sharp-pointed instrument to completely remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Loose material should be removed from the hole.
- (Optional) Two inches of coarse sand or fine gravel may be placed in the bottom of the hole to protect the soil from scouring and clogging of the pores.
- Test holes should be presoaked immediately prior to testing. Water should be placed in the hole to a minimum depth of six inches over the bottom and readjusted every 30 minutes for one hour.
- The drop in the water level during the last 30 minutes of the final presoaking period should be applied to the following standard to determine the time interval between readings for each percolation hole:
    - If water remains in the hole, the interval for readings during the percolation test should be 30 minutes.
    - If no water remains in the hole, the interval for readings during the percolation test may be reduced to 10 minutes.
- After the final presoaking period, water in the hole should again be adjusted to a minimum depth of six inches and readjusted when necessary after each reading. A nail or marker should be placed at a fixed reference point to indicate the water refill level. The water level depth and hole diameter should be recorded.
- Measurement to the water level in the individual percolation holes should be made from a fixed reference point and should continue at the interval determined from the previous step for each individual percolation hole until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.
- The drop that occurs in the percolation hole during the final period, expressed as inches per hour, should represent the percolation rate for that test location.
- The average measured rate must be adjusted to account for the discharge of water from both the sides and bottom of the hole and to develop a representative infiltration rate. The average/final percolation rate should be adjusted for each percolation test according to the following formula:

Infiltration Rate = (Percolation Rate)/(Reduction Factor)

Where the Reduction Factor is given by**:

$$R_f = \frac{2d1 - \Delta d}{DIA} + 1$$

With:

d_1 = Initial Water Depth (in.)

Δd = Average/Final Water Level Drop (in.)

DIA = Diameter of the Percolation Hole (in.)

The percolation rate is simply divided by the reduction factor as calculated above or shown in Table E.1 below to yield the representative infiltration rate. In most cases, the reduction factor varies from about two to four depending on the percolation hole dimensions and water level drop – wider and shallower tests have lower reduction factors because proportionately less water exfiltrates through the sides.

*** The area reduction factor accounts for the exfiltration occurring through the sides of percolation hole. It assumes that the percolation rate is affected by the depth of water in the hole and that the percolating surface of the hole is in uniform soil. If there are significant problems with either of these assumptions then other adjustments may be necessary.*

Step 4. Use design considerations provided in the infiltration BMP.

Table E.1
Sample Percolation Rate Adjustments

Perc. Hole Diameter, DIA (in.)	Initial Water Depth, D_1 (in.)	Ave./Final Water Level Drop, $\triangle d$ (in.)	Reduction Factor, R_f
6	6	0.1	3.0
		0.5	2.9
		2.5	2.6
	8	0.1	3.7
		0.5	3.6
		2.5	3.3
	10	0.1	4.3
		0.5	4.3
		2.5	3.9
8	6	0.1	2.5
		0.5	2.4
		2.5	2.2
	8	0.1	3.0
		0.5	2.9
		2.5	2.7
	10	0.1	3.5
		0.5	3.4
		2.5	3.2
10	6	0.1	2.2
		0.5	2.2
		2.5	2.0
	8	0.1	2.6
		0.5	2.6
		2.5	2.4
	10	0.1	3.0
		0.5	3.0
		2.5	2.8

Additional Potential Testing – Bulk Density

Bulk density tests measure the level of compaction of a soil, which is an indicator of a soil's ability to absorb rainfall. Developed and urbanized sites often have very high bulk densities and, therefore, possess limited ability to absorb rainfall (and have high rates of stormwater runoff). Vegetative and soil improvement programs can lower the soil bulk density and improve the site's ability to absorb rainfall and reduce runoff.

Macropores occur primarily in the upper soil horizons and are formed by plant roots (both living and decaying), soil fauna such as insects, the weathering processes caused by movement of water, the freeze-thaw cycle, soil shrinkage due to desiccation of clays, chemical processes, and other mechanisms. These macropores provide an important mechanism for infiltration prior to development, extending vertically and horizontally for considerable distances. It is the intent of good engineering and design practice to maintain these macropores when installing infiltration BMPs as much as possible. Bulk density tests can help determine the relative compaction of soils before and after site disturbance and/or restoration and should be used at the discretion of the designer/reviewer.

Soil Test Pit Log Sheet

Project: ______ **Date:** ______
Name: ______ **Soil Series:** ______
Location: ______ **Other:** ______
Test Pit # ______

Horizon	Depth (In.)	Color	Redox Features	Texture	Notes (if applicable)	Boundary

NOTES:

REDOX FEATURES

Abundance
Few .... < 2%
Common .. 2 - 20%
Many ..... > 20%

Contrast
faint
hue & chroma of matrix and redox are closely related.
distinct
matrix & redox features vary 1 - 2 units of hue and several unites of chroma & value.
prominent
Matrix & redox features vary several units in hue, value & chroma

COARSE FRAGMENTS (% of profile)

15-35%	35-65%	>65%
gravelly	very gravelly	extremely gravelly
channery	very channery	extremely channery
cobbly	very cobbly	extremely cobbly
flaggy	very flaggy	extremely flaggy
stony	very stony	extremely stony

BOUNDARY

Distinctness
abrupt...< 1" (thick) *gradual*..2.5 - 5"
clear.....1 - 2.5" *diffuse*....> 5

Topography
smooth - boundary is nearly level
wavy - pockets with width > than depth
irregular - pockets with depth > than width

HORIZONS

O - organic layers of decaying plant and animal tissue (must be greater than 12-18% organic carbon, excluding live roots).

A (topsoil) - mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material.

E - mineral horizon which the main feature is loss of silicate clay, iron, aluminum. Must be underlain by a B (alluvial) horizon.

B (subsoil) - mineral horizon with evidence of pedogenesis or illuviation (movement into the horizon).

C (substratum) - the un-weathered geologic material the soil formed in. Shows little or no sign of soil formation.

CITY OF BIRMINGHAM
ORDINANCE NO. ___

AN ORDINANCE TO AMEND PART II OF THE CITY CODE, CHAPTER 114 UTILITIES, to ADD ARTICLE VI. STORM WATER TO ADD DIVISION 6. STORM WATER UTILITY FEE

THE CITY OF BIRMINGHAM ORDAINS:

Part II of the City Code, Chapter 114 Utilities, shall be amended to add Article VI. Storm water, Division 6. Storm Water User Fee, as follows:

ARTICLE VI. STORM WATER

DIVISION 6. STORM WATER UTILITY FEE

Sec. 114-400. - Definitions.

The following words, terms and phrases, when used in this division, shall have the meanings ascribed to them in this section, except where the context clearly indicates a different meaning:

Runoff Potential: The runoff potential from a property is based on hydrologic principles for calculating runoff that use both the impervious surface area and the pervious surface area. Runoff potential is measured in square feet using the following formula:

Runoff Potential = 0.15x [Total Area – Impervious Area] +
0.9 x [Impervious Area]

Combined sewer system: Public sewers, drains, ditches, roads and retention ponds used for collecting and transporting storm water and non-storm water in the City.

Director: The City Engineer or such other person as the City Manager may designate.

Equivalent Storm Water Unit (ESWU): A subunit of measurement which relates the volume of storm water discharged from a lot based on the amount of total and impervious lot area, compared to the standard unit. The formula for an equivalent storm water unit (ESWU) is as follows:

1 ESWU = $\underline{(0.15\ (TA_S - IA_S) + (0.90\ (IA_S))}$
where,

TA_S = total area of standard unit;

IA_S = impervious area of standard unit;

0.15 = runoff coefficient for pervious area;

0.90 = runoff coefficient for impervious area.

One ESWU in the City is equal to the average runoff potential of the standard unit.

Impervious lot area: Impervious area means a surface area that is resistant to permeation by surface water.

Industrial sites: Those sites that contain industrial activities which require wastewater discharge permits as set forth in Section 114-202 of this Code.

Nonstorm water: All flows to the combined sewer system not defined as storm water in Section 114-199, or as determined by the director.

Pervious lot area: All land area that is not impervious. Pervious lot area equals the total lot area, minus the impervious lot area. Pervious lot area has a runoff coefficient equal to 0.15.

Separated Storm Water sewer system: Public sewers, drains, channels, ditches, roads and retention ponds used for collecting and transporting storm water in the City.

Standard unit: Single family residential parcel in the City within a lot size between 0.126 and 0.250 acres.

Storm Water: Storm water runoff, snow melt runoff and surface runoff and drainage.

Storm Water utility fee: The fee imposed for the use of that portion of the combined system that transports storm water, based on the number of ESWU's for a lot or parcel of land determined as provided in Section 114-402.

Storm Water sewer system: That portion of the combined sewer system and separated storm water sewer system that is attributable to the transportation and treatment of storm water.

User: An owner of property which directly or indirectly contributes to the combined sewer system.

Sec. 114-401. – Storm Water Utility Fees.

(a) All users shall pay a storm water utility fee proportional to the volume of storm water which is projected to discharge into the combined sewer system and storm water sewer system from their property.

(b) The City Commission shall, by resolution, set storm water utility fees at a rate which will recover from each user its share of the costs of the storm water sewer system attributable to the discharge of storm water from the users' property to the storm water system. The City shall use the revenues of the storm water utility fees to pay the costs of the water treatment operation and maintenance of the storm water sewer system, and for necessary improvements and additions to the storm water sewer system.

(c) The City may also collect from users fees imposed to pay the implementation and operation of any of the following:

(1) Monitoring, inspection and surveillance procedures;

(2) Reviewing discharge procedures and construction;

(3) Discharge permit applications; or

(4) Other fees as the City may deem necessary to operate the storm water sewer system.

Sec. 114-402. - Calculation of fees and appeals.

(a) Single Family Residential ESWU. All single family residential properties in each of the lot-size categories are assigned the same ESWU for that category. The ESWU values for the single-family residential categories are summarized in the fee schedule.

PROPERTY TYPE	SFR CLASS
Single-Family Residential, 0.125 acres or less	Class A
Single-Family Residential, 0.126 acres to 0.250 acres	Class B
Single-Family Residential, 0.251 acres to 0.500 acres	Class C
Single-Family Residential, 0.501 acres to 0.750 acres	Class D
Single-Family Residential, 0.751 acres to 1.000 acres	Class E
Single Family Residential, 1.001 acres or larger	Class F

(b) Non-Single Family ESWU. The storm water utility fee for non-single family lots shall equal the number of ESWU's for a given lot, multiplied by the annual rate established by the City Commission per ESWU per year. The formula for determining the number of ESWU's per non-single family lot shall be calculated from the amount of pervious and impervious lot area as follows:

$$\text{Number of ESWU's} = \frac{0.15\,(TA - IA) + 0.90\,(IA)}{\text{Average runoff potential of the standard unit/ESWU}}$$

where,

TA = total area of each lot (reported in square feet);

IA = impervious area of each lot (reported in square feet).

(c) Any property owner liable for a storm water utility fee may appeal the determination that the property utilizes the storm water system or the amount of a storm water utility fee, including a determination on a reduction in or the elimination of the fee under Section 114-402(a) and (b). An appeal may be based on the quantity of storm water runoff generated, the reductions established, the reductions allocated, or any other matter relating to the determination of the storm water utility fee.

(d) An appeal under subdivision (c) shall be heard by a storm water utility appeals board appointed by the local unit of government. The appeals board shall consist of 3 members, 2 of whom shall be licensed professional engineers not employed by the local unit of government.

(e) An appeal of a storm water utility fee shall not be brought more than 1 year after the fee was billed.

(f) To prevail in an appeal of a storm water utility fee, the appellant shall demonstrate in accordance with the requirements of the plan that the use of the system by the property is less than the amount used by the local unit of government in the calculation of that property's storm water utility fee, or the classification of the property type is in error, or there was a mathematical error in the calculation of the fee.

(g) The sole remedy for a property owner who prevails in an appeal of a storm water utility fee is a prospective correct recalculation of the storm water utility fee.

(h) If in an appeal of a storm water utility fee the appeals board finds that the requirements of subdivision (f) have not been met, that finding is conclusive until the property is modified to either increase or decrease the utilization of the system. The property owner remains eligible for reduction or elimination of fees under the storm water utility ordinance.

(i) A property owner making an appeal shall provide the appeals board with information necessary to make a determination.

(j) A person aggrieved by a decision of the appeals board on an appeal under this section may appeal to the circuit court in which the property is located. An appeal to the Circuit Court must be filed within thirty (30) days of the appeals board's decision.

Sec. 114-403. Credits.

(a) The purpose of this section is to provide for each property owner's control over contributions of storm flows to the storm water utility system and the related storm water utility fees and to advance protection of the public health, safety, and welfare.

(b) The City shall offer credits on an annual basis that will enable any property owner, through voluntary action, to reduce the storm water utility fees calculated for that property owner's property and will provide a meaningful reduction in the cost of service to the storm water system, or that shall be reasonably related to a benefit to the storm water system;

(1) Credits will only be applied if requirements outlined in this Chapter and other applicable sections of the City Code are met, including, but not limited to: completion of ongoing maintenance, guaranteed right-of-entry for inspections, and submittal of annual self-certification reports.
(2) Credits will be defined as either set fee reduction or percent (%) reductions applied as a credit adjustment to the fee calculation equation.
(3) Credits are additive to each credit category.
(4) As long as the storm water facilities or management practices are functioning as approved, the credit reduction will be applied to the fee. If the approved practice is not functioning as approved or is terminated, the credit reduction will be cancelled and the fee will return to the baseline calculation. Once the credit reduction has been cancelled, a customer may not reapply for credit for a period of 12 months and only then if the deficiency has been corrected, as determined by City inspection.
(5) Credits will be applied to the next complete billing cycle after the application has been approved.

(c) The director shall define a method for applying and granting credits on an annual basis, as well as criteria for determining the credits a property owner may receive. The director may, by regulation, establish credits for 1 or more of the following:

(1) Installation and maintenance of rain barrels, rain gardens, bioswales, cisterns, dry wells, infiltration trenches, porous pavement or pavers, or disconnecting footing drains;
(2) Installation and maintenance of a storm water control facility, or other water quantity controls; and
(3) Other actions of the property owner that, in the judgment of the director, result in a measurable reduction in storm water runoff.

Sec. 114-404. - Billing.

The billing for the storm water utility may be combined with the billing for other utility services. Final determinations on measurements per ESWU will be determined by the director.

Sec. 114-405. - Collection.

Unpaid storm water utility fees shall constitute a lien against the property affected. Fees which have remained unpaid for a period of six months prior to April 30 may be certified to the City Treasurer who shall place the fees on the next tax roll of the City. In the alternative, the City Commission may direct the City Attorney to take appropriate legal action to collect unpaid fees.

Ordained this _____ day of __________________, 2016. Effective upon publication.

____
Rackeline J. Hoff, Mayor

____
Laura M. Pierce, City Clerk

I, Laura M. Pierce, City Clerk of the City of Birmingham, do hereby certify that the foregoing ordinance was passed by the Commission of the City of Birmingham, Michigan at a regular meeting held ____________________, 2016 and that a summary was published ______________________, 2016.

____
Laura M. Pierce, City Clerk

FEE SCHEDULE

PROPERTY TYPE	SFR CLASS	AVERAGE RUNOFF POTENTIAL	ESWU
Single-Family Residential, 0.125 acres or less	Class A	3,166	0.7
Single-Family Residential, 0.126 acres to 0.250 acres	Class B	4,317	1.0
Single-Family Residential, 0.251 acres to 0.500 acres	Class C	6,716	1.6
Single-Family Residential, 0.501 acres to 0.750 acres	Class D	10,552	2.4
Single-Family Residential, 0.751 acres to 1.000 acres	Class E	13,094	3.2
Single Family Residential, 1.001 acres or larger	Class F	20,496	4.6

Non-Single Family ESWU. The storm water utility fee for non-single family lots shall equal the number of ESWU'S for a given lot, multiplied by the annual rate established by the City Commission per ESWU per year. The formula for determining the number of ESWU'S per non-single family lot shall be calculated from the amount of pervious and impervious lot area as follows:

$$\text{Number of ESWU's} = \frac{0.15\ (TA - IA) + 0.90\ (IA)}{4317 \text{ square feet/ESWU}}$$

where,

TA = total area of each lot (reported in square feet);

IA = impervious area of each lot (reported in square feet).

Storm Water Utility Fee Apportionment for the City of Birmingham

Storm Water Utility Fee Apportionment

Storm Water Utility Fee Apportionment Report:

- Section 1 – Executive Summary
- Section 2 – Background
- Section 3 – Purpose and Summary
- **Section 4, 5, 6 – Methodology**
- Section 7 – Apportionment
- **Section 8 – Administrative Recommendations**

Storm Water Utility Fee Apportionment

How does Storm Water enter Sewer?

- **Surface runoff to public drainage structures (catch basins & inlets)**
- Inflow through private foundation drains & yard drains
- Infiltration into private & public sewer pipes & structures

Storm Water Utility Fee Apportionment

What is Surface Runoff?

- When precipitation occurs…
  - Some is intercepted by trees/plants
  - Some collects and evaporates
  - Some is absorbed
  - Some infiltrates into soil
  - Remainder becomes surface runoff

Storm Water Utility Fee Apportionment

How is Surface Runoff generated?

- Primarily from Impervious surfaces
  - Building roofs
  - Pavements
- Also from Pervious surfaces to a smaller degree
  - Grass lawns & gardens
  - Landscape areas w/out membranes
- Runoff Coefficients developed for each type of surface

Storm Water Utility Fee Apportionment

General Methodology:

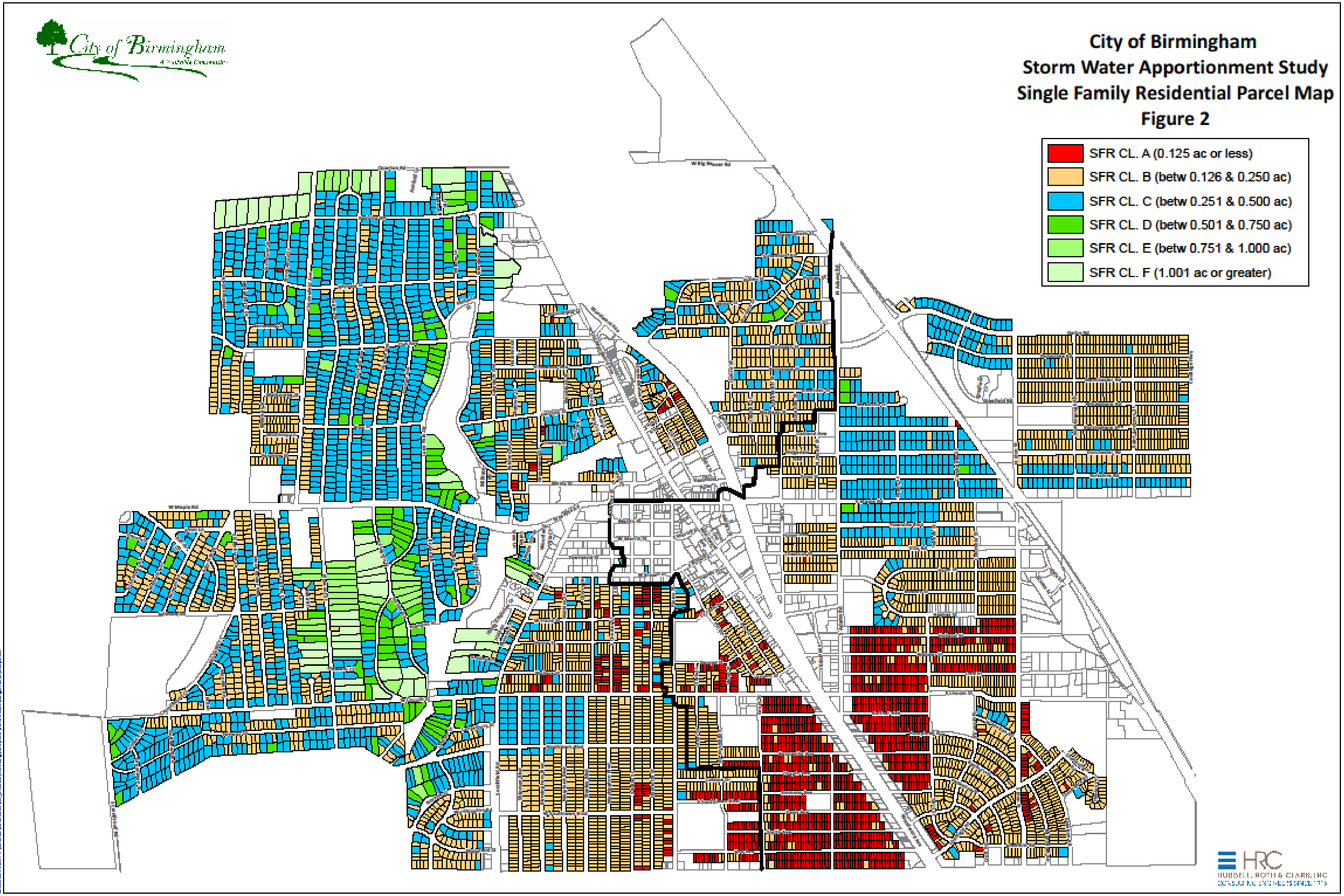
- Categorize similar types of properties
- Define a “standard unit”
- Determine Runoff Potential for the properties
- Equate particular Runoff Potential to the “standard unit” – Equivalent Storm Water Unit (ESWU)

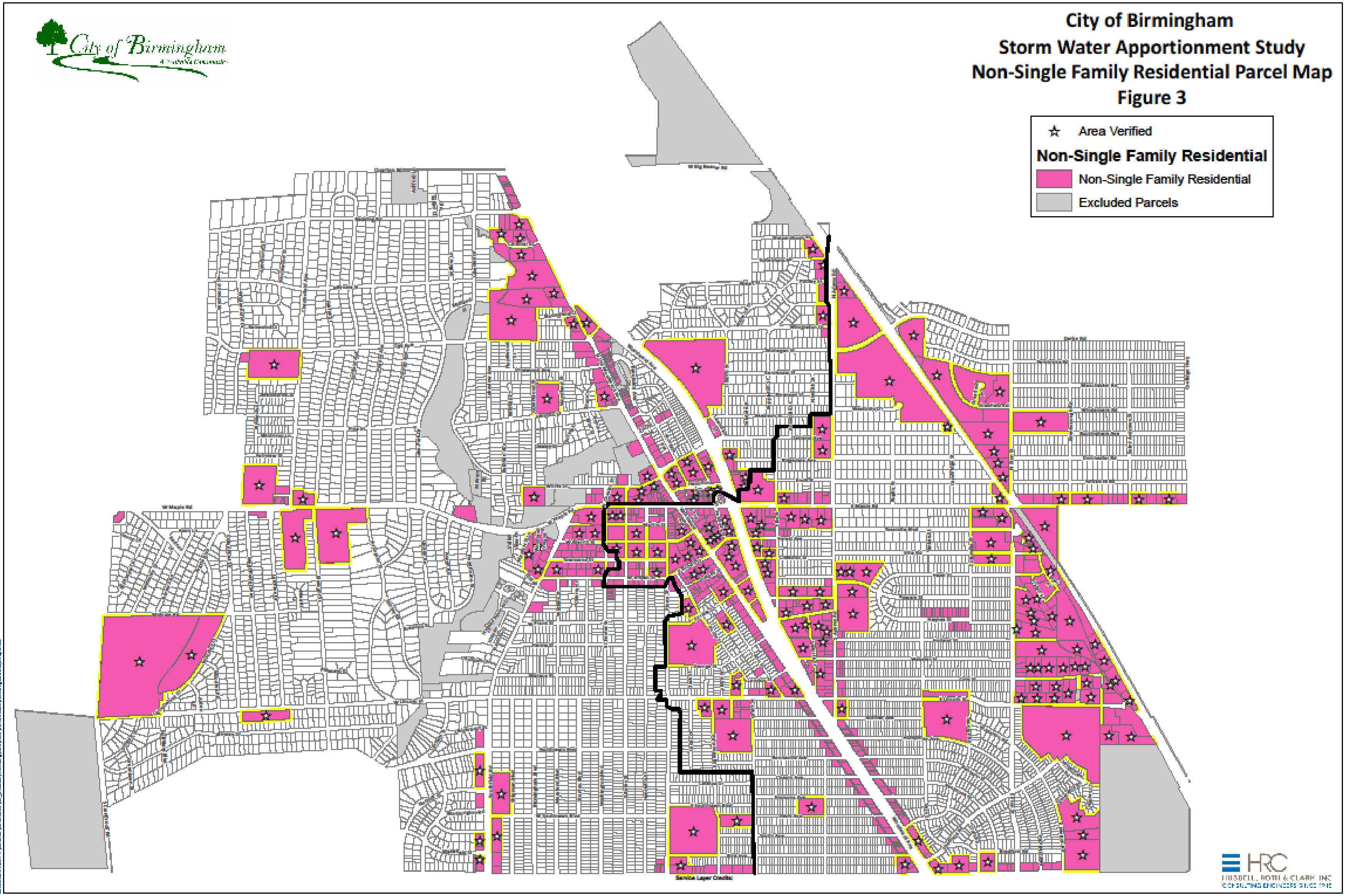
Storm Water Utility Fee Apportionment

How are Properties Categorized?

- Single Family Residential properties (SFR)
- Non-Single Family Residential properties (NSFR)
- SFR make up 91% of all properties by number, 72% by area
- See maps in Appendix A

City of Birmingham
Storm Water Apportionment Study
Single Family Residential Parcel Map
Figure 2




City of Birmingham
Storm Water Apportionment Study
Non-Single Family Residential Parcel Map
Figure 3
Area Verified
Non-Single Family Residential
Non-Single Family Residential
Excluded Parcels
HRC
HUBBELL, ROTH & CLARK, INC.

Storm Water Utility Fee Apportionment

Single Family Residential Properties:

- Six classifications based on lot area;
    - Class A 0.125 ac or less 1,375
    - Class B 0.126 to 0.250 ac 3,949
    - Class C 0.251 to 0.500 ac 1,716
    - Class D 0.501 to 0.750 ac 115
    - Class E 0.751 to 1.000 ac 43
    - Class F 1.001 ac or greater 47
- Average development characteristics determined for each SFR classification

Storm Water Utility Fee Apportionment

Non-Single Family Residential Properties:

- Includes ALL other types of properties:
  - Two-family & multi-family residential, condominiums
  - Public properties, schools, churches
  - Commercial, business, office, parking
- Number of NSFR properties – 719
- Development characteristics uniquely determined for each NSFR property

Storm Water Utility Fee Apportionment

What is Runoff Potential?

$$\mathbf{RP = 0.9 \times IA + 0.15 \times (TA\text{-}IA)]}$$

IA = Impervious Area TA = Total Area

0.9 = Runoff Coefficient for Impervious Area

0.15 = Runoff Coefficient for Pervious Area

- Part of standard engineering calculation for determining runoff from an area

Storm Water Utility Fee Apportionment

How are these areas measured?

- Total Area is based on Oakland County property data
- Public road right-of-way area deducted from TA for “metes & bounds” parcels
- Impervious Area based on SEMCOG GIS data, confirmed by visual check of aerial imagery for larger parcels

Storm Water Utility Fee Apportionment

How is using RP Proportional?

- Comparing physical characteristics of each property that impacts how runoff is generated from that property to the District as a whole
- Independent of precipitation
- Each property’s share of the total RP of the District – simplify by using ESWU concept

Storm Water Utility Fee Apportionment

What is the ESWU concept?

- Convert RP to ESWU value (Equivalent Storm Water Unit)
- RP for "standard unit" = 4,317 sq. ft.
- ESWU for "standard unit" = 1.0
- ESWU for other parcels calculated by dividing their RP by 4,317 sq. ft.

Storm Water Utility Fee Apportionment

ESWU for Single Family Residential Parcels:

- Average impervious area & total area for each SFR classification used to calculate the RP for that classification
- ESWU calculated by dividing RP for each classification by 4,317 sq. ft.
- ESWU value assigned to all properties within each classification

Storm Water Utility Fee Apportionment

ESWU for SFR Parcels – Example:

- SFR Class B (0.126 to 0.250 ac) – the "Standard Unit"
  - Number of Parcels = 3,949
  - Overall Area:

    Total = 690 ac   Ave = 7,628 sft
  - Impervious Area:

    Total = 384 ac   Ave = 4,231 sft
  - Runoff Potential =

    0.9*(4,231) + 0.15*(7,628-4,231) = 4,317 sft

Storm Water Utility Fee Apportionment

ESWU for Non-Single Family Residential Parcels:

- Unique impervious area & total area for each property used to calculate the RP for that property
- ESWU calculated by dividing RP for each property by 4,317 sq. ft.

Storm Water Utility Fee Apportionment

How is Apportionment Share Determined?

- Sum the ESWU's for each District
- Divide the ESWU for each property in the District by the sum of ESWU's
- ESWU value and calculated apportionment share listed for every property (Appendix B)

Storm Water Utility Fee Apportionment

Credits & Methods for Reducing Fees:

- Certain credits will be offered – measures must reduce amount of storm water that enters the sewer
  - Rain Barrels / Cisterns (intercept)
  - Rain Gardens / Bio-Swales (infiltrate)
  - Dry Wells / Infiltration Trenches (infiltrate)
  - Porous Pavement (infiltrate)
  - Disconnect Footing Drains (infiltrate)

Storm Water Utility Fee Apportionment

Credits & Methods for Reducing Fees:

- Measures that rely on infiltration – percolation testing
- Property owner responsible for applying for credits & certifying continued use and performance
- Low Impact Development (Appendix C)

City of Birmingham
A Walkable Community

MEMORANDUM

Engineering Dept.

DATE: May 10, 2017

TO: Storm Water Utility Appeals Board

FROM: Paul T. O'Meara, City Engineer

SUBJECT: Staff Determined Special Cases

The Storm Water Utility Appeals Board ordinance spells out the need for this Board, and the conditions under which it shall operate. It also defines the City Engineer (or his designee) as the "Director" in terms of the staff person making decisions pertaining to the daily administration of the ordinance. As will be reviewed in the next section of the agenda package, the Board will have criteria in which to consider an appeal. However, it is acknowledged that there are unique situations that do not fit well into the criteria established for apportioning the costs of this fee. In order to simplify the process for the public, as well as the Board, the Director shall have the authority to adjust those cases that are clearly unique in that billing them as initially determined would not be just. The following list summarizes the complete list of properties that have been adjusted to date. The Director shall keep a list of these adjustments, and as others are approved, they will be passed on to the Board for your information.

295 Abbey

As shown on the attached map, the majority of the property for this address is within Bloomfield Twp., and not subject to the new storm water fee. However, the owner also owns a small triangular parcel south of the City limit that forms the property's connection to Abbey Rd. (point of access). When first billed, this property was billed at the smallest rate possible, Class A, with an ESWU of 0.7. The Class A lots have a definition of being anything less than 0.125 ac. The acreage of this property is about 0.5 ac., less than half of the largest parcels within Class A. Since the parcel is too small to actually build on, a reduced charge was appropriate. The charge was changed to 50% of the normal Class A charge, or an ESWU of 0.35.

1040 Gordon Lane

Measuring over an acre, 1040 Gordon Lane was classified at the largest level possible, or Class F. The property is unique in that it has a small frontage on a private road (Gordon Lane) which itself has no public sewer (the homes are served by a public sewer installed along the rear lot line). Further, a small percentage of the lot is improved with roof or driveway, while the remainder is a natural ravine falling down to the Rouge River or adjacent Linn Smith Park. The home is connected to the sanitary sewer system, and likely creates some demand on the system via its footing drain system. The property was changed to the average level, Class B.

34200 Woodward Ave.

For properties with multiple tenants or owners, the City is sending out bills that divide the property equally by the number of tenants or owners involved. While this strategy may work for most properties, there are those where some tenants create a disproportional share of the demand, and must be adjusted. The above address, also known as Papa Joe's Gourmet Market, is an example. As shown on the adjacent aerial photo, red lines have been added to a picture of the roof to demonstrate that each tenant has their own area that they use, and they vary greatly in size. One of the small tenants received the bill and started asking questions. The Engineering Dept. notified the owner of the property, and asked them to suggest a fair distribution of the charges, based on how large their first floor square footage is. (Since all tenants share the parking lot, that was not subdivided for this exercise.)

We received the attached email from the owner suggesting a six way split, which looked proportional to the interior square footage of each unit, and the billings have been adjusted accordingly.

1845 Yorkshire Rd.

The owner of the above property also owns the parcel to their north, as highlighted on the attached map, which acts as an expanded backyard to the property occupied with a house. Because it has a separate tax ID number, it was billed as a separate parcel, so the owner is receiving a Class C invoice for the parcel with the house, and a Class B invoice for the vacant property.

Interestingly, when the square footage of the two lots is combined together, the total area still falls within a Class C charge. Since the property is being used as an unimproved backyard distant from any sewer or street, the Engineering Dept. agreed that one Class C charge for the total property is appropriate. Two important distinctions to consider on this lot are:

1. It is configured such that it cannot be redeveloped in the future as its own stand-alone property (other owners may own a second property that acts as a sideyard, but it can in fact be redeveloped if the owner chose to do so).
2. The fee for this property has not been waived. If the two properties together totaled an acreage that should be charged as a Class D, then the City would recommend charging it as one Class D property.

295 Abbey Rd.

1230 HARROW CIR
1205 HARROW CIR
1210 OXFORD RD
1170 OXFORD RD
270 HARROW CIR
290 HARROW CIR
1175 HARROW CIR
210 HARROW CIR
240 HARROW CIR
295 ABBEY ST
275 ABBEY ST
1130 OXFORD RD
Oxford Rd
Abbey St
289 ABBEY ST
1091 OXFORD ST
1088 OXFORD ST
267 ABBEY ST
1075 OXFORD ST
1064 OXFORD ST
Oxford St
268 ABBEY ST
1055 OXFORD ST
166 MAYWOOD AVE
207 ABBEY ST
256 ABBEY ST
1012 OXFORD ST
359 HENLEY ST
210 ABBEY ST
36000 WOODWARD AVE
205 ABBEY ST
Henley St
Henley
972 OXFORD ST
N
176 ABBEY ST
999 TWIN OAKS LN
971 OXFORD ST
950 OXFORD ST
35980 WOODWARD AVE
Miles
951 TWIN OAKS LN
175 ABBEY ST
0 0.0075 0.015 0.03 0.045 0.06

Image capture: Sep 2014

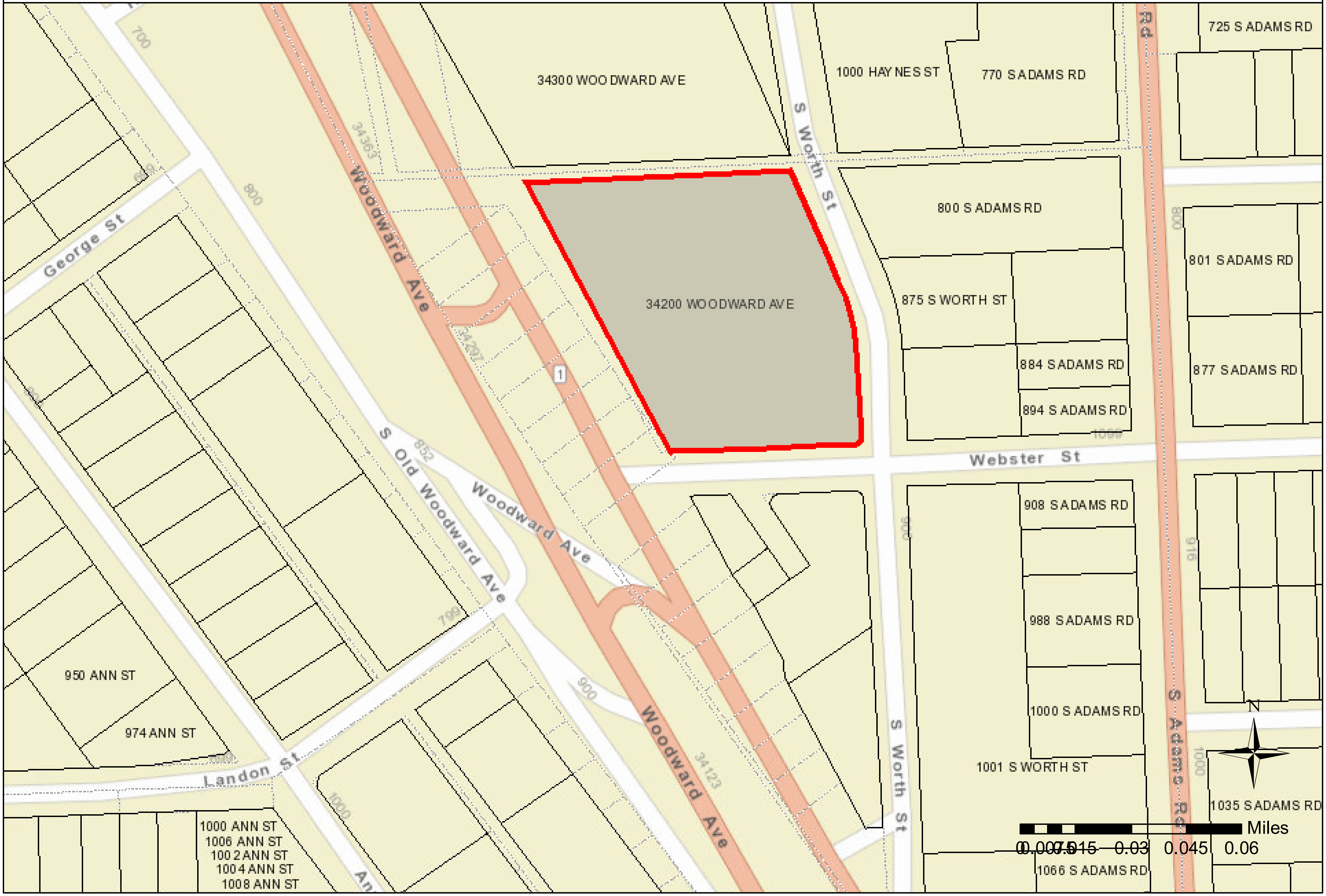
Birmingham, Michigan

Street View - Sep 2014

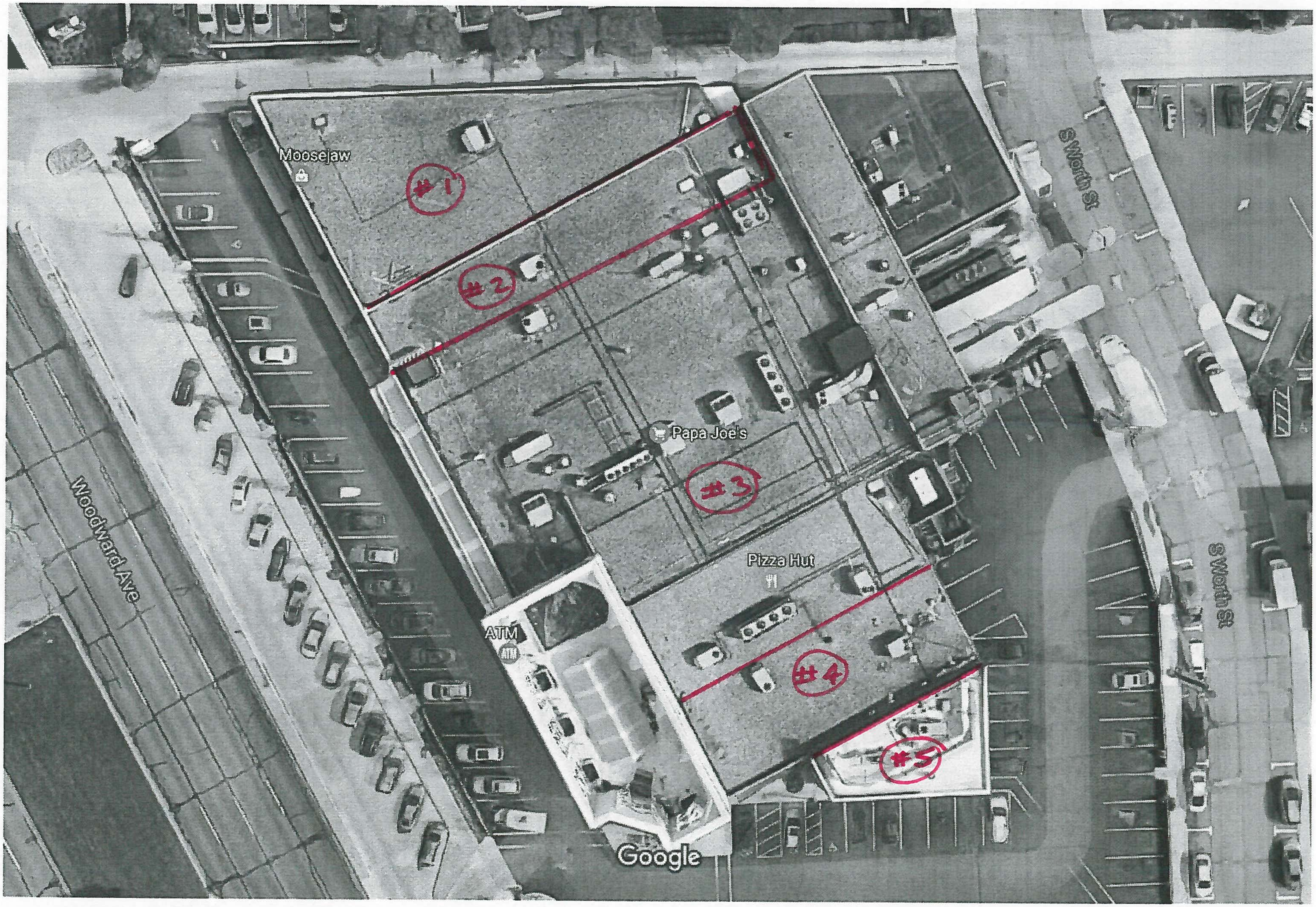
1040 Gordon Lane

Google Maps 1040 Gordon Lane

34200 Woodward Ave.



Google Maps 34200 Woodward Ave.



City of Birmingham
A Walkable Community

Paul O'Meara <pomeara@bhamgov.org>

FW: Papa Joe's Storm Water Utility Fee

1 message

Stacy Lewis <stacy.lewis@papajoesmarket.com> Thu, Mar 30, 2017 at 3:27 PM
To: pomeara@bhamgov.org

Hello Paul,

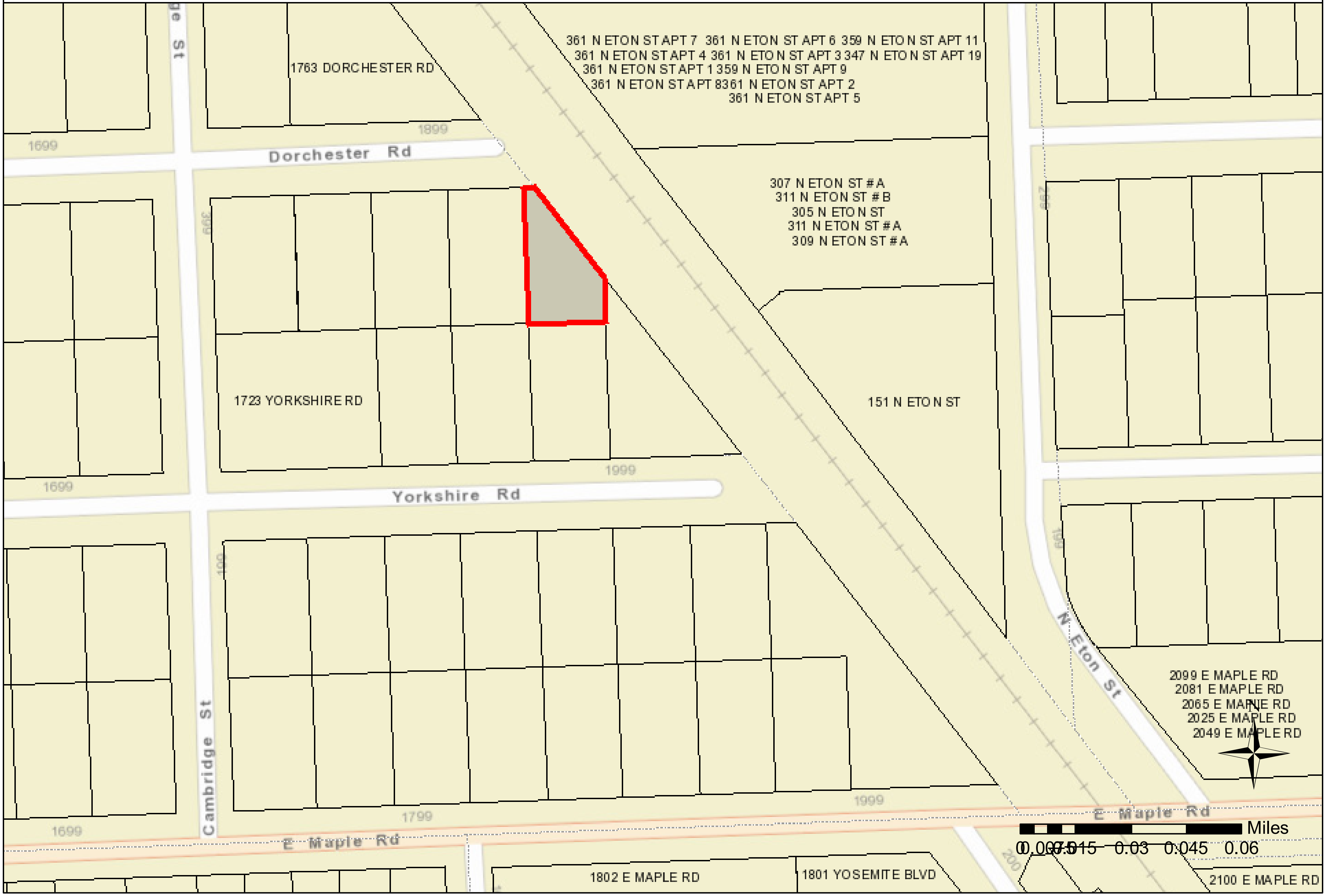
Sorry for the delay but I had to wait for approval. If you have any questions please let me know.

Here is a breakdown of the split:

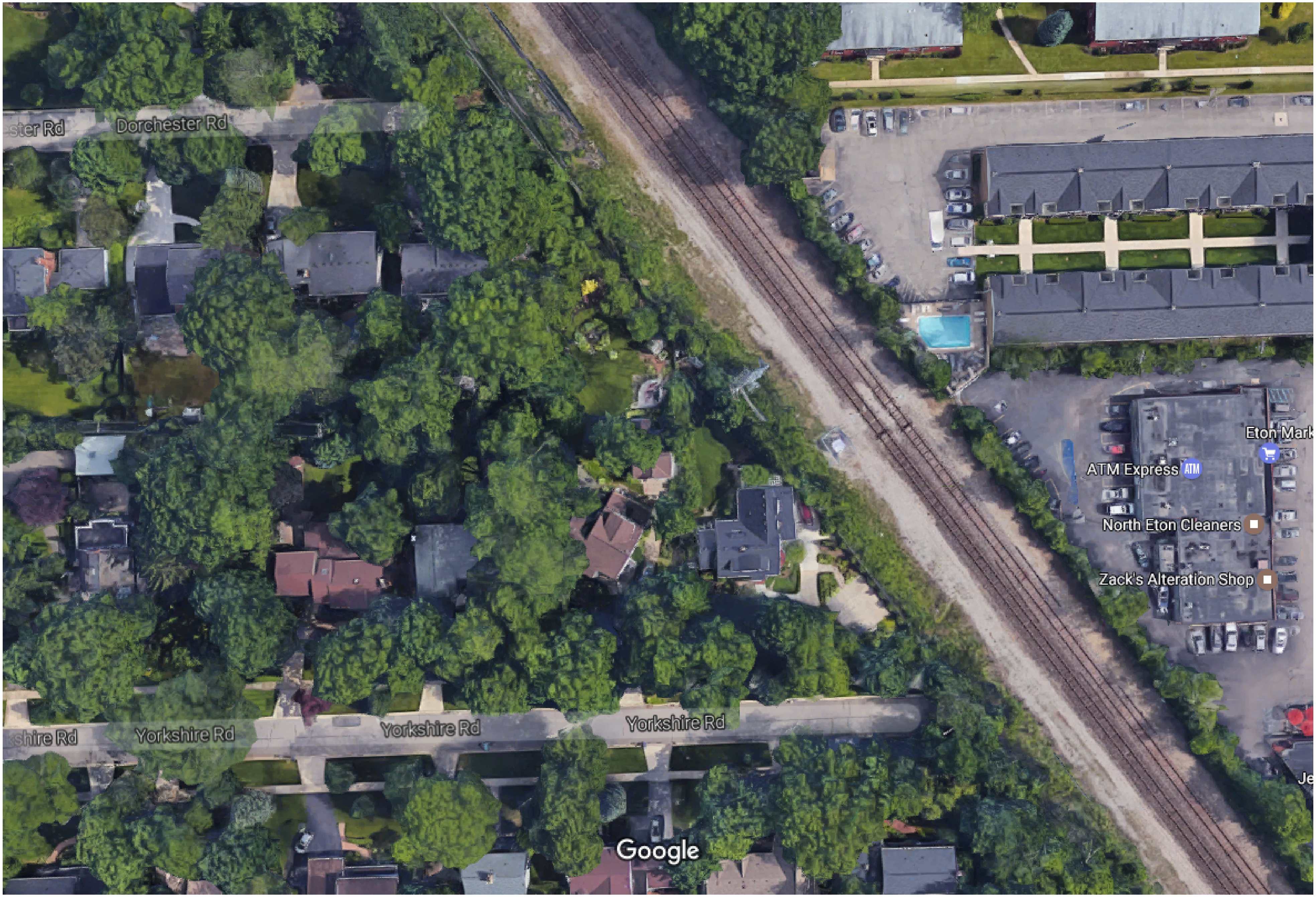
Tenant Name	Storm Drain Fee
Degiulio Kitchen & Bath	$62.10
Massage Envy	$86.71
Moosejaw	$194.52
Papa Joes Birmingham	$585.74
Bistro Joes	$121.65
Pizza Hut	$50.03
	$1100.75

Thanks-Stacy

1845 Yorkshire Rd.



Google Maps 1845 Yorkshire Rd.



City of Birmingham
A Walkable Community

MEMORANDUM

Engineering Dept.

DATE: May 11, 2017

TO: Storm Water Utility Appeals Board

FROM: Paul T. O'Meara, City Engineer

SUBJECT: Appeals for May, 2017 Meeting

1452 Buckingham Rd.

As noted in the previous materials, over 90% of the individual properties in the City are used as Single Family Residential (SFR). In order to simplify the ongoing administration of this ordinance, the City determined that it would be best to develop a simplified system wherein the level of development on each SFR parcel would not impact the charge being assessed. Attempting to measure the impervious surface of thousands of more parcels would have been time consuming given the brief amount of time allotted to complete this billing change. Worse yet, the City would then have to track the changes made each year on thousands of more parcels, most of which pay a relatively small fee. (Non-SFR parcels could not be simplified in this respect due to the wide variance of sizes and uses present in that class.)

While it is acknowledged that Mr. Hall's property may in fact produce less runoff than the average Class C parcel, even a vacant parcel with the same size dimensions would be charged the same. For any SFR property, the level of improvements thereon does not enter into the decision-making process. Further, the conditions presented here could be replicated many times for similar properties that could also then seek a similar reduction.

Given the above, the Engineering Dept. did not agree that the storm water runoff fee for this property should be reduced.

Mr. Hall has identified that there are other properties in close proximity to his that may be violating the ordinance relative to the disconnection of downspouts. The City does not have the ability to regularly search for violations of this ordinance. We rely on others such as Mr. Hall to help identify such issues. We will be following up with these other parties to ensure that compliance is achieved.

Application Date: 4-26-17

Received By: ___________

City of Birmingham
Michigan

Hearing Date: ________

Appeal # ___________

Storm Water Utility Appeals Board Application

Type of Appeal: ESWU Rate ✓ Credit ✓

Property Information:

Street address: 1452 Buckingham Ave.		**Sidwell Number:**	20-30-354-002
Owners name: Craig Hall		**Phone**	
Owners address: 1452 Buckingham Ave		**Email**	
City: State: Birmingham, MI	**Zip code:**		
Contact person: Craig Hall		**Phon**	

Petitioner Information:

Petitioner name: Craig Hall		**Phon**
Petitioner address: 1452 Buckingham Ave		**Ema**
City: Birmingham	**State:** MI	

Required Attachments:

- X Original Certified Survey
- Original Storm Water Credit application
- X Letter explaining reason for appeal
- Plan (to scale) documenting proposed changes for credit
- Percolation Test Data (if pertinent)
- X Required Backup Information as listed for each ESWU reduction or Credit category

General Information:

Prior to submitting for a Storm Water Utility Appeals Board review, you must contact the Engineering Dept. for a preliminary discussion on your submittal. The deadline is the **15th** of the previous month.

The review fee is **$50.00** for all appeals.

By signing this application I agree to conform to all applicable laws of the City of Birmingham. All information submitted on this application is accurate to the best of my knowledge.

As long as they do not limit my argument to immediately appeal my property's Storm Water Usage Fee.

CEH 4/26/17

Signature of Owner: Craig Hall Date: 4/26/17

General Information regarding Storm Water Credits:

All credits must be applied for by the property owner, and approved by the City Engineer. Design requirements and criteria for meeting variable credit values can be found on the Storm Water Utility Fee Credit webpage, or at the Engineering Department office. Approved credits will go into effect in the following yearly cycle, and require periodic renewal. The City has the right to revoke any credits given if the information provided is discovered to be false or if use of the measure is discontinued.

By signing this application, I agree to conform to all applicable laws of the City of Birmingham. All information submitted on this application is accurate to the best of my knowledge. Changes to the plans are not allowed without approval from the Director of Engineering. I understand that storm water credits will not apply to my account until the calendar year following approval of the application by the City Engineer.

Signature of Owner: [signature] Date: 4/26/17

As long as they do not limit my argument to immediately appeal my property's Storm Water Usage Fee and receive credit in lieu of a Storm Water Fee Reduction.
CGA 4/26/17

Low Impact Development Determination:

The applicant acknowledges that the ESWU determination provided by this submittal is based on the information provided and made available at the time of the application. A complete construction plan shall be prepared and submitted for a buiding permit before work begins. The City reserves the right to change the ESWU determination if the final construction plans materially change the intent of the project from what was submitted as a part of this application.

Signature of Owner:________________________ Date:____________

Storm Water Utility Fee Appeal
April 30, 2017 (NEW)

RECEIVED
APR 28 2017
CITY OF BIRMINGHAM
COMMUNITY DEVELOPMENT DEPARTMENT

Property ID: 20-30-354-002
1452 Buckingham Ave.
Birmingham, MI 48009
Craig Hall – Owner (248-703-1967)
Class C Property: .26 acre actual (between 0.251 to 0.500 acres)

Purpose

- To appeal my single family residential (SFR) property's Storm Water Utility Quarterly Fee of $95.20 as an appeal is granted under City Ordinance 2204; Section 114-402 (c).
- City Ordinance 2204; Section 114-402 (f) states, "to prevail in an appeal of a storm water utility fee, the appellant shall demonstrate in accordance with the requirements of the plan that use of the system by the property is less than the amount used by the local unit of government in the calculation of that property's storm water utility fee".
- To request that the Hubbell, Roth and Clark Run Off Potential (RP) formula/run off coefficients be applied specifically to my property, similar to how applied for non single family residential properties, to show that the City calculation over estimates my property's actual use of the sewer system.

Request (Adjust my ESWU from estimated 1.6 to actual .65)

- My property's 1Q 2016 water bill was $122.80. My 1Q 2017 water bill based on the new billing methodology went up to $200.10 – up a whopping 63% YOY or approx. $309.20/year!
- Request adjustment of my property's ESWU factor from 1.6 to .89 based on the actual impervious vs pervious land – this would adjust my quarterly Storm Usage Fee from $95.20 to $52.95 ($59.5 x .89).
- ***Then, adjust my property's ESWU factor a second time from .89 to .65 since my roof gutter down spouts all drain and percolate into my yard vs. flowing directly to the foundation footing sewer drains*** (ie, my garage & home roof sq. footage should be calculated using the 0.15 runoff coefficient for pervious areas vs. the 0.9 runoff coefficient for impervious areas).
- This adjustment would then decrease my quarterly Storm Usage Fee from $52.95 to $38.67/qtr. ($59.5 x .65).
- Alternatively, I request to be granted the $40/qtr. storm fee credit for disconnection of footing drains since my footing drains are minimally used if at all, due to the disconnected roof gutter down spouts that drain onto a pervious area.
- ***These adjustments would reduce my 1Q 2017 water bill to a total of $143.57 ($104.90 base + $38.67 storm fee). Still up $20.77/qtr. YOY (17% increase), but much less than the 63% increase the City is now requesting.***
- I am also requesting refund of the $50 required to appeal ESWU calculation for my property – there is no required appeal fee stated in the City Ordinance and frankly should be no fee to "fairly and accurately" adjust a City estimated ESWU that unfairly "taxes" my property to pay for other City property's water runoff.

Background

- As a result of lawsuit settlement filed by an overzealous Royal Oak attorney, City of Birmingham is changing its methodology of billing storm water to reflect each property's **estimated** contribution to storm water runoff. The City contracted an engineering firm (Hubbell, Roth, and Clark – HRC) to develop a methodology which would calculate the estimated potential storm water runoff for various types of properties. HRC researched the amount of pervious areas (where rainwater can soak in) and impervious areas (areas where rainwater cannot soak in) throughout the City. Based on this research, HRC developed a factor called Equivalent Storm Water Unit (ESWU). **Single family residential (SFR) properties were averaged together and classified by lot size so that properties of similar size would be assigned the same ESWU factor.** Non-single family residential properties were assigned an ESWU factor based on their individual parcel speccifics. (Source: City Mailer of New Methodology w/1st Qtr. water bill).

- (HRC Report; page 1-1): The runoff **potential** for a typical single family residential property is defined as a "standard unit", called an Equivalent Storm Water Unit (ESWU). **Other types of properties are assigned a multiple of the "standard unit"** by dividing their particular runoff potential by the "standard" runoff potential. The ESWUs are totaled for all properties being assessed, and each property's share of the total is determined by dividing their particular ESWU by the total of the ESWUs. Procedures will be implemented for property owners to appeal and adjust their ESWU assignments if it is found to be in error. The opportunity for property owners to receive certain credits to their storm water utility fee will be available when measures are taken by the property owner to reduce the amount of storm water that enters the City sewer system from their property.
- (HRC Report; page 3-1): The purpose of assessing a storm water utility fee is to apportion the sewage treatment charges in a manner that is proportional to the runoff potential from each property.
- (HRC Report; page 5-1): The ESWU for each of the six lot area categories for single-family residential properties is based on the **average** runoff potential for that category. For each group, the total impervious surface and pervious surface areas were summed up, and then divided by the number of parcels. Those areas were entered into the runoff potential equation to determine the average runoff potential for each category.

	Ave. RP	ESWU	Yr. Fee	Qtr
SFR Class B (0.126 to 0.250 acres)	4,317	1.0	$238	$59.20
SFR Class C (0.251 to 0.500 acres)	6,714	1.6	$381	$95.20

- Run Off Potential Formula Developed by HRC: The runoff potential from a property is based on hydrologic principles for calculating runoff that use both the impervious surface area and the pervious surface area. Runoff potential is measured in sq. ft. using the formula (City Ordinance 2204; Sec. 114-400):

RP = 0.15 x (Total Property Area – Impervious Area) + 0.9 x (Impervious Area)

- Equivalent Storm Water Unit (ESWU): A subunit of measurement which relates the volume of storm water discharged from a lot based on the amount of total and impervious lot area, compared to the standard unit. One ESWU in the City is equal to the average runoff potential of the standard unit. Impervious area means a surface area that is resistant to permeation by surface water (ie, buildings, concrete walkways, asphalt driveways, etc.). Pervious lot area is all land that is not impervious. The formula for an equivalent storm water unit (ESWU) is as follows (City Ordinance 2204; sec 114-400):

  1ESWU=0.15(Tot. area of std unit–impervious area of std. unit)+0.90(impervious area of std. unit)

  Note: 0.15 = runoff coefficient for pervious area; 0.90 = runoff coefficient for impervious area

- (City Ordinance 2204; sec 114-401): (a) all users shall pay a storm water utility fee proportional to the volume of storm water which is projected to discharge into the combined sewer system and storm water sewer system ***from their property***.
- (City Ordinance 2204; sec 114-402): (c) Single Family Residential ESWU. All single family residential properties in each of the lot size categories are assigned the same ESWU for that category. The ESWU values for the single-family residential categories are summarized in the fee schedule.

Single-Family Residential, 0.126 acres to 0.250 acres	Class B
Single-Family Residential, 0.251 acres to 0.500 acres	Class C

- (Bham.gov website – Storm Water Utility Ordinance; ESWU Background; page 4/6): In 1998, the Michigan Supreme Court decided a case, Bolt v City of Lansing, which dealt with the City of Lansing using its water/sewer bills to raise revenue **unrelated to the actual usage**. ***One of the factors the Court in Bolt determined is that the <u>storm water disposal fee must be in proportion to the amount of water that enters the sewer system from each parcel</u> or lot in the city.***

- (Bham.gov website – Storm Water Utility Ordinance; Disconnect Footing Drain): Disconnecting footing drains from the sewer service will **reduce** the amount of storm water that enters the sewer system.
- (Bham.gov website – Storm Water Utility Ordinance; Storm Water Credits; page 2/6): When considering an improvement that would qualify for a credit, it is important to consider how the improvement will be located. A sample Class B lot layout that shows how a base property with an ESWU of 1.0 can be found under Class B SFR example. The drawing shows how the front half of the property typically drains to the street, ***while the back half drains to the rear yard, where it tends to percolate into the ground*** (unless the property has been improved with a rear yard drainage system).
- (City Ordinance 2204; sec 114-402): (c) **any property owner** liable for a storm water utility fee **may appeal** the determination that the property utilizes the storm water system or the **amount of a storm water utility fee**, **including a determination on a reduction in or the elimination of the fee** under Section 114-402(a) and (b) **an appeal may be based on the quantity of storm water runoff generated**, the reductions established, the reductions allocated, **or any other matter relating to the determination of the storm water utility fee.** (f) **to prevail in an appeal of a storm water utility fee, the appellant shall demonstrate in accordance with the requirements of the plan that the use of the system by the property is less than the amount used by the local unit of government in the calculation of that property's storm water utility fee,** or the classification of the property type is in error, or there was a mathematical error in the calculation of the fee. (g) **the sole remedy for a property owner who prevails in an appeal of a storm water utility fee is a prospective correct recalculation of the storm water utility fee.**

Class B Standard Unit ESWU Calculation Observations (Exhibit 1)
- The Class B standard unit has a "whopping" 60% impervious area to total parcel area – HRC used a big house with small yard.
- This Class B standard unit has a total impervious area of 4,315 sq. ft. vs. my Class C property specific total impervious area of 2,845 sq. ft..
- Additionally, due to the 0.9 runoff coefficient assigned via formula to all home/garage roof total dimensions in the standard unit, the HRC formula clearly figures that all SFR home/garage roofs downspouts drain directly to the property footing drains that flow directly to the storm sewer.

My SFR Property: 1452 Buckingham Ave Specific Property Observations
- **(Exhibit 2)** includes certified copy of my property's survey.
- **(Exhibit 3)** shows my property's location in City and location on my Birmingham Estates City block.
- **(1)** My property has 11,344 sq. ft. or .26 of acre **(Exhibit 4).** My property is also classed in Class C (0.251 to 0.5 acres) so my property is right on entry edge into the Class C category and much smaller than the Class C category parcel average of .3755 acre *(the average SFR property in Class C category is 44% larger than my specific property).*
- **(2)** In comparison to the Class B Standard Unit, my specific property has a low 25% impervious to total parcel area vs. the standard unit of 60% **(Exhibit 4).**
- **(3)** The impervious sq. footage of the "Class B standard unit – is 4,315 sq. foot vs. my property actual impervious sq. footage of only 2,845 sq. ft. – the standard Class B unit represents 52% higher impervious sq. footage than my Class C property **(Exhibit 4)**!
- My property's Runoff Potential (RP) "specific property" calculation using the City approved formula is 3,835 vs. the City's estimate of 6,714 that was developed as a multiple of the standard unit **(Exhibit 4).**
- **Therefore, according to HRC formula, my property's actual ESWU should be .89 (3,835/4,317) vs. the 1.6 estimated by the City.**
- **(4)** Further, as you can see in the pics **(Exhibit 5),** my roof gutter downspouts are NOT connected to my house footing sewer drains. My roof gutter drains angle down away from my house and drain water down into my yard (pervious area) and tends to mostly percolate into the ground, thus reducing water runoff from the 0.9 factor used for roof/garage impervious area runoff in the HRC formula approved by the City *(please see Bham.gov website – Storm Water Utility Ordinance; Storm Water Credits; page 2/6: "the drawing shows how the front half of the property typically drains to the street,* ***while the back half drains to the rear yard, where it tends to percolate into the ground*** *(unless the property has been improved with a rear yard drainage system)."*
- The other homes on my same block listed in **Exhibit 4 (homes 2-5)** all have roof gutter drains connected directly to their footing drains; unlike my property where the roof gutter drains, drain water into my yard ***(pictures for each of the sample property's connected roof drains are in Exhibit 5).***

- **Therefore, using the runoff coefficient of 0.15 instead of 0.90 for my home and garage roofs sq. footage, results in an actual RP of 2,803 or an ESWU of .65 vs. the estimated 1.6 assigned by the City using estimates and averages (Exhibit 4).**
- Alternatively, rather than an ESWU adjustment downward for disconnected roof drain spouts, I request the $40/quarter Storm Fee credit for disconnection of footing drains since my home's footing drains are minimally used, if at all. My property's roof gutter drain spouts, drain directly to the yard that has a pervious area runoff coefficient of 0.15 vs. 0.90 coefficient for impervious areas.
- Finally, my SFR property slopes downward from the street with the first 20 ft of property towards the street being City owned. Therefore, 0% of my property's runoff ever reaches the front street's runoff gutters and therefore, all of my property runoff tends to percolate in to the ground and does not reach the sewers.

Summary (Adjust my ESWU from 1.6 to .65)

- The new City methodology based solely on averages, estimates, potential and an unrepresentative standard unit, ***grossly overstates*** the actual water runoff from my property and I am being unfairly "taxed" to support excessive run off from other City parcels.
- I am being treated unfairly for: (1) having the lowest possible total acreage in Class C, (2) for having a low % pervious vs. standard unit high % pervious; and, for (3) a SFR formula ESWU base calculation that factors in that my property's home/garage roof gutter drain outputs flow directly into the footing sewer drains and are therefore assigned a runoff coefficient of 0.90 vs. the correct runoff coefficient of 0.15 that should be used on my property due to my disconnected roof gutter down spouts.
- Using the RP/ESWU formula developed by HRC and used by the City to apply to my "specific" SFR property greatly decreases my ESWU resulting in a much lower Storm Usage Fee.
- If my property's ESWU is not adjusted downward to .65, this will subject me to an additional yearly tax of $226.12 (($95.2-$38.67) x 4) and this is NOT justified based on my property's actual RunOff per HRC formula.
- ***In closing, I have fairly & accurately demonstrated that use of the sewer system by my property is less than the amount projected by the local unit of government in calculation of my property's storm water utility fee; therefore, my property's ESWU should be adjusted downward. (City Ordinance 2204; sec 114-402 (f)).***

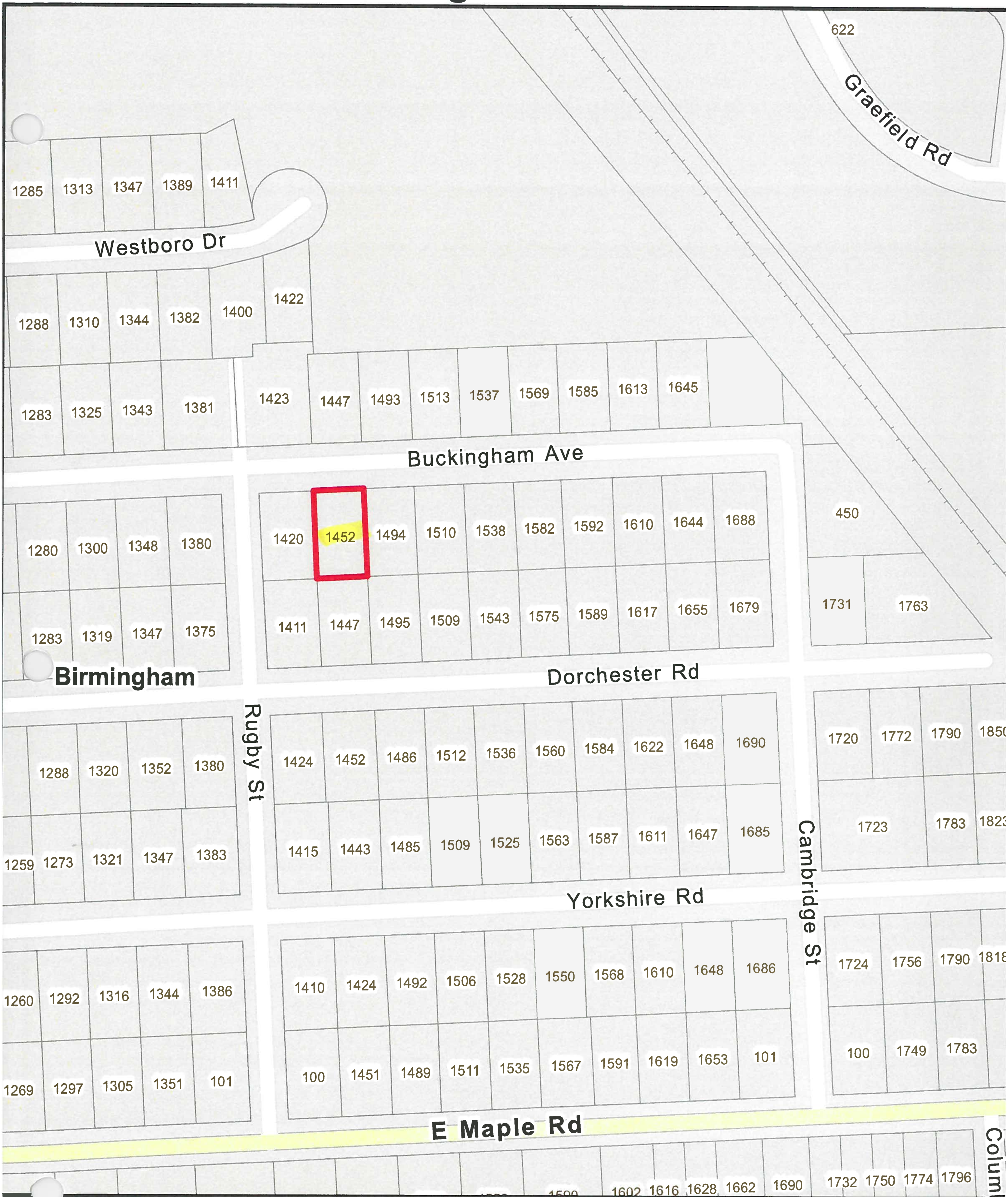
Your favorable reply would be appreciated.

Sincerely,

Craig Hall

Craig Hall
1452 Buckingham Ave.
Birmingham, MI 48009

Birmingham Estates



2 Foot Contours
5 Foot Contours
FEMA Base Flood Elevations
FEMA Cross Sections
100 yr - FEMA Floodplain
100 yr (detailed) - FEMA Floodplain
500 yr - FEMA Floodplain
FLOODWAY - FEMA Floodplain

Disclaimer: The information provided herewith has been compiled from recorded deeds, plats, tax maps, surveys and other public records. It is not a legally recorded map or survey and is not intended to be used as one. Users should consult the information sources mentioned above when questions arise. FEMA Flooplain data may not always be present on the map.

OAKLAND COUNTY MICHIGAN
Economic Development & Community Affairs
L. Brooks Patterson
Oakland County Executive

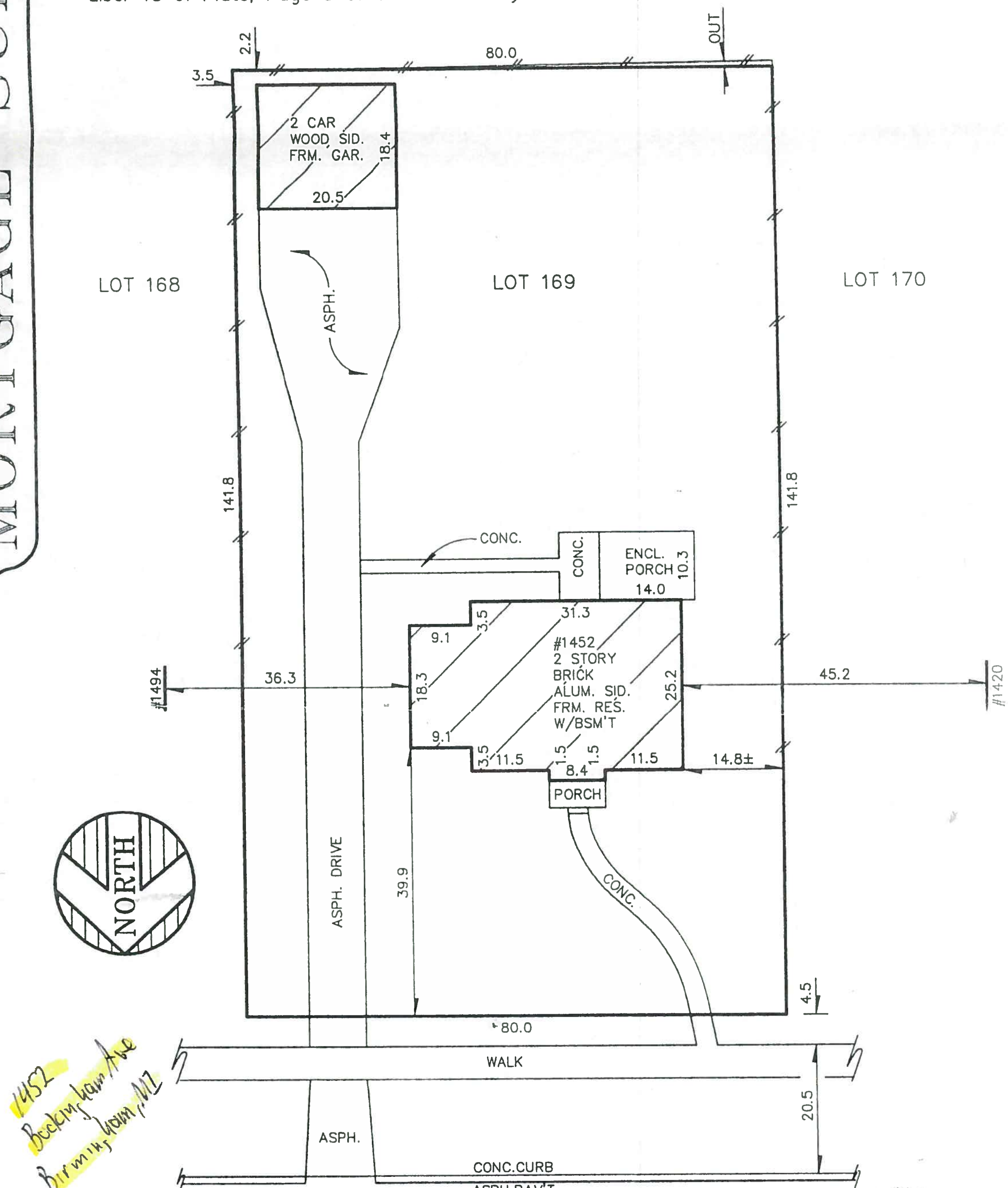
Date Created: 4/24/2017
NORTH
1 inch = 200 feet

		#1	#2	#3	#4	#5
	SFR CLASS B Std. Unit (sq. ft.)	SFR 1452 Buckingham (sq. ft.)	SFR 1420 Buckingham (sq. ft.)	SFR 1494 Buckingham (sq. ft.)	SFR 1493 Buckingham (sq. ft.)	SFR 1447 Buckingham (sq. ft.)
Pervious Areas						
Lawn, Landscaping						
Impervious Areas (IA)						
Asphalt/Concrete Drive	1,740	1,349	756	750	420	2,038
Concrete Walk	450	120	108	150	70	146
Building Roof/Patio/Deck	1,500	1,008	2,594	1,846	2,036	925
Garage Roof	625	368	894	564	644	374
IA =	4,315	2,845	4,352	3,310	3,170	3,483
Total Area of Parcel (TA)						
TA	7,200	11,344	11,344	11,344	11,344	11,344
Runoff Potential (RP)						
RP= 0.15(TA-IA) + 0.9 (IA)	4,316	3,835	4,966	4,184	4,079	4,314
Equivalent Storm Water Unit (ESWU)						
ESWU= RP/(RP standard unit)	1	0.89	1.15	0.97	0.94	1.00
ESWU=	1	0.89	1.15	0.97	0.94	1.00
RP standard unit	4,317	4,317	4,317	4,317	4,317	4,317
ESWU City Assigned	1	1.6	1.6	1.6	1.6	1.6
Runoff Potential City Assigned	4,317	6,714	6,714	6,714	6,714	6,714
Impervious % Total Parcel	60%	25%	38%	29%	28%	31%
Roof Gutter Drains Connected to Sewer	yes	no	yes	yes	yes	yes
Factor in Disconnected Roof Drains (Home/Garage sq. ft. at .15 percolation factor vs. 0.9 percolation factor)						
RP= 0.15(TA-IA) + 0.9 (IA)		2,803				
ESWU= RP/(RP standard unit)		0.65				

Note: Similar property dimensions accessed from https://gis.oakgov.com/PropertyGateway/Home.mvc (Exhibit II)

MORTGAGE SURVEY

Certified to: WELLS FARGO & PHILIP R. SEAVER TITLE COMPANY
Applicant: CRAIG E. HALL AND MICHELE R. HALL
Property Description:
Lot 169; BIRMINGHAM ESTATES SUB., of part of the S.W. 1/4 of Sec. 30, T.2 N., R.11 E., Troy Twp. (now City of Birmingham), Oakland County, Michigan, as recorded in Liber 13 of Plats, Page 5 of Oakland County Records



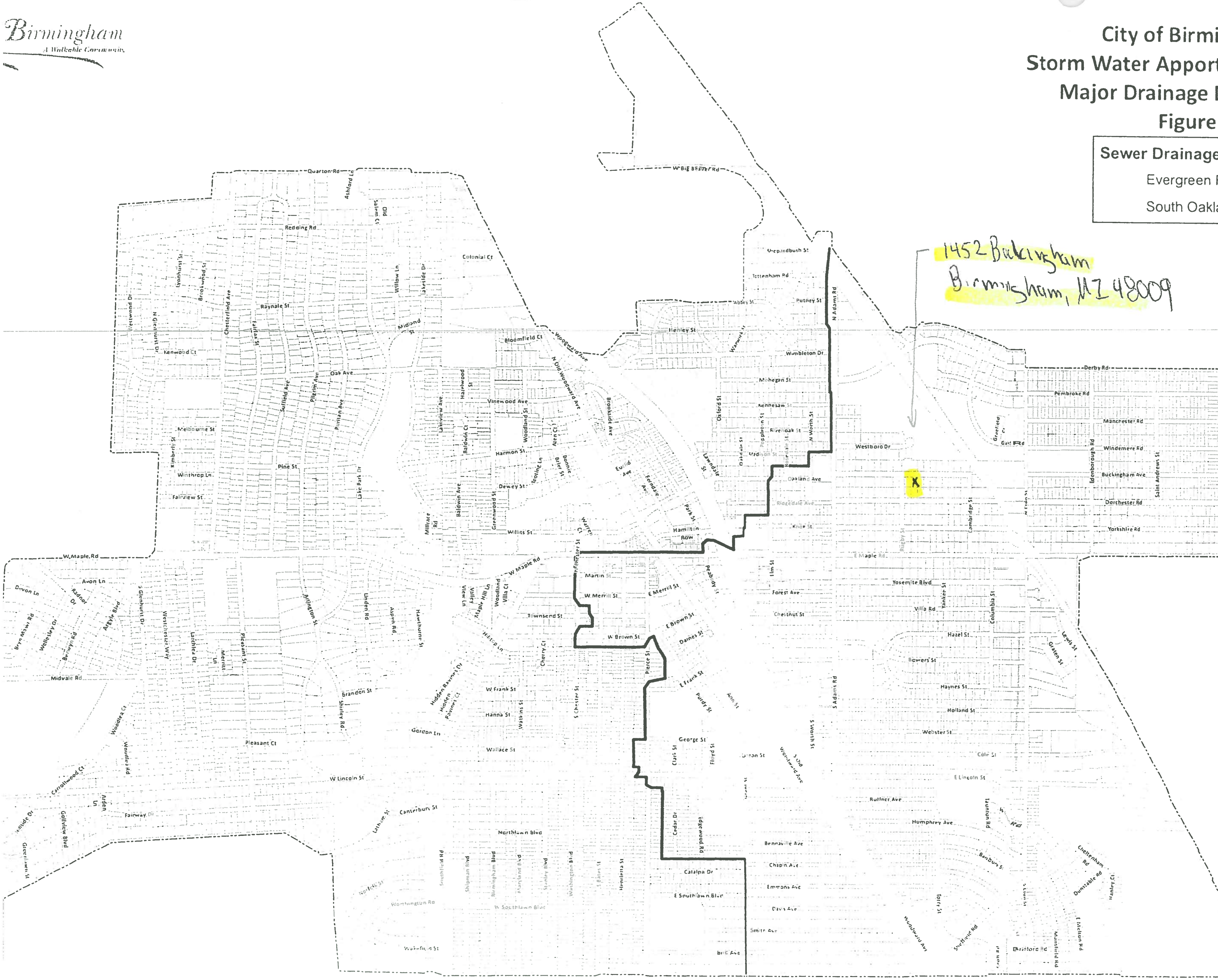
BUCKINGHAM RD. 75' WD.

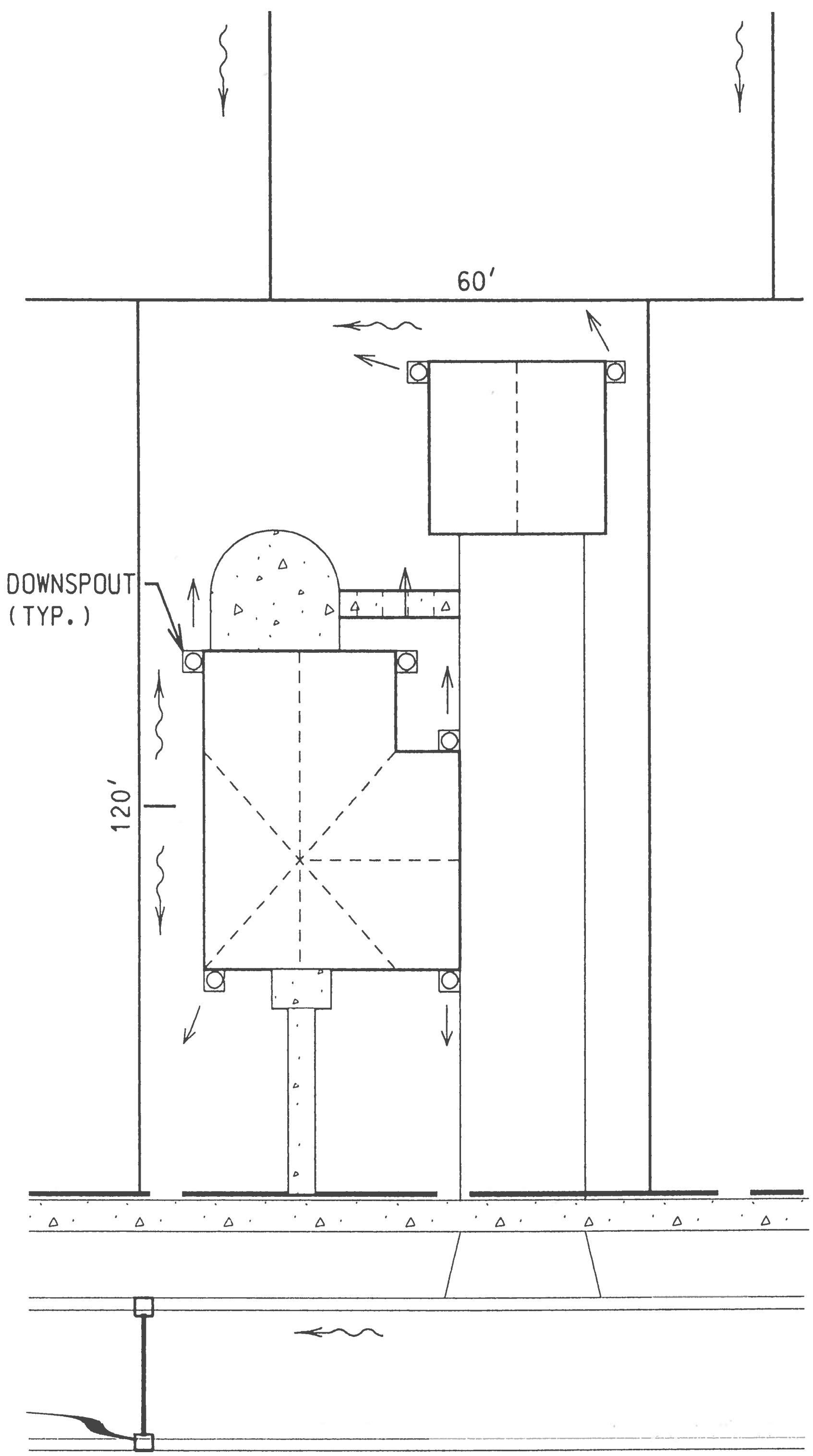
CERTIFICATE: We hereby certify that we have surveyed the above- described property in accordance with the description furnished for the purpose of a mortgage loan to be made by the forementioned applicants, mortgagor, and that the buildings located thereon do not encroach on the adjoining property, nor do the buildings on the adjoining property encroach upon the property heretofore described, except as shown. This survey is not to be used for the purpose of establishing property lines, nor for construction purposes, no stakes having been set at any of the boundary corners.

STATE OF MICHIGAN
LICENSED LAND SURVEYOR

Birmingham
A Walkable Community

City of Birmingham
Storm Water Apportionment Study
Major Drainage District Map
Figure 1





Pervious Areas

Lawn

Landscaping

Impervious Areas (IA)

Asphalt Drive	1,740 sft
Concrete Walk	450 sft
Building Roof	1,500 sft
Garage Roof	625 sft
IA =	4,315

Total Area of Parcel (TA)

TA = 7,200 sft

Runoff Potential (RP)

RP = 0.15(TA-IA) + 0.9(IA)

RP = 4,317

Equivalent Storm Water Unit (ESWU)

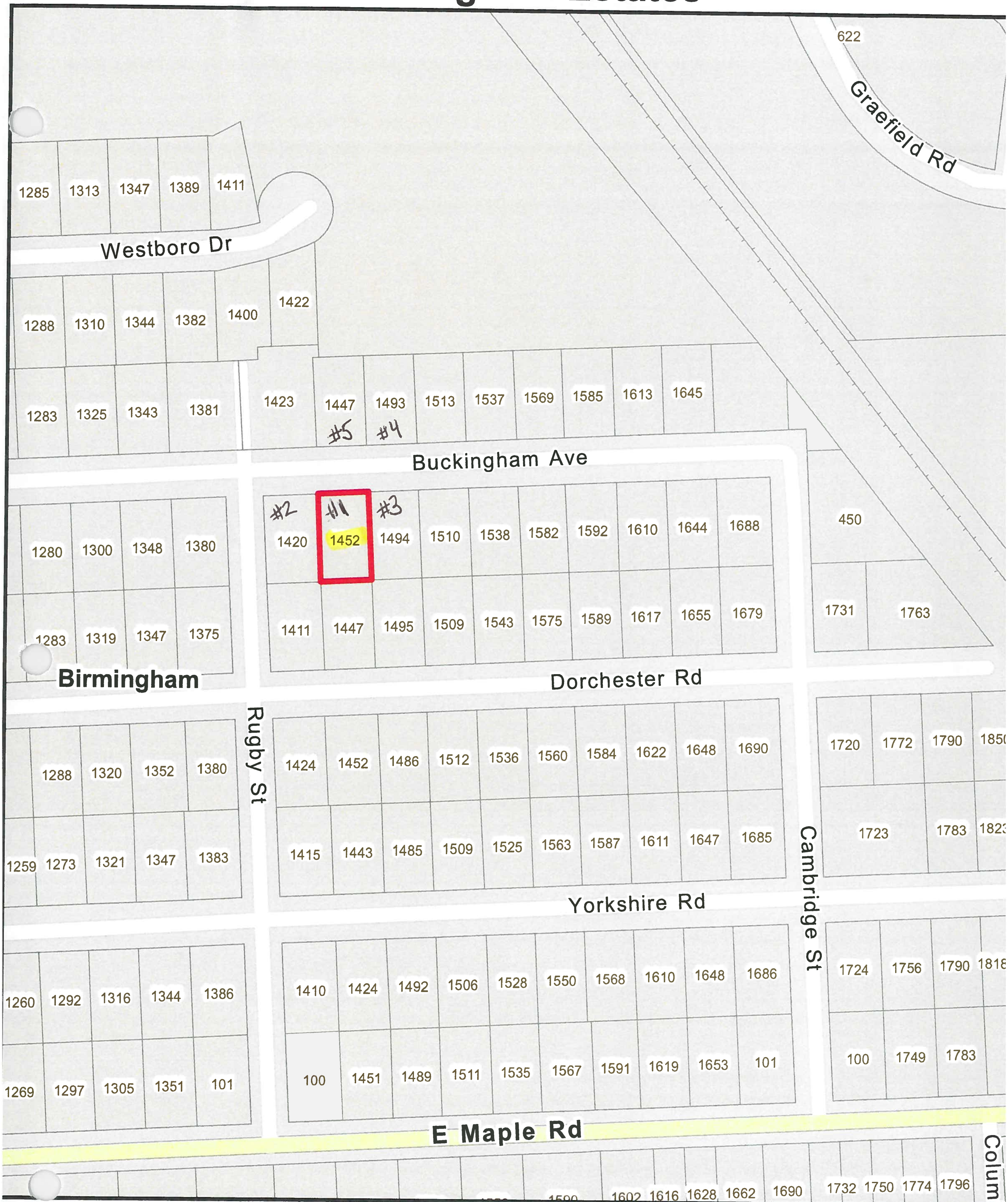
ESWU = RP / ($RP_{Standard\ Unit}$)

$\boxed{\text{ESWU} = 1.0}$

$RP_{Standard\ Unit}$ = 4,317 sft

EXAMPLE CLASS B SFR FOR CREDIT CALCULATION

Birmingham Estates



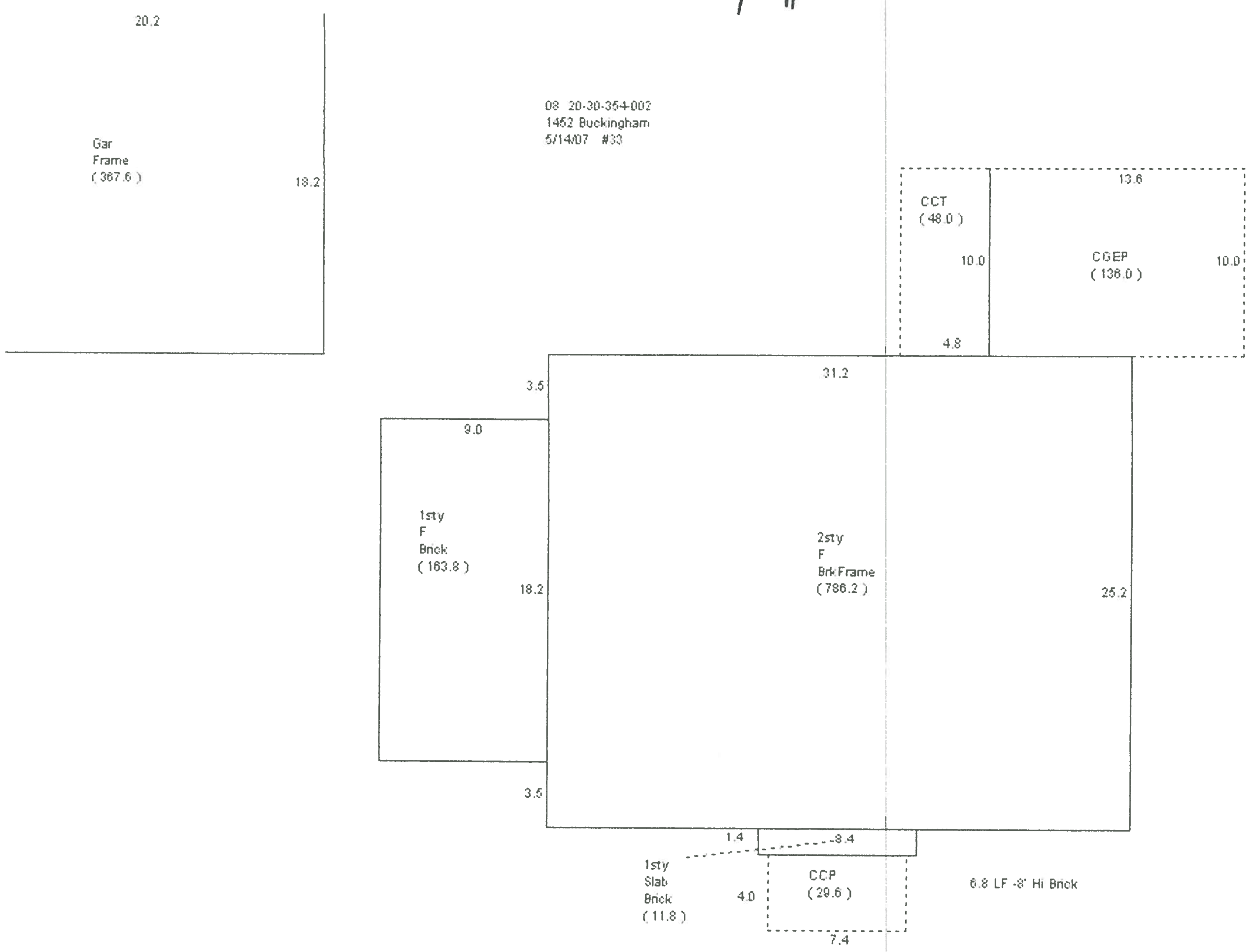
2 Foot Contours
5 Foot Contours
FEMA Base Flood Elevations
FEMA Cross Sections
100 yr - FEMA Floodplain
100 yr (detailed) - FEMA Floodplain
500 yr - FEMA Floodplain
FLOODWAY - FEMA Floodplain

Disclaimer: The information provided herewith has been compiled from recorded deeds, plats, tax maps, surveys and other public records. It is not a legally recorded map or survey and is not intended to be used as one. Users should consult the information sources mentioned above when questions arise. FEMA Flooplain data may not always be present on the map.

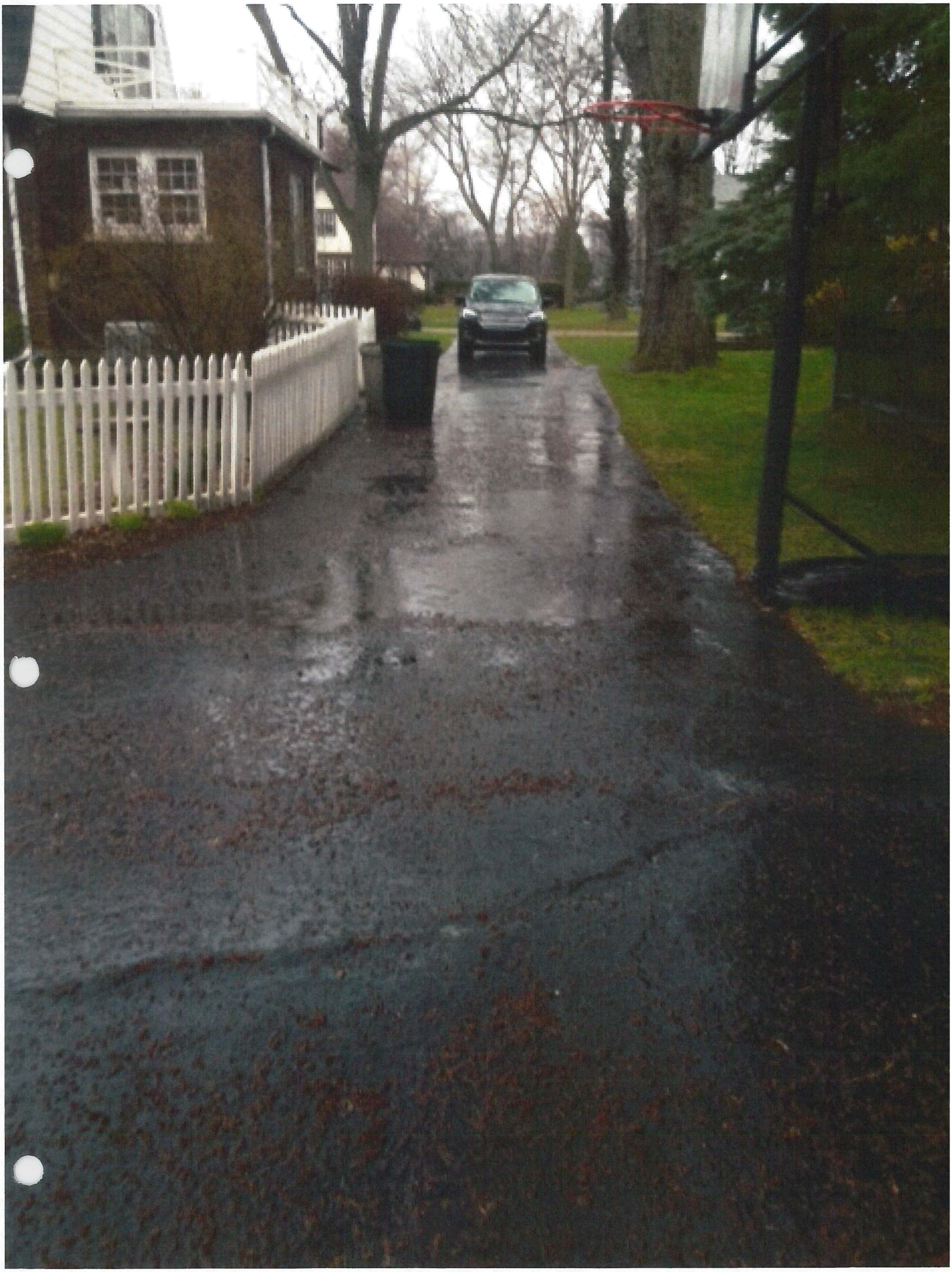
OAKLAND COUNTY MICHIGAN
Economic Development & Community Affairs
L. Brooks Patterson
Oakland County Executive

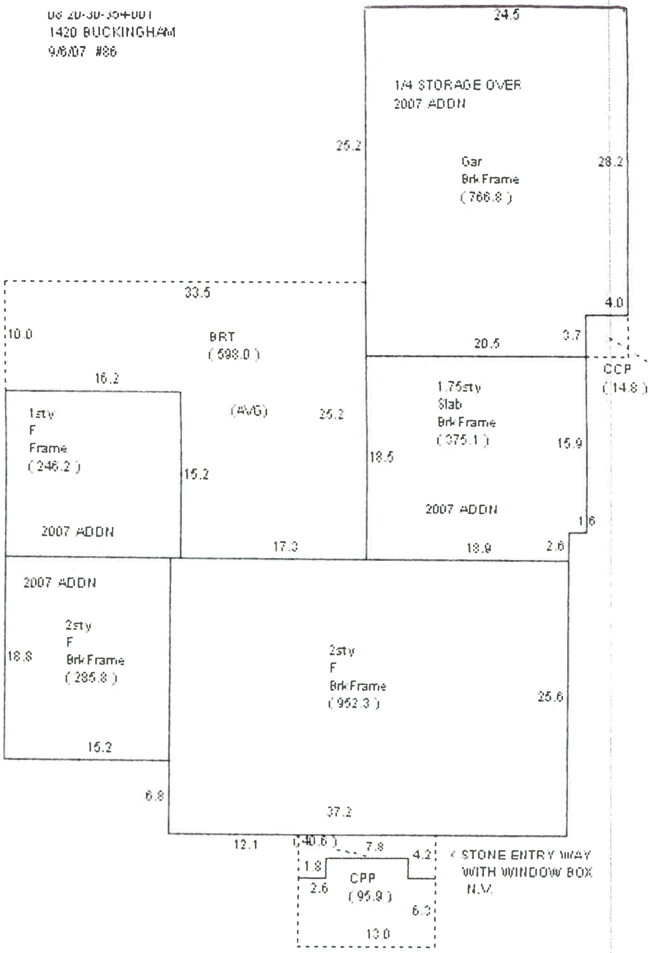
Date Created: 4/24/2017
NORTH
1 inch = 200 feet

1452 Buck


20.2
Gar
Frame
(367.6)
18.2
08 20-30-354-002
1452 Buckingham
5/14/07 #33
CCT
(48.0)
10.0
4.8
13.6
CGEP
(136.0)
10.0
31.2
3.5
9.0
1sty
F
Brick
(163.8)
18.2
2sty
F
Brk Frame
(786.2)
25.2
3.5
1.4
8.4
1sty
Slab
Brick
(11.8)
4.0
CCP
(29.6)
7.4
6.8 LF -8' Hi Brick

#1

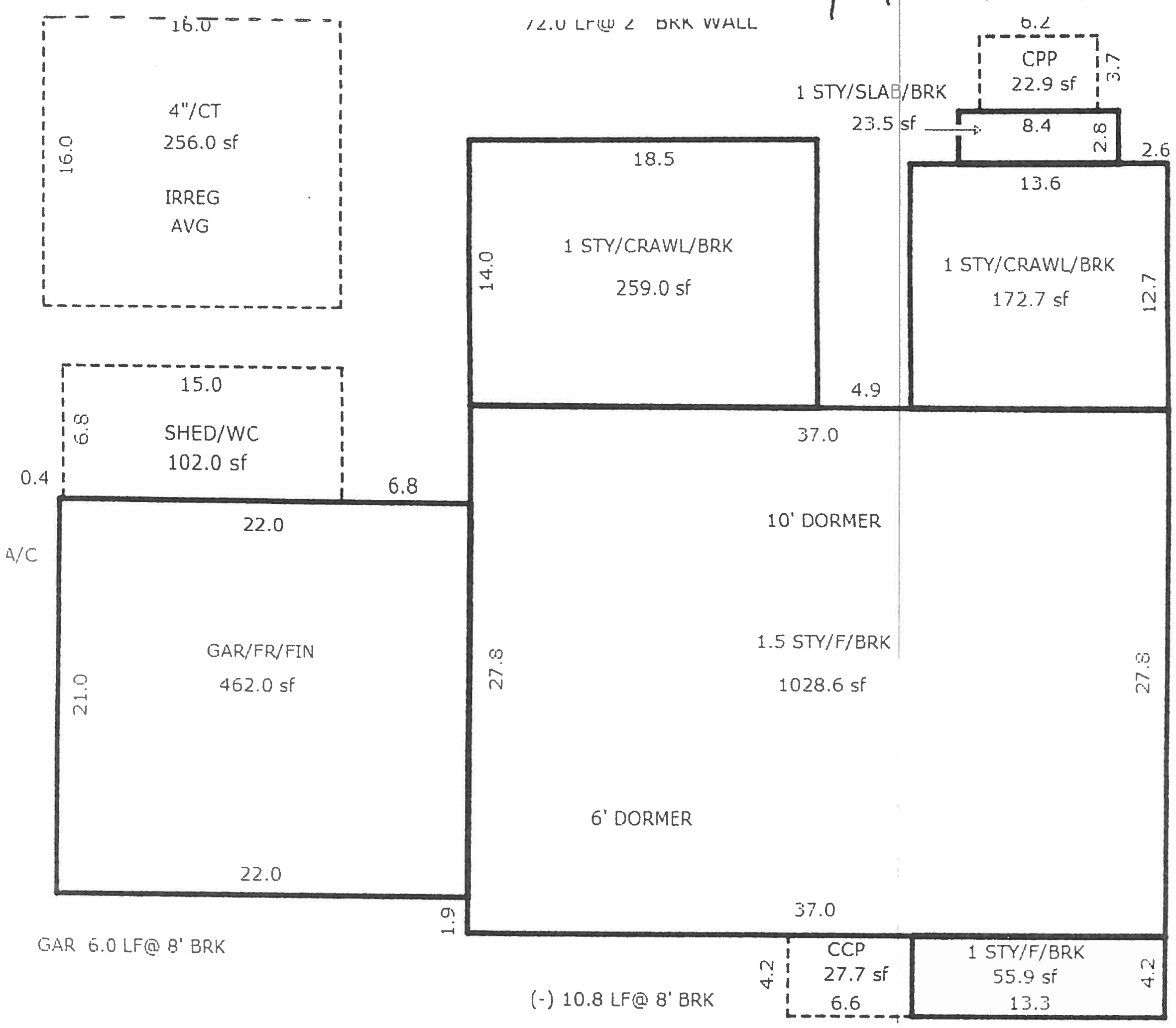



08 20-30-354-001
1420 BUCKINGHAM
9/6/07 #86
24.5
1/4 STORAGE OVER
2007 ADDN
25.2
Gar
Brk Frame
(766.8)
28.2
33.5
4.0
10.0
BRT
(598.0)
20.5
3.7
CCP
(14.8)
16.2
1sty
F
Frame
(246.2)
(AVG)
25.2
1.75sty
Slab
Brk Frame
(375.1)
15.9
18.5
15.2
2007 ADDN
2007 ADDN
1.6
17.3
18.9
2.6
2007 ADDN
2sty
F
Brk Frame
(285.8)
18.8
2sty
F
Brk Frame
(952.3)
25.6
15.2
6.8
37.2
12.1
(40.6)
7.8
4.2
1.8
CPP
(95.9)
2.6
6.3
13.0
< STONE ENTRY WAY
WITH WINDOW BOX
N.V.

1420 Buck

#2

1494 Buck

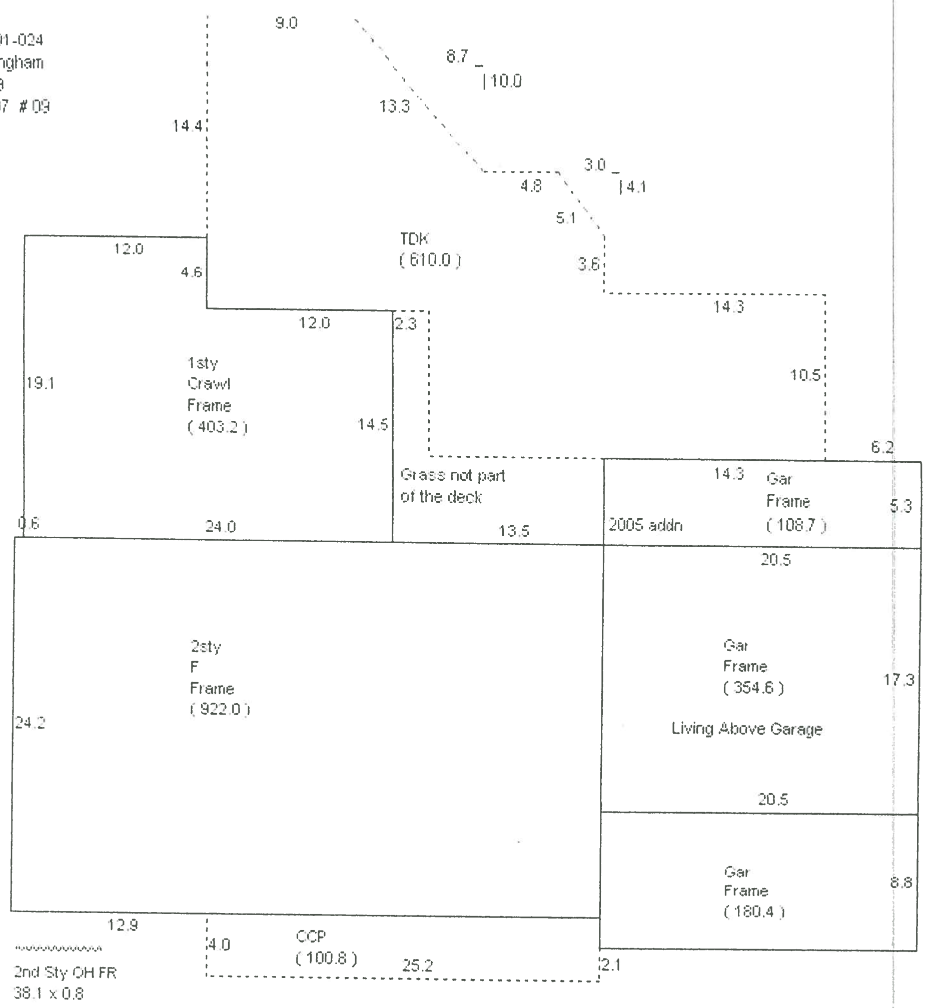

16.0
4"/CT
256.0 sf
16.0
IRREG
AVG
72.0 LF@ 2' BRK WALL
6.2
CPP
22.9 sf
3.7
1 STY/SLAB/BRK
23.5 sf
8.4
2.8
2.6
18.5
1 STY/CRAWL/BRK
259.0 sf
14.0
13.6
1 STY/CRAWL/BRK
172.7 sf
12.7
4.9
15.0
6.8
SHED/WC
102.0 sf
0.4
6.8
37.0
22.0
10' DORMER
A/C
GAR/FR/FIN
462.0 sf
21.0
27.8
1.5 STY/F/BRK
1028.6 sf
27.8
6' DORMER
22.0
37.0
1.9
GAR 6.0 LF@ 8' BRK
CCP
27.7 sf
4.2
6.6
1 STY/F/BRK
55.9 sf
13.3
4.2
(-) 10.8 LF@ 8' BRK

#3

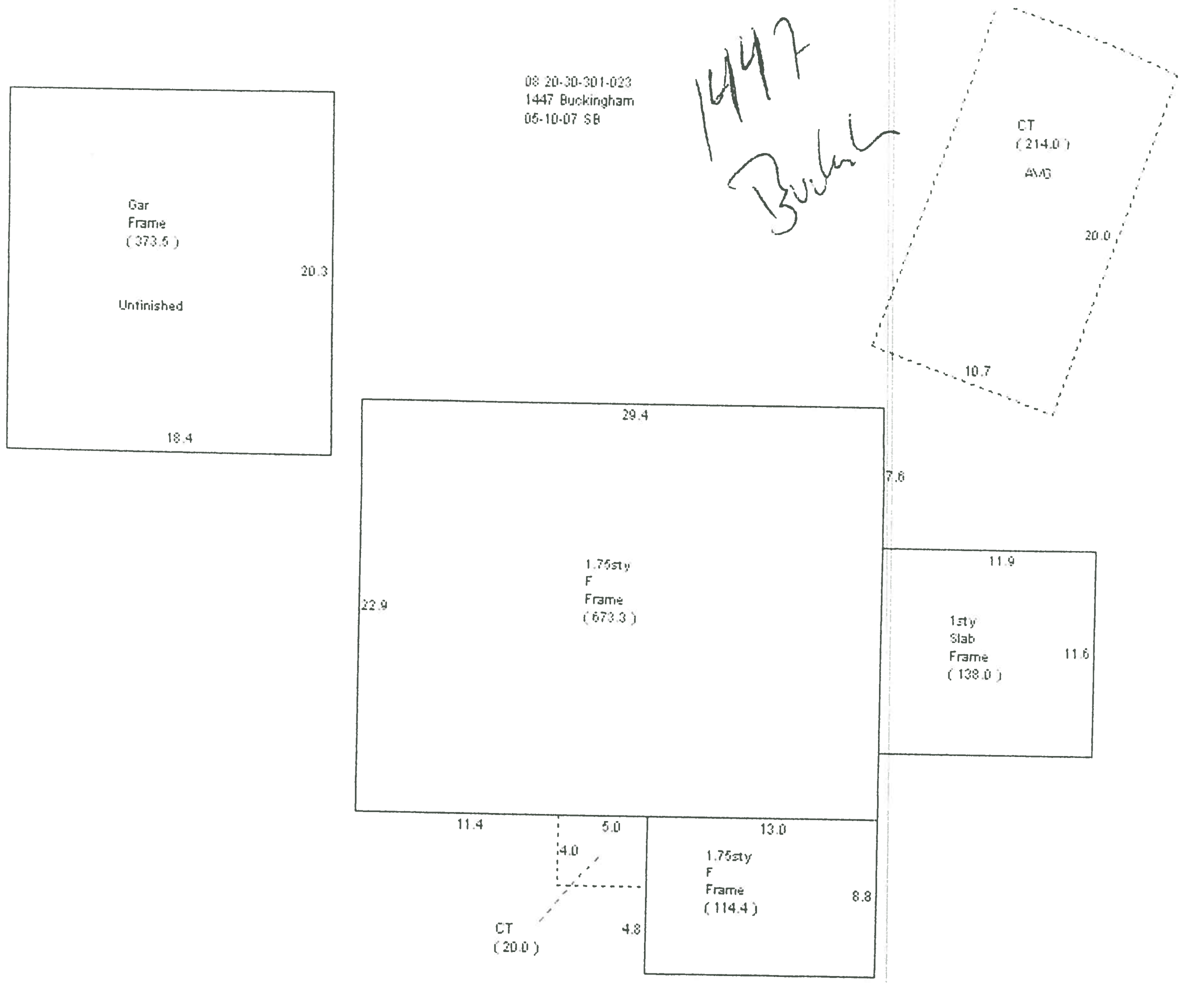
)-301-024
ickingham
7SB
)4-07 # 09

UnSketched SubAreas:
1sty, OH, Frame: 355,
1sty, OH, Frame: 30,

1493 Buckingham



#4


08 20-30-301-023
1447 Buckingham
05-10-07 SB
1447 Buck
Gar
Frame
(373.5)
20.3
Unfinished
18.4
CT
(214.0)
AVG
20.0
10.7
29.4
7.6
1.75sty
F
Frame
(673.3)
22.9
11.9
1sty
Slab
Frame
(138.0)
11.6
11.4
5.0
13.0
4.0
1.75sty
F
Frame
(114.4)
8.8
CT
(20.0)
4.8

#5