Attachment 2: Permeable Pavement Design Guidelines

Design of permeable pavement systems is critical if they are to function properly and efficiently. The area and shape are dependent on the site design, and selection of the surface material is dependent on intended site uses and desired appearance. The depth of the stone base can be adjusted depending on the management objectives, total drainage area, traffic load, and soil characteristics. The following design procedures are general guidelines that designers can follow.

Siting for Permeable Pavements

Permeable pavements are not suited for every site. Site evaluation is critical for the success of permeable pavement. For optimal performance locate systems on well-drained permeable soils. A geotechnical report/analysis is required whenever permeable pavement is used. It is the designer's responsibility to collect adequate information to ensure the system functions properly. An example Request for Geotechnical Services is attached to this document to assist the designer in communicating to the Geotechnical Company the type of services required. Permeable pavements should not be used until the site has met the minimum standards required for their use.

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates.
High ground water table depth to bottom of stone storage layer must be 4 feet or greater
Land surrounding and draining to the permeable pavement does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Design Guidelines

Permeable pavements infiltrate runoff through the permeable surface into the gravel subbase. Water is stored in the gravel subbase until it infiltrates the underlying soil or is carried away by an underdrain. Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the surface ponding and soil storage will take to drain. Adjust subbase depth or surface area until minimum design requirements are met. The gravel base and subbase must be designed in accordance with the expected traffic loads and required storage per the Storm Water Design and Specification Manual. Underdrains placed at the top of the aggregate bed can serve to minimize or prevent standing water in the structural surface. Underdrains must be designed to minimize chance of clogging and must meet release rate requirements. Underdrains can be set above subbase invert elevations to allow for detention storage. See Permeable Pavement Design Checklist and example design (**Attachment 3**) for calculating permeable pavement system performance.

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Ft. Wayne Storm Water Design Manual.
Assume a void ratio of approximately 40% for #8 washed stone
Design system with a level bottom; use a terraced system on slopes. Provide a positive slope for the bottom if the underlying soils have a high clay content or low permeability in general.
Maximum drain down time for the entire storage volume is 72 hours. Engineer may choose a shorter time based on site conditions and owner preference.
Storage volume must not occur within porous structural surface, but must be entirely contained within stone subbase.
Per City of Fort Wayne requirements, at least one underdrain shall be used for all porous pavement systems. Additional underdrains may be required based on layout and individual site conditions.

Table 3. Permeable Pavement Design Checklist

Section 1. Permeable Pavement Siting				
1	Slope of surrounding drainage area < 20%	Y/N	Y	
2	Setback from well (must be > 100 ft)		120	ft
3	Setback from buildings (must be > 10 ft)		12	ft
4	Geotechnical investigation complete	Y/N	Y	
5	Infiltration rate of native soils	i	0.55	in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$	399	ft
Section 2. Permeable Pavement Sizing				
7	Volume of runoff from design storm	V	1	acre-ft
8	Elevation of bottom of gravel subbase	$ELEV_{base}$	406	ft
9	Maximum depth of gravel subbase	D	3	ft
10	Dimensions of permeable pavement	L	300	ft
		W	100	ft
		A	30000	ft^2
11	Gravel subbase porosity	p	40	%
12	Estimated storage volume of permeable pavement	V_{BMP}	0.826446	acre-ft
Section 3. Permeable Pavement Performance*				
13	Drain down time w/ underdrain		48	hrs
14	Drain down time w/ underdrain and over drain		36	hrs

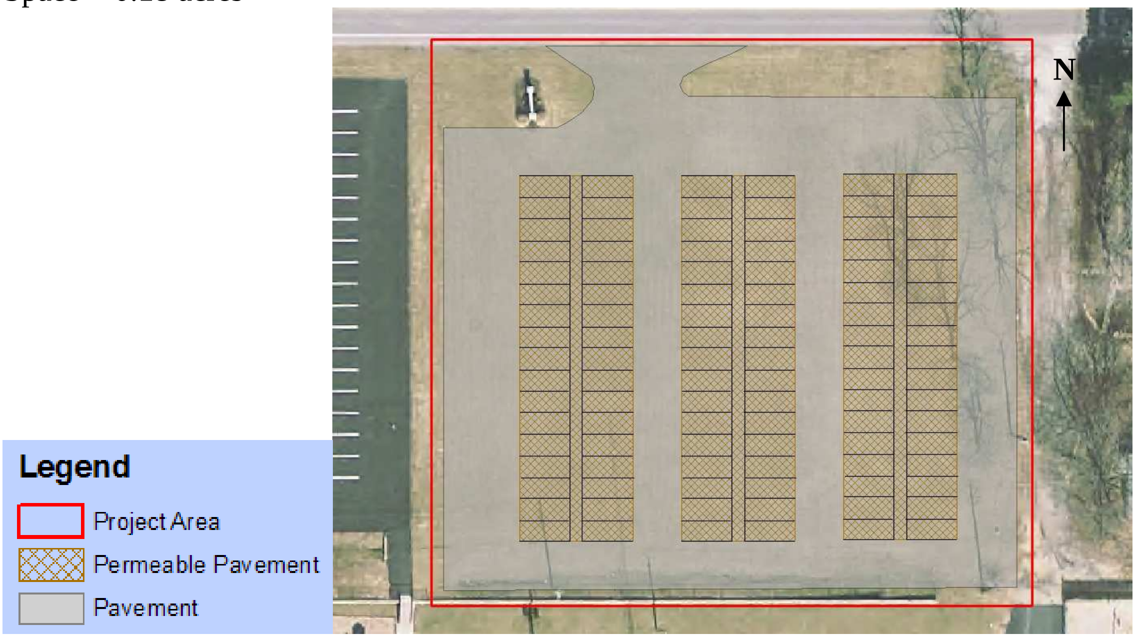
Attachment 3: Permeable Pavement Design Example

This design example walks through the use of the Permeable Pavement Design Guidelines contained in the Ft. Wayne Green Supplemental Document.

Collect Existing/Proposed Site Information

<u>Existing Conditions:</u>
Drainage Area = 1.08 acres
Type A Hydrologic Soils
Infiltration Rate = 0.5 in/hr

Proposed Conditions:
Parking Lot / Driveways = 0.51 acres
Pervious Pavement Area = 0.39 acres
Open Space = 0.18 acres



Permeable Pavement Design Checklist
Complete Section 1 and 2 of the Permeable Pavement Design Checklist with data from the geotechnical analysis and proposed design.

Permeable Pavement Design Checklist				
Section 1. Permeable Pavement Siting				
1	Slope of surrounding drainage area < 20%	Y/N	Y	
2	Setback from well (must be > 100 ft)		120	ft
3	Setback from buildings (must be > 10 ft)		12	ft
4	Geotechnical investigation complete	Y/N	Y	
5	Infiltration rate of native soils	i	0.7	in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$	399	ft

Section 2. Permeable Pavement Sizing				
7	Volume of runoff from design storm	V	0.27	acre-ft
8	Elevatlion of bottom of gravel subbase	$ELEV_{base}$	406	ft
9	Maximum depth of gravel subbase	D	3	ft
10	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A	17136	ft^2
11	Gravel subbase porosity	p	40	%
12	Estimated maximum storage volume of permeable pavement	V_{BMP}	0.472	acre-ft

Detention Storage Requirements

To be most effective and economically viable for a project, permeable pavement should be designed as a detention system. The outlet control will be the under drain and/or the infiltration rate of the underlying soil. Refer to Unit II, Chapter 4, Section 4.3.2 of the Design Manual to determine the storage volume required.

Drainage Area (A) = 1.08 acres

Required Storage Volume Determined per Section 4.3.2.1

Required Storage Volume, $S(t_d)$ = 1.08 * 3" * 1'/12" = **0.27 acre-ft**

Calculate Permeable Pavement Dimensions based on Detention Storage Requirements

Section 1. Permeable Pavement System				
1	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A_{BMP}	17136	ft^2
2	Depth of gravel subbase	D	2	ft
3	Gravel subbase porosity	p	40	%
4	Infiltration rate of native soils	i	0.5	in/hr
5	Storage Volume	S	0.315	acre-ft
6	Underdrain Diameter	d_u	0	in
7	Overdrain Diameter	d_o	0	in

Drain Down Time Requirements

The maximum drain down time for the entire storage volume is 72 hours. 1.) Finalize dimensions and depth of permeable pavement system. 2.) Compute volume of water that can infiltrate the soil in 72 hours.

Infiltration Rate = 0.5 in/hr
Permeable Pavement Area = 17136 ft^2
Porosity = 40%
Permeable Pavement Infiltration Area = 17136 ft^2 * 0.40 = 6854 ft^2
Time to Drain – 72 hrs

Calculate the volume of water infiltrating through the bottom of the permeable pavement system.

0.5 in/hr * 1ft/12in * 6854 ft^2 * 72 hrs * 1acre/43560 ft^2 = **0.47 acre-ft**

Maximum storage for the permeable pavement system is 0.315 acre-ft. The volume that can be infiltrated in 72 hours exceeds maximum volume of runoff the system can contain. The permeable pavement system can drain down the entire storage volume in less than 72 hours through infiltration into underlying soils.

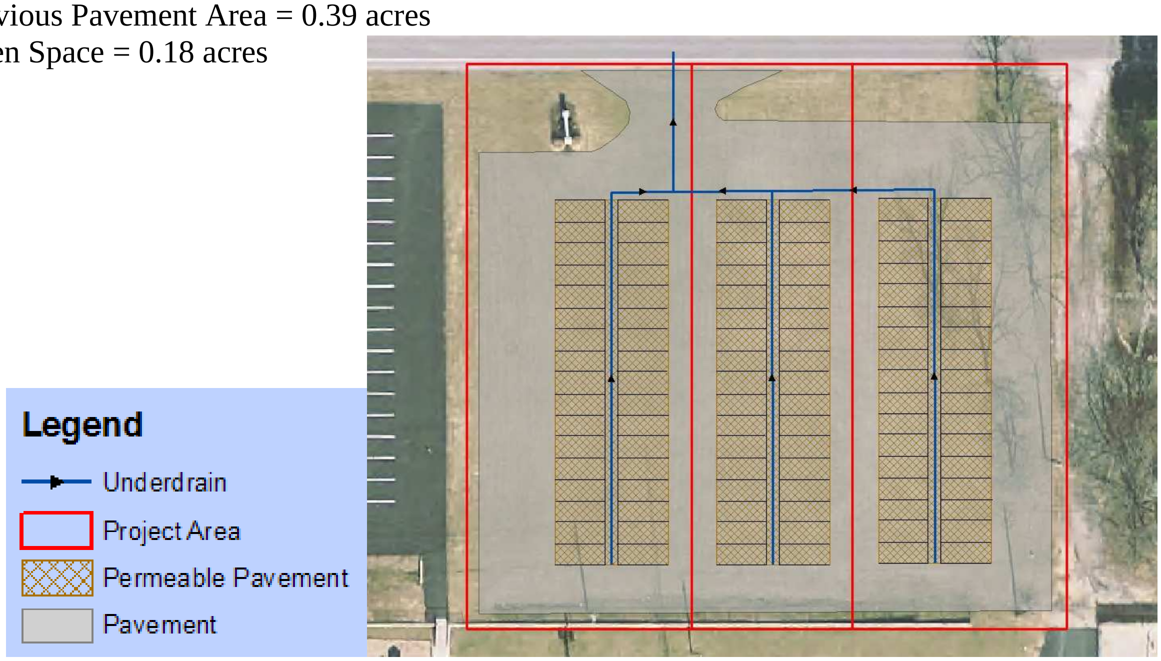
Permeable Pavement with Underdrain Design Example

This design example walks through the use of the Permeable Pavement Design Guidelines contained in the Ft. Wayne Green Supplemental Document.

Collect Existing/Proposed Site Information

<u>Existing Conditions:</u>
Drainage Area = 1.08 acres
Type D Hydrologic Soils
Infiltration Rate = 0.02 in/hr

<u>Proposed Conditions:</u>
Parking Lot / Driveways = 0.51 acres
Pervious Pavement Area = 0.39 acres
Open Space = 0.18 acres



Permeable Pavement Design Checklist
Complete Section 1 and 2 of the Permeable Pavement Design Checklist with data from the geotechnical analysis and proposed design.

Permeable Pavement Design Checklist				
Section 1. Permeable Pavement Siting				
1	Slope of surrounding drainage area < 20%	Y/N	Y	
2	Setback from well (must be > 100 ft)		120	ft
3	Setback from buildings (must be > 10 ft)		12	ft
4	Geotechnical investigation complete	Y/N	Y	
5	Infiltration rate of native soils	i	0.7	in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$	399	ft
Section 2. Permeable Pavement Sizing				
7	Volume of runoff from design storm	V	0.27	acre-ft
8	Elevatlion of bottom of gravel subbase	$ELEV_{base}$	406	ft
9	Maximum depth of gravel subbase	D	3	ft
10	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A	17136	ft^2
11	Gravel subbase porosity	p	40	%
12	Estimated maximum storage volume of permeable pavement	V_{BMP}	0.472	acre-ft

Detention Storage Requirements
To be most effective and economically viable for a project, permeable pavement should be designed as a detention system. The outlet control will be the under drain and/or the infiltration rate of the underlying soil. Refer to Unit II, Chapter 4, Section 4.3.2 of the Design Manual to determine the storage volume required.

Drainage Area (A) = 1.08 acres

Required Storage Volume Determined per Section 4.3.2.1

Required Storage Volume, $S(t_d)$ = 1.08 * 3” * 1’/12” = **0.27 acre-ft**

Calculate Permeable Pavement Dimensions based on Detention Storage Requirements

Section 1. Permeable Pavement System				
1	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A_{BMP}	17136	ft^2
2	Depth of gravel subbase	D	2	ft
3	Gravel subbase porosity	p	40	%
4	Infiltration rate of native soils	i	0.02	in/hr
5	Storage Volume	S	0.315	acre-ft
6	Underdrain Diameter	d_u	0	in
7	Overdrain Diameter	d_o	0	in

Drain Down Time Requirements
The maximum drain down time for the entire storage volume is 72 hours. 1.) Finalize dimensions and depth of permeable pavement system. 2.) Compute volume of water that can infiltrate the soil in 72 hours with.

Infiltration Rate = 0.02 in/hr
Permeable Pavement Area = 17136 ft^2
Porosity = 40%
Permeable Pavement Infiltration Area = 17136 ft^2 * 0.40 = 6854 ft^2
Time to Drain – 72 hrs

Calculate volume of water infiltrating through the bottom of the permeable pavement system.

0.02 in/hr * 1ft/12in * 6854 ft^2 * 72 hrs * 1acre/43560 ft^2 = **0.0189 acre-ft**

Maximum storage for the permeable pavement system is 0.315 acre-ft. The volume that can be infiltrated in 72 hours is less than maximum volume of runoff system can contain. Without an under drain this system will not meet 72 hour drain down requirement.

Design Underdrain for Permeable Pavement System
The permeable pavement system should be designed as detention storage. Detention storage designs require an outlet to rate flow through the system. The design must illustrate the drain down time of the permeable pavement system is less than 72 hours.

Two Options:

1.) A model calculating the depth of the permeable pavement system with flow being routed through the underdrain and overdrain (both modeled as orifices), and infiltration. The figure below illustrates the drain down time of the permeable pavement system

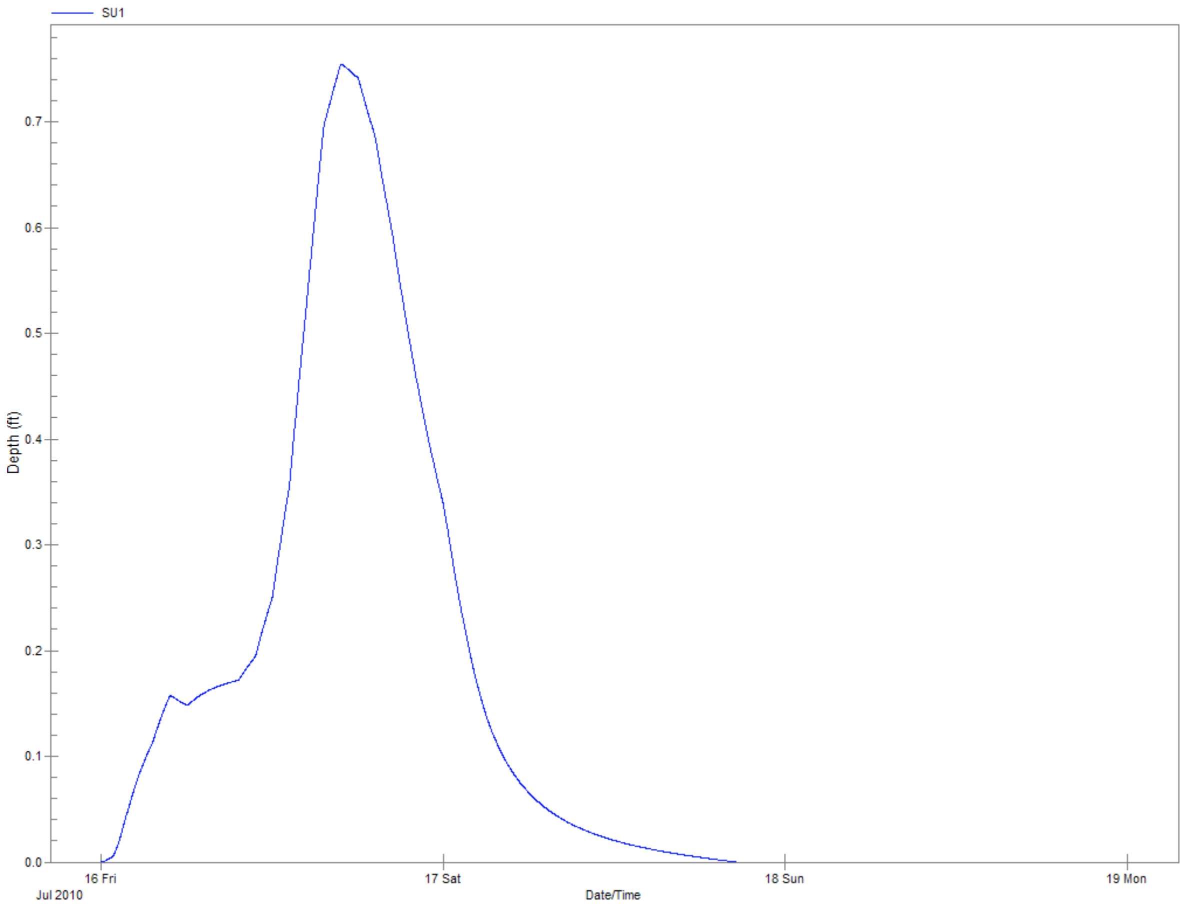


Figure 1. Graph of Depth vs Time for Permeable Pavement System

2.) Develop a rating curve with an underdrain, overdrain, and infiltration rate. Route runoff through the permeable pavement system as if it were a detention pond.

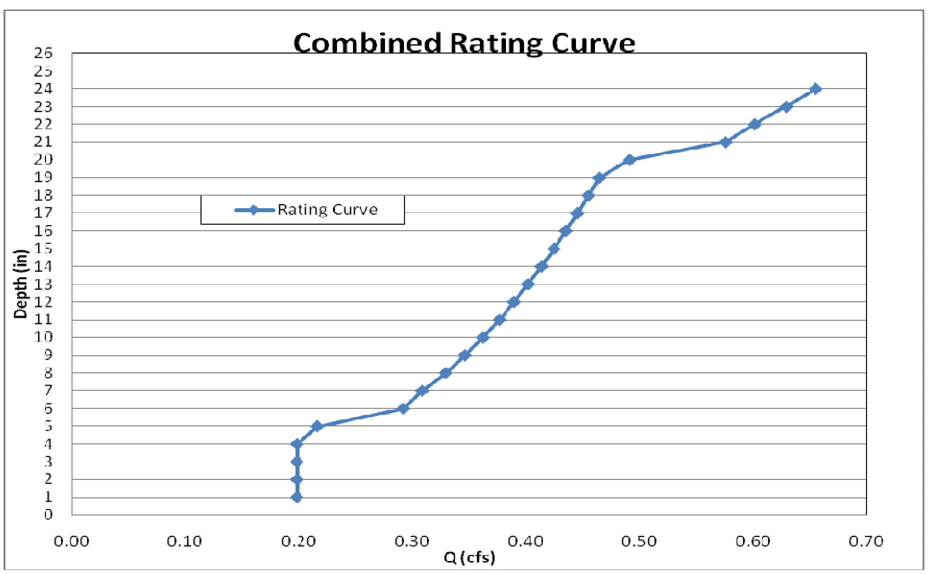


Figure 2. Combined Rating Curve for Permeable Pavement System

Table 3. Example of Rating Curve Calculations

Underdrain		
d_u	3	in
Depth	3	in
E	4.5	in
C	0.6	

Overdrain		
d_o	3	in
Depth	18	in
E	19.5	in
C	0.6	

	Underdrain		Overdrain		Infiltration	Total
Depth in	Head in	Flow cfs	Head in	Flow cfs	Flow cfs	Flow cfs
1	0	0.000	0	0.000	0.198	0.20
2	0	0.000	0	0.000	0.198	0.20
3	0	0.000	0	0.000	0.198	0.20
4	0	0.000	0	0.000	0.198	0.20
5	1	0.018	0	0.000	0.198	0.22
6	2	0.094	0	0.000	0.198	0.29
7	3	0.110	0	0.000	0.198	0.31
8	4	0.131	0	0.000	0.198	0.33
9	5	0.148	0	0.000	0.198	0.35
10	6	0.164	0	0.000	0.198	0.36
11	7	0.178	0	0.000	0.198	0.38
12	8	0.191	0	0.000	0.198	0.39
13	9	0.204	0	0.000	0.198	0.40
14	10	0.215	0	0.000	0.198	0.41
15	11	0.226	0	0.000	0.198	0.42
16	12	0.237	0	0.000	0.198	0.44
17	13	0.247	0	0.000	0.198	0.45
18	14	0.257	0	0.000	0.198	0.45
19	15	0.266	0	0.000	0.198	0.46
20	16	0.275	1	0.018	0.198	0.49
21	17	0.284	2	0.094	0.198	0.58
22	18	0.292	3	0.110	0.198	0.60
23	19	0.300	4	0.131	0.198	0.63
24	20	0.308	5	0.148	0.198	0.65

Attachment 4: Bioretention/Rain Garden Design Guidelines

Design of bioretention systems is somewhat flexible. The area, depth, and shape of the system can be varied to accommodate site conditions and constraints. The following design procedures are general guidelines that designers can follow. Bioretention areas should be feasible on site and sized for expected runoff volume. The following general guidelines can assist the designer in evaluating bioretention site applicability.

- Facilities can be placed close to the source of run-off generation.
- The site permits the distributed bioretention facilities.
- Available room for installation including setback requirements.
- Suitable soils availability.

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates
High ground water table depth to bottom of stone storage layer must be 4 feet or greater
Land surrounding and draining to the bioretention does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Bioretention areas are suitable for many types and sizes of development. To size/design a bioretention facility, the designer has to first determine the intended purpose of the bioretention. For example, what are the site requirements for water quality and quantity control? An example calculation for a 1.1 acre site is provided in the **Bioretention/Rain Garden Design Example, Attachment 5**.

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Ft. Wayne Storm Water Design Manual
Typical ponding depth of 6-18 inches (maximum 24 inches)
Minimum soil depth of 18 inches
Estimate drain down time of bioretention system. The maximum drain down time for surface water storage is 48 hours.
Include an underdrain if necessary to meet drain down requirements
Provisions shall be made for overflow during large storm events. An overflow weir or stormwater inlet may be required, on a case-by-case basis, depending on flow volume and site conditions. Size should be determined by 10 year storm with overflow away from building

Choose native plants, trees, and mulch appropriate for site

Table 3. Bioretention Design Checklist				
Section 1. Bioretention Siting				
1	Slope of surrounding drainage area < 20%	Y/N		
2	Setback from well (must be > 100 ft)			ft
3	Setback from buildings (must be > 10 ft)			ft
4	Geotechnical investigation complete	Y/N		
5	Infiltration rate of native soils	i		in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$		ft
Section 2. Bioretention Sizing				
7	Volume of runoff from design storm	V		acre-ft
8	Bioretention area	A		sq-ft
9	Soil depth	d_{soil}		ft
	Ponding depth	$d_{ponding}$		ft
11	Soil porosity	p		%
12	Estimated maximum storage volume of bioretention	V_{BMP}		acre-ft
Section 3. Bioretention Performance				
13	Drain down time (*infiltration only*)			hrs
14	Drain down time w/ underdrain			hrs
15	Drain down time w/ underdrain and over drain			hrs

Attachment 4: Bioretention/Rain Garden Design Guidelines

Design of bioretention systems is somewhat flexible. The area, depth, and shape of the system can be varied to accommodate site conditions and constraints. The following design procedures are general guidelines that designers can follow. Bioretention areas should be feasible on site and sized for expected runoff volume. The following general guidelines can assist the designer in evaluating bioretention site applicability.

- Facilities can be placed close to the source of run-off generation.
- The site permits the distributed bioretention facilities.
- Available room for installation including setback requirements.
- Suitable soils availability.

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates
High ground water table depth to bottom of stone storage layer must be 4 feet or greater
Land surrounding and draining to the bioretention does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Bioretention areas are suitable for many types and sizes of development. To size/design a bioretention facility, the designer has to first determine the intended purpose of the bioretention. For example, what are the site requirements for water quality and quantity control? An example calculation for a 1.1 acre site is provided in the **Bioretention/Rain Garden Design Example, Attachment 5**.

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Ft. Wayne Storm Water Design Manual
Typical ponding depth of 6-18 inches (maximum 24 inches)
Minimum soil depth of 18 inches
Estimate drain down time of bioretention system. The maximum drain down time for surface water storage is 48 hours.
Include an underdrain if necessary to meet drain down requirements

Provisions shall be made for overflow during large storm events. An overflow weir or stormwater inlet may be required, on a case-by-case basis, depending on flow volume and site conditions. Size should be determined by 10 year storm with overflow away from building
Choose native plants, trees, and mulch appropriate for site

Table 3. Bioretention Design Checklist

Section 1. Bioretention Siting				
1	Slope of surrounding drainage area < 20%	Y/N		
2	Setback from well (must be > 100 ft)			ft
3	Setback from buildings (must be > 10 ft)			ft
4	Geotechnical investigation complete	Y/N		
5	Infiltration rate of native soils	i		in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$		ft
Section 2. Bioretention Sizing				
7	Volume of runoff from design storm	V		acre-ft
8	Bioretention area	A		sq-ft
9	Soil depth	d_{soil}		ft
	Ponding depth	$d_{ponding}$		ft
11	Soil porosity	p		%
12	Estimated maximum storage volume of bioretention	V_{BMP}		acre-ft
Section 3. Bioretention Performance				
13	Drain down time (*infiltration only*)			hrs
14	Drain down time w/ underdrain			hrs
15	Drain down time w/ underdrain and over drain			hrs

Attachment 5: Bioretention/Rain Garden Design Example

This design example walks through the use of the Bioretention Design Guidelines contained in the Ft. Wayne Green Supplemental Document. This design example will require the bioretention/rain garden BMPs to account for the water quality volume from the roof top and parking area. Bioretention areas will be designed to disconnect the impervious area, route and treat runoff, and discharge to the storm sewer system.

Collect Existing/Proposed Site Information

<u>Existing Conditions:</u>
Drainage Area = 1.1 acres
Pre-Development CN = 74
Percent Impervious = 0%

<u>Proposed Conditions:</u>
Drainage Area = 1.1 acres
Post-Development CN = 89
Percent Impervious = 64 %

Detention Storage Requirements
Determine the storage required to capture the water quality volume. The water quality volume is the runoff produced from 1 inch of rainfall over the impervious area. The outlet control will be an overflow structure and infiltration.

Water Quality Volume Calculation:

$WQ_v = (P)(R_v)(A)/12$

where:
WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = 0.05+0.009(I) where I is the percent impervious cover
A = area in acres

Example:

A = 1.1 acres
Impervious Area = 0.7 acres
I = 64 %
$R_v = 0.05+0.009(64) = 0.626$

WQ_v= (1)(0.626)(1.1)/12 = **0.0574 acre-ft**

Assuming a 6" ponded depth, 0.12 acres of bioretention is necessary to capture and treat the water quality volume.

Drain Down Time Requirements
The maximum drain down time for the entire storage volume is 48 hours. Finalize dimensions and depth of bioretention system. Compute volume of water that can infiltrate the amended soil in 48 hours.

Infiltration Rate = 0.5 in/hr
Bioretention Area = 5227 ft^2
Porosity = 30%
Bioretention Infiltration Area = 5227 ft^2 * 0.30 =1568 ft^2
Time to Drain – 48 hrs

Calculate the volume of water infiltrating through the bottom of the bioretention system.
0.5 in/hr * 1ft/12in * 1568 ft^2 *48 hrs * 1acre/43560 ft^2 = **0.0719 acre-ft**

Maximum storage for the bioretention system is 0.0574 acre-ft. The volume that can be infiltrated in 48 hours exceeds maximum volume of runoff the system can contain. The bioretention system can drain down the entire storage volume in less than 48 hours through infiltration into underlying soils.

Attachment 6: Swale Design Guidelines

A swale is a vegetated open channel, planted with a combination of grasses and other herbaceous plants, shrubs, or trees. A traditional swale reduces peak flow at the discharge point by increasing travel time and friction along the flow path. Swales can provide some infiltration and water quality treatment; these functions can be enhanced by incorporating retentive grading, or check dams periodically along the length of the swale.

Siting for Swales

Swales are applicable in many urban settings such as parking, commercial and light industrial facilities, roads and highways, and residential developments. For instance, a swale is a practical replacement for roadway median strips and parking lot curb and gutter. Swales can be an effective means of decentralizing stormwater management so that primary detention facilities become less necessary.

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates
High ground water table depth to bottom of stone storage layer must be 4 feet or greater
Land surrounding and draining to the swale does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Design Guidelines

Swales are landscaped channels that convey stormwater and reduce peak flows by increasing travel time and flow resistance. Depending on design and underlying soil permeability, they can effectively reduce runoff volume and improve water quality. Check dams increase these functions by creating ponding areas where settling and infiltration can occur. As the number of check dams increases, a swale may resemble a series of bioinfiltration/bioretention basins while still being designed to convey peak flows. The first ponding area may be designed as a sediment forebay and function as a pretreatment practice for the remainder of the swale or other stormwater management facilities. An example calculation for a 1.1 acre site is provided in the **Swale Design Example, Attachment 7**.

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Ft. Wayne Storm Water Design Manual.
Swales may be trapezoidal or parabolic in shape. Recommended widths and slopes in this table may be used as a general guide for parabolic channels.

Check dams are recommended for most applications to improve infiltration and water quality. They are strongly recommended for swales in which flow in combination with soil, slope, and vegetation may result in erosive conditions.
Bottom Width = 2-8 feet
Side Slopes = 3-4 horizontal to one vertical recommended
Check dams evenly spaced, 6-12 inches high.

- Consider an underdrain under any of the following conditions:
  - in areas with separate storm sewers or direct discharge to receiving waters where infiltration is infeasible and the vegetated swale is needed only to provide water quality treatment;
  - in areas with combined sewers where sufficient detention or travel time can be designed into the system to meet release rate requirements; or
  - in combination with other storm infrastructure where the system as a whole meets storage and release criteria.
- Estimate the portion of Water Quality and Water Quantity requirements met by the design.
- Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long storage behind check dams will take to drain. The maximum drain time for the entire storage volume is 72 hours, but the Designer may choose a shorter time based on site conditions and Owner preference but no shorter than 24 hours. If storage does not drain in the time allowed, adjust channel shape, number of check dams, check dam height, or optional underdrain design. Adjust the design so that performance and drainage time constraints are met concurrently.
- Check the capacity of the swale system to perform during the 100 year regulatory event defined in the Stormwater Design and Specification Manual. An average ponding depth of 12 inches or less, and a maximum ponding depth of 18 inches is required. If higher stages are anticipated, vegetation should be selected per expected hydrologic conditions. Flow over check dams should be estimated using a weir equation, while underdrain conveyance should be modeled as a series outlet representing (1) infiltration rate over horizontal wetted area to (2) orifice flow at the underdrain daylight. Ultimately, the level of service provided on the site during large events is a joint decision of the Engineer and Owner based on safety, appearance, and potential property damage.
- Choose soil mix and swale vegetation. A minimum of 6 inches of prepared soil is recommended for the channel bottom and slopes. Provide a detail on the plans sheets including the proposed soil mix.

- Check resistance of the swale to erosion. For long term functionality, it is recommended that the swale convey the 2-year, 24-hour design storm without erosion. For water quality purposes, channel velocities during a water quality event should not exceed resuspension velocities (2.5 ft/sec). Adjusting soil mix, vegetation, and temporary or permanent stabilization measures as needed.

- Design inlet controls, outlet controls, and pretreatment if desired.

- Check that the design meets all requirements concurrently, and adjust design as needed.

- Complete construction plans and specifications.

Table 3. Swale Design Checklist				
Section 1. Swale Siting				
1	Slope of surrounding drainage area < 20%	Y/N		
2	Setback from well (must be > 100 ft)			ft
3	Setback from buildings (must be > 10 ft)			ft
4	Geotechnical investigation complete	Y/N		
5	Infiltration rate of native soils	i		in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$		ft
Section 2. Swale Sizing				
7	Volume of runoff from design storm	V		acre-ft
8	Bottom Width	W_{bottom}		ft
9	Side Slopes (z:1)	z		
	Depth	d		ft
10	Check Dams	No.		
		Spacing		ft
11	Slope	S		ft/ft
12	Estimated maximum storage volume of swale	V_{BMP}		acre-ft
Section 3. Swale Performance				
13	Capacity for 100 year event	Y/N		
14	Channel Velocity (for 2 year 24 hour event)	v		ft/s

Attachment 7: Swale Design Example

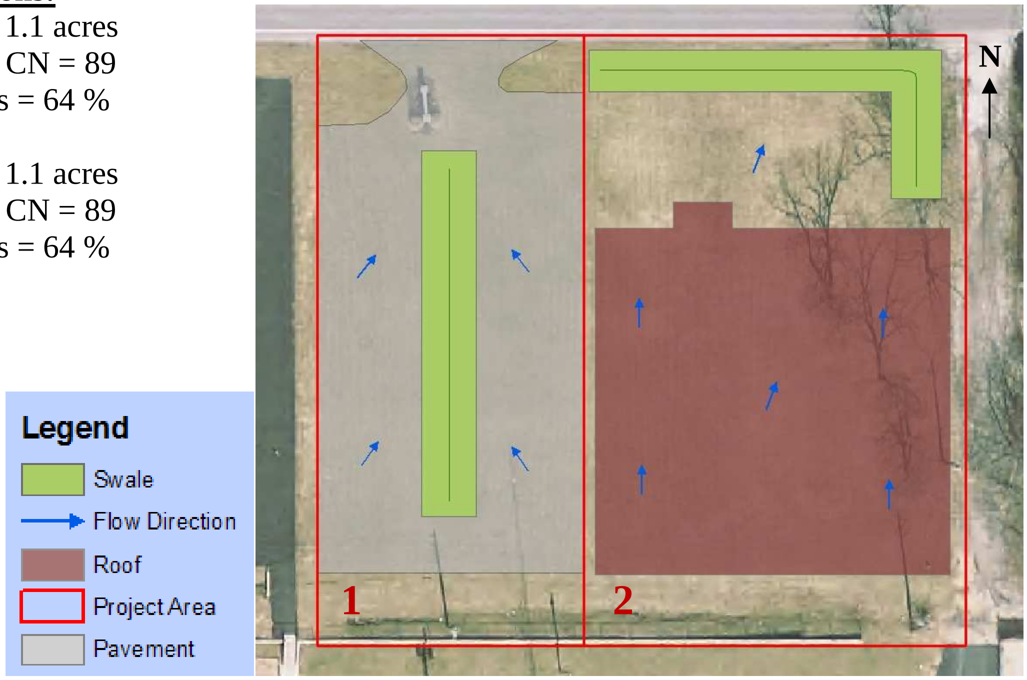
This design example walks through the use of the Swale Design Guidelines contained in the Ft. Wayne Green Supplemental Document. This design example will require two swales to account for the water quality volume from the roof top and parking area. The swales will be designed to disconnect he impervious area, route and treat runoff, and discharge to the storm sewer system.

Collect Existing/Proposed Site Information

<u>Existing Conditions:</u>
Drainage Area = 1.1 acres
Pre-Development CN = 74
Percent Impervious = 0%
Type A Hydrologic Soils
Infiltration Rate = 0.5 in/hr

Proposed Conditions:
Drainage Area 1 = 1.1 acres
Post-Development CN = 89
Percent Impervious = 64 %

Drainage Area 2 = 1.1 acres
Post-Development CN = 89
Percent Impervious = 64 %



Detention Storage Requirements
Determine the storage required to capture the water quality volume. The water quality volume is the runoff produced from 1 inch of rainfall over the impervious area. The outlet control will be an overflow structure and infiltration.

Water Quality Volume Calculation:

$WQ_v = (P)(R_v)(A)/12$

where:
WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = 0.05+0.009(I) where I is the percent impervious cover
A = area in acres

Example:
A = 1.1 acres
Impervious Area = 0.7 acres
I = 64 %
R_v = 0.05+0.009(64) = 0.626

WQ_v= (1)(0.626)(1.1)/12 = **0.0574 acre-ft**

Assuming a 6" ponded depth, 0.12 acres of swale is necessary to capture and treat the water quality volume.

Attachment 8: Rain Barrel/Cistern/Storage Tank Design Guidelines

Rain barrels, cisterns, and storage tanks are structures designed to intercept and store runoff from rooftops. Rain barrels are used on a small scale while cisterns and tanks may be larger. These systems may be above or below ground, and they may drain by gravity or be pumped. Stored water may be slowly released to a pervious area, used for irrigation, or plumbed into buildings per code for use inside. These techniques only serve as an effective stormwater control if the stored water is emptied between most storms, freeing up storage volume for the next storm.

Siting for Rain Barrel, Cistern and Storage Tanks

Rain Barrel: The most common use of rain barrels is connection of one roof leader (downspout) to a single barrel on a residential property. Stored water can provide irrigation for a garden or can be released slowly to a lawn. Barrels can either be purchased or can be built by the homeowner. They are ideal for gardeners and concerned citizens who want to manage stormwater without a large initial investment. They are also an easy retrofit. A design professional and stormwater design calculations are typically not needed. The labor and installation can generally be performed by the property owner or handyman. The materials necessary are generally low cost and can be found at local retail hardware or plumbing supply stores.

Cistern/Storage Tank: Surface tanks may be larger than rain barrels but serve the same function. They can be integrated into sites where a significant water need exists or rain harvesting and reuse is desired. They may drain by gravity or be pumped. These typically need design professional assistance for more complex water collection and delivery system design. Typically need to be installed to local code by a certified and bonded plumbing or construction contractor.

Table1. Minimum Design Elements
Storage devices designed to capture small, frequency storm events with opportunity for larger storm volume capture.
Storage techniques may include rain barrels, underground concrete or prefabricated tanks, above ground vertical storm volume capture.
Systems must provide for storage, overflow or bypass of large storm events per City of Fort Wayne Stormwater Design Manual
Placement of storage elements higher than areas where water will be reused may reduce or eliminate pumping needs.
For effective stormwater control, water must be used or discharge before the next storm event.
Most effective when designed to meet a specific water need for reuse.

Table 2. Suggested Storage Design Values	
Rain Barrel	50-150 gallons
Cistern	500-7,000 gallons
Larger Above Ground Tank	3,000-12,000 gallons

Design Guidelines
Identify opportunities and areas where water can be reused for irrigation, released to an infiltration area, or meet indoor use needs. Estimate the rate at which water can be reused. If the process of reuse is proposed to meet the Water Quality requirement, check the local stormwater design codes and ordinances. For irrigation or garden use, determine the water needs of the plants; an assumption of 1 inch per week over the soil area may be used for approximate results. Identify potential infiltration areas where water may be discharged to at a slow rate. The most important variable in designing a rain barrel, cistern, or storage tank it estimating the storage needed. A rough estimate may be obtained by performing a weekly water balance of rainfall and water reuse. To ensure the rain barrel has adequate storage a Design Professional should perform calculations to verify the rain barrel overflow has enough capacity. Depending on the complexity of system and/or intended reuse options, a Design Professional may need to be contracted to perform more rigorous analysis in order to best meet water demand needs.

Table 3. Rain Barrel, Cistern, and Storage Tank Design Guidelines
Identify roof leaders where rain barrels, cistern, or storage tank will be installed
Consider elevating the barrel by placing it on a stable platform to increase water pressure at ground level
If emptying the barrel manually, develop a plan so that it is partially or completely emptied on average every 3 to 4 days
Position the overflow hose to discharge larger storms. The overflow should be discharged to an area protected from erosion. At a minimum, direct the overflow to the same location as the roof leader before placing the storage tank.
Cisterns and larger storage tanks should be designed to local codes and ordinances, preparing complete construction plans and specifications.

The spreadsheet below illustrates a method for designing the rain barrel for residential use. Cisterns and storage tanks vary by manufacturer and design. The Design Professional must provide documentation proving the cistern or storage tank will provide adequate storage for runoff from roof area.

Section 1. Rain Barrel, Cistern, and Storage Tank Hydraulics				
1	Dimensions of Roof Draining to Barrel	L	81	ft
		W	63	ft
		A_{BMP}	5103	ft^2
2	Depth of Precipitation	P	2	in
3	Volume of Runoff from Roof	V	850.5	ft^3
			113.7	gal
4	Storage Volume of Barrel Receiving Runoff	V_{barrel}	200	gal
6	Outlet	d_{out}	2	in
7	Overflow	d_o	3	in

Outlet		
d_{out}	2	in
Depth	3	in
E	4	in
C	0.65	

Overflow		
d_o	3	in
Depth	36	in
E	37.5	in
C	0.65	

Depth in	Outlet Head in	Flow cfs	Overflow Head in	Flow cfs	Total Flow cfs
1	0	0.00	0	0.000	0.000
2	0	0.00	0	0.000	0.000
3	0	0.00	0	0.000	0.000
4	0	0.00	0	0.000	0.000
5	1	1.51	0	0.000	1.506
6	2	2.13	0	0.000	2.130
7	3	2.61	0	0.000	2.608
8	4	3.01	0	0.000	3.012
9	5	3.37	0	0.000	3.367
10	6	3.69	0	0.000	3.688
11	7	3.98	0	0.000	3.984
12	8	4.26	0	0.000	4.259
13	9	4.52	0	0.000	4.517
14	10	4.76	0	0.000	4.762
15	11	4.99	0	0.000	4.994
16	12	5.22	0	0.000	5.216
17	13	5.43	0	0.000	5.429

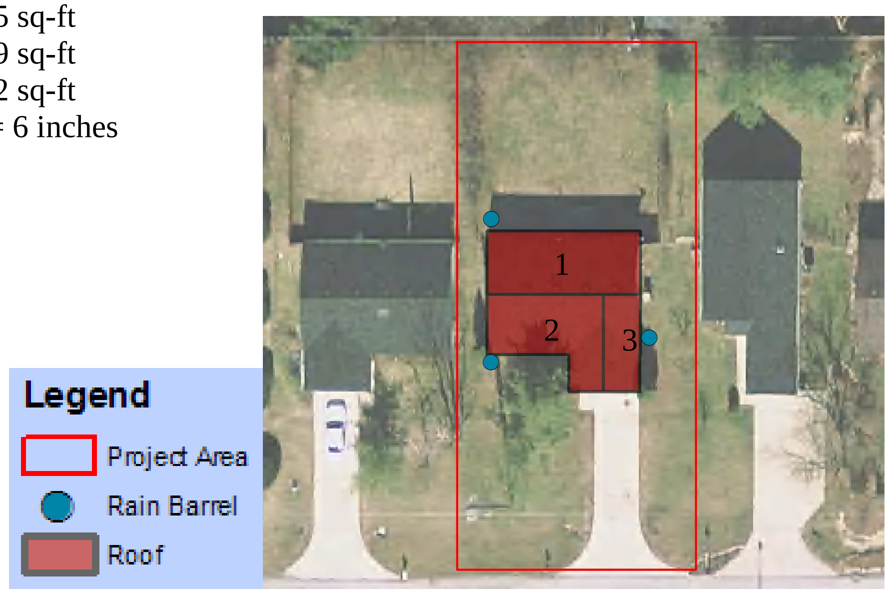
Attachment 9: Rain Barrel Design Example

This design example walks through the use of the Rain Garden Design Guidelines contained in the Ft. Wayne Green Supplemental Document.

Collect Existing/Proposed Site Information

<u>Existing Conditions:</u>
Roof Area = 1596 sq-ft

<u>Proposed Conditions:</u>
No. of Rain Barrels = 3
Roof Area 1 = 726.25 sq-ft
Roof Area 2 = 606.29 sq-ft
Roof Area 3 = 263.42 sq-ft
Precipitation Depth = 6 inches



Rain Garden Design Checklist

Storage Requirements

To be most effective and economically viable for a project, the design must identify which roof leaders can drain to the rain barrel and the area of the roof draining to each leader. This example will only include calculations for one rain barrel. The spreadsheet and methodology can be utilized for the other two rain barrels in this example.

Section 1. Rain Barrel, Cistern, and Storage Tank Hydraulics				
1	Dimensions of Roof Draining to Barrel	L	41.5	ft
		W	17.5	ft
		A_{BMP}	726.25	ft^2
2	Depth of Precipitation	P	6	in
3	Volume of Runoff from Roof	V	363.125	ft^3
			48.5	gal
4	Storage Volume of Barrel Receiving Runoff	V_{barrel}	55	gal
6	Outlet	d_{out}	2	in
7	Overflow	d_o	3	in

Outlet		
d_{out}	2	in
Depth	3	in
E	4	in
C	0.65	

Overflow		
d_o	3	in
Depth	29	in
E	30.5	in
C	0.65	

Depth in	Outlet Head in	Flow cfs	Overflow Head in	Flow cfs	Total Flow cfs
1	0	0.00	0	0.000	0.000
2	0	0.00	0	0.000	0.000
3	0	0.00	0	0.000	0.000
4	0	0.00	0	0.000	0.000
5	1	1.51	0	0.000	1.506
6	2	2.13	0	0.000	2.130
7	3	2.61	0	0.000	2.608
8	4	3.01	0	0.000	3.012
9	5	3.37	0	0.000	3.367
10	6	3.69	0	0.000	3.688

11	7	3.98	0	0.000	3.984
12	8	4.26	0	0.000	4.259
13	9	4.52	0	0.000	4.517
14	10	4.76	0	0.000	4.762
15	11	4.99	0	0.000	4.994
16	12	5.22	0	0.000	5.216
17	13	5.43	0	0.000	5.429
18	14	5.63	0	0.000	5.634
19	15	5.83	0	0.000	5.832
20	16	6.02	0	0.000	6.023
21	17	6.21	0	0.000	6.209
22	18	6.39	0	0.000	6.389
23	19	6.56	0	0.000	6.564
24	20	6.73	0	0.000	6.734
25	21	6.90	0	0.000	6.900
26	22	7.06	0	0.000	7.063
27	23	7.22	0	0.000	7.222
28	24	7.38	0	0.000	7.377
29	25	7.53	0	0.000	7.529
30	26	7.68	0	0.000	7.678
31	27	7.82	1	1.065	8.889
32	28	7.97	2	1.844	9.812
33	29	8.11	3	2.381	10.490
34	30	8.25	4	2.817	11.065
35	31	8.38	5	3.194	11.578

To ensure the rain barrel has adequate storage a Design Professional should perform calculations to verify the rain barrel overflow has enough capacity. Depending on the complexity of system and/or intended reuse options, a Design Professional may need to be contracted to perform more rigorous analysis in order to best meet water demand needs.

Attachment 10: Green Roof Design Guidelines

A green roof (vegetated roof/eco roof/roof garden) is a system consisting of waterproofing material, growing medium and vegetation. A green roof can be used in place of a traditional roof as a way to limit impervious site area and reduce stormwater runoff. The green roof design should attempt to mimic pre-developed site hydrology, reducing post-developed peak runoff rates to near pre-developed rates. Green roofs also help mitigate runoff temperatures by keeping roofs cool and retaining much of the runoff from typical storm events. Although many green roofs consist of lightweight growing medium and low-growing succulent vegetation, other more heavily planted systems are possible; in either case the design should be self-sustaining.

There are three basic types of green roofs (GRHC, 2008). An extensive green roof system is 6 inches or less in depth, and has a water saturation weight of 10-35 lbs/ft^2. It usually has limited accessibility and is planted with drought-tolerant succulent plants and grasses. A semi-intensive green roof contains material 25% above or below 6 inches. It may be partially accessible, has a water saturation weight of up to 50 lbs/ft^2 and has potential for greater plant diversity than an extensive roof. An intensive green roof is deeper than 6 inches and typically has a water saturation weight between 50-300 lbs/ft^2. These roofs are usually accessible to others besides maintenance and allow for great plant diversity. Each green roof project is unique, given the purpose of the building, its architecture and the preferences of its owner and end user. Since guidelines are constantly being upgraded and approved, the engineer is responsible for verifying that the design materials meet all current standards at the time of design. Green roof systems are typically comprised of the same components:

- Plant material
- Growing medium
- Filter fabric
- Drainage layer
- Insulation (optional)
- Waterproof membrane/root barrier
- Roof structure

Table 1. Recommended Design Procedure
Early communication between design team (developer, civil engineer, structural engineer, architect, landscape architect, planner, roofer, etc.) is important.
Investigate feasibility of the installation of a green roof. A structural engineer should verify that the roof will support the weight of the green roof system.
Determine the portion of roof that will have a green roof. Typically 10% or less of the green roof is composed of non-vegetated components such as gravel and pavers.
Extensive green roofs that have an engineered growing medium of at least 3 inches thick can be permitted as a water quality volume reduction equal to the area of the green roof.

Green roofs are not considered impervious surfaces when determining stormwater management requirements, but they are not zero discharge systems. The roof drainage system and the remainder of the site drainage system must safely convey roof runoff.
Develop a planting plan based on the thickness of planting media.
Complete construction plans and specifications.

Design Guidelines

The use of green roofs provides a quantitative benefit for both water quantity and quality management. The following paragraphs discuss the details of how a green roof affects the design, runoff quantity and quality.

Installing a green roof alters the surface response to rainfall with respect to runoff. A green roof will have a significant increase in storage capability when compared to a standard roof with little or no storage capability. The initial rainfall striking the soil of a green roof is absorbed until the soil is saturated.

The capacity of a green roof to absorb runoff is governed by planting media thickness, roof slope or "pitch", and rainfall depth. Consequently, runoff from and curve numbers (CN's) applied to a green roof may vary for the one (1), two (2), 10, and 100-year design storm events depending on individual design characteristics. To simplify the design and approval process, the City of Ft. Wayne has adopted a method where the post development CN used for green roofs when computing the hydrologic computations is adjusted by the average depth of the green roof soil. In general, the CN of a roof (98) may be reduced by 2 for each inch of planting soil. The following table provides sample soil depth and CN values.

Roof Thickness (in)	Curve Number (CN)
1	96
2	94
3	92
4	90
5	88
6	86

The use of these reduced curve numbers will account for reduced runoff from a green roof when the post-developed runoff rates are compared to the pre-developed runoff rates. Runoff depth is computed using the NRCS CN method. Retention, S, is a function of: land use, interception, infiltration, depression storage, and antecedent moisture. S has an empirical relationship with CN. Curve number, CN, is an index that reflects land use, hydrologic soil group, and treatment class.

$$S = \frac{1000}{CN} - 10$$

Runoff depth, Q, for a given rainfall depth, P in inches reflect volumes and are referred to as volumes because the depths occur over the entire area.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

A design example utilizing the NRCS CN method for calculating runoff depth is provided in Attachment 11.

Construction of a green roof in place of a standard impervious roof will also positively impact water quality design.

Below are the Design Calculations and Design Checklists spreadsheets.

Green Roof Design Calculations				
Section 1. Existing Roof Runoff				
1	Existing Roof Area	A	14803	sq-ft
2	Curve Number	CN	98	
3	Retention	S	0.20	
4	Rainfall Depth	P	1	in
5	Runoff Depth	Q	0.79	in
6	Runoff Volume	V	0.022	acre-ft
Section 2. Proposed Green Roof Runoff				
7	Green Roof Area	A	14803	sq-ft
8	Green Roof Soil Depth	d	6	in
9	Green Roof Curve Number	CN_{GR}	86	
10	Retention	S	1.63	
11	Rainfall Depth	P	1	in
12	Runoff Depth	Q	0.20	in
13	Runoff Volume	V	0.006	acre-ft
Section 3. Proposed Green Roof Storage				
14	Green Roof Area	A	14803	sq-ft
15	Rainfall Depth	P	1	in
16	Green Roof Soil Depth	d	6	in
18	Soil Dry Weight	W_{dry}	60	lbs/ft^3
19	Soil Saturated Weight	W_{sat}	90	lbs/ft^3
20	Runoff Retained	$V_{storage}$	1.80	gal/ft^2
			0.082	acre-ft

Green Roof Design Checklist				
Section 1. Engineering/Drainage Report Requirements				
1	Storage Volume Calculations	Y/N		
2	Emergency Overflow Calculations	Y/N		
3	Water Quality Volume Calculations	Y/N		
4	Water Quantity Volume Calculations	Y/N		
5	Structural Engineers Certification (for Retrofits)	Y/N		
Section 2. Plan Requirements				
6	Soil Depth	Y/N		
7	Impermeable Membrane	Y/N		
8	Filter Fabric	Y/N		
9	Soil Specifications	Y/N		
10	Drainage Layer	Y/N		
11	Plant Specifications	Y/N		
12	Filter Fabric	Y/N		
Section 3. O & M Manual Requirements				
13	Tabular Inspection Schedule	Y/N		
14	Site Diagram with Green Roof Area	Y/N		
15	Inspections Checklist	Y/N		
16	Startup Maintenance	Y/N		
17	Fertilizer Guidance	Y/N		
18	Plant Coverage Minimum Requirement (90%)	Y/N		
19	Emergency Overflow System Inspection	Y/N		
20	Wind and Rain Erosion Inspection	Y/N		
21	Weeding	Y/N		

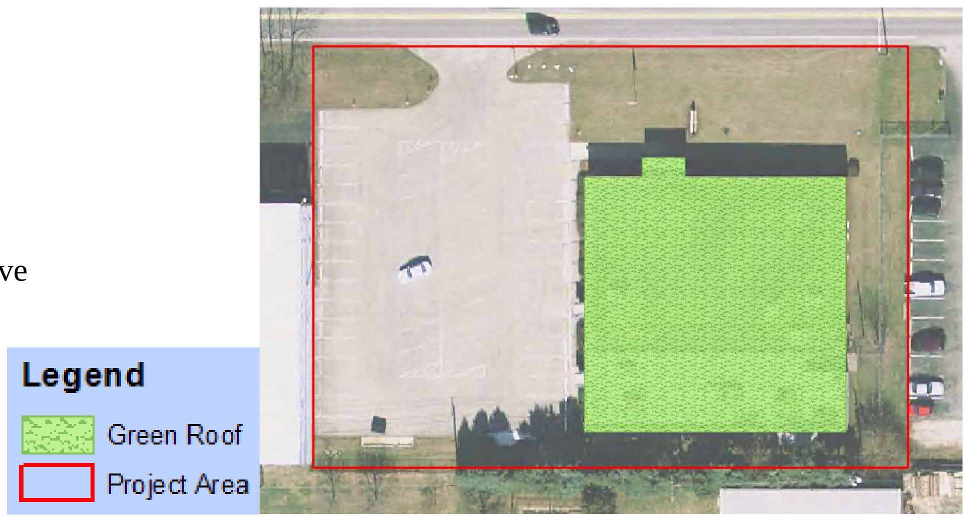
Attachment 11: Green Roof Design Example

This design example walks through the use of the Green Roof Design Guidelines contained in the Ft. Wayne Green Supplemental Document. This design example will illustrate the benefits of a green roof for reducing the runoff CN and providing water quantity benefits.

Collect Existing/Proposed Site Information

<u>Existing Conditions:</u>
Drainage Area = 1.26 acres
Roof/Parking Lot CN = 98
Lawn CN = 74
Pre-Development CN = 89
Percent Impervious = 63%

<u>Proposed Conditions:</u>
Drainage Area = 1.26 acres
Parking Lot CN = 98
Roof CN = 86
Lawn CN = 74
Post-Development CN = 86
Percent Impervious = 36%
Green Roof Type = Extensive
Planting Depth = 6 inches



Calculate Site Runoff

To illustrate the benefits of the green roof, existing and proposed site runoff should be compared. Refer to the Green Roof Design Guidelines for a description of the NRCS Curve Number method for calculating runoff and water quality benefits green roofs can provide.

Existing Site Runoff:

Land Use	CN	Area (sq-ft)
Roof	98	14803
Parking Lot	98	19588
Lawn	74	20495

Calculate Area Weighted CN:

$$CN = \frac{CN_1(A_1) + CN_2(A_2) + CN_3(A_3)}{A_1 + A_2 + A_3} = 89$$

Calculate S:

$$S = \frac{1000}{89} - 10 = 1.24$$

Calculate Q (P = 1 inch):

$$Q = \frac{[1'' - 0.2(1.24)]^2}{1'' + 0.8(1.24)} = 0.28''$$

Proposed Site Runoff:

Land Use	CN	Area (sq-ft)
Roof	86	14803
Parking Lot	98	19588
Lawn	74	20495

Calculate Area Weighted CN:

$$CN = \frac{CN_1(A_1) + CN_2(A_2) + CN_3(A_3)}{A_1 + A_2 + A_3} = 86$$

Calculate S:

$$S = \frac{1000}{86} - 10 = 1.63$$

Calculate Q (P = 1 inch):

$$Q = \frac{[1'' - 0.2(1.63)]^2}{1'' + 0.8(1.63)} = 0.20''$$

Calculate Runoff Retained in Green Roof

Installing a green roof alters the surface response to rainfall with respect to runoff. A green roof will have a significant increase in storage capability when compared to a standard roof. Estimates of the planting soils storage capacity are important values when calculating the runoff that can be expected to be absorbed. The dry soil weight and saturated soil weight values should be verified by members of the design team involved with planting soil specification. The design table provided in the Green Roof Design Guidelines is utilized in this example.

Section 3. Proposed Green Roof Storage				
14	Green Roof Area	A	14803	sq-ft
15	Rainfall Depth	P	1	in
16	Green Roof Soil Depth	d	6	in
18	Soil Dry Weight	W_{dry}	60	lbs/ft^3
19	Soil Saturated Weight	W_{sat}	90	lbs/ft^3
20	Runoff Retained	$V_{storage}$	1.80	gal/ft^2
			0.082	acre-ft

Water Quality Calculations

$WQ_v = (P)(R_v)(A)/12$

where:

WQ_v = water quality volume (acre-feet)

P = 1 inch of rainfall

R_v = 0.05+0.009(I) where I is the percent impervious cover

A = area in acres

Existing Site:

A = 1.26 acres

Impervious Area = 0.79 acres

I = 63 %

R_v = 0.05+0.009(64) = 0.617

WQ_v= (1)(0.617)(1.26)/12 = **0.065 acre-ft**

Proposed Site:

A = 1.26 acres

Impervious Area = 0.45 acres

I = 36 %

R_v = 0.05+0.009(36) = 0.374

WQ_v= (1)(0.374)(1.26)/12 = **0.039 acre-ft**