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APPENDICES

CHAPTER 1 – INTRODUCTION

A GENERAL INFORMATION

1 Introduction

In 1972, amendments made to the Clean Water Act created the National Pollution Discharge Elimination System (NPDES). This program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Over the years point discharges have been defined to include many types of discharges. Included in these discharge are construction runoff and runoff from storm drainage systems.

Under the program, states that meet certain criteria have the authority and responsibility to regulate discharges into these waters. In Kentucky this authority and responsibility lies with the Division of Water (DOW) in the Environmental and Public Protection Cabinet. The DOW regulates these discharges under Kentucky's version of the NPDES, the Kentucky Pollution Discharge Elimination System (KPDES).

The City of Richmond operates under the requirements of KPDES general stormwater permit for small municipal separate storm sewer systems (MS4). The City has six (6) minimum control measures that are required for implementation in order to be compliant with the MS4 stormwater permit. This manual is a culmination of Stormwater and Floodplain resources for design and construction of stormwater facilities in the City of Richmond.

2 Flood Hazards

Before any development, analyze existing and post-developed flood flow characteristics at stream crossings and drainage conveyance systems to determine their effects upon the developments and adjacent properties. Document changes to the pre-existing flood hazards. Include effects to private property both upstream and downstream including overtopping floodwaters diverted onto previously unaffected property.

3 Permits

Specific Federal, State, and local permits that will be needed for a project must be identified. A list of the major categories of applicable water related permits are given below:

- KPDES stormwater discharge permit for construction projects,;
- United States Army Corps of Engineers Section 404 Permits (Nationwide and/or Individual); and
- Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water, Section 401 Water Quality Certification and Floodplain Management.

In addition to the above permits, coordination is necessary with the following local agencies when projects are located in their jurisdictions: KYTC (Kentucky Transportation Cabinet).

B STORMWATER MANAGEMENT

1 Planning

To be truly effective, a stormwater management plan should consider the total scope of development (i.e., transportation, residential, commercial, industrial, and agricultural).

Before designing, a level of planning should be undertaken that would properly locate facilities and adequately address local concerns, permitting requirements, legal considerations, and other potential problems. The important point to emphasize is that the designer should become involved in the early stages of project development and not wait until the later design stages.

2 Water Quality and Quantity Issues

The issues that stormwater management is intended to address can be categorized as water quality or water quantity issues. Water quality issues deal with the degradation of runoff, and the protection of environmental resources. Planning for drainage and stormwater management facilities should include a consideration of the potential problems associated with stormwater quality. The following general rules should be followed:

- maximize stable open channels
- maximize use of vegetated linings
- minimize curb and gutter sections and their associated storm sewers
- minimize culvert lengths

Determinations of stormwater quantity are primarily useful for evaluating and mitigating the impact of a project from a flooding perspective. Land development can increase peak runoff rates and volumes from storm events which can lead to higher flood elevations in the absence of detention ponds (basins, storage areas). Appropriate hydrologic and hydraulic calculations presented in various chapters of this manual should be made to determine the required conveyance.

3 General Goals Of Drainage Facility Designs

Procedures contained in this manual should be used to evaluate the ability of a facility to accomplish the following goals for a particular area:

- Reduce runoff rates by increasing infiltration, and by storing precipitation and runoff where it falls then releasing them slowly.
- Protect areas subject to flood damages by keeping runoff confined to drainage facilities such as pipes or channels and by building appropriate flood control facilities.
- Minimize the degradation of water quality
- Protect special environmental resources

- ❖ Keep flood plain encroachment outside the limits of regulated floodways.

4 Stormwater Disposal

The following evaluations should be made when selecting the plan for disposal of stormwater runoff:

- ❖ Assess the capacity/adequacy of existing drainage systems.
- ❖ Assess the compatibility of design discharges with adopted drainage plans and regulatory criteria.
- ❖ Assess the potential need for retention or detention storage areas to mitigate the impacts of increased runoff if the increase cannot be handled by other project features.
- ❖ Assess the availability of right-of-way to construct a retention or detention pond within or outside the right-of-way.
- ❖ Determine the availability of alternative sites for storage of stormwater.
- ❖ Identify any unusual groundwater or soil conditions such as impermeable soil layers and locate the water table.
- ❖ Identify any jurisdictional or permitting restrictions.
- ❖ Identify karst drainage features and evaluate their capacity to convey runoff.

5 Detention / Retention Storage

Detention and/or retention basins can be used to store stormwater and release it at slower rates. Generally, post development discharges will be limited to their pre development discharge.

Any facility of this type should be constructed on right of way or easement. If there is insufficient right of way, alternate locations should be investigated. The local community may develop basins away from the site in conjunction with the highway project, or have a readily available basin close by. In either case project drainage should be directed to these facilities when appropriate.

6 Outlet Capacity

Newly constructed drainage systems have to be tied into an existing channel or storm sewer network. It is imperative that the designer determine the capacities of these existing systems. This may require obtaining information on the existing system for a significant distance downstream.

Another important consideration in designing drainage systems is to return drainage patterns back to their original conditions. Taking a watershed and routing it to a location that is different than existing drainage patterns should be avoided, unless it fits the community's storm water plan, or is the only feasible alternative. The overall community stormwater plan should be considered and plans should be made available to the regulators for comment.

7 Construction Considerations

Many serious construction problems arise because important drainage and water-related factors were overlooked or neglected in the planning and location of the project. With proper planning, many problems can be avoided or cost effective solutions developed to prevent extended damages. Such problems include but are not limited to:

- -soil erosion,
- sediment deposition,
- drainage and landslide,
- sinkholes and karst areas,
- timing of project stages,
- protection for aquatic habitat,
- protection of streams, lakes, and rivers, and
- protection of wetlands,
- temporary drainage measures.

Analysis of available data, proper scheduling of work, and other aspects involved in the early planning and location studies can alleviate many problems encountered in the construction of drainage facilities.

8 Post Construction Best Management Practice (BMP)

The term Post Construction Best Management Practice is a term used to define a group of design and construction techniques that are intended to address water quality and quantity issues for several years after the construction of a project. Unlike the BMPs developed from the Erosion Control Plan, Post Construction BMPs will remain in place long after the construction of the project is complete. Maintenance of post construction BMPs is a significant issue. Long-term agreements with the property owner are required to maintain these structures.

CHAPTER 2 – HYDROLOGIC CALCULATIONS

A FUNDAMENTALS

1 General Information

One of the first steps in the analysis and design of a drainage system is to determine discharges for a range of storms used to analyze the system. These storms range from a channel forming storm to a maximum probable storm.

It must be realized that any hydrologic analysis is only an approximation. The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex. There is not enough data available on the factors influencing the rainfall–runoff relationship to expect exact solutions. Compounding this problem is the significant variation in the amount of runoff from different surfaces. On some surfaces, such as paved areas, nearly all of the rainfall will translate to surface runoff. However on other surfaces such as forested areas, much of the rainfall will be absorbed, and a small percentage will be translated into runoff.

Available analytical methods can be grouped into the two broad categories of deterministic and statistical methods. Deterministic methods (rational formula, NRCS Unit Hygrograph) strive to model the physical aspects of the rainfall runoff process while statistical methods (USGS Regional Methods) utilize measured data to fit functions that represent the process.

2 Hydrology

Hydrology is the science dealing with the occurrence and movement of water upon and beneath the land areas of the earth. It overlaps and includes portions of other sciences such as meteorology and geology. The sequence of events, called the "hydrologic cycle," describes the various movements of water as it relates to the earth. These processes of water movements are:

- Precipitation
- Infiltration
- Evaporation, transpiration, interception
- Surface runoff
- Subsurface runoff and storage

The drainage engineer is concerned with surface runoff and relationships of rainfall to surface runoff. Total losses constitute the difference between total rainfall and the surface runoff available from that rainfall. Precipitation minus infiltration, evaporation, transpiration, interception, and groundwater storage equals surface runoff. Typically only total loss is considered in drainage investigations. In general, no attempt is made to evaluate separate losses. Surface runoff is sometimes called "excess rainfall."

3 Surface Runoff

Runoff comprises the movement of water overland or through channels. Runoff is affected by variations in precipitation. These variations may be characterized by:

- ❖ Seasonal fluctuations
- ❖ Long term variations as cycles of droughts and floods over periods of many years

Runoff rate is influenced by:

- ❖ Topographic features
- ❖ Geological formations
- ❖ Soil
- ❖ Vegetal cover
- ❖ Land usage

Runoff from small drainage areas (less than ten square miles) is affected by factors of physiography usually differing from those used for river basins.

Factors affecting runoff from small drainage areas are:

- ❖ Topography
- ❖ Soil type and depth
- ❖ Shape and slope of area
- ❖ Land usage
- ❖ Vegetal cover
- ❖ Condition and season of crops
- ❖ Method of tillage
- ❖ Antecedent soil moisture
- ❖ Stream patterns
- ❖ Pondage

Factors influencing runoff in river basins are:

- ❖ Topography, geology, and soil provinces
- ❖ Size and shape of basin
- ❖ Size and shape of tributary watershed
- ❖ General vegetal cover
- ❖ Infiltration losses
- ❖ Depression storage
- ❖ Channel storage

The foregoing factors may have greater influence on runoff rates and volumes than rainfall intensity alone. Frequency of peak runoff is not always the same as recurrence of like rainfall intensities in an area. Peak rate of runoff produced by rainfall of given amounts, distribution, and intensities cannot be expected to occur as often as such rainfall recurrence.

4 Peak Flow VS. Hydrograph Method

A consideration of peak flow rates for design is generally adequate for conveyance systems (e.g., storm drains or open channels). However, if the design must include flood routing (e.g. detention basins or complex conveyance networks), a flood hydrograph is usually required. Development of runoff hydrographs is usually accomplished using computer programs.

5 Peak Flow Methods

There are two methods recommended to determine peak flows:

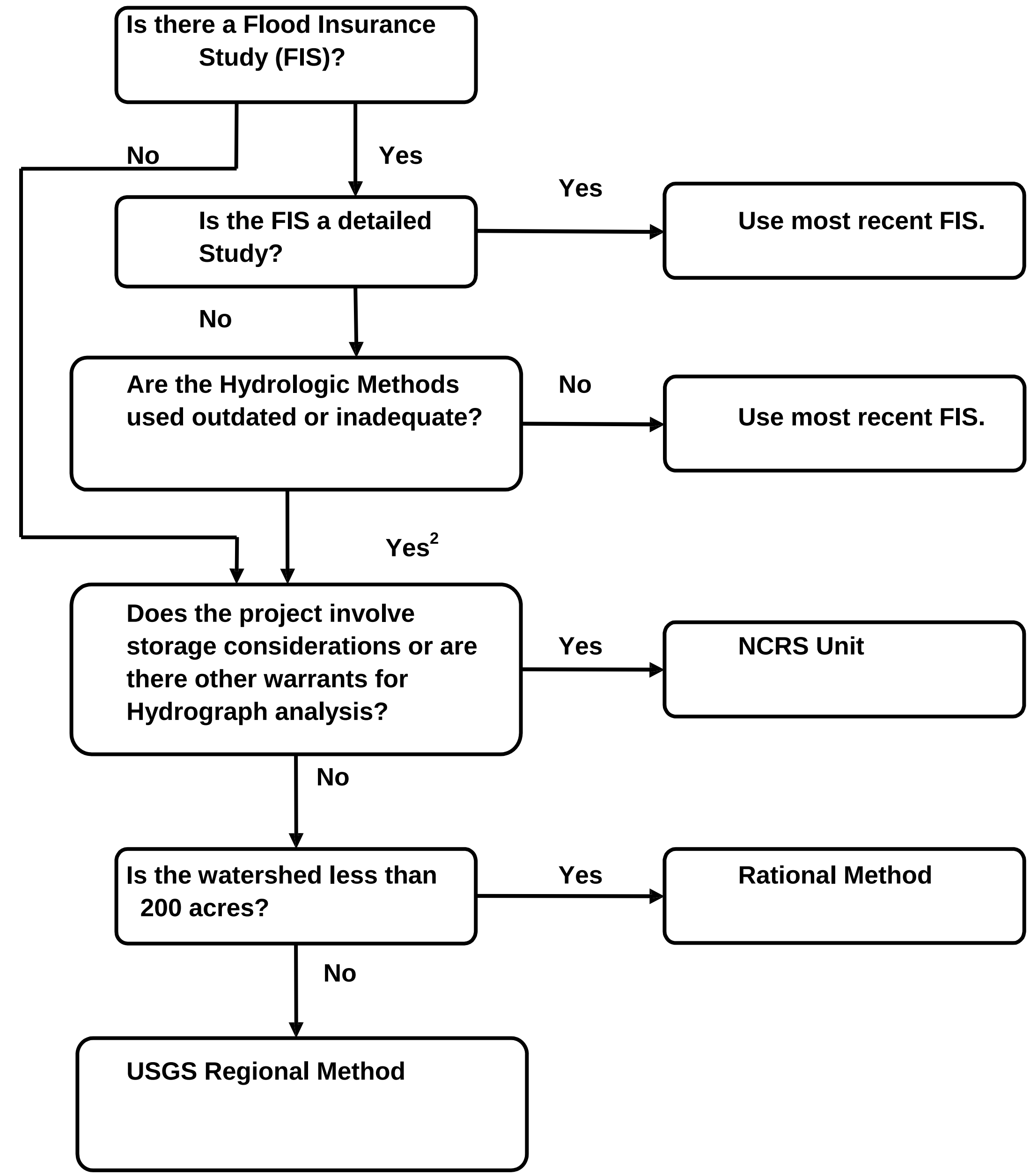
- ❖ Rational Method (Q = CIA) (Use Kinematic Wave Time of Concentration) Refer to
- ❖ Regional Method (Refer to USGS Water Resources Investigations Report 03 4180, "Estimating the Magnitude of Peak Flows for Streams in Kentucky for Selected Recurrence Intervals," published 2003)

6 Hydrograph Method

When performing hydrographic calculations, the Natural Resources Conservation Service (NRCS) Unit Hydrograph Method is recommended for use on KYTC projects.

7 Fully Developed Watershed Conditions

The possibility of future development can be considered in hydrologic calculations if the project team determines it is appropriate to do so or at the request of a local jurisdiction. This can be accomplished by assuming urbanized conditions (more impervious surfaces) in the areas of the watershed that have the potential for future development. This potential can be based on zoning information or other data available from local or county governments.



1. It is a FEMA requirement to use FIS hydrology when assessing flooding impacts in a Detailed Study Area. However, additional design and/or check storm calculations may be based on other methods.
2. It may be necessary to use the FIS flows to satisfy FEMA requirements, however additional flows can be calculated for design purposes.

Figure 2.1 Hydrologic Methods Flowchart

8 PRECIPATION FREQUENCY DATA

In 2004, the National Oceanic and Atmospheric Administration released "NOAA Atlas 14 Volume 2 for the Ohio Valley Region." The document provides documentation behind the Precipitation Frequency Data Server available on NOAA website at: **http://hdsc.nws.noaa.gov/hdsc/pfds/orb/ky_pfds.html.** Tabulated below is the information for City of Richmond.

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.343 (0.312-0.377)	0.403 (0.367-0.444)	0.468 (0.426-0.514)	0.518 (0.471-0.569)	0.583 (0.526-0.638)	0.632 (0.568-0.691)	0.680 (0.609-0.744)	0.728 (0.647-0.797)	0.791 (0.697-0.867)	0.838 (0.732-0.920)
10-min	0.546 (0.498-0.601)	0.644 (0.586-0.708)	0.747 (0.681-0.820)	0.827 (0.751-0.907)	0.926 (0.837-1.01)	1.00 (0.902-1.10)	1.08 (0.964-1.18)	1.15 (1.02-1.26)	1.24 (1.09-1.36)	1.31 (1.14-1.44)
15-min	0.682 (0.622-0.750)	0.808 (0.736-0.889)	0.944 (0.860-1.04)	1.04 (0.949-1.15)	1.17 (1.06-1.28)	1.27 (1.14-1.39)	1.36 (1.22-1.49)	1.45 (1.29-1.59)	1.56 (1.38-1.71)	1.65 (1.44-1.81)
30-min	0.933 (0.850-1.03)	1.11 (1.01-1.23)	1.34 (1.22-1.47)	1.51 (1.37-1.66)	1.73 (1.56-1.90)	1.91 (1.71-2.08)	2.08 (1.86-2.27)	2.25 (2.00-2.46)	2.48 (2.18-2.71)	2.65 (2.32-2.91)
60-min	1.16 (1.06-1.28)	1.40 (1.27-1.53)	1.71 (1.56-1.88)	1.96 (1.78-2.15)	2.30 (2.08-2.52)	2.58 (2.32-2.82)	2.86 (2.56-3.13)	3.15 (2.80-3.45)	3.55 (3.13-3.89)	3.86 (3.38-4.24)
2-hr	1.36 (1.24-1.50)	1.63 (1.48-1.79)	1.99 (1.81-2.19)	2.29 (2.07-2.51)	2.69 (2.42-2.96)	3.02 (2.70-3.31)	3.36 (3.00-3.69)	3.72 (3.29-4.08)	4.21 (3.69-4.63)	4.60 (4.00-5.07)
3-hr	1.46 (1.32-1.62)	1.75 (1.59-1.93)	2.14 (1.93-2.36)	2.46 (2.22-2.71)	2.90 (2.61-3.20)	3.26 (2.91-3.60)	3.64 (3.23-4.01)	4.04 (3.56-4.45)	4.59 (4.01-5.07)	5.04 (4.35-5.57)
6-hr	1.77 (1.61-1.94)	2.11 (1.93-2.32)	2.57 (2.35-2.83)	2.96 (2.69-3.25)	3.51 (3.17-3.84)	3.96 (3.56-4.33)	4.43 (3.95-4.84)	4.94 (4.37-5.40)	5.65 (4.95-6.19)	6.23 (5.39-6.84)
12-hr	2.11 (1.94-2.30)	2.52 (2.31-2.75)	3.07 (2.81-3.35)	3.52 (3.22-3.84)	4.17 (3.79-4.53)	4.70 (4.25-5.10)	5.25 (4.72-5.70)	5.85 (5.21-6.35)	6.68 (5.88-7.28)	7.36 (6.41-8.05)
24-hr	2.52 (2.38-2.69)	3.02 (2.85-3.21)	3.70 (3.48-3.93)	4.26 (4.00-4.52)	5.06 (4.72-5.37)	5.71 (5.32-6.06)	6.41 (5.93-6.81)	7.16 (6.57-7.61)	8.22 (7.45-8.76)	9.09 (8.14-9.72)
2-day	3.02 (2.84-3.21)	3.60 (3.40-3.83)	4.40 (4.14-4.68)	5.05 (4.74-5.36)	5.95 (5.56-6.31)	6.68 (6.22-7.09)	7.45 (6.89-7.91)	8.24 (7.58-8.78)	9.36 (8.51-10.0)	10.3 (9.24-11.0)
3-day	3.23 (3.05-3.43)	3.86 (3.65-4.09)	4.69 (4.42-4.97)	5.35 (5.04-5.67)	6.26 (5.87-6.63)	7.00 (6.53-7.41)	7.75 (7.20-8.22)	8.53 (7.88-9.07)	9.60 (8.78-10.3)	10.5 (9.48-11.2)
4-day	3.45 (3.26-3.65)	4.11 (3.89-4.35)	4.97 (4.70-5.26)	5.65 (5.33-5.98)	6.58 (6.18-6.95)	7.31 (6.85-7.73)	8.05 (7.51-8.53)	8.81 (8.18-9.35)	9.84 (9.04-10.5)	10.7 (9.72-11.4)
7-day	4.14 (3.91-4.40)	4.93 (4.65-5.23)	5.95 (5.59-6.31)	6.77 (6.36-7.18)	7.91 (7.40-8.39)	8.83 (8.23-9.37)	9.79 (9.07-10.4)	10.8 (9.92-11.5)	12.1 (11.1-13.0)	13.2 (12.0-14.2)
10-day	4.73 (4.46-5.01)	5.62 (5.30-5.95)	6.73 (6.34-7.13)	7.61 (7.17-8.05)	8.81 (8.26-9.33)	9.77 (9.13-10.3)	10.7 (9.99-11.4)	11.8 (10.9-12.5)	13.1 (12.0-14.0)	14.2 (12.9-15.2)
20-day	6.50 (6.14-6.89)	7.70 (7.27-8.17)	9.10 (8.59-9.64)	10.2 (9.58-10.8)	11.6 (10.9-12.3)	12.6 (11.9-13.4)	13.7 (12.8-14.5)	14.7 (13.7-15.7)	16.1 (14.9-17.2)	17.1 (15.8-18.3)
30-day	8.11 (7.67-8.58)	9.57 (9.05-10.1)	11.2 (10.6-11.8)	12.4 (11.7-13.1)	13.9 (13.1-14.7)	15.1 (14.2-16.0)	16.2 (15.2-17.1)	17.3 (16.1-18.3)	18.6 (17.3-19.8)	19.6 (18.2-20.9)
45-day	10.3 (9.73-10.8)	12.1 (11.4-12.7)	13.9 (13.1-14.6)	15.2 (14.4-16.0)	16.8 (15.9-17.6)	17.9 (16.9-18.9)	19.0 (17.9-20.0)	20.0 (18.8-21.1)	21.1 (19.9-22.3)	22.0 (20.6-23.2)
60-day	12.3 (11.8-13.0)	14.5 (13.8-15.2)	16.5 (15.7-17.4)	18.0 (17.1-18.9)	19.8 (18.8-20.8)	21.1 (20.0-22.1)	22.2 (21.1-23.4)	23.3 (22.0-24.5)	24.5 (23.1-25.9)	25.4 (23.9-26.8)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Figure 2.2 Precipitation Frequency from NOAA for Richmond (Please visit the NOAA website for current data)

B RETURN INTERVAL

1 General Information

Because it is not economically feasible to design a structure for the maximum runoff a watershed is capable of producing, City of Richmond has attempted to balance the costs of designing and constructing drainage facilities with the benefits and risks associated with the drainage structure. This is accomplished by analyzing drainage structures by using storm discharges that vary according to the risk involved.

Table 2 1 reflects the results of evaluating these issues and lists the various storms used to analyze drainage systems for the City.

The discharges used to analyze drainage systems are based on storms that are anticipated to recur within a specified return interval (also called recurrence interval, return period or flood frequency). The return interval is the average time interval between occurrences of a hydrologic event of a given or greater magnitude, usually expressed in years. The return interval is based on the average statistical time between storm events. Therefore a 50 year storm is expected to occur on average every 50 years.

Drainage facilities are analyzed using multiple storms of differing return intervals. The reason for this is that each analysis involving these various return intervals have different purposes and risks associated with them. The two primary types of storms used to analyze drainage systems are the Design Storm and the Check Storm. The return intervals used for these storms are based on the traffic volume, potential flood hazard to property, expected level of service, and the risk associated with damages from larger flood events.

Design Storm

The “design storm” or “design discharge” is primarily used to evaluate the level of protection that the drainage facility provides for the roadway. As can be seen from Table 2.1, the return intervals used to determine the design discharge are different for each type of drainage facility and the size of the road facility.

The design discharge values are used to evaluate the drainage facilities ability to meet certain design criteria. These criteria differ according to the type of drainage facility and the intended purpose of each drainage facility. These criteria are discussed in the applicable chapters in this manual for the type of facility being analyzed (culvert, bridge, storm sewer, etc).

Check Storm

The “Check Storm” is used to determine the offsite impacts to surrounding property and to evaluate the facilities performance under more severe flooding conditions. The 100 year storm (1%) is the standard most used to determine the impacts to surrounding properties. The National Flood Insurance Program (NFIP) specifies the use of the 100 year storm (1%) for this purpose. The NFIP requirements generally apply to watersheds larger than one square mile and are based primarily on damage to insurable buildings. Refer to the appropriate chapter for the drainage facility in question to determine how to apply the check storms.

2 Application

The following table shows appropriate return intervals for each indicated situation. Design storm return intervals are indicated by a "D". Check storms are denoted by a "C". Other storms that are required to meet a specific purpose are indicated by an "X". See the appropriate chapter for the type of drainage facility being designed for discussion on how these storms are used to analyze the facility.

Table 2.1, Return Intervals for Drainage Analysis				
Situation	**Return Interval (years)**			
Type	**10 yr 24hr**	**25 yr 24hr**	**100 yr 6hr**	**100 yr 24hr**
Culverts (1)		D		C
Storm Sewer (2)		D		C
Inlet Spread(3)	X			
Ditch capacity / Ditch Lining shear	D			
Detention or Retention Basin	D	D	D	D
No Impact Certification				X
Letter of Map Revision (FEMA)				X

1) The Headwater of the Culverts must be less than 1.5D (1.5 x diameter of the pipe) for the 100yr 24hr storm
2) Storm sewer pipes should be checked to ensure that the hydraulic grade line resulting from the 100 year 24hr storm (1%) does not surcharge into the roadway.
3) Pavement inlet spacing spread calculations shall be based on four (4) in/hr Rainfall intensity.

C RATIONAL METHOD

1 Introduction

The City of Richmond's standard practice is to use the Rational Method for determining peak flow from drainage areas less than 20 acres. Although the 20 acre limitation is a widely used standard upper limit for the Rational Method, engineering judgment should be used to determine if a watershed smaller than 20 acres requires other methods. The Rational Method formula estimates discharge according to the equation below. The accuracy of this formula is highly dependent upon the user's ability to select an appropriate runoff coefficient and to calculate the time of concentration.

Rational Formula

$$Q = C \times I \times A$$

Q = Peak runoff discharge (ft^3/s)

C = Runoff Coefficient for the drainage area
I = Average Rainfall intensity (inch/hr) for a duration equal to the time of concentration, Tc
A = Drainage area (acres)

2 *Rational Method Assumptions*

It is useful for the designer to understand the assumptions behind the Rational Method.

- ❖ Peak discharge is assumed to occur when the entire watershed is contributing to the flow.
- ❖ Rainfall Intensity is assumed to be uniform across the entire drainage area and for a duration equal to the time of concentration (T_C).
- ❖ The return interval for the peak flow rate is the same as that of the average rainfall intensity for a given time of concentration (i.e., the 10 year rainfall intensity produces the 10 year peak runoff).
- ❖ The fraction of rainfall that becomes runoff, also known as the runoff coefficient (C), is assumed to be independent of rainfall intensity, volume, or antecedent moisture conditions. It is also assumed to be constant over the course of the entire rainfall duration.

3 *Runoff Coefficient (C)*

Only a portion of the total storm water falling on an area will reach the drainage structure. Many factors govern the percent of runoff, including rate of evaporation, rate of transpiration, volume of infiltrated water, and volume of ponded water. The runoff coefficient attempts to condense all of these factors into one value. Table 2.2 lists typical C values for various land coverage types:

Table 2.2 Runoff Coefficients for Rational Formula

Type of Drainage Area	**Runoff Coefficient, C**
Business:	
Downtown areas	0.70 0.95
Neighborhood areas	0.50 0.70
Residential:	
Single family areas	0.30 0.50
Multi units, detached	0.40 0.60
Multi units, attached	0.60 0.75
Suburban	0.25 0.40
Apartment dwelling areas	0.50 0.70
Industrial:	
Light areas	0.50 0.80
Heavy areas	0.60 0.90
Parks, cemeteries	0.10 0.25
Playgrounds	0.20 0.40
Railroad yard areas	0.20 0.40
Unimproved areas	0.10 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 0.10
Sandy soil, average, 2 7%	0.10 0.15

Sandy soil, steep, 7%	0.15 0.20
Heavy soil, flat, 2%	0.13 0.17
Heavy soil, average, 2 7%	0.18 0.22
Heavy soil, steep, 7%	0.25 0.35
Streets:	
Asphaltic	0.70 0.95
Concrete	0.80 0.95
Brick	0.70 0.85
Drives and walks	0.75 0.85
Roofs	0.75 0.95

The C factor of a complex area is determined by calculating a weighted C value using the appropriate C factor for each subarea. The following table shows an example of determining a weighted C factor for a composite area.

Table 2.3, EXAMPLE: Weighted C Factor

Surface	C Factor	Area (%)	Product
Watertight roof surfaces	0.75	10	0.08
Traffic bound pavement	0.90	15	0.14
Concrete pavement	0.80	25	0.2
Slightly pervious soil, with turf	0.25	50	0.13
Weighted C Factor Result		**100**	**0.55**

4 Time of Concentration (TC)

The time of concentration (Tc) is the time (usually in minutes) for excess runoff to travel from the most hydraulically distant point of the watershed to the outlet/design point. In order to estimate the average design rainfall Intensity (I) in the Rational Method, the duration of the storm is assumed to be equal to the time of concentration for the watershed. Once the time of concentration is determined, the intensity is selected from an Intensity Duration Frequency relationship for the computed storm duration (equal to the time of concentration). High Tc values result in lower intensities, while lower Tc values result in higher intensities. It recommended using a minimum value of five (5) minutes for Tc in order to avoid extremely high storm intensity values.

Time of concentration is composed of three components: overland flow, shallow concentrated flow, and channel flow. The practice has been to incorporate shallow concentrated flow into the channel flow component thereby reducing the calculations to overland and channel flow. However, it is permissible to include all three types of flow. The equation for time of concentration is:

Time of Concentration

$$T_c = T_o + T_s + T_{ch}$$

Where:

T_C= Total time of concentration (minutes)
T_O= Overland flow travel time (minutes)
T_S= Shallow concentrated flow travel time (minutes)
T_{ch}= Channel flow travel time (minutes)

Overland Flow Travel Time

Overland flow, or sheet flow, is the shallow flow of runoff on plane surfaces. These flows typically occur at the head of a watershed or subbasin where the runoff has not accumulated enough mass to form a definable swale or channel. Typical depth ranges from less than an inch to two (2) inches. Impacting this flow is a friction value expressed as an effective roughness coefficient. It includes many factors that are difficult to observe or measure such as raindrop impact, drag over the plane surface, and resistance by obstacles such as litter, crop ridges, and rocks. Representative values of surface roughness for various surfaces are listed in Table 2.3

NRCS Overland Flow Travel Time

$$T_o = \frac{.42}{P2^{0.5}} \times \left(\frac{N x L}{\sqrt{S}}\right)^{0.8}$$

Where:

T_O = Overland flow travel time (minutes)
P_2 = 2 Year, 24 Hour rainfall depth (inches), can be obtained from the Precipitation Data Frequency Server, See DR 201
N = Manning's Roughness Coefficient for Overland Sheet flow
L = Overland flow length (feet)
S = Slope of Overland flow length (feet per foot)

Representative values for overland flow length are difficult to determine. Generally, 300 feet is considered to be a maximum length for overland flow and, therefore, it should be the maximum value on projects. Selecting a longer value as opposed to a shorter value for this length does not ensure a more conservative hydraulic design. In fact selecting shorter overland flow lengths is a more conservative hydraulic practice because storm intensity is inversely proportional to overland flow length. The FWHA publications "Hydraulic

Table 2.3 Manning's Roughness (N) for Overland Flow	
Surface	**Value**
Paved Surfaces	
Smooth surfaces (concrete, asphalt, gravel or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Fields	
Residue cover $\leq$ 20 percent	0.06
Residue cover > 20 percent	0.17
Range (natural)	0.13
Grass	
Short grass prairie	0.15
Dense grasses	0.24

Bermuda grass	0.41
Woods	
Light underbrush	0.40
Dense underbrush	0.80

Engineering Circular 22" (HEC 22) and "Highway Hydrology" (HDS 2) both offer some guidance on overland flow distances.

Shallow Concentrate Flow Time

After short distances, sheet flow tends to concentrate in rills and gullies of increasing proportions and begins moving at a much faster rate. Such flow is referred to as shallow concentrated flow. The velocity of such flow can be estimated using an empirical relationship between the velocity and slope.

Shallow Concentrated Flow

$$V_S = k \times S^{0.50}$$

Where:

V_S = Average shallow concentrated velocity (feet per second)
k = intercept coefficient (Table 2.4)
S = Shallow Concentrated Slope, (feet per foot)

Table 2.4, Intercept Coefficients for Velocity vs. Slope	
K[1]	**Land cover/ flow regime**
0.249	Forest with heavy ground litter, hay meadow
0.499	Trash fallow or minimum tillage cultivation; contour or strip cropped; woodland
0.699	Short grass pasture
0.899	Cultivated straight row
1.000	Nearly bare and untilled; alluvial fans in western mountain regions
1.499	Grassed waterway
1.610	Unpaved
2.030	Paved area; small upland gullies

Channel and Pipe Travel Time

Overland and/or shallow concentrated flow empties into channels or pipes where it is conveyed to the outlet point. The transition between shallow concentrated flow and channel flow is assumed to occur where either the blue line stream is visible on USGS quadrangle sheets or when the channel is visible on aerial photographs or field inspections. The Manning's equation in often used to estimate average flow velocity in the channel or pipe. A channel typical of the entire channel length should be used to estimate channel velocity. Alternately, the channel flow can be divided up into multiple s to determine the total channel travel time.

Manning's Equation

$$V = \frac{1.486}{n} \times R^{0.67} \times S^{0.50}$$

Where:

V = Average channel velocity (feet per second
n = Manning's roughness coefficient
R = Hydraulic radius [A/P] (feet)
S = Slope (feet per foot)

In areas where it is difficult to determine the hydraulic radius, such as swale ditches and indeterminate flow paths, it is permissible to assume values of R = 0.20 feet for paved surfaces and R = 0.40 feet for unpaved surfaces.

Channel Travel Time Equation

$$T_t = L /(60 \times V)$$

Where:

V = Average velocity for channel segment
L = Segment flow length
T_t =Travel time per channel segment

5 *Storm Intensity (I)*

The rainfall intensity (I) is the average rainfall rate (in/h) for a duration equal to the time of concentration for a selected return interval. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Rainfall Intensity Duration curves.

The storm intensity for a particular return interval and duration of storm varies across the state. Statistical methods have been used to determine these storm intensities. These methods analyze past records of storm intensity duration relationships for various return periods to produce storm intensity duration frequency (IDF) relationships in the form of tables or curves. These IDF relationships shall be obtained from the NOAA Precipitation Frequency Data Server described in .

IDF curves are often plotted as storm intensity (iph) versus storm duration (min). The designer should become familiar with the IDF curves and their relationships. General relationships should be observed:

- The actual reoccurrence interval for any storm is not accurately predictable. A 100 year storm has a 1% chance of occurring in any particular year while a 25 year storm has a 4% chance of occurring in any particular year.
- Short duration storms usually produce the highest storm intensities while longer duration storms usually produce lower storm intensities.
- Intensity is a direct function of maximum travel time or time of concentration (Tc). Longer travel times produce lower intensities while shorter travel times produce higher intensities.

D NRCS UNIT HYDROGRAPH

1 Introduction

A hydrograph is a graph of the time distribution of runoff from a particular point in a watershed. Hydrograph design is only necessary in certain cases when timing of the runoff becomes important. Detention basin design is the most common type of drainage analysis that requires hydrograph calculations. However, complex storm sewer designs or watershed analysis may necessitate the use of hydrographs. As a general rule, peak flow design will suffice for most highway drainage designs. The City of Richmond has adopted the Natural Resources Conservation Service (NRCS) Unit Hydrograph Method for these types of analyses. The NRCS was formerly known as the Soil Conservation Service (SCS). Some publications still refer to this method as the SCS method, however both acronyms refer to the same method.

The techniques developed by NRCS for calculating rates of runoff require the same basic data as the Rational Method, drainage area, a runoff factor, time of concentration, and rainfall depths. However, the NRCS approach considers additional factors such as the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and an infiltration rate that decreases during the course of a storm. With the NRCS method, the direct runoff can be calculated for any storm, either real or fabricated, by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess.

2 Rainfall

The NRCS method is based on a 24 hour storm event. For Kentucky this rainfall distributed base on a Type II time distribution. The storm distributions are “typical” time distributions which the NRCS has prepared from rainfall records for various regions of the country.

3 Hydrologic Soil Groups

Soil properties influence the relationship between runoff and rainfall because soils have differing rates of infiltration. Infiltration is the movement of water through the soil surface into the soil. Based on infiltration rates, NRCS has divided soils into four hydrologic soil groups as follows:

Group A - Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well drained sands and gravels.

Group B - Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C - Soils having a moderately high runoff potential due to slow infiltration rates. These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D - Soils having a high runoff potential due to very slow infiltration rates.

These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious parent material.

The NRCS soil group can be identified at a site using either soil characteristics or county soil surveys. The soil characteristics associated with each group are listed above and provide one means of identifying the SCS soil group. County soil surveys, which are made available by Soil Conservation Districts, give detailed descriptions of the soils at locations within a county; these surveys are usually the better means of identifying the soil group. Many of the more recent reports actually categorize the soils into these four groups. The NRCS also has a web application called the "Web Soil Survey" that contains much soil information through a GIS based web browser. As of the publication date of this, the website address for this application is located at the following address: **http://websoilsurvey.nrcs.usda.gov/app/**

4 Curve Numbers

In hydrograph applications, runoff is often referred to as rainfall excess or effective rainfall, all defined as the amount by which rainfall exceeds the capability of the land to infiltrate or otherwise retain the rainwater. The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types and land slope.

Land use is the watershed cover, and it includes both agricultural and nonagricultural uses. Items such as type of vegetation, water surfaces, roads and roofs are all part of the land use. Land treatment applies mainly to agricultural land use, and it includes mechanical practices (e.g., contouring, terracing) and management practices (e.g., rotation of crops).

NRCS uses a combination of soil conditions and land use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area when the soil is not frozen. The higher the CN, the higher the runoff potential.

Tables 2.5 and 2.6 presents the NRCS curve number values for the different land uses, treatments and hydrologic conditions; separate values are given for each soil group. For example, the CN for a wooded area with good cover and soil group B is 55; for soil group C, the CN would increase to 70. If the cover (on soil group B) is poor, the CN will be 66. These tables are based on an average antecedent moisture condition; i.e., soils that are neither very wet nor very dry when the design storm begins. Curve numbers should be selected only after a field inspection of the watershed and a review of zoning and soil maps. For areas with differing curve numbers, a weighted curve number can be calculated by the same methods described for weighted C factors in .

Table 2.6 uses Hydrologic Condition to determine the appropriate Curve Numbers. Hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year round cover; (c) amount of grass or close seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

Tables 2.5 & 2.6 have been simplified from most published versions of the curve number tables. Credit is given to certain agricultural conservation practices such as conservation tillage, land contouring and land terracing. Also more cover types are included in other published curve number tables. If the designer feels a more detailed determination of the curve number values are warranted, more information can be obtained from Hydraulic Design Series No. 2 (HDS 2) "Highway Hydrology" published by the Federal Highway Administration and Chapter 9 of "The National Engineering Handbook, Part 630," published by the NRCS.

*** Table 2.5 NRCS Curve Numbers For Urban Areas**

Cover Type	**Curve Numbers For Hydrologic Soil Group**			
	A	B	C	D
Fully developed urban areas[a] (vegetation established)				
Lawns, open spaces, parks, golf courses, cemeteries, etc.				
Good condition; grass cover on 75% or more of the area	39	61	74	80
Fair condition; grass cover on 50% to 75% of the area	49	69	79	84
Poor condition; grass cover on 50% or less of the area	68	79	86	89
Paved parking lots, roofs, driveways, etc. (excl. right of way)	98	98	98	98
Streets and roads				
Paved with curbs and storm sewers (excl. right of way)	98	98	98	98
Gravel (incl. right of way)	76	85	89	91
Dirt (incl. right of way)	72	82	87	89
Paved with open ditches (incl. right of way)	83	89	92	93

Cover Type	**Average % impervious**	**Curve Numbers For Hydrologic Soil Group**			
		A	B	C	D
Commercial and business areas	8	89	92	94	95
Industrial districts	7	81	88	91	93
Row houses, town houses, and residential with lots sizes 0.05 ha or less (0.12 acres or less)	6 5	77	85	90	92
Residential: average lot size					
0.1 ha (0.25 acres)	3	61	75	83	87
0.135 ha (0.33 acres)	3	57	72	81	86
0.2 ha (0.5 acres)	2	54	70	80	85
0.4 ha (1.0 acres)	2	51	68	79	84
0.8 ha (2.0 acres)	1	46	65	77	82

*This table is abbreviated from its original form in HDS 2

Table 2.6 NRCS Curve Numbers For Agricultural & Forested Areas					
Cover Type	Hydrologic Condition	Curve Numbers for Hydrologic			
		A	B	C	D
Row crops	Poor	72	81	88	91
	Good	67	78	85	89
Small grain	Poor	65	76	84	88
	Good	63	75	83	87
Pasture or range	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77

*This table is abbreviated from its original form in HDS 2

5 *Rainfall Runoff Relationship*

A relationship between accumulated rainfall and accumulated runoff was derived by NRCS from experimental plots for numerous soils and vegetative cover conditions. Data for land treatment measures (e.g., contouring, terracing) from experimental watersheds were included. The equation was developed mainly for small watersheds for which only daily rainfall and watershed data are ordinarily available. It was developed from recorded storm data that included the total amount of rainfall in a calendar day but not its distribution with respect to time. The NRCS runoff equation is therefore a method of estimating direct runoff from a 24 hour or 1 day storm rainfall. The equation is:

Equation Direct Runoff

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

Where:

Q = accumulated direct runoff, inches
P = accumulated rainfall (potential maximum runoff), inches
Ia = initial abstraction including surface storage, interception and infiltration prior to runoff, inches
S = potential maximum retention, inches

It is worthwhile noting that Q in the NRCS runoff equation is a depth of runoff and not a flow rate as with most other hydrologic calculations. While Q and P have units of depth, they reflect volumes and are often referred to as volumes because it is usually assumed that the same depths occurred over the entire watershed area.

The relationship between Ia and S was developed from experimental watershed data. It removes the necessity for estimating Ia for common usage. The empirical relationship used to estimate the initial abstraction is shown below.

Equation Initial Abstraction

$$Ia = 0.2S$$

Substituting 0.2S for Ia in the equation, the NRCS rainfall runoff equation becomes:

Equation Direct Runoff

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

Equation above represents the basic equation for computing the accumulated runoff depth, Q, for a given accumulated rainfall depth, P.

Additional empirical analyses were made to estimate the value of S. The studies found that S was related to soil type, land cover, and the hydrologic condition of the watershed. These are represented by the runoff curve number (CN), which is used to estimate S by:

Equation Maximum Potential Retention

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

Where:

S = potential maximum retention, inches

CN = index that represents the combination of a hydrologic soil group and a land use and treatment class

6 *NRCS Dimensionless Unit Hydrograph*

Two types of unit hydrographs are used in the NRCS procedure to develop the direct runoff hydrograph that will be used in the design of the drainage facility. These are unit hydrographs and the dimensionless unit hydrograph.

A unit hydrograph (UH) represents the time distribution of flow resulting from a unit of precipitation (usually 1 inch) of direct runoff occurring over a watershed in a specified time. A dimensionless unit hydrograph represents the composite of many unit hydrographs. The dimensionless unit hydrograph is plotted in non dimensional units of time versus time to peak and discharge at any time versus peak discharge.

In the development of the NRCS Unit Hydrograph Method, unit hydrographs were evaluated for a large number of actual watersheds and then made time ordinates by the time to peak. An average of these dimensionless unit hydrographs was computed. The time base of the dimensionless unit hydrograph was approximately 5 times the time to peak, and approximately 3/8 of the total volume occurred before the time to peak; the inflection point on the recession limb occurs at approximately 1.7 times the time to peak, and the UH has a curvilinear shape. The NRCS dimensionless unit hydrograph is shown in Figure 2.3.

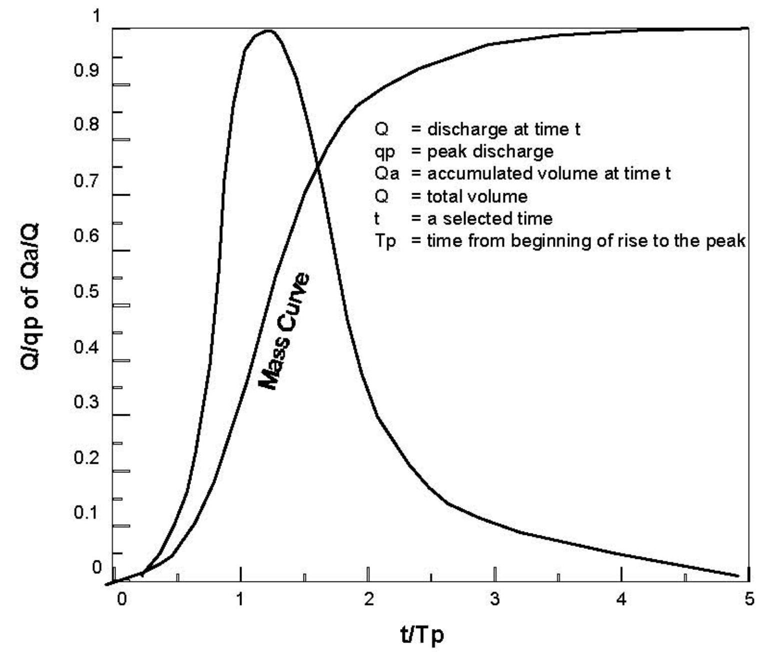


Figure 2.3 NRCS Dimensionless Unit Hydrograph

7 *Watershed Lag & Time of Concentration*

There is a delay in time, after a rain event, before the runoff reaches its maximum peak. This delay is a watershed characteristic called lag. The lag is defined as the time from the center of mass of excess rainfall to the time to peak of the hydrograph. Steep slopes, compact shape and an efficient drainage network tend to make lag time short and peaks high; flat slopes, elongated shape and an inefficient drainage network tend to make lag time long and peaks low.

Lag is related to the time of concentration and may be estimated from it. In hydrograph analysis, time of concentration (Tc) is defined in two ways:

- The time for runoff to travel from the hydraulically most distant point in the watershed to outlet or point in question.
- The time from the end of excess rainfall to the point of inflection on the receding limb of the unit hydrograph.

The first definition is used to calculate the time of concentration. The NRCS derived the following empirical relationship between lag and time of concentration:

Equation Lag Time

$$L = 0.6\ Tc$$

Where:

L = watershed lag in minute
Tc=Time of Concentration

Table 405 4 Ratios for Dimensionless Unit Hydrograph and Mass Curve		
Time Ratios t/Tp	Discharge Ratios q/qp	Mass Curve Ratios Qa/Q
0	0.000	0.000
0.1	0.030	0.001
0.2	0.100	0.006
0.3	0.190	0.012
0.4	0.310	0.035
0.5	0.470	0.065
0.6	0.660	0.107
0.7	0.820	0.163
0.8	0.930	0.228
0.9	0.990	0.300
1.0	1.000	0.375
1.1	0.990	0.450
1.2	0.930	0.522
1.3	0.860	0.589
1.4	0.780	0.650
1.5	0.680	0.700
1.6	0.560	0.751
1.7	0.460	0.790
1.8	0.390	0.822
1.9	0.330	0.849
2.0	0.280	0.871
2.2	0.207	0.908
2.4	0.147	0.934
2.6	0.107	0.953
2.8	0.077	0.967
3.0	0.055	0.977
3.2	0.040	0.984
3.4	0.029	0.989
3.6	0.021	0.993
3.8	0.015	0.995
4.0	0.011	0.997
4.5	0.005	0.999
5.0	0.000	1.000

8 NRCS UNIT HYDROGRAPH PEAK DISCHARGE

For purposes of comparison, the curvilinear dimensionless unit hydrograph (UH) can be approximated by a triangular dimensionless UH that has similar characteristics.

It is important to recognize that the triangular dimensionless UH is not a substitute for the curvilinear dimensionless UH. The curvilinear UH is always used in hydrologic computations. The triangular dimensionless UH is only used to develop an expression for computing the peak discharge of the curvilinear UH.

The dimensionless unit hydrograph is used to develop a unit hydrograph for the watershed being analyzed. In order to convert the dimensionless UH to a UH for the watershed being analyzed it is necessary to determine the peak flow and time to peak. Using the relationships shown in Figure 405 2, NRCS developed an equation for the peak discharge of the unit hydrograph:

Equation Unit Hydrograph Peak Flow

$$q_p = K_p \text{ x } A \text{ x } Q / T_p$$

Where:

q_P = unit hydrograph peak discharge (cfs)
K_P = peak rate factor equal to 484 (dimensionless)
A = drainage area (mi^2)
Q = direct runoff, (inches)
Tp = time to peak (hours)

By definition the unit hydrograph represents the time distribution of flow resulting from a unit of precipitation. Therefore, when using English units, Q in the above will be equal to 1 inch.

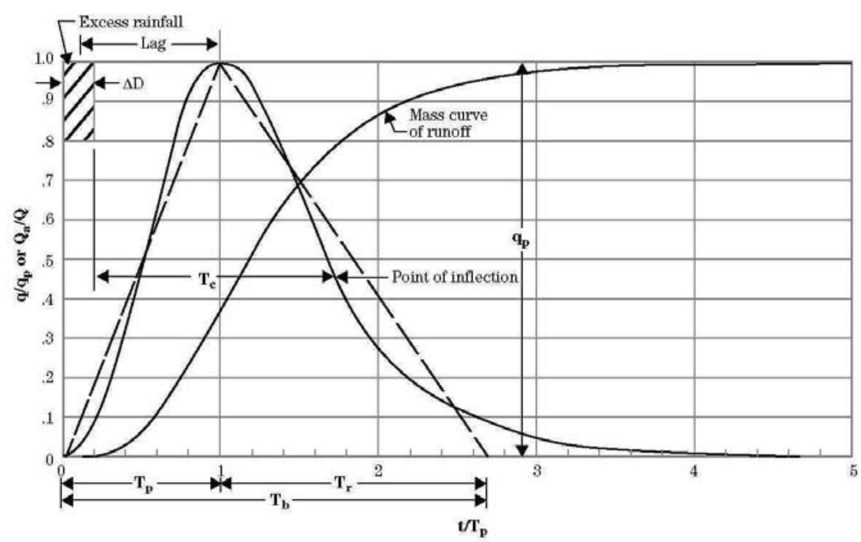


Figure 2.4 NRCS Dimensionless Curvilinear Unit Hydrograph and Equivalent Triangular Hydrograph

Referring to figure 2.4, the time to peak can be expressed by the following relationship:

Equation Time to Peak

$$T_p = \frac{\Delta D}{2} + L$$

Where:
ΔD = duration of unit excess rainfall (hours)
L = Lag time (hours)

Unit hydrograph analysis involves dividing up precipitation events into smaller unit storms (more specifically into smaller durations of excess precipitation). The duration of these unit storms is ΔD. The unit hydrograph developed for a watershed is often referred to as a ΔD hour unit hydrograph. Substituting equations, the time to peak can be expressed as:

Equation Time to Peak

$$T_p = \frac{\Delta D}{2} + 0.6Tc$$

As mentioned earlier, the inflection point on the recession limb of the NRCS dimensionless UH occurs at approximately 1.7 times the time to peak. Again referring to Figure 2.3, a relationship between the time to peak and time of concentration can now be established:

$$Tc + \Delta D = 1.7Tp$$

Using equations above a relationship between ΔD and Tc can be established:

$$\Delta D = .133Tc$$

9 *APPLICATION AND LIMITATIONS*

Applying the NRCS Unit Hydrograph methodology to develop design hydrographs requires a significant amount of tedious calculations if performed by hand. However the advent of computer technology has made this method easy to apply. Most off the shelf hydrology programs that do hydrograph analysis have the NRCS unit hydrograph elements programmed into them. As noted earlier, the input required for the NRCS UH method include the drainage area, a runoff factor, time of concentration, and rainfall depths.

CHAPTER 3 - FLOODPLAIN MANAGEMENT

A NATIONAL FLOOD INSURANCE PROGRAM

1 General

For decades, the national response to flood disasters was limited to building flood control works (dams, levees, seawalls, etc.) and providing disaster relief to flood victims. To compound the problem, the public could not buy flood coverage from insurance companies, and building techniques to reduce flood damage were often overlooked. In the face of mounting flood losses, Congress created legislation to establish a floodplain management program to reduce annual flood losses through more careful planning and providing property owners with affordable flood insurance. The result of this legislation was the National Flood Insurance Program (NFIP). The NFIP is a very comprehensive program that deals with a plethora of floodplain management topics. This manual only covers portions of the program that affect highway construction and only constitutes a very small portion of the program.

"Floodplain Management" means operating an overall community program of corrective and preventive measures for reducing flood damage, including (but not limited to) emergency preparedness plans and other measures aimed at the present and future use of the floodplain. Floodplain management includes specific local codes and ordinances that provide standards for the location and design of development within flood-prone areas. These measures may be adopted in any manner that is legally enforceable for a particular community. Typically, they take the form of zoning, subdivision or building requirements, and/or a special purpose floodplain ordinance.

A key element of the NFIP was mapping of the nations flood prone areas. Two primary concepts used in identifying these areas were floodplains and floodways. The language adopted by the NFIP has several specific terms that all relate to floodplains and floodways.

Generally speaking, a floodplain is defined as any land area that is susceptible to being inundated by water from any source. The NFIP adopted the 100 year flood as the standard for determination of floodplain limits for purposes of the program. In the NFIP program, the 100 year flood is referred to as the Base Flood and the resulting water surface elevations are referred to as Base Flood Elevations or (BFE). The limits of the 100 year floodplain as shown on the NFIP maps are referred to as Special Flood Hazard Areas (SFHA's).

Another key concept in the program is the floodway. Generally speaking, the floodway is the part of the floodplain kept clear of obstructions to allow the passage of floodwater. As adopted by the NFIP, the Regulatory Floodway is defined as "A floodplain management tool that is the regulatory area defined as the channel of a stream, plus any adjacent floodplain areas, that must be kept free of encroachment so that the base flood discharge can be conveyed without increasing the BFEs more than a specified amount."

Not all streams will have floodways established. This depends on the amount of detail that has been invested into the flood study for the stream. In areas that have been subject to detailed FEMA studies, Special Flood Hazard Areas and BFEs or flood depths will be shown on the NFIP Maps. In most cases, areas with detailed studies will also show floodways on the NFIP maps.

2 Flood Insurance

The National Flood Insurance Act of 1968, as amended, (42 U.S.C. 4001-4127) requires that communities adopt adequate land use and control measures to qualify for insurance. Federal criteria promulgated to implement this provision contain the following requirements which can affect certain projects:

- In riverine situations, when the Administrator of the Federal Insurance Administration has identified the flood prone area, the community must require that until a floodway has been designated, no use, including land fill, be permitted within the floodplain area having special flood hazards for which base flood elevations have been provided; unless it is demonstrated that the cumulative effect of the proposed use, when combined with all other existing and reasonably anticipated uses of a similar nature, will not increase the water surface elevation of the 100-year flood more than one foot at any point within the community.

- After the floodplain area having special flood hazards has been identified and the water surface elevation for the 100-year flood and floodway data have been provided, the community must designate a floodway which will convey the 100-year flood without increasing the water surface elevation of the flood more than the surcharge at any point and prohibit, within the designated floodway, fill, encroachments, and new construction and substantial improvements of existing structures which would result in any increase in flood heights within the community during the occurrence of the 100-year flood discharge.

- The participating cities and/or counties agree to regulate development in the designated floodplain and floodway through regulations adopted in a floodplain ordinance. The ordinance requires that development in the designated floodplain be consistent with the intent, standards and criteria set by the National Flood Insurance Program.

3 Flood Disaster Protection

The Flood Disaster Protection Act of 1973 (Pl 93-234, 87 Stat. 975) denies Federal financial assistance to flood prone communities that fail to qualify for flood insurance. Formula grants to states are excluded from the definition of financial assistance, and the definition of construction in the Act does not include highway construction; therefore, Federal aid for highways is not affected by the Act. The Act does require communities to adopt certain land use controls to qualify for flood insurance. These land use requirements could impose restrictions on the construction of projects in floodplains and floodways in communities that have qualified for flood insurance. A floodway, as used here and as used with the National Flood Insurance Program, is that portion of the floodplain required to pass a flood that has a 1-percent chance of occurring in any 1-year period without cumulatively increasing the water surface elevation more than a selected surcharge, usually one foot.

4 Local Community

The local community with land use jurisdiction, whether it is a city, county, or state, has the responsibility for enforcing National Flood Insurance Program (NFIP) regulations in that community, if the community is participating in the NFIP. Consistency with NFIP standards is a requirement for Federal-aid highway actions involving regulatory floodways. The community, by necessity, is the one who must submit proposals to Federal Emergency Management Agency (FEMA) for amendments to NFIP ordinances and maps in that community should that be necessary.

Determination of the status of a community's participation in the NFIP and review of applicable NFIP maps and ordinances are, therefore, essential first steps in conducting location hydraulic studies and preparing environmental documents. To determine if a community is participating in the NFIP, refer to the Community Status Book maintained by FEMA. The community status books for the various states can be found at the following website: **http://www.fema.gov/fema/csb.shtm**

Every community participating in the NFIP will have a designated Local Floodplain Coordinator. The Local Floodplain Coordinator is the local communities' primary point of contact for NFIP issues. The City of Richmond Planning & Zoning staff must be contacted to for additional information and requirements.

5 NFIP Maps

Where NFIP maps are available, their use is mandatory in determining whether a highway location alternative will include an encroachment on the base floodplain. Before the Map Modernization Project, three types of NFIP maps were published:

- Flood Hazard Boundary Map (FHBM),
- Flood Boundary and Floodway Map (FBFM), and
- Flood Insurance Rate Map (FIRM).

A FHBM is based on a detailed hydraulic study and, therefore, the floodplain boundaries shown are approximate. A FBFM is derived from detailed hydraulic studies and should provide reasonably accurate information. A FBFM shows the 100 Year and 500 Year Floodplain boundaries and Floodways. The hydraulic data from which the FBFM was derived are available from FEMA's contractor. This is normally in the form of a computer input data records for calculating water surface profiles.

The FIRM is generally produced at the same time as the FBFM, using the same hydraulic model .A FIRM shows the insurance rate zone and base flood elevations where detailed studies were conducted. The FIRM for the more recent mappings also shows the Floodway boundaries.

Communities may or may not have published one or more of the above maps depending on their level of participation in the NFIP. Information on community participation in the NFIP is provided in the "National Flood Insurance Program Community Status Book" which is published semiannually for each State.

In 1997 FEMA developed the Map Modernization Program to modernize the flood insurance mapping for the entire country. Communities that have had their maps updated through this project will have all necessary information contained in their FIRMs. The new maps do not have separate FHBMs or FBFMs. A distinctive feature of the new FIRM is that the mapping is based on aerial photography and GIS technology.

6 Executive Order 11988

Presidential Executive Orders (E.O.) have the effect of law in the administration of programs by Federal agencies. These laws apply directly to federal agencies. While executive orders do not directly apply to State Highway Department, any highway project using federal money has to follow these Executive Orders.

Executive Order 11988, May 24, 1977, (Federal Register, April 26, 1979 (44 CFR 24678, and 23 CFR 650, Subpart A) requires each Federal agency, in carrying out its activities, to take the following actions:

- ❖ Reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains; and

- ❖ Evaluate the potential effect of any actions it may take in a floodplain, to assure its planning programs reflect consideration of flood hazards and floodplain management.

B FLOODPLAIN MANAGEMENT POLICY

1 General

It should be noted that this chapter only speaks to design criteria as it applies to the NFIP, which is primarily concerned with limiting damage to surrounding properties. Drainage structures should be analyzed using design storm criteria as well.

2 Encroachment Concept

Encroachments are defined as any construction, placement of fill or similar alteration of topography in a floodplain or floodway that reduces the area available to convey floodwaters. Most highway drainage structures that cross a stream will require some encroachment into a floodplain. Floodplains are generally very wide, and avoiding them entirely is often not economical.

Encroachments into floodways are treated differently than encroachments into floodplains. Encroachments into floodways should be avoided; however, there are cases when an encroachment into floodway may be acceptable.

3 Applicability

As a general rule, floodplain encroachment criteria apply to streams with drainage areas that are larger than one square mile. However, some floodplains and floodways for streams with smaller drainage areas are shown on the NFIP maps. If stream impact occurs on a mapped floodplain or floodway, the criteria in this chapter will apply regardless of drainage area.

4 Coordination Required For All Encroachments

Any encroachment into a floodplain or floodway that meets the applicability requirements, requires coordination with City of Richmond Planning and Zoning department (Local Floodplain Coordinators) and the Division of Water.

The design engineer will send notification letters to the Division of Water (DOW) and/or Local Floodplain Coordinators outlining the projects impacts for these encroachments. These letters will be sent immediately following the development of hydraulic models for the project. These letters will contain the following information at a minimum:

- Location and description of the proposed hydraulic structures
- Information on the affected area such as: community name, effective date of study, community number, panel number and location of impact relative to any sections shown on the FIRMs
- Brief description of the specific impacts of each of these structures.

5 Allowable Increase (Rise)

The extent of an encroachment into a floodplain is quantified by the amount of increase in water surface elevations caused by the encroachment for the 100 year storm (1%). As mentioned earlier, FEMA refers to this storm as the Base Flood and the resulting water surface elevations as the Base Flood Elevations (BFE). Limits to the amount of increase that is allowable in the BFEs are promulgated in the NFIP standards and in some cases in a city ordinance.

If the project does not involve an Interstate, the project team may base this allowable increase on thresholds called for in a city ordinance. For purposes of this manual, allowable increases based on city ordinances will be referred to as "local allowable increases." When there is no such city ordinance or the project is located on an Interstate system, the allowable increase will be one foot.

This increase is based on a cumulative effect. Therefore if an existing structure (or other encroachment in the project vicinity) has already caused increases in the BFEs, a new structure will only be allowed to increase the BFEs by an amount equal to the allowable rise less the rise created by the existing structure.

6 Encroachments Into Floodplains Without Detailed Studies

The analysis and coordination involved with encroachments into floodplains is dependent on the level of study to which a stream has been subjected. To determine if an area has been subject to a detail study, BFEs will be shown on the NFIP maps. If BFE is shown, the stream has been subject to a detail study.

Encroachment On A FEMA Mapped Floodplain Without A Detailed Study

Where detailed studies have not been performed, and a floodplain is shown on the FEMA maps, the stream has been studied with approximate techniques. Streams that have been subject to approximate studies will show the floodplain as Zone A. In communities where no detailed flood insurance studies have been performed, the Base Flood Elevations will have to be determined by hydraulic modeling. Once the Base Flood Elevations have been established, the crossing (or any other impact) should be designed to keep increases to the Base Flood Elevations less than the allowable increase as discussed in 8.

Encroachment On An Unidentified Floodplain

Since 101 of the 120 counties in Kentucky have some FEMA mapping, all communities will be considered FEMA mapped. Notwithstanding the exceptions noted in the paragraph below, any encroachment into floodplains in this category should follow the criteria described above under “Highway Encroachment On A FEMA Mapped Floodplain Without A Detailed Study”.

On unidentified floodplains, the project team may elect to increase the allowable rise criteria. As mentioned earlier, it must be demonstrated that increasing this allowable rise is the only feasible alternative for the project. When this option is chosen, flooding easements must be purchased that include the limits of the proposed 100 year floodplain.

7 Encroachments Into Floodplains With Detailed Studies

Encroachment on a FEMA Mapped Floodplain With a Detailed Study, and a Floodway Shown with No Encroachment Into the Floodway

In most detailed study areas, floodways will be shown inside the limits of the floodplain. In these situations design the highway crossing (or any other impact) in a manner such that their components are excluded from the floodway. This is the simplest way to be consistent with the standards and should be the initial alternative evaluated when floodways are shown.Once it is proven that the project does not encroach on the floodway, no further analysis is necessary. To make a determination of whether or not the project encroaches on a floodway, it is usually necessary to obtain the hydraulic models upon which the FEMA mapping is based.

Encroachment On A FEMA Mapped Floodplain With A Detailed Study, but Without a Floodway Shown

In rare instances a floodplain may be mapped via a detailed study but no floodway delineated. In communities where a detailed flood insurance study has been performed but no regulatory floodway designated, the highway crossing (or any other impact) should be designed to keep increases to the Base Flood Elevations less that the allowable increase as discussed in 8. This analysis shall be based on technical data from the flood insurance study.

8 No Rise (No Impact) Floodway Encroachment

If a project element encroaches on the Floodway as shown on the NFIP map but has no effect on the Floodway water surface elevation (such as piers in the Floodway), the project may normally be considered as being consistent with the standards. This is justified if hydraulic conditions can be improved so that no water surface elevation increase or change in lateral limits of the floodway or floodplain is reflected in the computer printout for the new conditions. This is what is commonly referred to as a “No Rise” or “No Impact” certification.

If a floodway is encroached upon, this may trigger a rigorous review process by which specific modeling guidelines must be followed to ensure that a floodway encroachment is not causing any change to the horizontal and vertical limits of the floodplain and floodway. A FEMA review may be required. The No Rise certification will be completed by the designer and submitted with the hydraulic models to the Local Floodplain Coordinator and the Central Office Drainage Engineer. This process should take place immediately after the dimensions and layout of the hydraulic structure are determined.

9 Coordination With FEMA

The encroachments described in 8 through 10 do not generally require coordination with FEMA. However, it is intended that there should be coordination with FEMA, through the Local Floodplain Coordinator, in situations where administrative determinations are needed involving a regulatory Floodway or where flood risks in NFIP communities are significantly impacted. The circumstances which would ordinarily require coordination with FEMA include the following:

1. A proposed crossing encroaches on a regulatory floodway and the No Rise criteria described in 8 cannot be met. This would require an amendment to the floodway map and a map revision.

2. A proposed crossing encroaches on a floodplain shown on an NFIP Map and the maximum one-foot increase in the base flood elevation would be exceeded. This will require a map revision.

3. A local community is expected to enter into the regular program within a reasonable period, and detailed floodplain studies are under way.

4. A local community is participating in the emergency program, and base

FEMA flood elevation in the vicinity of insurable buildings is increased by more than one foot. Where insurable buildings are not affected, it is sufficient to notify FEMA of changes to base flood elevations as a result of project construction.

At a minimum, coordination means furnishing to FEMA, through the Local Floodplain Coordinator, a preliminary site plan, water surface elevation information, and technical data in support of a map revision request as required. The designer will prepare this information and forward it to the Local Floodplain Coordinator and FEMA.

10 Map Revisions

Some encroachments into floodplains or regulatory floodways will require a map revision. It cannot be stressed enough that map revisions should be avoided. When a map revision is required, it is imperative that the process be initiated in the early project phases. As soon as the dimensions and layout of the hydraulic structure involved are determined, the map revision process should be initiated.

Map revisions should be coordinated with the Central Office Drainage Engineer and the Local Floodplain Coordinator.

Details of the requirements for map revisions can be found in the FEMA document “Guidelines and Specifications for Flood Hazard Mapping Partners.” Volume 2 of this document details the processes for Map Revisions.

CONDITIONAL LETTERS OF MAP REVISION (CLOMR) & LETTERS OF MAP REVISION (LOMR)

Revisions to NFIP maps that are not substantial are accomplished by dissemination of a letter describing the changes. Although there are many different types of these letters, most projects that require a map revision will likely involve the Conditional Letter of Map Revision (CLOMR) and the Letter of Map Revision (LOMR).

If the project team decides that a map revision is appropriate for the project, the projects designer will initiate the CLOMR process. This process is essentially a request made to FEMA to modify the floodplain or regulatory floodway based on the proposed construction.

Once the project is complete, the City of Richmond will request a letter from the Design Engineer certifying the project was constructed according to the plans and asbuilts. This information will be sent to FEMA for initiation of the LOMR process. This essentially validates the conditions stated in the original COLOMR and finalizes the results in an official map change.

PHYSICAL MAP REVISIONS

When proposed changes to an NFIP map are determined by FEMA to be substantial, a Physical Map Revision will be required. Physical Map revisions require a higher level of review by FEMA, and have considerable costs associated with them. For more information see the aforementioned "Guidelines and Specifications for Flood Hazard Mapping Partners" published by FEMA.

CHAPTER 4 – OPEN CHANNEL HYDRAULICS

A INTRODUCTION

1 Open Channel Flow

Open-channel systems will often be used to collect and convey storm water. The open channels discussed in this chapter range from small manmade roadside channels that convey small local drainage areas to large natural channels that act as the primary storm water conveyance for a large geographic areas.

An open channel is defined as any conduit in which liquid flows with a free surface such as a stream, roadside ditch, depressed median, slope flume, or pipe flowing part full.

Although open channel hydraulic principles apply to both roadway ditches and stream channels, the analysis techniques and assumption are different for each of them.

2 General Design Considerations

The following general guidelines shall be considered in open channel design:

- Open channels shall be designed such that elevations of the water surface in the channel do not cause undue flooding of the proposed facility or damage to adjacent property.
- Open channels shall be designed to be stable against erosive forces of water.
- Use of grass lined channels shall be maximized as a drainage conveyance system due to their positive impacts on water quality. The use of turf reinforcing mats should be considered when natural vegetation alone will not withstand the expected erosive forces.

3 Roadside Ditches

Roadside ditches include the manmade channels used to convey local drainage to a larger drainage system. Roadside ditches:

- Are constructed channels with regular geometric cross sections uniformly shaped
- May be lined with a protective material to prevent erosion
- Are generally designed and analyzed assuming steady, uniform flow assumptions

4 Stream Channels

Stream channels are generally naturally shaped channels that usually drain larger areas than roadside ditches. Steam channels are:

- usually natural channels with their size and shape determined by natural

forces,
- usually compound in cross section with a main channel for conveying low flows and a floodplain to transport flood flows, and
- usually shaped in cross section and plan form by the long-term history of sediment load and water discharge that they experience.
- usually analyzed with step – backwater techniques.

This manual addresses stream channel design only as it pertains to hydraulic considerations minor disturbances to stream channels to facilitate new construction.

B CHANNEL CLASSIFICATION

1 Stream Channels

Stream channels include any drainage feature that is currently or ever has been a natural feature. Stream channels are generally larger than roadside ditches and are usually associated with large hydraulic structures such as bridges and culverts. However, stream channels can include very small channels that are not wet year round. Stream channels are sometimes relocated or modified to accommodate the construction of highways. Although there are cases where changes to stream channels will be necessary, this practice should be avoided if possible.

2 Road Ditches

Roadside ditches are manmade channels constructed to convey water. There are several different types of roadside ditches, roadside ditches usually have a “v” or flat bottom shape.

NORMAL DITCHES

Normal ditches refer to ditches that are constructed as a continuous grading operation with the roadway. The location and grade of normal ditches is controlled by the typical section and the horizontal and vertical alignment of the roadway. Normal ditches are usually associated with cut sections and run parallel to the highway.

SPECIAL DITCHES

Special ditches are used where the normal ditch geometry must vary from the typical section for hydraulic purposes. If a ditch is constructed wider, deeper, on a different grade, or is shaped differently than the typical roadway section normal ditch, then it is classified as a special ditch.

SURFACE DITCHES

These ditches are formed by excavating the ditch shape into the existing ground line surface. Surface ditches are primarily used at the base of fills to collect to roadway drainage or to intercept off site drainage before it reaches the toe of the fill. A flat bottom shape is generally used for surface ditches because of ease of construction. Judgment must be used in placing surface ditches in close proximity to the toe of slope for highway fills.

INTERCEPTOR DITCHES

Interceptor ditches are used to intercept water and convey it in a controlled manner. Interceptor ditches are used for varying reasons such as:

- Divert water around a project
- Separate clean off site water from sediment laden construction runoff
- Collect water at the top of cut slopes to prevent erosion of the slope
- Divert water to a controlled outlet point.

3 Roadside Ditch Geometry Considerations

The following guidelines are provided for guidance in determining the geometry of roadside ditches.

- Maintain grades of at least 0.5%
- Side slopes should not exceed the recommendations of the projects geotechnical reports.
- For ditches running along the toe of a fill, provide adequate distance between the toe of fill and the ditch. If the ditch carries large amounts of runoff it is desirable to place them 10' from the toe of the fill.
- For ditches located in close proximity to the pavement structure, make the ditch deep enough to provide subgrade drainage for the pavement structure.
- Aggregate linings should follow thickness recommendations specified
- Avoid sharp bends and abrupt grade changes that could lead to erosion of the channel.
- Roadside safety considerations should be considered when determining the geometry of ditches and channels.

C CHANNEL HYDRAULICS

1 Open Channel Flow Types

The classification of open channel flow can be summarized as follows

Steady Flow
- Uniform Flow
- Non-uniform Flow
  - Gradually Varied Flow
  - Rapidly Varied Flow

Unsteady Flow
- Unsteady Uniform Flow (rare)
- Unsteady Non-uniform Flow

- Gradually Varied Unsteady Flow
- Rapidly Varied Unsteady Flow

Steady, uniform flow and steady, non-uniform flow are the most common types of flow encountered in highway engineering hydraulics.

The following definitions apply to the open channel flow classification outline listed above:

- Steady flow - A flow in which the flow rate or quantity of fluid passing a given point per unit of time remains constant.
- Uniform flow - Flow of constant cross section and average velocity through a reach of channel during an interval of time.
- Non uniform flow - A flow in which the velocities vary from point to point along the stream or conduit
- Steady uniform flow - the quantity and velocity are the same at all points along the channel. For this condition the cross section of flow must be constant, such as ditches and excavated channels with unvarying cross sections. Steady, uniform flow is generally analyzed with single-section methodologies
- Steady non uniform flow - the quantity of flow is constant at any point, but the velocity varies. This type of flow is most common in natural streams and is commonly encountered in the design of large highway stream crossings. By subdividing the channel reach, the available flow formulas, which assume steady uniform flow, may be used to analyze the reach. Steady, non-uniform flow is analyzed with step-backwater methodologies.
- Laminar or streamline flow - all particles move parallel to each other
- Turbulent flow - swirls and eddies are prevalent

2 Equation of Continuity

If steady flow exists throughout a reach of any channel there is continuity of discharge or, as commonly stated, continuity of flow. The mean velocities at all cross sections having equal areas are equal. If the areas are not equal, the velocities are inversely proportional to the areas of the respective cross sections.

Thus, A_1V_1 and A_2V_2 are the respective products of area and mean velocity at any two cross sections in an open channel where continuity of flow exists.

Continuity Equation

$$A_1V_1 = A_2V_2 \text{ and } V_1/V_2 = A_2/A_1$$

3 Hydraulic Radius

The hydraulic radius has a dimension of depth, and for very wide channels with shallow depths, the value approaches average depth.

Equation Hydraulic Radius

$$R = A/P$$

Where :

R = hydraulic radius
A = area of cross section of flow
P = length of wetted perimeter

4 *Energy*

According to Bernoulli's conservation of energy principal, the total energy head at an upstream cross section is equal to the total energy head at a downstream section plus the energy head loss between the two sections. Energy of the water may be of two forms: potential energy due to depth of the water and elevation above some zero datum plane and kinetic energy due to velocity. Potential energy is represented by potential head depth plus height ($y + Z$), above the zero datum plane, in feet; and kinetic energy is represented by the velocity head ($V^2/2g$), in feet. Referring to Figure 4.1 the total head at point 1 in a stream is equal to the total head at point 2 in the stream plus head losses occurring between the two points:

Energy Equation

$$y_1 + V_1^2/2g + Z_1 = y_2 + V_2^2/2g + Z_2 + h_L$$

5 *Specific Energy*

It is often convenient to consider the energy content with respect to the channel bottom. This is called the specific energy, or specific head, and is equal to the depth of the water plus the velocity head ($y + V^2/2g$). The slope of the energy line is a measure of the friction slope or rate of energy head lost due to friction($S = h_L /L$).

For small channels, the specific energy is constant. Thus the friction loss, hf is equal to the elevation difference between the two points in the channel ($Z_1 - Z_2$).

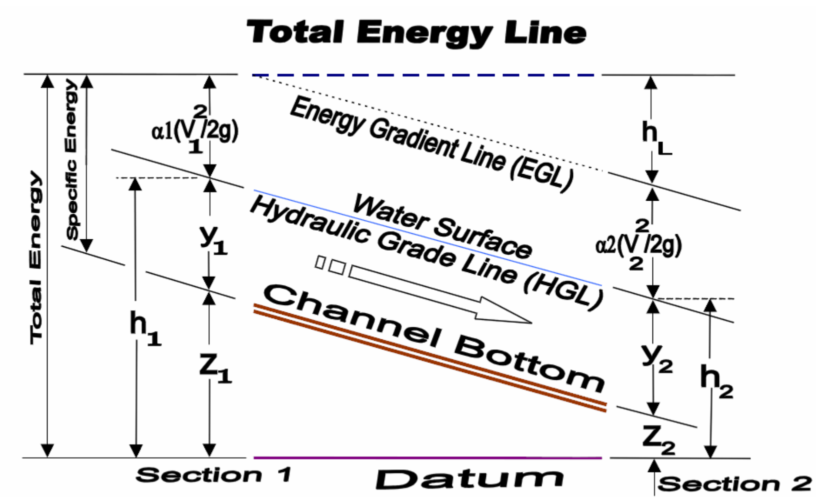


Figure 4.1 Total Energy Diagram

For large channels, the specific energy cannot be assumed constant and a standard step backwater procedure must be used. By trial and error, the above energy equation is balanced using the Manning's equation below.

6 MANNING'S EQUATION

Manning's formula for computing flow in open channels is widely used because of its simplicity:

Manning's Equation

$$V = (1.49/n)(R^{0.67})(S^{0.5})$$

Where :

V = velocity, feet per second
R = hydraulic radius, feet
S = slope of channel, feet per feet
n = roughness coefficient

The roughness coefficient, n, accounts for the character of:

- Stream or channel bed
- Banks or side slopes
- Vegetation both in channel and on banks

7 Manning's N & Relative Roughness

The selection of an appropriate Manning's n value for design purposes is often based on observation and experience. In theory, Manning's n is dependent on the surface roughness of the material the water is flowing over or through and the depth of flow over the surface. The ratio of the roughness of the material to the depth of flow is termed relative roughness. For shallow flow over rough surfaces the relative roughness is high and the Manning's n value can vary significantly with depth. Shallow flow occurs when the height of the roughness of the surface is about one-tenth or more of the depth of flow.

Values of n for use in Manning's formula for excavated or natural streams are given in Table C-1 below.

Table 4.1 Values of roughness coefficient "n" (uniform flow)

Type of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
A. Earth, straight and uniform	0.016	0.018	0.020
1. Clean, recently completed	0.018	0.022	0.025
2. Clean, after weathering	0.022	0.025	0.030
3. Gravel, uniform section, clean	0.022	0.027	0.033
B. Earth, winding and sluggish			

1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
C. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
D. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
E. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120

Table 4.1 Values of roughness coefficient "n" (uniform flow)

Type of Channel and Description	Minimum	Normal	Maximum
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
NATURAL STREAMS			
A. Minor Streams (top width at flood stage < 100 feet)			
1. Streams on Plain			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as 4, but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. Bottom: gravels, cobbles, and few bolders	0.030	0.040	0.050
b. Bottom: cobbles with large bolders	0.040	0.050	0.070
B. Flood Plains			
1. Pasture, no brush			
a. Short grass	0.025	0.030	0.035
b. High grass	0.030	0.035	0.050
2. Cultivated area			
a. No crop	0.020	0.030	0.040
b. Mature row crops	0.035	0.035	0.045
c. Mature field crops	0.030	0.040	0.050
3. Brush			
a. Scattered brush, heavy weeds	0.035	0.050	0.070
b. Light brush and trees in winter	0.035	0.050	0.060

c. Light brush and trees in summer	0.040	0.060	0.080
d. Medium to dense brush in winter	0.045	0.070	0.110
e. Medium to dense brush in summer	0.070	0.100	0.160
4. Trees			
a. Dense Willows, summer, straight	0.110	0.150	0.200
b. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
c. Same as b. but with heavy growth of sprouts	0.050	0.060	0.080
d. Heavy stand of timber, a few downed trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
e. Same as d. but with flood stage reaching branches	0.100	0.120	0.160
C. Major Streams (top width of flood stage > 100 feet) The n value is less than similar minor streams because banks offer less effective resistance.			
1. Regular section with no boulders or brush	0.025	N/A	0.060
2. Irregular and rough section	0.035	N/A	0.100

8 Froude Number

An extremely important parameter in open-channel flow is the Froude Number. The Froude Number is a dimensionless parameter defined as the ratio of the inertia forces to the gravity forces. It is normally expressed as:

Equation Froude Number

$$Fr = \frac{V}{\sqrt{gy}}$$

Where:

Fr = Froude Number
V = Velocity of flow, m/s (ft/s)
g = Acceleration of gravity, m/s2 (ft/s2)
y = Depth of flow, m (ft)

V and y can be the mean velocity and depth in a channel or the velocity and depth in the vertical. If the former are used, then the Froude Number is for the average flow conditions in the channel. If the latter are used, then it is the Froude Number for that vertical at a specific location in the cross section.

When the Froude Number is 1.0, the flow is critical; values of the Froude Number greater than 1.0 indicate supercritical or rapid flow and smaller than 1.0 indicate subcritical or tranquil flow. The velocity and depth at critical flow are called the critical velocity and critical depth. The channel slope which produces critical depth and critical velocity is the critical slope. The change from supercritical to subcritical flow is often abrupt (particularly if the Froude Number is larger than 2.0) resulting in a phenomenon known as the hydraulic jump.

Critical depth and velocity for a particular discharge are only dependent on channel size and shape and are independent of channel slope and roughness. Critical slope depends upon the channel roughness, channel geometry, and discharge. For a given critical depth and velocity, the critical slope for a particular roughness can be computed by Manning's equation.

Supercritical flow is difficult to control because abrupt changes in alignment or in cross section produce waves which travel downstream, alternating from side to side, sometimes causing the water to overtop the channel sides. Changes in channel shape, slope, alignment, or roughness cannot be reflected upstream. In supercritical flow, the control of the flow is located upstream. Supercritical flow is common in steep flumes, channels, and mountain streams.

Subcritical flow is relatively easy to control for flows with Froude Numbers less than 0.8. Changes in channel shape, slope, alignment, and roughness affect the flow for small distances upstream. The control in subcritical flow is located downstream. Subcritical flow is common in channels, flumes and streams located in the plains regions and valleys where slopes are relatively flat.

Critical depth is important in hydraulic analysis because it is always a hydraulic control. The flow must pass through critical depth in going from subcritical flow to supercritical or going from supercritical flow to subcritical. Although, in the latter case a hydraulic jump usually occurs.

Typical locations of critical depth are:

- At abrupt changes in slope when a flat (subcritical) slope is sharply increased to a steep (supercritical) slope.
- At channel constrictions such as a culvert entrance, flume transitions, etc. under some conditions.
- At the unsubmerged outlet of a culvert or flume on a subcritical slope, discharging into a wide channel, steep slope channel (supercritical), or with a free falls at the outlet.
- At the crest of an overflow dam, weir, or embankment.
- At bridge constrictions where the bridge chokes the flow.

9 Depth of Flow

Depth of flow in an open channel depends upon four factors:

1. Quantity of flow, Q
2. Slope of channel, S:

    - Water surface is parallel to channel bed at normal depth.
    - Normal depth is approached in long reaches of uniform sections but is difficult to determine on many small streams due to irregular stream geometry. It is recommended that average cross sections be used to determine normal depth.

3. Mannings' roughness of channel, n
4. Shape of cross section as reflected by hydraulic radius, R

For given values of Q, S, n, and R, the normal depth, d_n, may be found by applying the Manning formula. For given values of Q, n, and R, and a varying slope, the depth will vary:

1. When the slope is flat:
   - ❖ Normal depth, dn, is large
   - ❖ Flow is controlled by conditions downstream

2. As slope increases:
   - ❖ Normal depth decreases
   - ❖ Velocity increases

3. When the slope reaches a certain value, control passes from downstream to upstream:
   - ❖ Slope is critical slope, Sc
   - ❖ Normal depth, dn, equals critical depth, dc
   - ❖ Critical depth, dc, varies with different channels or flow discharges

4. As the slope increases beyond critical:
   - ❖ Normal depth decreases
   - ❖ Velocity increases

Critical depth, dc, and critical velocity, Vc, are:

1. Dependent upon
   - ❖ Discharge
   - ❖ Size of area
   - ❖ Shape of channel

2. independent of roughness of channel

Critical slope, S_c, is dependent upon:

1. Discharge
2. Size of Area
3. Roughness of channel

10 Single Section Analysis

The single-section analysis method (slope-area method) is simply a solution of Manning's equation for the normal depth of flow given the discharge and cross section properties including geometry, slope and roughness. It implicitly assumes the existence of steady, uniform flow; however, uniform flow rarely exists in either artificial or natural stream channels. Nevertheless, the single-section method is often used to design artificial channels for uniform flow in the following cases:

- ❖ Calculating depth in roadside ditches to determine capacity and checking freeboard considerations
- ❖ Calculating depth for channel lining analysis
- ❖ Calculating tailwater values for culvert or storm sewer analyses
- ❖ Developing stage-discharge rating curve in a channel for tailwater determination at a culvert or storm drain outlet

- ❖ Calculating starting depths for step backwater analyses

11 Step-Backwater Analysis

Step-backwater analysis is useful for determining unrestricted water surface profiles where a highway crossing is planned and for analyzing how far upstream the water surface elevations are affected by a culvert or bridge. Because the calculations involved in this analysis are tedious and repetitive, it is recommended that a computer program be used for this purpose.

STANDARD-STEP METHOD

The computation of water surface profiles is based on the standard-step method in which the stream reach of interest is divided into a number of subreaches which are bounded by cross sections. The cross sections are spaced such that the flow is gradually varied in each subreach. The energy equation is then solved in a step-wise fashion for the stage at one cross section based on the stage at the previous cross section.

The method requires definition of the geometry and roughness of each cross section as discussed in C-7 “Manning’s n & Relative Roughness.” Manning’s n values can vary both horizontally across the section and vertically. Expansion and contraction head loss coefficients, variable main channel and overbank flow lengths, and the method of averaging the slope of the energy grade line can all be specified.

Flow through bridges and culverts may violate the assumptions inherent in gradually varied flow. When this happens, other methods are used to calculate the water surface profile in the vicinity of the bridge or culvert.

PROFILE CALCULATIONS

Water surface profile computation requires a beginning value of elevation or depth (boundary condition) and proceeds upstream for subcritical flow and downstream for supercritical flow. In the case of supercritical flow, critical depth is often the boundary condition at the control section but, in subcritical flow, uniform flow and normal depth may be the boundary condition. The starting depth in this is usually determined by the single-section method (slope-area method).

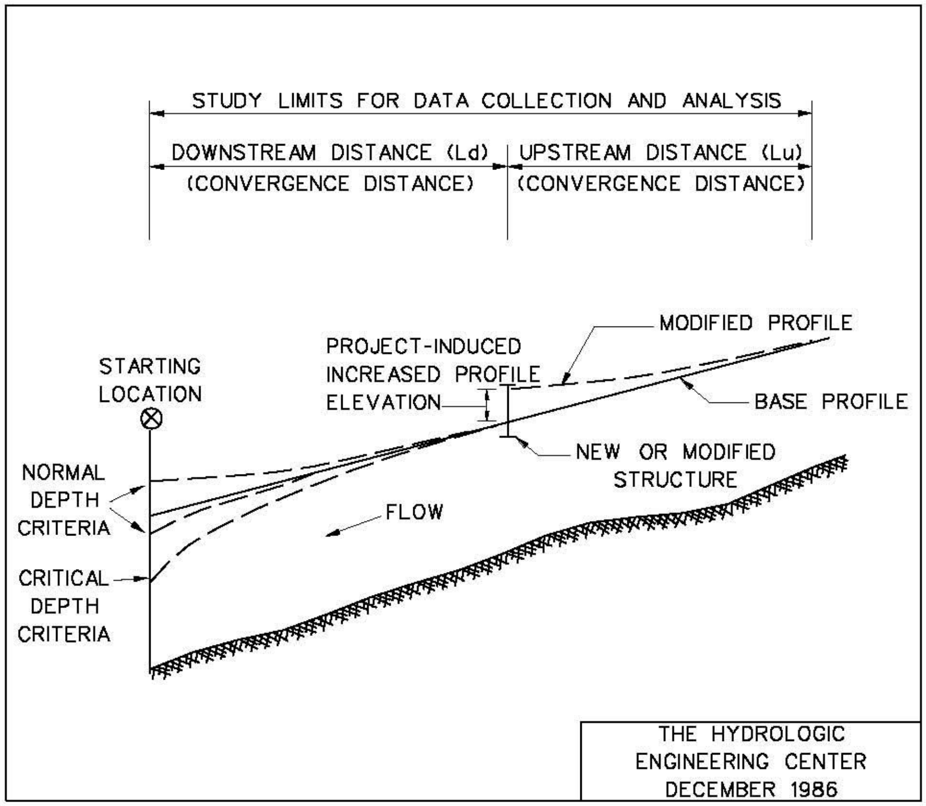


Figure 4.2 Water Surface Profile Study Limits

Given a long enough stream reach, the water surface profile computed by step-backwater will converge to normal depth at some point upstream for subcritical flow. Establishment of the upstream and downstream boundaries of the stream reach is required to define the limits of data collection and subsequent analysis. Calculations must begin sufficiently far downstream to assure accurate results at the structure site, and continued a sufficient distance upstream to accurately determine the impact of the structure on upstream water surface profiles. This is shown in Figure 4.2.

D CHANNEL LININGS

1 General

Channel lining materials fall into two classes: rigid or flexible channel linings. From an erosion control standpoint, the primary difference between rigid and flexible channel linings is their response to changes in channel shape (i.e. the width, depth and alignment). Flexible linings are able to adjust to some change in channel shape while rigid linings cannot. The ability to sustain some change in channel shape improves the overall integrity of the channel lining and reduces maintenance. Flexible linings also have several other advantages compared to rigid linings. They are generally less expensive, permit infiltration and exfiltration and can be vegetated to have a natural appearance. Flexible linings are preferred over rigid linings.

Rigid linings prevent infiltration but contribute to high velocities that often cause scour at the end. Despite the non-erodible nature of rigid linings, they are susceptible to failure from foundation instability. The high cost of this type of lining demands that the situation be analyzed adequately to ensure that this lining type will function as designed.

The linings commonly used are show below:

- ❖ Flexible Linings
  - Grass
  - Turf Reinforcing Mat
  - Aggregate Lining
  - Mattress Units (Gabions)

- ❖ Rigid Linings
  - Concrete Paving
  - Grouted Riprap
  - Modular Block

2 Grass Lining

Grass lining is one of the most common long-term channel linings. Grass lining can be accomplished either by seeding or by sodding. Seeding provides a grass lining at a low cost but there is a transition period between seeding and vegetation establishment. Temporary protective methods such as hydroseeding or Erosion Control Blanket will hold the seeds in place. For seeded, grass lined channels Erosion Control Blanket is required to protect the seed.

Sodding allows for an immediate application of grass lining at a higher cost than seeding. Sodding expands the use of grass lining and also serves to transition into more rigid linings. Composite linings using sodding are desirable in some applications and should be studied carefully. If sodding is able to withstand the expected flows, it is the preferred channel lining in urban applications when immediate establishment of vegetation is desired.

3 Turf Reinforcing Mat

The concept of turf reinforcement is to provide a structure to the soil/vegetation matrix that will both assist in the establishment of vegetation and provide support to mature vegetation. To be effective, Turf Mats must be used where vegetation can establish itself. Although they are considered long term, mats do degrade over long periods of time.

Turf Reinforcing Mats are preferred over aggregate lining in instances where vegetation can be established. When compared to aggregate linings, they offer similar levels of erosion protection and provide water quality benefits.

Turf Reinforcing Mats are not suitable for outlet protection. When rock outlet protection is needed at the end of a culvert and has to transition into a channel lined with Turf Reinforcing Mat, specify the extension of the outlet protection for a distance of 3’ over the upstream edge of the Turf Reinforcing Mat.

The bid items for turf reinforcement mats are Turf Reinforcement Mat 1, 2, 3 or 4 depending on the type used. The units of measurement for these pay items are in square yards.

4 Aggregate Lining

Aggregate lining is considered a permanent lining. Three types of aggregate lining are available. Each successive class provides greater erosion prevention capability. Aggregate lining are effective solutions for cases when establishment of vegetation may become a problem.

- Class II channel lining - crushed aggregate that ranges in size from five to nine inches. Minimum thickness of lining is 15 inches.
- Class III channel lining - crushed aggregate that ranges in size from 0.25 to 1.5 cubic feet. Minimum thickness of lining is 24 inches.
- Class IV - variable size rock obtained from or near a job site with a specified D50 and quality. Class IV rock is most commonly used as an alternate to channel lining class III.

The bid items, measurement units and D_{50} values for aggregate linings are shown below:

Bid Item	**Units**	**D_{50}**
Channel Lining, Class II	Ton	0.5’
Channel Lining, Class III	Ton	1.0’
Channel Lining, Class IV	Cubic Yard	1.0’

To estimate tonnage of aggregate linings, assume the unit weight is ½ ton per square yard per foot of depth (111 pounds/cubic foot). This assumes 60-70% solid density.

5 Mattress Units

Mattress units, also called gabion baskets, consist of a wire mattress filled with crushed aggregate that ranges in size from 1.5 to 5.0 inches. Aggregate filled mattresses have a wide range of use and can offer a competitive alternate to paving on steep grades.

6 Paved Lining

Paved ditch lining is placed as reinforced concrete along the bottom section of a ditch. Due to the high failure rate of paved lining channels, paved lining will be used only in extreme cases.

Sometimes it is advantageous to pave ditches which are on very flat slopes in order to lessen sedimentation and reduce flow depth. Hydraulic analysis is necessary for this determination.

Wherever paved ditches are terminated on soil, erosion is certain to occur. The erosion can be minimized by ending the ditch on as flat of a slope as possible. For instance, paved ditches should not be ended at the top of a stream bank but ended in the stream flowline. Generally, some riprap should be placed at the end of any paved ditch which ends on soil.

7 Grouted & Partially Grouted Riprap

Grouted riprap is a constructed by lining a channel or slope with rip rap and filling the voids with concrete or grout forming a monolithic armor. Because fully grouted riprap is a rigid structure, it will not conform to settlement or toe undermining as loose riprap does. Therefore, fully grouted riprap is susceptible to mass failure, especially if pore water is not allowed to drain properly. Although the revetment is rigid, it is not particularly strong and even a small loss of toe or bank support can result in the failure of large portions of the structure.

An alternative to fully grouted riprap is partially grouted riprap. In general, the objective is to increase the stability of the riprap without sacrificing its flexibility. Partial grouting of riprap may be well suited for areas where rock of sufficient size is not available to construct a loose riprap revetment.

E STREAM CHANNEL CONSIDERATIONS

1 General

Stream channels are classified essentially as natural channels. Stream channels often involve complex rapidly changing flow conditions and are environmentally sensitive to changes.Stream channels often drainage large areas and carry significant amounts of runoff. Because of this, modifications to stream channels require environmental and hydraulic considerations beyond that required for uniform roadside ditches.

2 Natural Stream Types

Natural streams are classified into 3 different types. Although there are numerous definitions of these steam types, it is widely accepted that the 3 basic types of natural streams are Ephemeral, Intermittent, and Perennial. The United States Army Corps of Engineers (USACE) defines these streams as follows:

- ❖ Ephemeral stream: An ephemeral stream has flowing water only during, and for a short duration after, precipitation events in a typical year. Ephemeral stream beds are located above the water table year-round. Groundwater is not a source of water for the stream. Runoff from rainfall is the primary source of water for stream flow.
- ❖ Intermittent stream: An intermittent stream has flowing water during certain times of the year, when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from rainfall is a supplemental source of water for stream flow.
- ❖ Perennial stream: A perennial stream has flowing water year-round during a typical year. The water table is located above the stream bed for

most of the year. Groundwater is the primary source of water for stream flow. Runoff from rainfall is a supplemental source of water for stream flow.

Another common term used to describe steams is “blue line streams”. United States Geological Survey (USGS) maps show Intermittent and Perennial streams as blue lines, hence the term “blue line stream”. It should be noted that the determination of stream types as shown on USGS maps follows the USGS definition, which is different than the USACE definition presented above.

3 Quantifying Stream Impacts

In order to quantify the impacts to streams it is necessary to determine the horizontal limits of what is considered to be a part of the stream. The methods to determine of the limits of a stream vary significantly.

In most instances this limit is bounded by the ordinary high water mark. The USACE defines the ordinary high water mark as; “that line on the shore established by the fluctuations of water and indicated by physical characteristics such as clear, natural line impressed on the bank, shelving, changes in the character of soil, destruction of terrestrial vegetation, the presence of litter and debris, or other appropriate means that consider the characteristics of the surrounding areas.” In cases where the ordinary high water marks cannot be defined, the limits of the 2 year storm can be used to estimate the ordinary high water mark.

Once there is a determination made of the limits of a stream, stream impacts are either measured linearly, or by the amount of area of stream disturbed. In the linear case, the impact is simply measured as the length of disturbance below the ordinary high water mark as measured along the stream. In the area case, it is measured as the area of stream impacted (as defined by the limits described above).

4 Stream Impact Thresholds

As noted in B-1, stream channels include any drainage feature that is currently or has ever been a natural drainage feature. This definition is inclusive of all three types of steams discussed in E-2. Impacts to any stream channels that exceed certain thresholds require coordination with other state and federal agencies.

Since these thresholds vary significantly between the various state and federal agencies, the determination of these impacts is left to the Division of Environmental Analysis. Although some environmental agencies do not extend their jurisdiction to include ephemeral streams, this determination should be made by the Division of Environmental Analysis. Projects that have stream impacts to stream channels exceeding the following thresholds shall be coordinated with the Division of Environmental Analysis:

- Disturbances to stream channels that exceed 300 linear feet
- Disturbances to stream channels that result in a loss of waters of more that 0.1 acres

5 Channel Changes

When a stream channel is reconstructed, and the reconstruction exceeds the impact thresholds in E-4, it is referred to as a channel change. The possibility of any Channel Change should be identified in the Conceptual Design phase when the preliminary line and grade plans are developed. Reconstruction or impacts to streams that fall below the aforementioned thresholds are treated as roadside ditches and should be designed as such.

6 Wetland Impacts

Identifying the extent of wetlands is a complicated process that is not covered in this manual. It is imperative to determine the location of any wetland impacts early in the project's design phase. Any possible impact to a wetland must be coordinated through the Division of Environmental Analysis.

7 Avoidance of Stream & Wetland impacts

By far the most effective way to deal with steam and wetland impacts is to avoid them altogether. Avoidance of these impacts is desired from both an environmental and fiscal standpoint. As of the writing of this section of the Drainage manual, the mitigation costs of impacts to streams and wetlands were estimated to be:

- $72,000 per acre for wetlands
- $120 - $320 per linear foot for stream impacts

8 Permitting and other Environment Considerations

There are many permitting and environmental considerations that should be considered when dealing with impacts to stream channels. Most of these considerations are related to hydraulic structures such as culverts or bridges. However, any work that creates a disturbance to a stream channel, should account for environmental and permitting considerations.

CHAPTER 5 – CULVERTS

A GENERAL

1 Introduction

Generally speaking, culverts are hydraulic conduits used to convey water from one side of a highway and/or entrance to the other. Culverts are generally a single run of pipe or box section that is open at both ends (this is what distinguishes culverts from storm sewers). Culverts can be designed hydraulically to take advantage of submergence at the inlet to increase hydraulic capacity.

Hydraulically a culvert is different than a storm sewer because storm sewers have multiple openings which accept water. Culverts generally collect all the water that they convey at the inlet of culvert. Since water is typically flowing in a channel, the water is usually spread out much wider than the culvert opening. Directing the water into the culvert introduces losses that cause water to pond at the inlet.

Another aspect of culvert design is the selection of the culvert inlet and outle t. These appurtenances usually consist of headwalls and may be constructed with or without wings. Headwalls may be designed to fit the fill slopes of the highway, or the fill material can be graded to match the headwall. Culvert headwalls are attached to the ends of a culvert to reduce erosion, inhibit seepage, retain the fill, improve the aesthetic and hydraulic characteristics and make the ends structurally stable. Headwalls are broadly classified as safety headwalls and non safety headwalls. The use of no headwall is also a design choice.

2 Hydraulic Structure Types

There are many different hydraulic structure types utilized for culverts. Table 5.1 summarizes these structures. Some of the structures listed in this table are used in storm sewer construction as well. Hydraulic structures that are used for culverts are precast box culverts, cast in place box culverts, pipes and bottomless structures.

Table 5.1 Hydraulic Structure Types Used For Culverts

TYPE	SHAPE	MATERIAL	SIZE DESIGNATION
Precast Box Culvert (DR C)	Single Cell or Multi-Cell Rectangle	concrete[1]	span x rise (feet)
Cast In Place Box Culvert (DR C)	Single Cell or Multi-Cell Rectangle	concrete	span x rise (feet)

Pipe (DR B)	Circular	concrete, steel, aluminum, and plastic	Diameter (inches)
	Pipe Arch	concrete, steel and aluminum	Equiv. Circ. Pipe or span x rise -for small sizes- (inches) -for large sizes- (feet)
	Elliptical	concrete, steel and aluminum	Equiv. Circ. Pipe or span x rise (inches)
	Circular Structural Plate	steel and aluminum	diameter (inches)
	Arch Structural Plate	steel and aluminum	span x rise (feet)
3-Sided Structures 2 (DR 604)	Non-circular steel and aluminum	structural plate steel and aluminum	span x rise (feet)
	Parabolic or Semi-Circular Concrete and Steel	special	span x rise (feet)

1. Box culverts are available in metal as well; however these are not typically used on projects.
2. 3-Sided structures are prefabricated shapes such as arches or boxes that are bottomless. The shapes are typically placed on strip footing foundations.

Large culverts are often compared to bridges when determining a hydraulic structure type for a particular location. The following general guidance is given to aid in this comparison.

Culverts are used:

- where bridges are not hydraulically required,
- where debris and ice are tolerable, and
- where more economical than a bridge.
- Bridges are used:
- where culverts cannot be used,
- where more economical than a culvert,
- to satisfy land-use requirements,
- to mitigate environmental harm caused by a culvert,
- to avoid floodway encroachments, and
- to accommodate ice and large debris.

3 Large Drainage Structures

Large drainage structures require collection of more significant field information that what is required for smaller structures. Large drainage structures include any structure that meets the following criteria.

- All bridges
- Culvert pipes with a diameter (or equivalent) of 54" or more.
- Culvert pipes with improved inlets
- All cast in place box culverts
- All precast or metal box culverts 4' span x 4' rise or larger
- All bottomless (3 sided) structures

B PIPE

1 General

Pipes are fully enclosed structures that are used to transport water. Pipes are circular, arched or elliptical in shape. The pipes have various shapes, materials and fabrication techniques. This becomes important when contractors select pipes specified in the plans. Table 5.1 lists several different types of pipes commonly used by their shape, material and fabrication technique.

Table 5.1 Pipe Types	
Circular Pipe	
Description, Material & Fabrication	**Designation**
Reinforced Concrete Pipe	RCP
Spiral Rib Steel Pipe	SRS
Corrugated Steel Pipe with Helical Seam	CSPHS
Corrugated Steel Pipe with Longitudinal Seam	CSPLS
Corrugated Steel Pipe with Longitudinal Seam with Steel Bolts	CSPLSSB
PolyVinyl Chloride Pipe	PVC
High Density PolyEthylene Pipe	HDPE
Spiral Rib Aluminum Alloy Pipe	SRA
Corrugated Aluminum Alloy Pipe with Longitudinal Seam with Steel Bolts	CAPLSSB
Corrugated Aluminum Alloy Pipe with Helical Seam	CAPHS
Non-Circular Culvert Pipe	
Description, Material & Fabrication	**Designation**
Reinforced Concrete Pipe Arch	RCPA
Reinforced Concrete Horizontal Elliptical Pipe	RCHEP
Reinforced Concrete Vertical Elliptical Pipe	RCVEP
Corrugated Steel Pipe Arch	CSPA
Spiral Rib Steel Pipe Arch	SRSA
Corrugated Aluminum Alloy Pipe Arch	CAPA
Corrugated Aluminum Alloy Pipe Arch with Aluminum or Steel Bolts	CAPAASB
Spiral Rib Aluminum Alloy Pipe Arch	SRAA

2 Pipe Materials

The materials used for pipe on City of Richmond projects include:

- Reinforced Concrete
- Steel With a Protective Metallic Coating of:
- Aluminum Type 2
- High Density Polyethylene
- Polyvinyl Chloride

3 Additional Protective Measures

Additional protective measures may be required to mitigate the effects of corrosion and/or abrasion. Metal (which includes Steel and Aluminum Alloy) pipe may require additional protective measures applied to the base metal product such as:

- Bituminous Coating
- Bituminous Paving
- Polymeric Coating

Reinforced Concrete pipe may require extra protection in the form special requirements for the class of pipe, reinforcement, wall thickness and the compressive strength of the concrete.

4 Wall Thicknesses

Pipe dimensions are generally stated in terms of the internal measurements. The designer often needs to know the wall thicknesses of pipe materials. This becomes especially important when sizing vault structures for storm sewers. Since concrete pipes have the largest outside diameter for a given pipe size, they should be used to check outside dimensions in critical situations such as sizing pipe chambers.

Perhaps the most comprehensive reference for wall thicknesses for the various concrete pipes and reinforced concrete box culvert sections is the Headwall Supplement to the Standard Drawings (KYTC). The wall thicknesses for the various pipe sizes are labeled as “T” on these drawings and are tabulated for the various pipe sizes. Wall thicknesses for the various pipe types vary according to the size of the pipe. An estimate of the outside diameter of a circular concrete pipe can be obtained from the following formula:

Wall Thickness Equation for Circular Concrete Pipes

$$T = \frac{D_I}{12} + 1$$

Where:
T = Wall Thickness (in)
DI = Inside Diameter (in)

C BOX CULVERTS

1 Precast Reinforced Concrete Box Culvert Sections

Precast Reinforced Concrete Box Culvert Sections are rectangular shaped sections that can be used for culverts and storm sewer applications. These sections are constructed of reinforced concrete and are typically cast at a plant and delivered to the construction site.

WALL THICKNESSES
Wall thicknesses for these structures are shown on RDH-1000 through RDH-1135 (KYTC Standard Drawings). The wall thickness is shown as “T” in these drawings and is tabulated much like the concrete pipes. The dimensions shown in the Standard Drawings are for box sections that have a cover height of 2’ or more. For this situation, the bottom and top slab and the left and right wall thicknesses are the same for each box section size. However, when cover heights are below 2’, the top and bottom slabs are thicker for box culvert sections with a span of 6’ or less. Table 5.2 gives the top and bottom wall thickness for these box culverts.

Table 5.2
Wall Thicknesses for Reinforced Concrete Box Culvert Section, Cover Height Less Than 2’

Span	Top Slab Thickness (Inches)	Bottom Slab Thickness (Inches)
3’	7	6
4’	7.5	6
5’	8	7
6’	8	7

2 Cast In Place Reinforced Concrete Box Culverts (RCBC)

Cast in place box culverts are reinforced concrete structures that are formed and placed at the construction site. These structures need to be specially designed by a licensed Structural Engineering in the State of Kentucky.

CHAPTER 6 – INLETS AND STORM SEWERS

A GENERAL

1 Storm Sewer Definition

City of Richmond defines a storm sewer as two or more inlets, manholes or junction boxes connected by a series of pipes.

2 Function & Design Process

The function of a storm sewer system is to collect storm runoff, convey the water to an outlet point and discharge the flow in an environmentally acceptable manner. The design is, at a minimum, a four step process with some iteration until a final design is achieved.

- Determine the location of inlets into the storm sewer. This involves spacing the inlets at locations that will limit the spread and provide access for maintaining the system. Based on roadway geometrics and traffic safety requirements, more inlets may be needed. Determine where existing systems or inlets will tie into the proposed and where the system outfall points will be.
- Calculate the inflow into the system. This involves determining the peak runoffs of drainage areas draining toward the inlets and checking if the spread and interception capacity are acceptable. If not, additional inlets may be required or inlet locations may have to be adjusted to meet drainage requirements.
- Determine the size of the storm sewer pipe required to convey the runoff for the design event and whether the system design criteria are met.
- Evaluate the impacts of the discharge at the outfall on adjacent property owners and downstream receiving waters. Determine if energy dissipation or channel lining is required to protect the outlet from excessive erosion. Determine if the design meets the Post Construction BMP requirements from local agencies, such as MS4s, or the Division of Water.

3 Junction

The designer shall provide inlets, junction boxes, or manholes at every break in horizontal or vertical alignment. This arrangement allows access to the ends of all sections of pipe in the system to clear potential obstructions.

4 Easements

The developer shall dedicate easements to storm sewer piping. Width of an storm sewer easement shall be at a minimum 12' wide. The table below is a minimum guideline. The City of Richmond retains the right to require additional easement width based on site specific issues.

Table A-1
Easement Widths

Utility in Easement	Width Required (ft) min.
Storm Sewer <6' deep	12
Storm Sewer 6'-10' deep	15
Storm Sewer >10' deep	20

Storm Sewer (any depth) with other utilities	20, other utility owners may require additional width to the amount listed.

B INLET

1 Inlet Classification

City Of Richmond drainage inlets are classified as curb inlets, drop inlets, and special purpose inlets. Curb inlets are further classified as curb opening, grated, or combination inlets. Drop inlets are primarily used in ditches, depressed medians, and as yard drains. Special purpose inlets are those such as bridge deck drains (scuppers), spring boxes, slotted drains and outlet structures for detention or retention ponds. City of Richmond follows the KYTC Standard Drawing and Specifications on all new construction.

2 Standard Inlets

Drainage inlets are designed for a multitude of situations as indicated in the KYTC Standard Drawings. The Standard Drawings provide flexibility by allowing minor modifications to the inlet based on the situation. Most curb inlets can be used with any curb shape and pipe chambers are designed to fit a variety of combinations of pipe sizes. Slopes of drop inlets may be flattened and aprons may be eliminated or added. Ladder systems or Epoxy set Plastic coated steel rod steps shall be placed in structures for ease of maintenance

In all instances where structural limits for a proposed installation exceed the Standard Drawings, the designer shall provide a separate detail sheet for the plans depicting the modifications and sufficiently detailing the non-standard structure so that the contractor can bid the item. The modifications in structural aspects of the inlet shall be reviewed and approved by the Division of Structural Design prior to use on the project.

The following considerations should be noted in regards to KYTC inlets, manholes, and junction boxes shown in the Standard Drawings:

- ❖ KYTC inlets depicted in the standard drawings are designed to have a maximum depth of 15 feet. KYTC junction boxes, drop boxes and manholes have limitations of eight (8) to nine (9) feet in the Standard Drawings. A Type B Manhole has structural design and out to 60 feet of fill height in the Standard Drawings.
- ❖ All KYTC inlets, junctions, and manholes (except for Drop Box Inlet Type 12) are bid per each individual structure regardless of chamber size or riser height. Type 12 inlets are bid by linear feet.
- ❖ Inlet pipe chambers should be designed such that the outside limits of a proposed pipe will fit entirely inside the chamber
- ❖ KYTC inlets, manholes, and junction boxes are constructed according to Section 710 of “Standard Specifications for Road and Bridge Construction.”

3 General Placement Guidelines

The following general rules apply to inlet placement:

- An inlet is required at the uppermost point in a gutter section where gutter capacity criteria is violated. This point is established by moving the inlet (and thus changing the drainage area) until the tributary flow does not violate spread or depth criteria. Successive inlets are spaced by locating the point where the sum of the bypassing flow and the flow from the additional contributing area is less than or equal to the gutter capacity as calculated by spread or depth criteria.

- To prevent pedestrian or vehicular hazards, inlets are normally used at intersections to prevent flow from crossing intersecting streets. It is desirable to intercept 100 percent of the flow along a street before it is released into an intersecting street or an intersection. Inlets in intersections should be placed on straight curb sections near the point where the curb line starts its radius to meet the curb from the adjacent street, unless there is a sag point in the radius.

- Inlets are required in areas just upstream of where the street cross slope changes and causes the water to flow across to the pavement and not in the gutterline. The purpose of these inlets is to reduce the traffic hazard from street cross flow. Sheet flow across the pavement at these locations is particularly susceptible to icing.

- Inlets should be located at any point where side drainage enters streets and may overload gutter capacity. Where possible, these side drainage inlets should be located to intercept side drainage before it enters the street.

- Inlets shall be placed at all sag points in gutters, medians, and channels.

- Flanking inlets should be placed at major sag points where significant ponding may occur, and no other outlet exists except through the system.

- Inlets are used upstream of bridges to prevent pavement drainage from flowing onto the bridge decks and downstream of bridges to intercept drainage from the bridge.

- As a matter of general practice, inlets should not be located within driveway areas.

- Inlet structures can serve as access holes in storm sewer systems and should be used in lieu of manholes or junction boxes where the benefit of extra stormwater interception is achieved at minimal additional cost.

- Inlets should be placed immediately upstream of median breaks, and entrance/exit gore ramps.

- Inlets should be placed immediately upstream of crosswalks.

- Avoid adding curb inlets in intersection radiuses where high truck traffic can be expected, due to how easily they can be damaged. The larger curb lengths can be problematic to construct in the radius. Curb Box Type F inlets are especially vulnerable to damage from trucks.

- A goal in Drainage design should be to emulate natural drainage and existing drainage patterns, insofar as practical.

4 *Composite Gutter Sections*

In most instances the standard design is to match the gutter cross slope and the pavement cross slope. Although this design is usually sufficient, composite gutters may be used to increase the capacity of gutters and inlets. Composite gutters are created by sloping the gutter line at a steeper grade than the adjoining pavement (i.e., 2% pavement cross slope with 4% gutter cross slope) Using a composite gutter section concentrates more flow in the gutter line thereby reducing the spread of water on the pavement and increasing the capacity of the inlets. The use of composite gutters with greater than 2% algebraic difference between gutter cross slopes and road cross slopes should be discouraged due to break over grade limits and problems that will develop with pavement overlays.

5 *Curb Box Inlets*

Curb inlets are usually located in the curb line or incorporated into the design of a raised median and may be one of several configurations. Most of these inlets consist of two or three units for construction purposes which include a bottom phase, a riser section (when needed), and a top phase. The bottom phase is also known as the pipe chamber. Ladder systems or Epoxy set Plastic coated steel rod steps shall be placed in structures for ease of maintenance.

Curb opening inlets have a depressed slot (referred to as a curb opening or throat) constructed through the curb for water to pass into an inlet pipe chamber. Access to the pipe chamber is through a manhole lid on top of the inlet located behind the curb line.

Combination inlets may consist of a curb opening with a grate in the gutter or a slotted drain pipe with a grate in the gutter. The grate is removable to provide access to the pipe chamber.

6 *Drop Box Inlets*

These inlets consist of an opening in the top of a pipe chamber covered by one or more grates. Several grate designs are used, based on the purpose of the inlet. Grated inlets do not have a slot or throat through the curb. They have a pipe chamber, with or without a riser section, and use a variety of grate configurations to cover the access to the pipe chamber. These inlets may be located in gutterlines, channels, medians, parking lots and other areas where curbs are present. The back portion of the inlet is usually formed to match an adjacent curb.

The interception capacity and efficiency of a grate inlet depends on the amount of water flowing over the grate, the size and configuration of the grate and the velocity of flow in the ditch, median, or gutter.

Drop box inlets are placed in ditch lines to ensure that ditch flow capacity is not exceeded. They also are used at required points of interception, such as in a sag or other ponding locations. Drop box inlets are used in lieu of headwalls where traffic safety is a consideration. Ditch inlets are recommended whenever a clear zone is provided.

7 Slotted Drain Pipes

Slotted drain pipe is usually located in areas associated with curbs. It consists of a circular corrugated metal culvert with a riser welded along the top of the pipe that extends up to a grate that intercepts sheet flow and/or reduces ponding of surface runoff. The riser assembly is tall enough to allow the pipe to be located at or near the subgrade level.

Slotted drain pipes are an alternative form of pavement drainage when clogging is not an issue and they have a variety of applications. They can be used on curbed or uncurbed sections and offer little interference to traffic. They can also be used to add capacity to existing systems to deal with increased runoff due to widening.

Slotted drain pipe installations do not require the use of drop boxes. There are instances where site conditions, increased costs caused by inlet construction, and/or best engineering practices may dictate the use of slotted pipe alone. Likewise, a drop box inlet with a section of slotted pipe can be used as a combination inlet.

Slotted drain pipes are sized and spaced in the same manner as curb opening inlets, functioning as if they are weirs with flow entering from the side. One linear foot of slotted drain pipe is assumed hydraulically equivalent to one linear foot of curb opening. The interception capacity is dependent upon the flow depth, inlet length, and total flow.

C MANHOLES AND JUNCTIONS

1 General

Manholes or junction boxes shall be provided at breaks in horizontal or vertical alignment where it is not feasible to construct an inlet. Another primary consideration in locating these structures is to provide access to the storm sewer for maintenance purposes. Refer to the access point spacing criteria set for the allowable maximum spacing of access points. It should be noted that some inlets provide manhole access as well. Ladder systems or Epoxy set Plastic coated steel rod steps shall be placed in structures for ease of maintenance

D STORM SEWER PIPE

Storm Sewer Pipe Types

The following types of circular culvert pipes may be used:

- Spiral Rib Steel Pipe
- Reinforced Concrete Pipe
- Corrugated Steel Pipe with Helical Seam

- ❖ Corrugated Steel Pipe with Longitudinal Seam
- ❖ Spiral Rib Aluminum Alloy Pipe
- ❖ Corrugated Aluminum Alloy Pipe with Helical Lock Seam
- ❖ Corrugated Aluminum Alloy Pipe with Longitudinal Seam
- ❖ High Density Polyethylene (HDPE)

The designer may use the following types of noncircular culvert pipes:

- ❖ Reinforced Concrete Pipe Arch
- ❖ Reinforced Concrete Horizontal Elliptical Pipe
- ❖ Reinforced Concrete Vertical Elliptical Pipe
- ❖ Corrugated Steel Pipe Arch
- ❖ Spiral Rib Steel Pipe Arch
- ❖ Corrugated Steel Elliptical Pipe
- ❖ Corrugated Aluminum Alloy Pipe Arch
- ❖ Corrugated Aluminum Alloy Elliptical Pipe
- ❖ Spiral Rib Aluminum Alloy Pipe Arch

Note that in some large fill locations a hydraulically acceptable pipe may have to be upsized to a larger pipe to meet fill requirements. For example, the 30' is the largest fill height allowed over pipes with diameters from 12"-21".

E STORM SEWER HYDRAULICS

1 General

The hydraulic design of a storm sewer system consists of determining the location, sizes, slopes, and elevations for a system of underground conduits necessary to transport surface runoff to a disposal site. The following data is necessary for a storm sewer system design:

- ❖ Location and geometric design of the project, including elevations
- ❖ Location and elevation of existing outlets
- ❖ Location and elevation of existing inlets
- ❖ Map delineating drainage areas and pertinent topography
- ❖ Location of underground utilities, bridge substructures, buildings, and other installations that may affect the location of the storm sewer
- ❖ Location of existing or planned storm sewers that may connect to the proposed system
- ❖ Storm sewers may be designed by open channel or pressure flow methods. For new systems, the open channel method is preferred.

In pressure flow design, energy grade line calculations are performed and the hydraulic grade line of the design storm must not be allowed to surcharge the junction to the point of flooding the roadway. Pressure flow design will be used where necessary or where it has been shown to be economically practical and feasible.

2 Design and Check Storms

It is City of Richmond policy to use open channel design methodology for the design flow where possible. Storm sewer systems are typically designed to accommodate a 10-year design storm. Pipes located in sags are designed to accommodate the 25-year storm. In this context, sag refers to the situation where water has no way out except through the pipe itself, such as the outlet of a storm sewer system at the lowest point in the road. The 100-year storm is used to ensure that off-site impact is acceptable.

3 Hydraulic Capacity

The hydraulic capacity of a storm drain is controlled by its size, shape, slope, and friction resistance. Several friction flow formulas have been advanced that define the relationship between flow capacity and these parameters. The most widely used formula for gravity and pressure flow in storm drains is Manning's Equation.

4 Storm Sewer Open Channel Design Procedure

In open channel design, the storm sewer system is sized based on the Manning equation. Maximum pipe flow occurs at approximately 93% of depth; therefore designing for 80% flow depth will be slightly conservative. It is standing practice to design pipes to carry the design storm at 80% flow depth, which is hydraulically nearly the same as full pipe flow. To design a storm sewer system using the open channel design, the designer shall:

1. Locate and calculate the existing flows at the proposed outlets while maintaining the existing drainage patterns to these outlets where possible to avoid flow diversions.

2. Select the types of inlets to be used, locate the drop inlets that will be connected to the system and space the curb inlets to intercept the expected design discharges for the allowable spread.

3. Lay out the storm sewer system on a map or schematic drawing of the project, connecting all inlets to available outfall areas. The designer must remember to incorporate the existing drainage patterns into the design as determined in the first step.

4. Plot a profile of the proposed project and existing ground surface along the proposed location of the storm sewer and include the location of all proposed manholes, inlets, and junctions.

Note: During this process, the designer should keep in mind the relative elevations between the outfall pipe and all proposed inlets and manholes. Avoid abrupt changes in slope from steep to mild. Design slopes to maintain a velocity of at least two (2) fps to avoid deposition of sediment. Also avoid deep trenches, particularly in rock or where shoring will be required.

5. Consider the location of utilities, particularly those that cannot be changed or otherwise disturbed, such as sanitary sewers.

6. The impact on any new construction such as bridge piers, abutments, or other structure foundations must be considered.

7. Starting at the most remote upstream intake structure of the storm sewer system, number each pipe junction systematically using appropriate labels, such as MH1 (ManHole #1), I2 (Inlet #2), J3 (Junction #3), and OF (Outfall) or by station.

Note: This labeling system is to be shown on the drainage maps, computer input and output, and all summary forms.

8. Determine the land use and acreage or CA (runoff coefficient times drainage area, in acres) that contributing runoff to each inlet in the system for the rational method.

Note: It may be necessary to sum the CA values for areas with different runoff coefficients.

9. Determine the maximum time of concentration to the first intake structure. This is the sum of the overland flow from the drainage area and any travel time through existing conduits, channels, swales to this structure.

10. Determine the rainfall intensity (I) for a storm with a duration equal to the time of concentration (Step 9) for the selected design frequency.

Note: The product of this rainfall intensity (I) and the total CA to the first intake structure equals the discharge for the section of pipe from the first intake structure to the next downstream structure or junction (Q = CIA).

11. Determine an appropriate pipe size that meets approximately 80% flow depth at design flow criteria for the first pipe.

12. At the second junction, determine the value of CA, if any, for the additional area contributing at that point and add this value to the CA value for the first junction.

13. Compute storm sewer travel time from the first to the second junction (in minutes) through the pipe and add it to the time of concentration to the first junction to compute a cumulative travel time to the second junction through the storm sewer system.

14. Calculate the time of concentration for any drainage area contributing to the second junction.

15. Use the larger of the two values calculated in steps 13 and 14 to compute rainfall intensity at the second junction. Use this intensity and the cumulative CA at the second junction (step 12) to compute the discharge and to size the pipe from the second junction to the next downstream junction.

16. Repeat the above procedure for the remainder of the system, obtaining new values of rainfall intensity and increasing discharge values at each successive junction.

5 Pressure Flow Design

The designer shall follow pressure flow design procedure when gravity flow design is exceeded. Pressure flow design requires the calculation of the Hydraulic Grade Line (HGL). The HGL is a line coinciding with the level of flowing water at any point along an open channel. In closed conduits flowing under pressure, the hydraulic grade line is the level to which water would rise in a vertical tube at any point along the pipe. The designer uses the HGL to determine the acceptability of a proposed storm drainage system by establishing the elevation to which water will rise at the inlets when the system is operating under design conditions.

The HGL, a measure of flow energy, is determined by subtracting the velocity head (V2/2g) from the Energy Grade Line (EGL). The EGL represents the total available energy in the system (kinetic plus potential). The EGL equals the sum of the pressure head, the velocity head, and the elevation head. If the HGL is above the inside top (crown) of the pipe, pressure flow exists. Conversely, if the HGL is below the crown of the pipe, open channel flow conditions exist.

Inlet surcharging and possible access hole or manhole lid displacement can occur if the HGL rises above the ground surface. A design based on open channel conditions must be carefully planned as well, including evaluation of the potential for excessive and inadvertent flooding created when a storm event larger than the design storm pressurizes the system. As hydraulic calculations are performed, the designer should frequently verify the existence of the desired flow condition. Storm drainage systems can often alternate between pressure and open channel flow conditions from one section to another.

6 HGL / EGL Calculations

The computation of the hydraulic grade line requires that all energy losses be determined. These losses result from:

- Pipe Friction Losses
- Exit Losses
- Bend Losses
- Transition Losses
- Junction Losses
- Inlet and Access Hole Losses

Pipe friction losses account for most of the major loss in a storm sewer system. Inlet and access hole losses are the most prevalent type of minor losses in a storm sewer system. Inlet and access hole losses apply to inlets, manholes, and junctions that have pipe chambers to receive the connected pipes. Inlet and access hole loses have been subject to considerable research. A thorough discussion of these losses may be found beginning in section 7.1.6, of the FHWA's HEC-22, "Urban Drainage Design Manual (2001)."

F INLETS AND STORM SEWER DESIGN CRITERIA

1 Allowable Spread for Pavement Inlets

After considering the "General Placement Rules", the designer will place pavement inlets in a manner that will limit the spread in driving lanes according to Table 6.1. The rainfall intensity used to develop flow rates to pavement inlets shall be four (4) inches/hour.

Table 6.1 Allowable Spread for Pavement Inlet Spacing		
Traffic Volume	**Speed**	**Design Spread Encroachment Into Driving Lane**
Interstate or Parkway	All Speeds	0’
Non Interstate or Parkway ADT > 1500	> 45 mph	3’
	≤ 45 mph	6’
Local Subdivision Streets	All Speeds	8’

2 Inlets in Channels

The designer shall place drop inlets in median and roadside channels at the following locations:

- ❖ Where the channel capacity is unable to contain the design storm due to either of the following situations:
  - Depth in channel becomes deep enough to violate freeboard criteria for roadside channels.
  - Depth in channel becomes deep enough to violate allowable shear stress criteria for the channel
- ❖ In sag locations created by the surrounding grade. Where convenient outlet points are available to dispose of water
- ❖ Other considerations include:
  - Locate inlets in channels in a manner that will maintain existing drainage patterns.
  - Check headwater elevations over grates and in channels for the 100-year check storm to ensure damage to surrounding property is not occurring.

3 Maximum Access Point Spacing

The designer shall provide an inlet, manhole, or junction box at every break in horizontal or vertical alignment and at minimum distances along the storm sewer network to provide access for maintenance. Use Table 6.2 from AASHTO’s “Model Drainage Manual” to determine the maximum spacing between access points in a storm sewer.

Table 6.2 Maximum Access Point Spacing	
Pipe Size (in)	**Suggested Maximum Spacing (ft)**
12 - 24	300
27 - 36	400
42 - 54	500

≥ 60	1000

4 Physical Pipe Requirements

Design all storm sewer pipe to have a minimum cover one (1) foot from the top of the pipe to the bottom of the pavement subgrade if under pavement and one (1) foot to the top of the ground if not under the pavement.

The minimum size of pipe permitted in any storm sewer system with regards to traffic is:

- ❖ For storm sewer pipe not under traffic:
  - Twelve (12) inches for pipe lengths less than twenty-five (25)feet
  - Fifteen (15) inches for pipe lengths greater than or equal to twenty-five (25) feet
- ❖ For storm sewer pipe under traffic:
- ❖ Eighteen (18) inches for all lengths:

5 Physical Inlet, Junction & Manhole Requirements

The inlets, junctions, and manholes used by City of Richmond all have physical limitations. Design these structures according to the following guidelines:

- ❖ Ensure that pipes entering these structures fall within the ranges for the maximum and minimum pipe sizes listed on the Standard Drawings.
- ❖ Ensure that the heights of the inlets, junctions, and manholes meet the limitations noted on the Standard Drawings.
- ❖ Ensure that pipe chambers are large enough to intercept the incoming pipes.

Note: These dimensions should be checked assuming concrete pipe will be used and should account for adverse angles of the pipes entering the chambers.

When not noted otherwise in the Standard Drawings, set minimum heights for inlets as follows:

- ❖ For cross drainage (pipe under pavement), the minimum height is the pipe diameter, plus the pipe thickness, plus one foot cover, plus pavement thickness (D + t + 1.0’ + pavement thickness).
- ❖ For pipes outside cross drainage limits parallel to or leading away from the roadway, the minimum height is the pipe diameter, plus the pipe thickness, plus one foot cover, measured from the gutter line elevation to the top of the pipe (D + t + 1.0’).

6 Storm Sewer Hydraulics

The designer shall design storm sewer systems to:

- Convey the 25-year storm (design storm) at a depth equal to or less than 80% of the diameter or rise for pipes located in sags which have no exit except through the pipe. If project restrictions will not allow this, design the system for pressure flow and ensure that the resulting hydraulic grade line elevations will not surcharge into to the roadway.

- Convey the 10-year storm (design storm) at a depth equal to or less than 80% of the diameter or rise for pipes not located in a sag condition. If project restrictions will not allow this, design the system for pressure flow and ensure that the resulting hydraulic grade line elevations will not surcharge into to the roadway.

- Keep Hydraulic Grade Line elevations for the 100-year storm (check storm) below levels that will cause damage to adjacent property

- Maintain a minimum velocity of 2 feet per second.

7 Quality Assurance – Post Construction Inspection

All Storm Sewer lines shall be camera tested at the Developer's expense and certified by the Design Engineer prior to acceptance by the City. When conducting a CCTV inspection of newly constructed storm sewer pipes, it is necessary to determine if pipe joints are less than or greater than manufacturer's tolerances specified to maintain a watertight joint. All pipes installed in the field shall be installed per manufacturer requirements and will be "pushed home" to minimize open joints.

The following acceptable pipe gap tables were developed based upon research and coordination with technical experts from pipe manufacturers. The allowable gap distances listed below are the maximum joint separations acceptable to maintain a water tight joint. The information presented in these tables is based upon various joint designs as of the date of publication of this Manual. Subsequent changes in joint design by manufacturers may necessitate revisions to these charts.

ADS - N-12 Watertight Pipe

Pipe Diameter (in.)	Allowable Gap for N-12 Watertight Pipe (in.)
12	2
15	2
18	2
24	1 1/4
30	3
36	1 5/8
42	1 1/2
48	2
60	2 1/8

Reinforced Concrete Pipe (RCP)

Pipe Diameter (in.)	Allowable Gap for RCP (in)

12-36	1/2
42	1 1/4
48	1 1/4
54	1 7/8
60	1 3/4
72	1 5

Deflection shall be per 2005 AASHTO Bridge Committee - LRFD Bridge Construction Specifications: Section 30:

- For locations where pipe deflection exceeds 5 percent of the inside diameter, an evaluation shall be conducted by the Contractor and submitted to the Engineer for review and approval considering the severity of the deflection, structural integrity, environmental conditions, and the design service life of the pipe. Pipe remediation or replacement shall be required for locations where the evaluation finds that the deflection could be problematic. For locations where pipe deflection exceeds 7.5 percent of the inside diameter, remediation or replacement of the pipe is required.

- Pipes shall be checked for deflection using a mandrel or any other device approved by the Engineer or “where direct measurements are made, a measurement shall be taken once every 10.0 ft. (3 m) for the length of the pipe.

- At least 10 percent of the total project footage on the project shall be randomly selected by the Engineer and inspected for deflection.

- Pipe Connections with structures shall have a concrete collar poured from the outside of the structure and non-shrink grout formed on the inside of the structure.

STORM SEWER PLAN REVIEW CHECKLIST

Project Name ____

Date ______________________ Revision (circle Y/N) Date of Revision________

The purpose of this checklist is to facilitate the review process. This checklist gives the minimum requirements needed for The City of Richmond's review. All items shall be checked as included or marked N/A. The omission of required items may be cause for rejection of the submittal without review.

Required Items to be Shown and/or Labeled on Plans or with Report and Exhibits

_______Location Map
_______Owner Name & Address
_______Property Boundaries
_______Adjacent Property Owners
_______Street Name & R/W
_______Existing & Proposed Easements
_______Offsite Drainage Areas
_______Inlet Drainage Areas
_______Drainage Flow Arrows
_______Pipe, Length, Size, Slope, Type, Number
_______Pipe Profiles for Through Drainage
_______Existing & Proposed Drainage Structures
_______Pipe Chart
_______Channel Profiles for Through Drainage
_______Headwall Invert Elevations
_______Existing & Proposed Topography & Contours, Including Area 50' Outside of Property Boundary

______Inlet Type(s)
______Headwall Type
______Headwater @ Culvert Pipes (10-yr & 100-yr)
______Inlet Grate & Invert Elevations
______Proposed Sanitary Sewer & Connections
______Existing Sanitary Sewers
______Existing & Proposed Utilities
______Existing & Proposed Structures
______Existing & Proposed Impervious Areas
______Erosion & Sediment Controls
______Standard Silt Control Notes
______Standard Underground Utility Notes
______Standard Floodplain Note
______Plan Date
______Revision Date
______Registered Professional Stamp & Signature
______Water Surface Profile (Hydraulic Grade Line is acceptable) for 10 year and 100 year storm events shown on profiles in plans or exhibits.

Additional Information (If Applicable)

_______Notice of Intent to Ky DOW (copy City)
_______Downstream Capacity Analysis
_______Sinkhole Geotechnical Analysis
_______Detention Analysis (Include Checklist)
_______Floodplain Analysis
_______Letter of Permission for Offsite Work
_______100-yr FEMA & Local Regulatory Floodplain

______Stormwater Pollution Prevention Plan (SWPPP)
______ACOE approval (for Work near or in Wetlands/Waters of the U.S.)
______ACOE Approval for Work Near Floodwall
______KTC Approval
______KY DOW Approval (Floodplain/Stream Crossing)

Note: The Engineer that Stamped the Submitted Plans Must Sign the Checklist.

____ ____________________
Signature Date

CHAPTER 7 – DETENTION/RETENTION POND DESIGN

A PURPOSE

The purpose of this design guide is to summarize in one location the requirements for designing detention/retention ponds in the drainage manual

B HYDROLOGIC DESIGN CRITERIA

Minimum Requirement requires projects to reduce the impacts of stormwater runoff from impervious surfaces and land cover conversions. This includes controlling the discharge from a project site such that the stormwater discharge from a threshold discharge area shall match developed discharge durations to pre-developed discharge durations for the range of pre-developed discharge rates for 10yr-24hr, 25yr-24hr, 100yr-6hr, and 100yr-24hr storms. The purpose of the requirement is protecting streams from stream bank erosion.

The pre-developed condition to be matched shall be a forested land cover, unless reasonable historic information is available that indicates otherwise.

A continuous simulation hydrologic model shall be used for designing detention ponds. Detention/Retention basin analysis MUST be performed using SCS Methods.

A flow control facility (detention pond is one type of flow control facility) is required for projects that:

- Create 5,000 square feet or more of effective impervious surfaces in a discharge area.
- Projects that through a combination of effective impervious surfaces and converted pervious surfaces, causes a 0.1 cubic feet per second increase in the 100-year recurrence interval flow frequency from a threshold discharge area.

Effective impervious surfaces are those impervious surfaces connected via sheet flow or discrete conveyance to a drainage system. If runoff from an impervious surface is infiltrated or dispersed into native vegetation or amended soils is considered ineffective.

C POND AESTHETICS

Detention ponds should be made an attractive feature of the urban environment. Aesthetic considerations should be incorporated into the design including:

- Curvilinear design (non-rectangular)
- Landscape plantings above the water level of the pond.
- Design to allow public use for recreation during dry season. Play area, volleyball court, etc.
- Incorporate the detention pond into other on-site features such as walking trails, picnic area, etc.
- Consider combined detention and wetland/wetpond to provide permanent pool volume to enhance year-round aesthetics.

D SPECIAL REQUIREMENTS

If the detention pond includes a constructed berm above existing ground, a permit must be obtained from Kentucky Division of Water prior to construction. According to Kentucky Division of Water, a dam is defined as:

"*A dam is defined as any impounding structure that is either 25 feet in height, measured from the downstream toe to the crest, or has a maximum impounding capacity of 50 acre-feet of water. Structures that fail to meet these criteria but have the potential to cause significant property damage or pose a threat to life in the downstream area are regulated in the same manner as dams. All such structures except federal dams and those permitted by the Division of Mine Reclamation and Enforcement must be reviewed, and a stream construction permit must be issued by this office.*"

Detention ponds shall be located within separate tracts (not easements) with a minimum of 20-ft separation between the tract lines and any improvements (including fill or cut slopes) associated with the detention pond.

E DESIGN PROCESS

The following generalized design process is suggested for detention pond design:

- Evaluate project site for suitability including area available, depth to bedrock, presence of wetlands depth to water table, etc. If a detention pond is deemed suitable to the site proceed with the design process.
- Using a hydrologic model (HCS) input all contributing basin information and setup model to route contributing basin to a detention pond. Be sure to include the estimated area of the detention pond as an impervious area.
- Get preliminary pond dimensions--depth, volume, etc. and a preliminary control structure design.
- Locate pond to approximate dimensions on the site plan accounting for access roads, tract line setbacks, point of discharge, etc.
- If proposing a trapezoidal pond, refine the preliminary calculations to finalize the pond dimensions. Be sure to account for the volume of any access ramps required, revise the original estimate of pond area assumed as impervious, and adjust the design accordingly.
- If proposing a curvilinear design, layout proposed curvilinear design with approximately the same volume and area as the trapezoidal pond designed above.
- Create a stage/storage table to input pond to hydrologic model.
- Make pond size and discharge structure modifications as necessary to meet discharge criteria. Adjust assumed impervious area of pond to match calculated area in finalizing design.
- Design emergency spillway and calculate maximum water surface elevation based on a plugged outlet structure. Add required freeboard to get top of berm elevations.
- Layout pond design and grading on drainage plans and be sure to address all applicable design details such as access roads, ramps, berm construction, fencing, control structure, inlets and outlets per detention pond design requirements. Show design and maximum water surface elevations on plan drawing.
- Show in drainage plans and construction drawings at least one pond cross-section through control structure. Indicate design and maximum water surface elevations.
- Provide details and specifications for control structures, inlet and outlet piping, slope treatments, emergency spillways, seeding or Sodding, berms, etc.

- Establish stormwater tract boundaries based on detention pond design. Boundary should be no closer than 5-feet to grading catch points or structures.
- Prepare a landscaping plan showing plantings within the stormwater tract which contains the detention pond.
- Include all design calculations, assumptions, modeling parameters, etc. in the Drainage Report for the project.

F POND GEOMETRY & STRUCTURAL DESIGN

- Dissipate energy at inlet and outfall per design criteria
- Interior side slopes shall not be steeper than 3H:1V
- Retaining walls and rockeries are allowed if designed by a licensed professional and a fence is provided at the top of the wall.
- Ponds shall be designed as flow-through systems maximizing the flow path between inlet and outlet to prevent sedimentation.
- Flows may not enter the pond from the control structure or outflow conveyance system.
- A debris barrier (trash rack) shall be installed on the pond outlet to the control structure. Debris barriers shall be installed on pond inlet pipes.
- Pond Berm Embankments:
- Exterior and interior side slopes steeper than 2H:1V shall be designed by geotechnical engineer.
- Excavate “key” equal to 50% of the berm embankment cross-sectional height and width, or as determined by a geotechnical engineer.
- Construct on suitable base soils either consolidated native soil or adequately compacted and stable fill soils as determined by a geotechnical engineer.
- Place in 6-inch lifts and compact to 95% of maximum dry density as recommended by geotechnical engineer
- Provide anti-seepage collars on pipes through embankments ponding greater than 8-feet of water.
- Exposed earth on embankment shall be sodded or seeded. No trees or shrubs shall be planted on berms taller than 4 feet. Trees or shrubs planted on berms 4 feet or smaller shall not exceed 20 feet mature height and have a fibrous root system.
- Minimum berm width is 15-feet where maintenance access is provided, otherwise minimum top width is 10-feet
- Pond berm embankments greater than 25ft in height require design by a geotechnical engineer.

G SETBACKS

Setbacks from the maximum water surface (pond elevation when emergency spillway is passing the 100-year event):

- 2-foot minimum vertical clearance to structures within 25 feet.
- 20-feet horizontal to:
  - Property lines and onsite structures
  - Building sewer lines
  - Tract property boundary line

H ACCESS ROADS & RAMPS

These are guidelines for access roads and ramps for detention ponds. These include:

- ❖ A 15-foot wide access easement shall be provided from a public street or right-of-way to the detention pond. Access shall be surfaced with a 12-foot width of crushed rock or lattice block pavement or other acceptable surface. The easement shall include easement markers at each corner of easement, at angle points and at least every 100-ft along the easement length.
- ❖ An access road shall be provided to the control structure and other drainage structures associated with the pond (e.g, inlet or bypass structures).
- ❖ If pond maintenance will be provided from the access road, the access road shall extend around the pond perimeter.
- ❖ Access road design criteria include:
  - 15% maximum grade. (12% maximum grade to control structure)
  - Outside turning radius of 40-feet minimum.
  - 12-feet width minimum.
  - Provide paved apron where access road connects to paved public roadway.
  - Provide asphalt, gravel, or modular grid pavement surface.
  - When length of road exceeds 75-feet a vehicle turnaround must be provided for a design vehicle with a 31 foot length and inside wheel path radius of 40-ft.
  - Vehicle access shall be limited by a locking gate or bollards. Gates are required if pond is fenced and must be located only on a straight section of road.
- ❖ Access ramps provide access to the bottom of a pond for maintenance, repair and sediment removal. They are required unless the pond is small enough that a trackhoe with a maximum reach of 20-ft can reach all areas of the pond from a perimeter access road.
- ❖ Access ramp design criteria include:
  - 12-feet width minimum.
  - 15% maximum grade if surfaced to access road standard.
  - 12% maximum grade for alternative ramp surface using geotextile over native soils, and 6 inches of crushed rock surface.
  - Extend ramp to bottom of pond if pond bottom is greater than 1,500 square feet, otherwise ramp may end 4 feet above the pond bottom.

I CONTROL STRUCTURE

The interior dimensions for a control structure must be a minimum of 4ft x 4ft. with 6" concrete walls. The base of the structure must be a minimum of 8"thick concrete with placed above 8" compacted DGA. The structure typically contacts multiple orifices to control the various storm events.

Most control structures include at least one restrictor orifice. Orifices shall meet the following requirements:

- ❖ Minimum orifice diameter is 4 inches. This may be too large to meet minimum target release rates.
- ❖ Orifices may be constructed on a tee section or on a baffle.
- ❖ If using multiple orifices, the top orifice may be located too high to be physically constructed, in which case a notch weir could be used to meet performance requirements.

- ❖ Consider backwater affects of water surface elevations downstream of the conveyance system. High tailwater elevations may affect the restrictor system.
- ❖ At least one foot of separation between the invert elevation of the outlet pipe and the elevation of the lower orifice shall be provided

J OVERFLOW PROTECTION

- ❖ A primary overflow must be provided to pass the 100-year developed peak flow over or around the restrictor system. (typically a riser pipe within the control structure).
- ❖ A secondary inlet to the control structure must be provided. This may be a grated opening to the control structure or a "birdcage" overflow structure. A grated opening shall be designed to pass the 100-year developed peak flow. Vertical bars spaced 4- inches on center shall be provided within the window opening.
- ❖ Where an emergency overflow would discharge toward a steep slope, consider providing both an emergency overflow structure in addition to the spillway.
- ❖ Provide an emergency spillway sized to pass the 100-year developed peak flow for constructed berms over 2-feet in height. The emergency spillway shall meet the following design criteria:
  - The emergency spillway must be placed 6" above the 100yr-24hr storm.
  - Design the spillway as a broad-crested weir. The minimum side slopes of the weir must be more than 4h:1v
  - Establish the flow elevation through the emergency spillway. A minimum of 6 inches of freeboard shall be provided above the maximum water surface elevation through the spillway.
  - Discharge directly to the downstream conveyance system or another acceptable discharge point.
  - Armored to full width, beginning at a point 2 ft below the 100yr-24hr water elevation inside the pond and extending it across the berm embankment to downstream where the emergency overflow reenters the conveyance system.
  - Alternative armoring of 6" concrete pavement may be provided for spillways

K SIGNAGE & FENCING

- ❖ Fence required where slopes greater than 3H:1V above the emergency overflow water surface elevation or higher or where there is a wall greater than 30-inches in height.
- ❖ Public stormwater pond tracts shall be fenced. Place fence 1-foot inside the tract boundary or a minimum of 5 feet from the top slope catch point.
- ❖ Public drainage ponds fence shall be 6-ft chain link.
- ❖ Wood fence allowed in subdivisions. Use pressure treated posts and cedar, pressure treated fir, or hemlock rails and fence boards.
- ❖ Pond shall have an information sign. Applicant shall submit sign design and proposed location.
- ❖ Easement shall be signed.
- ❖ Access easement shall be signed.

L PLANTINGS & LANDSCAPING

- ❖ As required by minimum requirement, all disturbed area of the project to be landscaped shall implement to restore soil quality and depth.
- ❖ All disturbed or exposed soils shall be planted and/or landscaped.
- ❖ Seed should be at a rate of (KY 31- 85% at 350 lb/acre or Nexus Rye Grass 15% at

75 lb/acre)

- ❖ Pond interior side slopes and bottom shall be sodded or seeded with an appropriate seed mixture.
- ❖ All remaining areas of the tract should be planted with grass or landscaped
- ❖ Other than the above requirements, a specific landscape plan for ponds is not specified. However, if landscaping is provided, the following general criteria should be considered:
  - Plant no trees or shrubs within 25-feet of inlet or outlet pipes or drainage structures. Species with roots that seek water such as willow or poplar shall be avoided within 50-ft of structures.
  - Trees and shrubs should be planted in clumps to form "landscape islands." Landscape islands should be a minimum of 6 feet apart and 6 feet from any fences or other barriers. The 6-feet allows a mower to pass between the landscape islands.
  - Plant evergreen trees or trees with relatively little leaf fall in areas draining to the pond.
  - Deciduous trees shall be set back from the pond so that branches do not extend over the pond.

M SUBMITTAL INFORMATION

Include the following in any submittal documentation for the project:

- ❖ Show on the work map included in the Drainage Report the following:
  - Limits of contributing drainage basins per threshold discharge area for pre-development and developed conditions
  - Summary of areas by type (impervious, native, landscape).
  - Location of clear path of overflow to downstream collection point.
  - Natural drainage channels.
- ❖ Include in the construction plans and specifications:
  - Catch points for cuts and fills.
  - Tract boundaries and easements and location of easement markers.
  - Details, construction notes and specifications for all structures and materials.
  - Planting plan showing plant species, quantity, location and any special planting requirements.
  - Channel protection from path of overflow to downstream collection point.
  - Pond cross-section through control structure.
  - Cross-sections – access roads, ramps, and spillway.
  - Design and maximum water surface shown in plan view & pond cross-section.
  - Proposed design & location for the stormwater facility information sign.
- ❖ Include in the Drainage Report for the project:
  - Design calculations for overflow structures and emergency spillway.
  - Document facility meets any setback requirements.
  - If pond is to provide infiltration and detention document soils testing requirements as for an infiltration facility.
  - Hydrologic modeling results including a schematic of the model setup referencing model basin identifiers to basins and sub-basins shown in the work map.

N STORMWATER RUNOFF QUALITY TREATMENT STANDARD

In urban areas the first flush of runoff pollutants carries a heavy load of pollutants from impervious areas such as streets and parking areas that can negatively impact receiving streams by altering the water chemistry and water quality. Capturing the "First Flush" of pollutants is one way to improve water quality leaving the MS4. The goal of this stormwater runoff quality treatment standard is to establish the water quality volume (WQV) metric and provide treatment for the WQV.

The term "water quality volume" is generally used to define the amount of storm water runoff from any given storm that should be captured and treated in order to remove a majority of storm water pollutants on an average annual basis. Therefore, daily precipitation records were retrieved from the UK Ag Weather Station website between 1971 and 2010 for the Lexington climatology station. The data was sorted by depth with zero or trace amounts removed and the total number of rainfall events was multiplied by 0.8 to determine the event depth at which 80% of the total number of events were equal to or less than. The resulting depth was 0.6 inches.

The water quality volume (WQV) can then be calculated using the formula below:

$$WQ_V = \left(\frac{A * d}{43560\,ft^2 * 12in} \right)$$

Where:

WQ_V = Ac•ft
A = Impervious area (ft^2)
d = 0.6 (in)

The calculated WQV shall be treated in combination or alone, by management measures that are designed, built, and maintained to treat, filter, flocculate, infiltrate, screen, evapotranspire, harvest and reuse stormwater runoff, or otherwise manage the stormwater runoff quality.

O STANDARDS FOR PROTECTION OF HIGH QUALITY WATERS (HQW)

Areas of development and/or re-development that result in new or expanded discharge from the MS4 shall:

- Provide sufficient detention, storage, or infiltration BMPs to maintain or improve upon pre-construction flow in order to protect the existing in-stream designated water uses; and
- Provide the necessary BMPs that focus on removal of pollutants most common to the type of development occurring in order to maintain the level of water quality that protects existing uses. BMPs selected for the site shall be approved by the local MS4 Coordinator or their designee.
- Areas of redevelopment will be required to meet the same water quantity criteria as new development, and will need to provide water quality treatment at a level equivalent to 20% of the requirement for new development. BMPs will be approved on a case-by-case basis by the local permitting authority to provide reasonable assurance that the BMPs selected are appropriate for the site and pollutants of concern.

Regulatory Specifications:
KYR10 follows 401 KAR 10:030, Section 1(3) (Antidegradation Policy – High Quality Waters), which says a surface water shall be classified as a high quality water (HQW) if the surface water is not listed as an outstanding national resource, an exceptional water, or does not meet the criteria for impaired water. Currently, ~90% of the waters of the Commonwealth are categorized as HQWs and are subject to antidegradation implementation procedures, which requires maintaining and protecting existing in-stream water uses and the level of water quality necessary to protect the existing uses.

P UNDERGROUND DETENTION

General Description
Underground detention is typically utilized on sites where developable surface area is at a minimum. Underground detention facilities can be either box-shaped facilities constructed with reinforced concrete, facilities constructed with large diameter metal or plastic pipe or commercially-available proprietary underground systems, such as Arch systems. No Stone Pits or completely stone filled vaults shall be allowed.

Pollutant Removal Capabilities
Underground detention facilities are not capable of significant pollutant removal. Therefore, because underground detention is not intended for water quality treatment, it must be used in a treatment train approach with other structural BMPs that provide treatment of the WQv. This will prevent the underground pipe systems or vaults from becoming clogged with trash or sediment and significantly reducing the maintenance requirements.

Planning and Design Standards
If underground detention is allowed by the local municipality, the following standards shall be considered minimum design standards for the design of underground detention. Underground detention that are not designed to these standards will not be approved. The local municipality shall have the authority to require additional design conditions if deemed necessary.

A. LOCATION AND SITING

- ❖ The maximum contributing drainage area to be served by a single underground detention vault or tank is 25 acres.
- ❖ Flood protection controls should be designed as final controls for on-site stormwater. Therefore, underground detention will typically be located downstream of structural stormwater BMPs that are designed to provide treatment of the water quality volume (WQv)
- ❖ Underground detention shall be placed in an easement that is recorded with the deed and shown on the plan. The easement shall be located 15 feet from the outside limits of the underground detention structure. Minimum setback requirements for the easement shall be as follows unless otherwise specified by Planning and Zoning:
    - From a public water system well
    - From a private well – 50 feet; if the well is down gradient from a land use that must obtain a Special Pollution Abatement Permit, then the minimum setback is 250 feet
    - From a septic system tank/leach field – 50 feet
    - From a city owned sanitary sewer gravity line – 7.5 feet
    - From a city owned sanitary sewer force main – 10 feet

- The easement shall be located 15 feet from the outside limits of the underground detention structure.

❖ The first floor elevation (FFE) for any structure adjacent to underground detention shall have an elevation no lower than 2 feet above the emergency spillway elevation.

B. GENERAL DESIGN

Underground detention shall consist of the following elements, designed in accordance with the specifications provided in this section.

❖ An outlet structure;
❖ An emergency bypass; and
❖ Maintenance access.
❖ Underground detention systems that are used to provide extended detention of the channel protection volume or water quality volume shall have watertight joints and piping.
❖ Routing calculations must be used to demonstrate that the storage volume is adequate.
❖ Adequate maintenance access must be provided for all underground detention systems. Access must be provided over the inlet pipe and outflow structure.
❖ Access openings can consist of a standard frame, grate and solid cover, or a removable panel. Vaults with widths of 10 feet or less should have removable lids.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

❖ Underground detention vaults and tanks must meet structural requirements for overburden support and traffic loading if appropriate.
❖ Detention Vaults: Minimum 3,000 psi structural reinforced concrete may be used for underground detention vaults. All construction joints must be provided with water stops. Cast-in-place wall sections must be designed as retaining walls. The maximum depth from finished grade to the vault invert should be 20 feet.
❖ Detention Pipes: The minimum pipe diameter for underground detention is 36 inches.

D. INLET and OUTLET STRUCTURES

❖ Additional outlets are sized for peak flow control (based upon hydrologic routing calculations) and can consist of weirs, orifices, outlet pipes, combination outlets, or other acceptable control structures.
❖ Water shall not be discharged from underground detention in an erosive manner. Riprap, plunge pools or pads, or other energy dissipaters are to be placed at the end of the outlet to prevent scouring and erosion. If a pond outlet discharges immediately to a channel that carries dry weather flow, care should be taken to minimize disturbance along the downstream channel and streambanks, and to reestablish a forested riparian zone in the shortest possible distance (if the downstream area is located in a vegetated buffer).

E. EMERGENCY BYPASS

❖ A high flow bypass shall be included in the underground detention design to safely pass flows greater than the maximum storm used by the local jurisdiction or in the event of outlet structure blockage or mechanical failure. The bypass shall be located so that downstream structures will not be impacted by emergency discharges.

F. MAINTENANCE ACCESS

- ❖ A maintenance right-of-way or easement having a minimum width of 15 feet shall be provided from a driveway, public or private road. The maintenance access easement shall have a maximum slope of no more than 15% and shall have a minimum unobstructed drive path having a width of 12 feet, appropriately stabilized to withstand maintenance equipment and vehicles.
- ❖ The maintenance access shall extend to the forebay (if included) and outlet works, and, to the extent feasible, be designed to allow vehicles to turn around.
- ❖ No Rock Pits or completely rock filled vaults shall be allowed.

G. DESIGN PROCEDURES

In general, engineers should perform the same design procedures when designing underground detention as typical above grade detention basins.

H. MAINTENANCE REQUIRMENTS AND INSPECTION CHECKLIST

Regular inspection and maintenance is critical to the effective operation of underground detention as designed. It is the responsibility of the property owner to maintain all stormwater BMPs in accordance with the minimum design standards and other guidance provided in this manual. The local municipality has the authority to impose additional maintenance requirements where deemed necessary.

This page provides guidance on maintenance activities that are typically required for underground detention, along with a suggested frequency for each activity. Individual underground detention locations may have more, or less, frequent maintenance needs, depending upon a variety of factors including the occurrence of large storm events, overly wet or dry (i.e., drought) regional hydrologic conditions, and any changes or redevelopment in the upstream land use. Each property owner shall perform the activities identified below at the frequency needed to maintain the pond in proper operating condition at all times.

Inspection Activities	**Suggested Schedule**
After several storm events or an extreme storm event, inspect for: signs of clogging of the inlet or outlet structures and sediment accumulation.	As Needed
Inspect for: trash and debris; clogging of the outlet structures and any pilot channels; excessive erosion; sediment accumulation in the basin and inlet/outlet structures; tree growth on dam or embankment; the presence of burrowing animals; standing water where there should be none; vigor and density of the grass turf on the basin side slopes and floor; differential settlement; cracking; leakage; and slope stability.	Semi-annually
Inspect that the outlet structures, pipes, and downstream and pilot channels are free of debris and are operational. Note signs of pollution, such as oil sheens, discolored water, or unpleasant odors. • Check for sediment accumulation in the facility. • Check for proper operation of control gates, valves or other mechanical devices.	Annually
Maintenance Activities	**Suggested Schedule**
Perform structural repairs to inlet and outlets. Clean and remove debris from inlet and outlet structures.	Monthly or as needed
Repair damage to inlet or outlet structures, control gates, valves, or other	As Needed

mechanical devices, undercut or eroded areas.	
Monitor sediment accumulations, and remove sediment when the pond volume has become reduced significantly.	As Needed

Use of the inspection checklist that is presented on the next page is encouraged to guide the property owner in the inspection and maintenance of underground detention facilities. The local municipality can require the use of this checklist or other form(s) of maintenance documentation when and where deemed necessary in order to ensure the long-term proper operation of the underground detention facilities. Questions regarding stormwater facility inspection and maintenance should be referred to the local jurisdiction.

INSPECTION CHECKLIST AND MAINTENANCE GUIDANCE UNDERGROUND DETENTION INSPECTION CHECKLIST

Location: ________________Owner Change since last inspection? Y N Owner Name, Address, Phone: __________________ Date: _Time: ______Site conditions:___________

Inspection Items	Satisfactory (S) or Unsatisfactory (U)	Comments/Corrective Action
Inlet/Outlet Structures		
Clear of debris and functional?		
Trash rack clear of debris and functional?		
Sediment accumulation?		
Condition of concrete/masonry?		
Metal pipes in good condition?		
Control valve operational?		
Pond drain valve operational?		
Outfall channels function, not eroding?		
Other (describe)?		
Pond Bottom		
Excessive sedimentation?		

If any of the above inspection items are **UNSATISFACTORY**, list corrective actions and the corresponding completion dates below:

Corrective Action Needed	Due Date

Inspector Signature: ______ Inspector Name (printed)____

6 Example Schematics

Figure 7. Example Underground Detention Pipe System

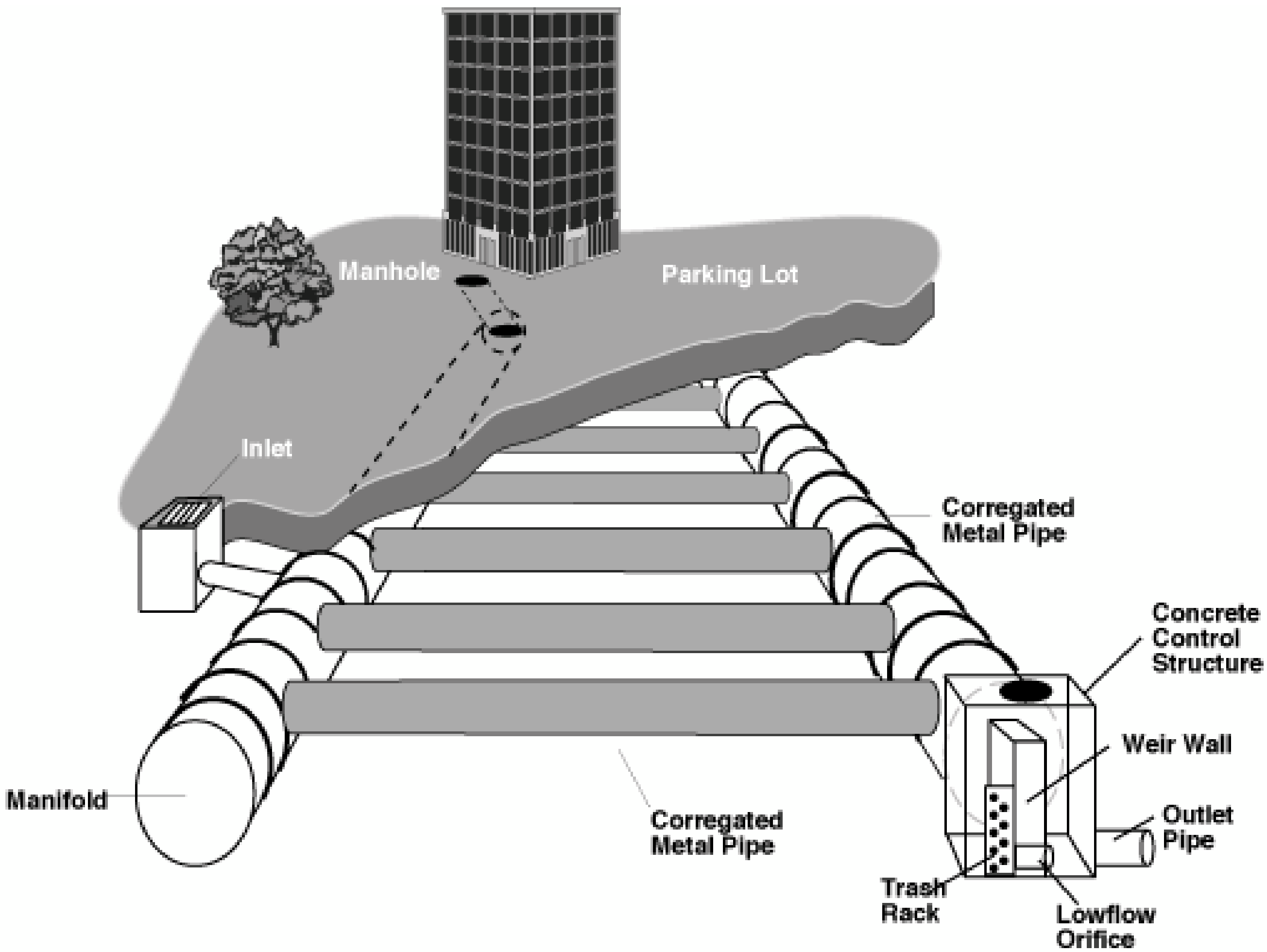


Figure 8. Schematic of a Typical Underground Detention Vault

(Source: WDE, 2000)

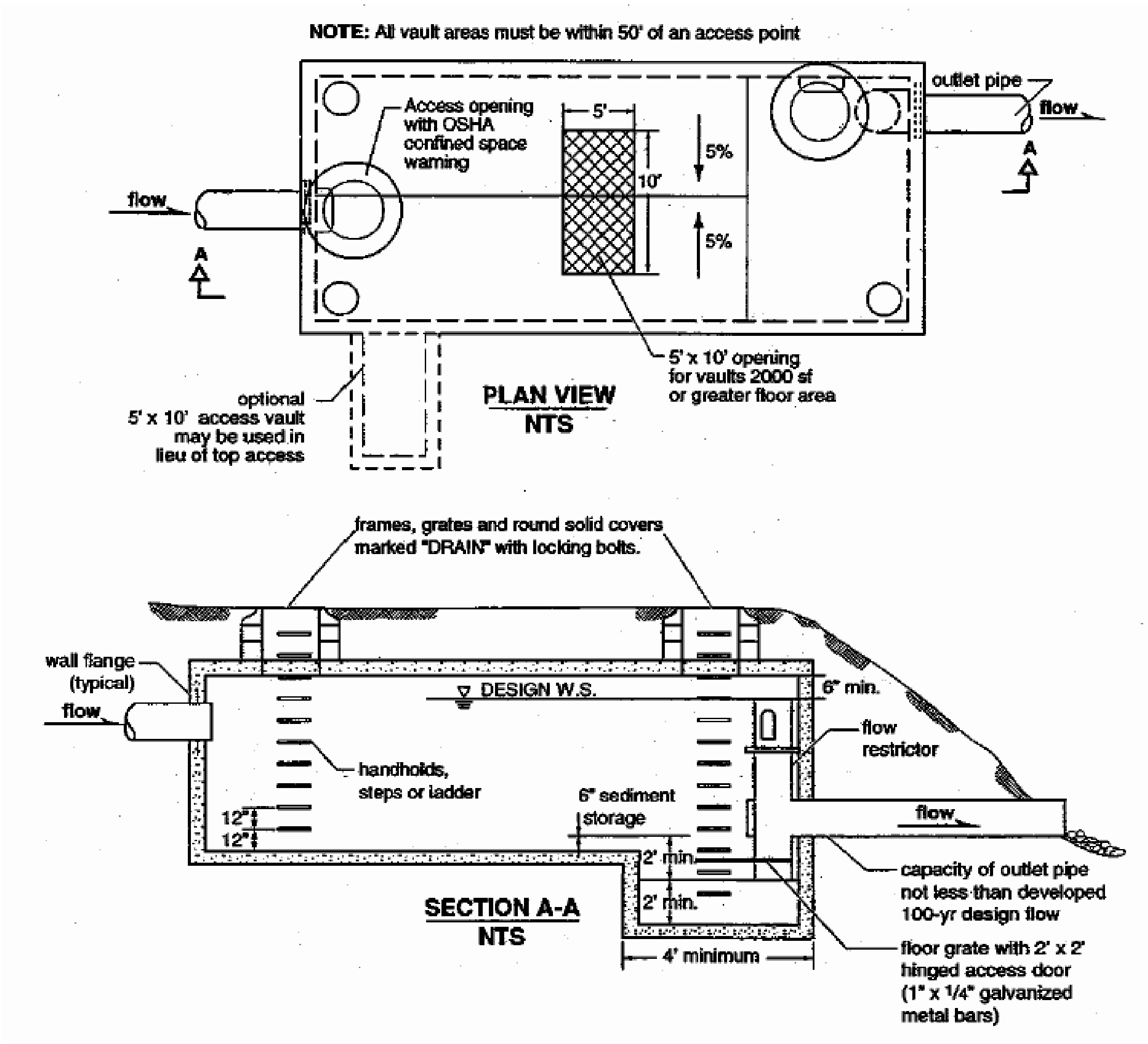
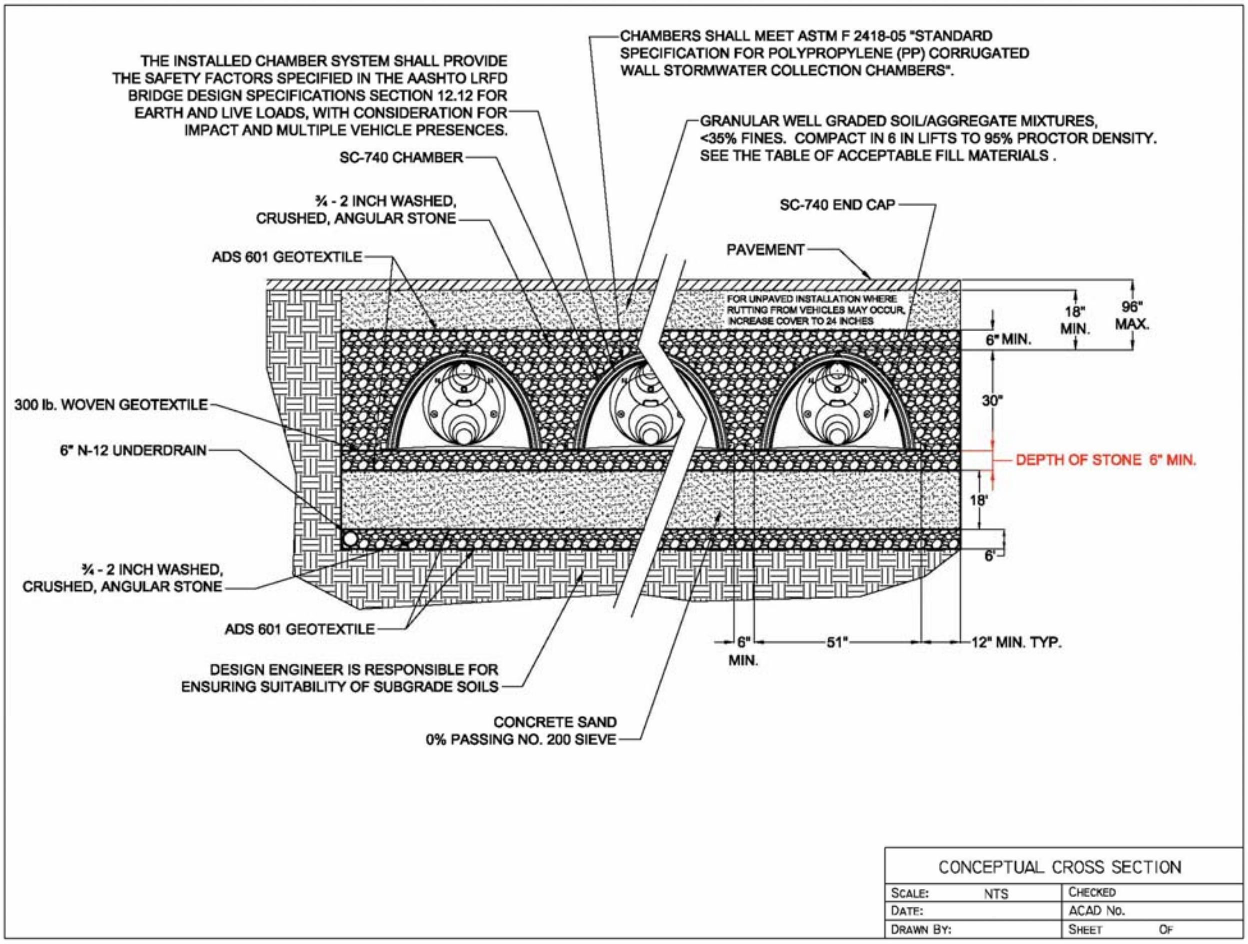


Figure 9. Schematic of a Typical Underground Arch System

(Source: ADS, Stormtech)



Applicant Use	DETENTION BASIN REVIEW CHECKLIST	Official Use
	HYDROLOGIC DESIGN	
	Verify input model for pre-development and developed land use, soil type and areas are consistent with site plan and other documentation.	
	Interconnected Pond simulation model used to size detention pond utilizing SCS runoff hydrographs.	
	If separate threshold discharge areas exist, verify that they meet criteria	
	If impervious areas are not included in model because they are considered ineffective, verify that dispersion criteria are met per appropriate BMP to designated impervious area as ineffective.	
	Verify model report is submitted and verify that detention facility meets discharge criteria.	
	Verify model computer file is submitted with project, consider running model to verify report conclusions.	
	Check that layout of detention pond and control structure design shown on site plans/drainage plans is consistent with results of model.	
	A schematic of the hydrologic modeling parameters (network diagram of model, or equivalent) should be provided with basin designations matching basin designations on drainage work map required to be included in the Drainage Report.	
	SPECIAL REQUIREMENTS	
	Is a permit from Division of Water Required	
	Is a separate tract established that encompasses the detention pond, access roads, and associated appurtenances and structures and is there is at least a 20-ft separation between any facility, the catch point of fill or cut slopes, or access road to the tract line.	
	POND GEOMETRY & STRUCTURAL DESIGN	
	Interior side slopes steeper than 3H:1V are provided with protective fencing.	
	If interior or exterior side slopes steeper than 2H:1V are proposed, is the design addressed in the geotechnical report by a licensed professional engineer with geotechnical expertise.	
	If retaining walls or rockeries are proposed have they been designed by a licensed professional engineer.	
	Is the flow path from pond inlet to outlet maximized to the extent feasible to prevent sedimentation? Verify that the inlet to the pond is not via the control structure or outflow conveyance system.	
	Is a debris barrier (trash rack) provided for the pond outlet and for any pond inlet pipes.	
	If an embankment is proposed (i.e. berm construction above existing grade) to impound water, a geotechnical engineer is required to design the embankment for slopes steeper than 2H:1V and greater than 6-ft in height.	
	Is a pond berm embankment “key” equal to 50% of the berm embankment cross-sectional height and width included in the design?	
	Is the pond berm embankment constructed on fill soils? If so, a geotechnical engineer shall provide design and design should be included in geotechnical report.	
	Are anti-seepage collars provided on pipes through embankments ponding greater than 8-ft of water.	
	Is any pond berm embankment soils and compaction specified by a geotechnical engineer?	

	Is all exposed earth on embankment either sodded or seeded? No trees or shrubs are allowed to be planted on berms taller than 4 feet. Trees or shrubs planted on berms 4 feet or smaller shall not exceed 20 feet mature height and have a fibrous root system.	
	Is the top of berm width at least 10-feet, or as recommended by a geotechnical engineer? If the top of berm is to be used for maintenance access, minimum width is 15-feet.	
SETBACKS		
	Is the maximum water surface elevation shown on the drainage plan and also shown in the pond cross-section?	
	Is there at least a 2-foot vertical clearance from the maximum water surface to any structures (buildings) within 25-feet?	
	Is there at least a 20-foot horizontal separation from the maximum water surface to property lines, structures, sewer lines and the tract property boundary line?	
ACCESS ROADS		
	Is access to the detention pond provided from a public street or right-of-way?	
	For access to the detention pond outside of the public right-of-way is a minimum 15-foot easement provided? Is the easement provided with a minimum 12-foot width all weather surface such as crushed rock ?	
	Is an access road provided to the control structure and other drainage structures associated with the detention pond? If pond maintenance is to be performed from the access road (i.e. no ramp to pond bottom) the access road should extend around the pond perimeter.	
	Is the pond access road grade less than 15% and less than 12% to the control structure?	
	Minimum horizontal curve radius 40-feet.	
	If access road length exceeds 75-ft a turnaround must be provided for a 31-ft length design vehicle with an inside wheel path radius of 40-ft.	
	Is paved apron provided where access road connects to paved public roadway?	
	Is a gate or are bollards provided for the access road? Vehicle access shall be limited by a locking gate or bollards. Gates are required if pond is fenced and must be located only on a straight section of road?	
ACCESS RAMPS		
	Access ramp required unless applicant demonstrated that a 20-ft reach track hoe can access all areas of the pond from the perimeter access road? Perimeter access road shall be extended around entire perimeter of pond (see above).	
	Access ramp grade less than 15%.	
	Access ramp width at least 12-feet.	
	Access ramp section of suitable design to provide year round access? Standard section of geotextile over native soils with 6-inches of crushed rock allowed, but slope limited to 12% maximum for this design.	
	Ramp extended to bottom of pond for bottom area greater than 1,500 square feet? Otherwise ramp may end 4 feet (measured horizontally) from pond bottom.	

	CONTROL STRUCTURE	
	Orifice(s) and weirs sizes and elevations match hydrologic model output.	
	Control structure detail provided in plans	
	Minimum clear space of 6-inches provided from top of riser to bottom of structure lid.	
	Minimum orifice diameter > 4”	
	Backwater affects possible for outlet pipe? If so, have they been analyzed for.	
	1-ft separation from bottom of structure to lowest orifice?	
	1-ft minimum separation from lowest orifice to outlet pipe invert?	
	Capacity of overflow riser adequate to pass 100-year storm?	
	Grated bar inlet structure provided and designed to pass 100-year storm? Bar spacing 4”.	
	EMERGENCY SPILLWAY	
	Emergency spillway provided and designed to pass 100-year developed peak flow?	
	Minimum freeboard above maximum water surface elevation of 6-inches.	
	Discharge from spillway or overflow directly to downstream conveyance system or other acceptable discharge point.	
	Armored to full width, beginning at a point 2 ft below the 100yr-24hr water elevation inside the pond and extending it across the berm embankment to downstream where the emergency overflow reenters the conveyance system.	
	SIGNAGE AND FENCING	
	Fencing provided where pond slope greater than 3H:1V above emergency overflow water surface, or where there are walls greater than 30-inches in height.	
	If a public facility – pond tract fenced with 6-ft chain link.	
	Wood fence or other alternative fencing/shrubbery screening allowed for private facilities.	
	PLANTINGS & LANDSCAPING	
	Disturbed soil quality and depth restored ?	
	Pond interior side slopes and bottom sodded or seeded with appropriate seed mixture	
	All remaining areas of storm pond tract seeded, sodded or landscaped ?	
	No trees or shrubs within 25-feet of inlet or outlet pipes or drainage structures.	
	No water seeking plants such as willow or poplar within 50-ft of structures.	
	Trees and shrubs planted in clumps to form landscape island a minimum of 6-feet apart and 6-feet to fences and other barriers.	
	Evergreen trees or trees with little leaf fall in areas draining to pond.	
	Deciduous tree set back from pond so branches do not extend over pond.	

SUBMITTAL INFORMATION		
	DRAINAGE REPORT	
	Is the report Stamped, Signed, & Bound Storm Water Report by Licensed PE in KY?	
	Is the Project Name & Location?	
	Is the Owner Name & Contact Information?	
	Is the Engineer Name & Contact Information?	
	Is the date of submittal listed?	
	Is the Design Narrative (Existing Site, Proposed Development, etc.) included?	
	Is the Project Location Map shown?	
	Is a USGS Map for with Project Site shown (1" = 1000' or better)?	
	Is the Soil Type Map & Soil Classification shown?	
	Is the project within a Flood Insurance Rate Map (FIRM)?	
	Is the Existing Drainage Area Map Whole Site (1" = 50' or better) shown?	
	Is the Sub-Watersheds delineated?	
	Are the Sub-Watersheds labeled (must co-relate to the model)?	
	Are the C-Factor or CN for each Sub-Watershed?	
	Are the Impervious Area shown with a Hatched Pattern?	
	Is Detention Basin Analysis performed using SCS Method?	
	Does the Sub-Water sheds information match the Drainage Area Maps?	
	Is the Plan View of the interconnectivity of Watersheds shown?	
	Is TR-55 Methodology for Time of Concentration (Tc) used?	
	Hydrologic modeling results including schematic of model setup referencing model basin identifies to basins and sub-basins shown in the work map and hydrologic model.	
	Work map showing sub basins and basins contributing to the detention pond with basin identifies corresponding to the nomenclature used in the hydrologic model.	
	Summary table of contributing sub basins identifying soil type and areas of impervious, landscape, forest, etc. corresponding to hydrologic model inputs.	
	Document how all required facility setbacks are met.	
	Geotechnical report including analysis of embankment berms, slope stability for steep slopes located within setback distances or within 300-ft of the top of a slope designated a landslide hazard area, retaining wall design, and any other analysis required by geotechnical engineer.	
	If pond is to provide for infiltration and detention, document soils testing requirements per infiltration facility standards.	
	Design calculations for overflow structures, emergency spillway, and outfall protection.	
	Show on work map the location of natural drainage channels and show a clear path of overflow to downstream collection point from emergency spillways.	

CONSTRUCTION DRAWINGS		
	Show existing topography based on field verified survey.	
	Show proposed topography and extend proposed topography to catch points.	
	Show tract boundaries and easements with widths and location of easement markers.	
	Planting plan showing plant species, quantity, location and any special planting requirements.	
	Design and maximum water surface shown in plan view.	
	Design and maximum water surface shown in pond cross-section	
	Provide at least one pond cross-section through the control structure.	
	Details of emergency spillway provided.	
	Details of control structure shown – include control structure detail showing elevations of orifices, riser overflow, top of structure, etc.	
	Proposed design and location of information sign including sign specifications.	

AS-BUILT HYDROLOGY / DETENTION POND

Project:____ **Date:** ____________

Land Development Permit #__________________________

Engineer:_______________________________________

E-Mail:____

Phone:____

The following is the minimum information required in a standard hydrology study submitted to the City of Richmond. Additional information may be required for site specific conditions. It shall be at all times the responsibility of the engineer of record to accurately model and report the conditions on the site. The City of Richmond accepts no responsibility for errors or omissions from this report.

Please submit an As-Built Hydrology report, one set of As-Built Survey drawings, and an annotated copy of these comments to the City of Richmond Planning & Zoning for review. Direct questions regarding the checklist and submittal requirements to City of Richmond Planning & Zoning at 859-623-1000.

ASBUILT SURVEY FOR WET OR DRY DETENTION PONDS

1. ☐ Survey is signed, sealed and dated by a Registered Land Surveyor licensed in the state of Kentucky.
2. ☐ Contours are shown at 1-foot intervals.
3. ☐ Bottom of pond elevations are shown to enable verification of positive drainage.
4. ☐ Top of wall shots or dam elevation statement is included on the survey to verify freeboard. Top width of embankment is shown.
5. ☐ The required water quality volume for each pond is shown on the survey.
6. ☐ The maximum limits of ponding are shown. The 100-year water surface elevation is shown.
7. ☐ The location of the pond is shown with respect to property lines, R/W lines, buildings, other easements, etc.
8. ☐ A detail the outlet control structure showing pertinent dimensions and elevations of weirs, orifices, outfall pipes, etc is included on the survey.
9. ☐ Water quality and channel protection orifices include filtration/trash rack to reduce the likelihood of clogging.
10. ☐ 15-foot access and maintenance easement are shown around the pond. The access easement is sloped at 20% or flatter

AS-BUILT HYDROLOGY STUDY FOR WET AND DRY DETENTION PONDS

1. ☐ Hydrology is signed, sealed and dated by a Professional Engineer licensed in the state of Kentucky.

2. ☐ Water quality volume provided in the as-built pond is equal or greater than the as-designed volume. The elevation of the water quality volume is indicated on the stage/storage table. Revisions to water quality orifice size/elevation are justified by calculations.

3. ☐ Channel protection volume provided in the as-built pond is equal or greater than the as-designed volume. The elevation of the channel protection volume is indicated on the stage/storage table. Revisions to channel protection orifice size/elevation are justified by calculations.

4. ☐ The post development storm flows do not exceed the predevelopment storm flows for the 10yr-24hr, 25yr-24hr, 100yr-6hr, 100yr-24hr design storms.

5. ☐ Stage/storage relationship, 100-year hydrographs for all basins and routed pond(s) are provided. The beginning routing elevation for the as-built pond is provided.

6. ☐ Use the following tables as an example to organize the hydrology information.

Pond #1					
Design Storm	As-Designed Release Rates (cfs)	As-Built Release Rates (cfs)	As-Designed Water Surface Elevation (ft)	As-Built Water Surface Elevation (ft)	As-Built Freeboard Provided (ft)
10yr-24hr					
25yr-24hr					
100yr-6hr					
100yr-24hr					

Pond #1						
	Water Quality Volume (cf)	Channel Protection Volume (cf)	Diameter of Water Quality Orifice (ft)	Elevation of Water Quality Orifice (ft)	Diameter of Channel Protection Orifice (ft)	Elevation of Channel Protection Orifice (ft)
As-Designed						
As-Built						

CHAPTER 8 – LOW IMPACT DEVELOPMENT BMPs

A Introduction

Low Impact Development (LID) is a planning and design approach to site development that is gaining popularity throughout the State of Kentucky. Its attractiveness lies in its potential to reduce on-site and off-site stormwater impacts, reduce infrastructure costs to developers and municipalities, and promote development that is "softer on the land" compared with typical traditional development. This approach, which is applicable to residential, commercial and industrial projects, and scalable to urban, suburban and rural settings, often is linked with efforts by citizens and municipalities to foster more sustainable, livable communities. LID is a "common sense" approach to stormwater.

LID aims to mimic pre-development hydrology, treat stormwater as close to its source as possible, provides opportunities for groundwater recharge, preserve natural drainage systems and open space, and incorporate small-scale controls that replicate natural processes in detaining and filtering stormwater. LID uses the "divide and conquer" theory to treat relatively small amounts of stormwater and utilize it in beneficial ways. This contrasts with conventional stormwater management approaches geared to concentrating and collecting runoff and exporting it off-site as a waste product.

LID techniques offer many benefits to a variety of stakeholders:

Developers:

- ❖ Reduce land clearing and grading costs
- ❖ Potentially reduce infrastructure costs (streets, curbs, gutters)
- ❖ Reduce storm water management costs
- ❖ Potentially reduce impact fees and increase lot yield
- ❖ Increase lot and community marketability

Municipalities:

- ❖ Protects the health and safety of a community by reducing stormwater impacts
- ❖ reduces or eliminates nonpoint source pollutants from reaching waterways
- ❖ Protect regional flora and fauna by reducing stream bank erosion
- ❖ Balance growth needs with environmental protection
- ❖ Reduces municipal infrastructure and utility maintenance costs (streets, curbs, gutters, storm sewer)
- ❖ enhances both physical health (by increasing opportunities to walk and exercise outside) and mental health (by improving the visual quality of the environment and thereby reducing stress and mental fatigue)
- ❖ Increase collaborative public/private partnerships

Environment:

- ❖ Preserve integrity of ecological and biological systems
- ❖ Protect site and regional water quality by reducing sediment, nutrient, and toxic loads to water bodies
- ❖ Reduce impacts to local terrestrial and aquatic plants and animals
- ❖ Preserve trees and natural vegetation

Green Infrastructure (GI): an integrated systems approach to stormwater management that mimic natural processes that captures, infiltrates, evaporates, and/or reuses stormwater. Green infrastructure uses soils, topography, and vegetation in a way that minimizes the impacts of anthropogenic disturbance and maintains the pre-development hydrology and water quality of urban environments.

The goal of GI is to design an urban environment that remains a functioning part of an ecosystem rather than existing apart from it. This is an innovative approach to urban stormwater management that strategically integrates stormwater controls throughout the urban landscape and does not rely solely on conventional end-of-pipe structural practices.

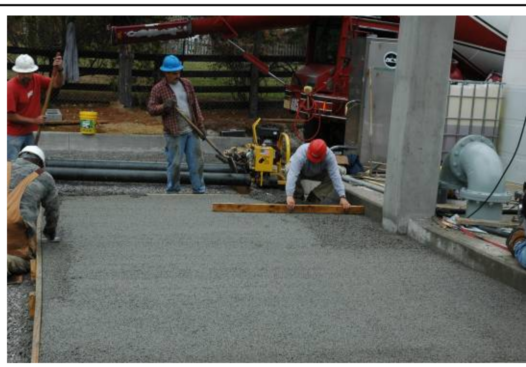
B Green Infrastructure Benefits

Green Infrastructure practices have the potential to address one, two or all three of the following stormwater related issues: reduce volume runoff, reduce peak discharge and improve water quality for residential, commercial and industrial projects. Green Infrastructure relies on a systems approach model to address stormwater runoff. As a result, an individual site or project may contain two, three or more GI practices operating independently or in a treatment train format to capture, infiltrate or harvest rain water. Some features can be used as pre-treatment so that the pollutants can be captured as quickly as possible in the treatment train, thus eliminating adverse effects further downstream. Some of these pre-treatment options include solids traps, oil and water separators, forebays, etc.

1. Green Infrastructure Practices

The following section provides photographs of the most common green infrastructure practices. Each GI practice has its advantages and appropriate applications. This section assesses these and describes each practice in terms of: suitability, limitations, land area demands, relative costs, and maintenance.

Permeable Pavement: pervious concrete, porous asphalt, permeable pavers (concrete and brick)



Pervious Concrete – During Placement

Pervious Concrete – After Rain Event – LFUCG South Elkhorn Pump Station

Permeable Concrete Pavers – Ronald McDonald House Charities of Bluegrass

Previous Asphalt – Ronald McDonald House Charities of Bluegrass

Vegetative Roofs / Vegetative Walls: extensive (growing media 2 – 6 inches deep), intensive (growing media 6 inches to 4 feet deep)

Green Roof Example – Bernheim Forest

Green Wall Example – New York City

Capture / Harvesting / Reuse:
Rain Barrels / Cisterns: appropriate for residential, commercial and industrial sites, rainwater reuse includes irrigation for lawns and planting beds and interior/exterior non-portable water use

Rain Barrel - Residential

Rain Barrel - Commercial

Manufactured Systems - Underground Storm Water Storage: similar to above ground rain barrels or cisterns, can be used to meet storm water detention requirements.


Underground Stormwater Storage


Underground Stormwater Storage-detail

Downspout disconnection: rain water directed to flow over permeable surfaces such as grass, directed away from buildings


Downspout disconnection


Downspout disconnection

Tree Box Filters: mini filtration areas beneath trees or shrubs contained within an in-ground unit.


Tree Box Filter – Gainesway Pond, Lexington, KY


Tree Box Filter – Gainesway Pond, Lexington, KY

Vegetative Swales: grasses or native plantings designed to accept rain water flow, filter and infiltrate into the ground


Vegetative Grass Swale, Lexington, KY


Vegetative Grass Swale

Rain Gardens/Bio-retention: native grasses, wildflowers, plant material combined with amended soils to allow for rainwater infiltration and evapotranspiration


Rain Garden, Cincinnati, Ohio


Rain Garden, Cincinnati, Ohio

Street Trees: appropriately placed Street trees reduces storm water runoff of takes rainwater through evapotranspiration and reduces heat island effect


New Street Trees


Mature Street Trees

2. Incentives

Current incentives to implement green infrastructure practices include the following:

- Potentially reduces infrastructure costs for storm water management
- potential increase in lot and community marketability
- potential reduction in land clearing and grading costs
- potential synergies for meeting storm water quality and quantity and landscape requirements for City of Richmond

The EPA has produced two green infrastructure report entitled "*Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure*" August, 2010, and " Reducing Stormwater Cost through Low Impact Development (LID) Strategies and Practices" December, 2007 highlights case studies from across the US demonstrating the benefits of Green Infrastructure practices including associated cost savings.

3. Select Green Infrastructure Specifications

This manual provides additional information on select BMP practices. The BMPs listed below does not limit the use of other BMPs suitable for your construction site. It is important to know that one BMP is not suitable for all situations. Choose BMPs with care given to the environment is it being proposed in and the goal of the BMP use. BMPs may require certified installers that must approve and over see the installation of the BMP. Additional documentation may be required by the Planning and Zoning staff.

C Permeable Pavement

1 Description

Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. A variety of permeable pavement surfaces are available, including pervious concrete (PC), porous asphalt (PA) and permeable interlocking concrete pavers (IP). While the specific design may vary, all permeable pavements have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric installed on the bottom (See Figures 1 and 2).

Figure 1. Cross Section of Typical Permeable Pavement
(Source: Hunt & Collins, 2008)

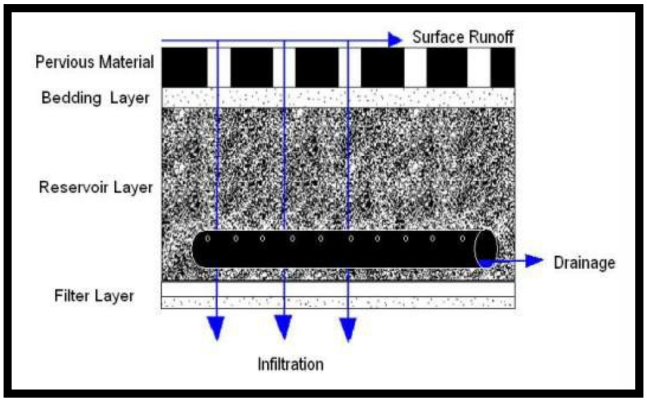
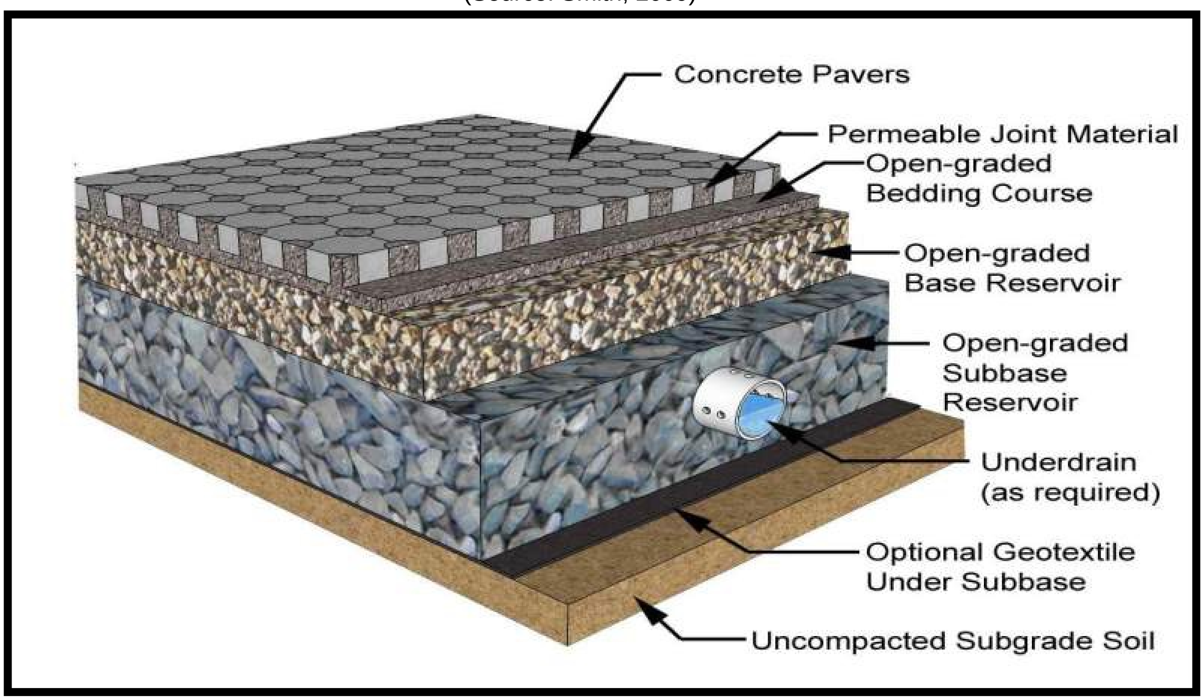


Figure 2. Permeable Pavement Typical Detail
(Source: Smith, 2009)



The thickness of the reservoir layer is determined by both a structural and hydrologic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. In low-infiltration soils, some or all of the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in the native soils permit, permeable pavement can be designed without an underdrain, to enable full infiltration of runoff. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

Permeable pavement is typically designed to treat stormwater that falls on the actual pavement surface area, but it may also be used to accept run-off from small adjacent impervious areas, such as impermeable driving lanes or rooftops. Careful sediment control of these adjacent areas is needed to avoid clogging of the down-gradient permeable pavement. Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Permeable pavement promotes a high degree of runoff volume reduction and nutrient removal, and it can also reduce the effective impervious cover of a development site.

2 Performance

The overall stormwater functions of permeable pavement are shown in Table 1.

Table 1. Summary of Stormwater Functions Provided by Permeable Pavement

<table>
<tr><th>Stormwater Function</th><th>Level 1 Design</th><th>Level 2 Design</th></tr>
<tr><td>Annual Runoff Volume Reduction (RR)</td><td>45%</td><td>75%</td></tr>
<tr><td>Channel Protection</td><td colspan="2">o Use RRM spreadsheet to calculate a Curve Number (CN) adjustment; OR
o Design extra storage (optional, as needed) in the stone underdrain layer to accommodate larger storm volumes, and use NRCS TR-55 Runoff Equations[1] to compute a CN adjustment.</td></tr>
<tr><td>Flood Mitigation</td><td colspan="2">Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.</td></tr>
<tr><td colspan="3">1 NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).</td></tr>
</table>

Sources: CWP and CSN (2008) and CWP (2007)

The choice of what kind of permeable pavement to use is influenced by site-specific design factors and the intended future use of the permeable surface. A general comparison of the engineering properties of the three major permeable pavement types is provided in Table 2, although designers should check with product vendors and their local review authority to determine their specific requirements and capabilities. Designers should also note that there are other paver options, such as concrete grid pavers and reinforced turf pavers that function in the same general manner as permeable pavement.

Table 2. Comparative Properties of the Three Major Permeable Pavement Types

Design Factor	Porous Concrete	Porous Asphalt	Interlocking Pavers
Scale of Application	Small and large scale paving applications	Small and large scale paving applications	Micro, small and large scale paving applications
Pavement Thickness [1]	5 to 8 inches	3 to 4 inches	3 inches [1, 8]
Bedding Layer [1, 8]	None	2 inches No. 57 stone	2 inches of No. 8 stone
Reservoir Layer [2, 8]	No. 57 stone	No. 2 stone	No. 2 stone 3-4 inches of No.57 stone
Construction Properties [3]	Cast in place, seven day cure, must be covered	Cast in place, 24 hour cure	No cure period; manual or mechanical installation of pre-manufactured units, over 5000 sf/day per machine
Design Permeability [4]	10 feet/day	6 feet/day	2 feet/day
Construction Cost Comparison	Middle	Lowest	Highest
Min. Batch Size	500 sq. ft		NA
Longevity[6]	20 to 30 years	15 to 20 years	20 to 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature Reduction	Cooling in the reservoir layer	Cooling in the reservoir layer	Cooling at the pavement surface & reservoir layer
Colors/Texture	Limited range of colors and textures	Black or dark grey color	Wide range of colors, textures, and patterns
Traffic Bearing Capacity [7]	Can handle all traffic loads, with appropriate bedding layer design.		
Surface Clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable stone jointing materials
Other Issues		Avoid seal coating	Snowplow damage
Design Reference	American Concrete Institute # 522.1.08	Jackson (2007) NAPA	Smith (2006) ICPI

[1] Individual designs may depart from these typical cross-sections, due to site, traffic and design conditions.

[2] Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks.

[3] ICPI (2008)

[4] NVRA (2008)

[6] Based on pavement being maintained properly, Resurfacing or rehabilitation may be needed after the indicated period.

[7] Depends primarily on on-site geotechnical considerations and structural design computations.

[8] Stone sizes correspond to ASTM D 448: *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*.

3 Design Table

The major design goal of Permeable Pavement is to maximize nutrient removal and runoff reduction. To this end, designers may choose to use a baseline permeable pavement design (Level 1) or an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the design must meet all design criteria shown in the right hand column of Table 3.

Table 3. Permeable Pavement Design Criteria

Level 1	Level 2
Tv = (0.64)(Rv)(A) / 12 – the volume reduced by an upstream BMP [1]	Tv = (0.75)(Rv)(A) / 12
Soil infiltration is less than 0.5 in./hr.	Soil infiltration rate exceeds 0.5 in./hr.
Underdrain required	Underdrain not required; ***OR*** If an underdrain is used, a 12-inch stone sump must be provided below the underdrain invert; ***OR*** The Tv has at least a 48-hour drain time, as regulated by a control structure.
CDA = The permeable pavement area plus upgradient parking, as long as the ratio of external contributing area to permeable pavement does not exceed 2:1.	CDA = The permeable pavement area
[1] The contributing drainage area to the permeable pavements should be limited to paved surfaces, to avoid sediment wash-on, and sediment source controls and/or a pre-treatment strip or sump should be used. When pervious areas are conveyed to permeable pavement, pre-treatment must be provided.	

4 Physical Feasibility & Design Applications

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

Available Space. A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Soils. Soil conditions do not constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Groups (HSG) C or D usually require an underdrain, whereas HSG A and B soils often do not. In addition, permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain.

If the proposed permeable pavement area is designed to infiltrate runoff without underdrains, it must have a minimum infiltration rate of 0.5 inches per hour. Initially, projected soil infiltration rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site infiltration measurement. Native soils must have silt/clay content less than 40% and clay content less than 20%.

Designers should also evaluate existing soil properties during initial site layout, and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of HSG A or B soils shown on NRCS soil surveys should be considered as primary locations for all types of infiltration.

External Drainage Area. Any external drainage area contributing runoff to permeable pavement should generally not exceed twice the surface area of the permeable pavement, and it should be as close to 100% impervious as possible. Some field experience has shown that an upgradient drainage area (even if it is impervious) can contribute particulates to the permeable pavement and lead to clogging (Hirschman, et al., 2009). Therefore, careful sediment source control and/or a pre-treatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section.

Pavement Slope. Steep slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. Designers should consider using a terraced design for permeable pavement in sloped areas, especially when the local slope is several percent or greater.

The bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater. However, a maximum longitudinal slope of 1% is permissible if an underdrain is employed. Lateral slopes should be 0%.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head may be needed to drive flows through underdrains. Flat terrain may affect proper drainage of Level 1 permeable pavement designs, so underdrains should have a minimum 0.5% slope.

Minimum Depth to Water Table. A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Setbacks. Permeable pavement should not be hydraulically connected to structure foundations, in order to avoid harmful seepage. Setbacks to structures and roads vary, based on the scale of the permeable pavement installation (see Table 4 above). At a minimum, small- and large-scale pavement applications should be located a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines. Setbacks can be reduced at the discretion of the local program authority for designs that use underdrains and/or liners.

Informed Owner. The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuum sweeping) to maintain the pavement's hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them.

High Loading Situations. Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail.

Groundwater Protection. **Section** 1.i of this specification presents a list of potential stormwater hotspots that pose a risk of groundwater contamination. Infiltration of runoff from designated hotspots is highly restricted or prohibited.

Limitations. Permeable pavement can be used as an alternative to most types of conventional pavement at residential, commercial and institutional developments, with two exceptions:

- ❖ Permeable pavement should not been used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes and roadway shoulders; and
- ❖ Permeable pavement should not be used to treat runoff from stormwater hotspots, as noted above.

Design Scales. Permeable pavement can be installed at the following three scales:

a The smallest scale is termed ***Micro-Scale Pavements***, which applies to converting impervious surfaces to permeable ones on small lots and redevelopment projects, where the installations may range from 250 to 1000 square feet in total area. Where redevelopment or retrofitting of existing impervious areas results in a larger foot-print of permeable pavers (small-scale or large- scale, as described below), the designer should implement the Load Bearing, Observation Well, Underdrain, Soil Test, and Building Setback criteria associated with the applicable scale.

b ***Small-scale pavement*** applications treat portions of a site between 1,000 and 10,000 square feet in area, and include areas that only occasionally receive heavy vehicular traffic.

c ***Large scale pavement*** applications exceed 10,000 square feet in area and typically are installed within portions of a parking lot.

Table 4 outlines the different design requirements for each of the three scales of permeable pavement installation.

Table 4. The Three Design Scales for Permeable Pavement

Design Factor	Micro-Scale	Small-Scale Pavement	Large-Scale
Impervious Area Treated	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	More than 10,000 sq. ft.
Typical Applications	Driveways Walkways Court Yards Plazas Individual Sidewalks	Sidewalk Network Fire Lanes Road Shoulders Spill-Over Parking Plazas	Parking Lots with more than 40 spaces Low Speed Residential Streets
Most Suitable Pavement	IP	PA, PC, and IP	PA, PC and IP
Load Bearing Capacity	Foot traffic Light vehicles	Light vehicles	Heavy vehicles (moving & parked)
Reservoir Size	Infiltrate or detain some or all of the Tv	Infiltrate or detain the full Tv and as much of the CPv and design storms as possible	

External Drainage Area?	No	Yes, impervious cover up to twice the permeable pavement area may be accepted as long as sediment source controls and/or pretreatment is used	
Observation Well	No	No	Yes
Underdrain	Rare	Depends on the soils	Back-up underdrain
Required Soil Tests	One per practice	Two per practice	One per 5000 sq. ft of proposed practice
Building Setbacks	5 feet down-gradient 25 feet up-gradient	10 feet down-gradient 50 feet up-gradient	25 feet down-gradient 100 feet up-gradient

Regardless of the design scale of the permeable pavement installation, the designer should carefully consider the expected traffic load at the proposed site and the consequent structural requirements of the pavement system. Sites with heavy traffic loads will require a thick aggregate base and, in the case of porous asphalt and pervious concrete, may require the addition of an admixture for strength or a specific bedding design. In contrast, most micro-scale applications should have little or no traffic flow to contend with.

5 Design Criteria

a Sizing of Permeable Pavement:

Structural Design. If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavement involves consideration of four main site elements:

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Bedding and Reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (CBR) (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally rules out their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- KYTC Standard specifications for Road and Bridge Construction. current edition;
- AASHTO Guide for Design of Pavement Structures, current edition, and,
- AASHTO Supplement to the Guide for Design of Pavement Structures, current edition.

Hydraulic Design. Permeable pavement is typically sized to store the Water Quality Treatment Volume (T_V) or another design storm volume in the reservoir layer. The infiltration rate typically will be less than the flow rate through the pavement, so that some underground reservoir storage will usually be required. Designers should initially assume that there is no outflow through underdrains, using **Equation 1** to determine the depth of the reservoir layer, assuming runoff fully infiltrates into the underlying soil:

Equation 1

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f)\}}{V_r}$$

Where:

- d_p = The depth of the reservoir layer (ft.)
- d_c = The depth of runoff from the contributing drainage area (not including the permeable paving surface) for the Treatment Volume (Tv/A_c), or other design storm (ft.)
- R = A_c/A_p = The ratio of the contributing drainage area (A_c, not including the permeable paving surface) to the permeable pavement surface area (A_p) [NOTE: With reference to Table 4, the maximum value for the Level 1 design is R = 2, (the external drainage area A_c is twice that of the permeable pavement area A_p; and for Level 2 design R = 0 (the drainage area is made up solely of permeable pavement A_p]**.**
- P = The rainfall depth for the Treatment Volume (Level 1= 0.6 in; Level 2= 0.75 inch), or other design storm (ft.)
- i = The field-verified infiltration rate for native soils (ft./day)
- t_f = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
- V_r = The void ratio for the reservoir layer (0.4)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 2**.

Equation 2

$$d_{p\text{-}max} = \frac{(i/2 \times t_d)}{V_r}$$

Where:

$d_{p\text{-}max}$ = The maximum depth of the reservoir layer (ft.)
i = The field-verified infiltration rate for the native soils (ft./day)
V_r = The void ratio for reservoir layer (0.4 – see assumptions, below)
t_d = The maximum allowable time to drain the reservoir layer, typically 1 to 2 days (days)

The following design assumptions apply to **Equations 1 and 2**:

- The contributing drainage area (A_c) should not contain pervious areas.
- For design purposes, the native soil infiltration rate (i) should be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5”/hr.
- The void ratio (V_r) for No. 57 stone = 0.4.
- Max. drain time for the reservoir layer should be not less than 24 nor more than 48 hours.

If the depth of the reservoir layer is too great (i.e. d_p exceeds $d_{p\text{-}max}$), or the verified soil infiltration rate is less than 0.5 inches per hour, then the design method typically changes to account for underdrains. The storage volume in the pavements must account for the underlying infiltration rate and outflow through the underdrain. In this case, the design storm should be routed through the pavement to accurately determine the required reservoir depth. Alternatively, the designer may use **Equations 3 through 5** to approximate the depth of the reservoir layer for designs using underdrains.

Equation 3 can be used to approximate the outflow rate from the underdrain. The hydraulic conductivity, *k*, of gravel media is very high (~17,000 ft./day). However, the permeable pavement reservoir layer will drain increasingly slower as the storage volume decreases (i.e. the hydraulic head decreases). To account for this change, a conservative permeability coefficient of 100 ft. /day can be used to approximate the average underdrain outflow rate.

Equation 3

$$q_u = k \times m$$

Where:

q_u = Outflow through the underdrain (per outlet pipe, assumed 6-inch diameter) (ft./day)
k = Hydraulic conductivity for the reservoir layer (ft./day – assume 100 ft./day)
m = Underdrain pipe slope (ft./ft.)

Once the outflow rate through the underdrain has been approximated, **Equation 4** is used to determine the depth of the reservoir layer needed to store the design storm.

Equation 4

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f) - q_u \times t_f\}}{Vr}$$

Where:

d_p = Depth of the reservoir layer (ft.)
d_c = Depth of runoff from the contributing drainage area (not including the permeable pavement surface) for the Treatment Volume (Tv/A_c), or other design storm (ft.)
R = A_c/A_p = The ratio of the contributing drainage area (A_c) (not including the permeable pavement surface) to the permeable pavement surface area (A_p)
P = The rainfall depth for the Treatment Volume (Level 1 = 1 inch; Level 2 = 1.1 inch), or other design storm (ft.)
i = The field-verified infiltration rate for the native soils (ft./day)
t_f = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
V_r = The void ratio for the reservoir layer (0.4)
q_u = Outflow through Underdrain (ft/day)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 5**.

Equation 5

$$d_{p\text{-}max} = \frac{\{(i/2 \times t_d) + (q_u \times t_d)\}}{Vr}$$

Where:

$d_{p\text{-}max}$ = The maximum depth of the reservoir layer (ft.)
i = The field-verified infiltration rate for the native soils (ft./day)
V_r = The void ratio for the reservoir layer (0.4)
t_d = The time to drain the reservoir layer (day – typically 1 to 2 days)
q_u = The outflow through the underdrain (ft./day)

If the depth of the reservoir layer is still too great (i.e. d_p exceeds $d_{p\text{-}max}$), the number of underdrains can be increased, which will increase the underdrain outflow rate.

Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet.

Soil Infiltration Rate Testing

To design a permeable pavement system *without* an underdrain, the measured infiltration rate of subsoils must be 0.5 inch per hour or greater. A minimum of one test must be taken per 1,000 sq. ft. of planned permeable pavement surface area. In most cases, a single soil test is sufficient for micro-scale and small-scale applications. At least one soil boring must be taken to confirm the underlying soil properties *at the depth where infiltration is designed to occur* (i.e., to ensure that the depth to water table, or depth to bedrock is defined). Soil infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed permeable pavement system.

Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in Table 3 above, and designed according to the product manufacturer’s recommendations.

Internal Geometry and Drawdowns

- ***Elevated Underdrain.*** To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain should be installed with a stone jacket that creates a
- 12 to 18 inch deep storage layer *below* the underdrain invert. The void storage in this layer can help qualify a site to achieve Level 2 design.
- ***Rapid Drawdown.*** When possible, permeable pavement should be designed so that the target runoff reduction volume stays in the reservoir layer for at least 36 hours before being discharged through an underdrain.
- ***Conservative Infiltration Rates*.** Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

Pretreatment

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment may be appropriate if the pavement receives run-on from an adjacent pervious or impervious area.

For example, a gravel filter strip can be used to trap coarse sediment particles before they reach the permeable pavement surface, in order to prevent premature clogging.

Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The placement and/or design should be such that the incoming runoff is not captured (e.g., placing the perforations on the underside only).
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system.
- Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for the management of extreme event flows.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system (typically in remote areas). The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

Reservoir layer

The thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions. A professional should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional storage and structural stability.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface.

Underdrains

The use of underdrains is recommended when there is a reasonable potential for infiltration rates to decrease over time, when underlying soils have an infiltration rate of less than 1/2-inch per hour, or when soils must be compacted to achieve a desired Proctor density. Underdrains can also be used to manage extreme storm events to keep detained stormwater from backing up into the permeable pavement.

- An underdrain(s) should be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- The underdrain outlet can be fitted with a flow-reduction orifice as a means of regulating the stormwater detention time. The minimum diameter of any orifice should be 0.5 inch.
- An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

Maintenance Reduction Features

Maintenance is a crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment, which can be reduced by the following measures:

- ***Periodic Vacuum Sweeping.*** The pavement surface is the first line of defense in trapping and eliminating sediment that may otherwise enter the stone base and soil subgrade. The rate of sediment deposition should be monitored and vacuum sweeping done once or twice a year. This frequency should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. At least one sweeping pass should occur at the end of winter.
- ***Protecting the Bottom of the Reservoir Layer.*** There are two options to protect the bottom of the reservoir layer from intrusion by underlying soils. The first method involves covering the bottom with nonwoven, polypropylene geotextile that is permeable, although some practitioners recommend avoiding the use of filter fabric since it may become a future plane of clogging within the system. Permeable filter fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. The second method is to form a barrier of choker stone and sand. In this case, underlying native soils should be separated from the reservoir base/subgrade layer by a thin 2 to 4 inch layer of clean, washed, choker stone (ASTM D 448 No. 8 stone) covered by a layer of 6 to 8 inches of course sand.
- ***Observation Well.*** An observation well, consisting of a well-anchored, perforated 4 to 6 inch (diameter) PVC pipe that extends vertically to the bottom of the reservoir layer, should be installed at the downstream end of all large-scale permeable pavement systems. The observation well should be fitted with a lockable cap installed flush with the ground surface (or under the pavers) to facilitate periodic inspection and maintenance. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event.
- ***Overhead Landscaping.*** Most local communities now require from 5% to 10% (or more) of the area of parking lots to be in landscaping. Large-scale permeable pavment applications should be carefully planned to integrate this landscaping in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface.

Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. Table 5 below, describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending whether the system is PC, PA or IP (see Table 2 above). A general comparison of different permeable pavements is provided in Table 6 below, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 5. Material Specifications for Underneath the Pavement Surface

	Specification	Note
Bedding Layer	PC: None PA: 2 in. depth of No. 8 stone IP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57	ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone PA: No. 2 stone IP: No. 57 stone	ASTM D448 size No. 57 stone (e.g. 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines.
Underdrain	Use 4 to 6 inch diameter perforated PVC (AASHTO M 252) pipe, with 3/8-inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications). Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Filter Layer	The underlying native soils should be separated from the stone reservoir by a thin, 2 to 4 inch layer of choker stone (e.g. No. 8) covered by a 6 to 8 inch layer of coarse sand (e.g. ASTM C 33, 0.02-0.04 inch).	The sand should be placed between the stone reservoir and the choker stone, which should be placed on top of the underlying native soils.
Filter Fabric (optional)	Use a needled, non-woven, polypropylene geotextile with Grab Tensile Strength equal to or greater than 120 lbs (ASTM D4632), with a Mullen Burst Strength equal to or greater than 225 lbs./sq. in. (ASTM D3786), with a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" Soil subgrade, using FHWA or AASHTO selection criteria.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

Table 6. Different Permeable Pavement Specifications

Material	Specificatio	Not
Permeable Interlocking Concrete Pavers	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Paver s	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C 1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.
Pervious Concrete	Void content: 15% to 25 %. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 Mpa. Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

6 Regional & Special Case Design Adaptations

The design adaptations described below permit permeable pavement to be used on a wider range of sites. However, it is important not to force this practice onto marginal sites. Other runoff reduction practices are often preferred alternatives for difficult sites.

Clay Soils

In areas where the underlying soils are not suitable for complete infiltration, permeable pavement systems with underdrains can still function effectively to reduce runoff volume and nutrient loads.

- ❖ If the underlying soils have an infiltration rate of less than 0.5 in./hr., an underdrain must be installed to ensure proper drainage from the system.
- ❖ Permeable pavement should not be installed over underlying soils with a high shrink/swell potential.
- ❖ To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain configuration may be used.

Cold Climate and Winter Performance

In cold climates and winter conditions, freeze-thaw cycles may affect the structural durability of the permeable pavement system. In these situations, the following design adaptations may be helpful:

- ❖ To avoid damage caused by freezing, designs should not allow water to pond in or above the permeable pavement. Ensure complete drainage of the permeable pavement system within 24 hours following a rainfall event.

- ❖ Extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size, to reduce the freezing potential.
- ❖ Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the permeable pavement.
- ❖ Sand should never be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since it will quickly clog the system.
- ❖ When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt (PA), pervious concrete (PC) and interlocking pavers (IP) can be plowed similar to traditional pavements, using similar equipment and settings.
- ❖ Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Magnesium chloride should never be used on porous concrete.

7 Construction

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

Necessary Erosion & Sediment Controls

- ❖ All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- ❖ Permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should be clearly marked on all construction documents and grading plans. To prevent soil compaction, heavy vehicular and foot traffic should be kept out of permeable pavement areas during and immediately after construction.
- ❖ During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.
- ❖ Any area of the site intended ultimately to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub base, base and surface materials.

Permeable Pavement Construction Sequence

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified to depending on whether Porous Asphalt (PA), Pervious Concrete (PC) or Interlocking Paver (IP) designs are employed.

Step 1. Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen bedding materials.

Step 2. As noted above, temporary erosion and sediment (E&S) controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials that are contaminated by sediments must be removed and replaced with clean materials.

Step 3. Excavators or backhoes should work from the sides, where possible, to excavate the reservoir layer to its appropriate design depth and dimensions. This practice will reduce compaction problems. For micro-scale and small-scale pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so that cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4. The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or filter fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (NOTE: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design.)

Step 5. Filter fabric should be installed on the bottom and the sides of the reservoir layer. In some cases, an alternative filter layer may be warranted. Filter fabric strips should overlap down-slope by a minimum of 2 feet, and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of filter fabric 1 foot below the surface to prevent sediments from entering into the reservoir layer. Excess filter fabric should not be trimmed until the site is fully stabilized.

Step 6. Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down towards the outlet at a grade of 0.5% or steeper. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure that there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7. Moisten and spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8. Install the desired depth of the bedding layer, depending on the type of pavement, as follows:

- **Pervious Concrete:** No bedding layer is used.
- **Porous Asphalt:** The bedding layer for porous asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D 448 No.57 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four (4) passes of a 10-ton steel drum static roller.
- **Interlocking Pavers:** The bedding layer for open-jointed pavement blocks should consist of 1-1/2 to 2 inches of washed ASTM D 448 No.8 stone. The thickness of the bedding layer is to be based on the block manufacturer's recommendation or that of a qualified professional.

Step 9. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

- **Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007).
  - Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230^{o}F and 260^{o}F, with a minimum air temperature of 50^{o}F, to ensure that the surface does not stiffen before compaction.
  - Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
  - The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti- stripping agents must be added to the mix.
  - Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
  - Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
  - Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine that the facility is draining properly.

- **Installation of Pervious Concrete.** The basic installation sequence for pervious concrete is outlined by the American Concrete Institute (2008). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor

Certification Program offered by the National Ready Mix Concrete Association (NRMCA). The basic installation procedure is as follows:

- Drive the concrete truck as close to the project site as possible.
- Water the underlying aggregate (reservoir layer) before the concrete is placed, so that the aggregate does not draw moisture from the freshly laid pervious concrete.
- After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
- Compact the pavement with a steel pipe roller. Care should be taken so that over-compaction does not occur.
- Cut joints for the concrete to a depth of 1/4 inch.
- The curing process is very important for pervious concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least seven (7) days. Do not allow traffic on the pavement during this time period.

❖ **Installation of Interlocking Pavers.** The basic installation process is described in greater detail by Smith (2006).

- Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement (IP) systems require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard KYTC curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.
- Place the No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four (4) passes of a 10-ton steel drum static roller until there is no visible movement. The first two (2) passes are in vibratory mode, with the final two (2) passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
- Place and screed the bedding course material (typically No. 8 stone).
- Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third (1/3) of the full unit size.
- Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with KYTC No. 8 stone, although KYTC No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
- Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
- Do not compact within 6 feet of the unrestrained edges of the pavers.
- The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a significant rainfall (1/2 inch or greater) or artificial flooding to determine whether the facility drains properly.

Construction Inspection

Inspections before, during and after construction are needed to ensure that permeable pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- ❖ Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- ❖ The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- ❖ Check the aggregate material to confirm that it is clean and washed, meets specifications and is installed to the correct depth.
- ❖ Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- ❖ Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- ❖ Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- ❖ Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- ❖ Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles that are often produced shortly after conventional asphalt is laid down.

8 Maintenance

Maintenance Agreements

Section 6 of the Ordinance No. 12-51 specifies the circumstances under which a maintenance agreement must be executed beween the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

In addition, the maintenance agreements should also note which conventional parking lot maintenance tasks must be *avoided* (e.g., sanding, re-sealing, re-surfacing, power-washing). Signs should be posted on larger parking lots to indicate their stormwater function and special maintenance requirements.

When micro-scale or small-scale permeable pavement are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a deed restriction, drainage easement or other mechanism enforceable by the qualifying local program to help ensure that the permeable pavement system is maintained and functioning. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

Maintenance Tasks

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. Most installations work reasonably well year after year with little or no maintenance, whereas some have problems right from the start.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the stones between pavement blocks.

Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications.

Maintenance of permeable pavement is driven by annual inspections that evaluate the condition and performance of the practice. The following are suggested annual maintenance inspection points for permeable pavements:

- The drawdown rate should be measured at the observation well for three (3) days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after three days, this is a clear sign that clogging is a problem.
- Inspect the surface of the permeable pavement for evidence of sediment deposition, organic debris, staining or ponding that may indicate surface clogging. If any signs of clogging are noted, schedule a vacuum sweeper (no brooms or water spray) to remove deposited material. Then, test sections by pouring water from a five gallon bucket to ensure they work.
- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration, such as slumping, cracking, spalling or broken pavers. Replace or repair affected areas, as necessary.
- Check inlets, pretreatment cells and any flow diversion structures for sediment buildup and structural damage. Note if any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Generally inspect any contributing drainage area for any controllable sources of sediment or erosion.

Based on inspection results, specific maintenance tasks will be triggered and scheduled to keep the facility in operating condition.

9 Community & Environmental Concerns

Compliance with the Americans with Disabilities Act (ADA). Porous concrete and porous asphalt are generally considered to be ADA compliant. Most localities also consider interlocking concrete pavers to be complaint, if designers ensure that surface openings between pavers do not exceed 1/2 inch. However, some forms of interlocking pavers may not be suitable for handicapped parking spaces. Interlocking concrete pavers interspersed with other hardscape features (e.g., concrete walkways) *can* be used in creative designs to address ADA issues.

Groundwater Protection. While well-drained soils enhance the ability of permeable pavement to reduce stormwater runoff volumes, they may also increase the risk that stormwater pollutants might migrate into groundwater aquifers. Designers should avoid the use of infiltration-based permeable pavement in areas known to provide groundwater recharge to aquifers used for water supply. In these source water protection areas, designers should include liners and underdrains in large-scale permeable pavement applications (i.e., when the proposed surface area exceeds 10,000 square feet).

Stormwater Hotspots. Designers should also certify that the proposed permeable pavement area will not accept any runoff from a severe stormwater hotspot. Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk of spills, leaks or illicit discharges. Examples include certain industrial activities, gas stations, public works areas, petroleum storage areas. For potential hotspots, restricted infiltration means that a minimum of 50% of the total T_V must be treated by a filtering or bioretention practice prior to the permeable pavement system. For known severe hotspots, the risk of groundwater contamination from spills, leaks or discharges is so great that infiltration of stormwater or snowmelt through permeable pavement is *prohibited*.

Underground Injection Control Permits. The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control (UIC) Program, which is administered either by the EPA or a delegated state groundwater protection agency. In general, the EPA (2008) has determined that permeable pavement installations are not classified as Class V injection wells, since they are always wider than they are deep.

Cold Climate or Winter Time Operation. Experience has shown that permeable pavement can operate properly in snow and ice conditions, and there is evidence that a permeable surface increases meltwater rates compared to conventional pavement (thereby reducing the need for deicing chemicals). However, in larger parking lot applications certain snow management practices need to be modified to maintain the hydrologic function of the permeable pavement. These include not applying sand for traction and educating snowplow operators to keep blades from damaging the pavement surface. The jointing material for interlocking concrete paver systems (typically No. 8 stone) can be spread over surface ice to increase tire traction.

Air and Runoff Temperature. Permeable pavement appears to have some value in reducing summer runoff temperatures, which can be important in watersheds with sensitive cold-water fish populations. The temperature reduction effect is greatest when runoff is infiltrated into the sub-base, but some cooling may also occur in the reservoir layer, when underdrains are used. ICPI (2008) notes that the use of certain reflective colors for interlocking concrete pavers can also help moderate surface parking lot temperatures.

Vehicle Safety. Permeable pavement is generally considered to be a safer surface than conventional pavement, according to research reported by Smith (2006), Jackson (2007) and ACI (2008). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement.

D Vegetated Roof

1 Description

Vegetated roofs (also known as *green roofs, living roofs* or *ecoroofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Vegetated roofs capture and temporarily store stormwater runoff in the growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

There are two different types of vegetated roof systems: *intensive* vegetated roofs and *extensive* vegetated roofs. Intensive systems have a deeper growing media layer that ranges from 6 inches to 4 feet thick, which is planted with a wider variety of plants, including trees. By contrast, extensive systems typically have much shallower growing media (2 to 6 inches), which is planted with carefully selected drought tolerant vegetation. Extensive vegetated roofs are much lighter and less expensive than intensive vegetated roofs and are recommended for use on most development and redevelopment sites.

NOTE: This specification is intended for situations where the primary design objective of the vegetated roof is stormwater management and, unless specified otherwise, addresses extensive roof systems.

Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or LEED points, architectural considerations, visual amenities and landscaping features, which are often maximized with intensive vegetated roof systems. However, these design objectives are beyond the scope of this specification.

Vegetated roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Extensive vegetated roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

2 Performance

The overall stormwater functions of vegetated roofs are summarized in Table 7.

Table 7. Summary of Stormwater Functions Provided by Vegetated Roofs[1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	60%
Channel Protection & Flood Mitigation [2]	Use the following Curve Numbers (CN) for Design Storm events: 1-year storm = 64; 2-year storm = 66; 10-year storm = 72; and the 100 year storm = 74	

[1] Sources: CWP and CSN (2008) and CWP (2007).
[2] See Miller (2008), NVRC (2007) and MDE (2008)

3 Design Table

The major design goal for Vegetated Roofs is to maximize nutrient removal and runoff volume reduction. To this end, designers may choose the baseline design (Level 1) or choose an enhanced (Level 2) design that maximizes nutrient and runoff reduction. In general, most intensive vegetated roof designs will automatically qualify as being Level 2. Table 8 lists the design criteria for Level 1 and 2 designs.

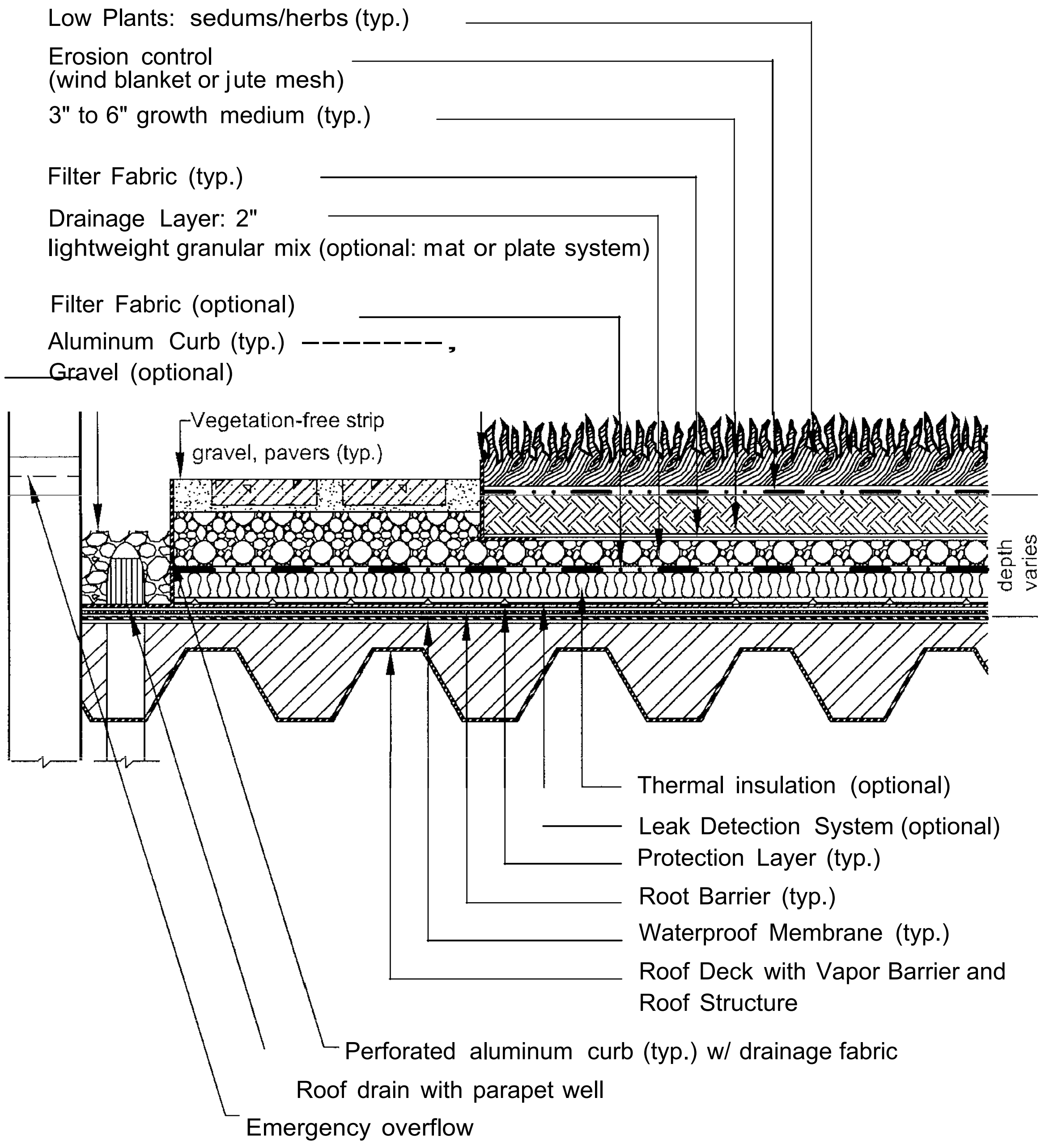
Table 8. Green Roof Design Guidance

Level 1 Design (RR:45; TP:0; TN:0)	Level 2 Design (RR: 60; TP:0; TN:0)
Tv = 1.0 (Rv)[1] (A)/12	Tv = 1.1 (Rv)[1] (A)/12
Depth of media up to 4 inches	Media depth 4 to 8 inches
Drainage mats	2-inch stone drainage layer
No more than 20% organic matter in media	No more than 10% organic matter in media
All Designs: Must be in conformance to ASTM (20014) International Green (Vegetated) Roof Stds.	
[1]Rv represents the runoff coefficient for a conventional roof, which will usually be 0.914. The runoff reduction rate applied to the vegetated roof is for “capturing” the Treatment Volume (Tv) compared to what a conventional roof would produce as runoff.	

4 Typical Details

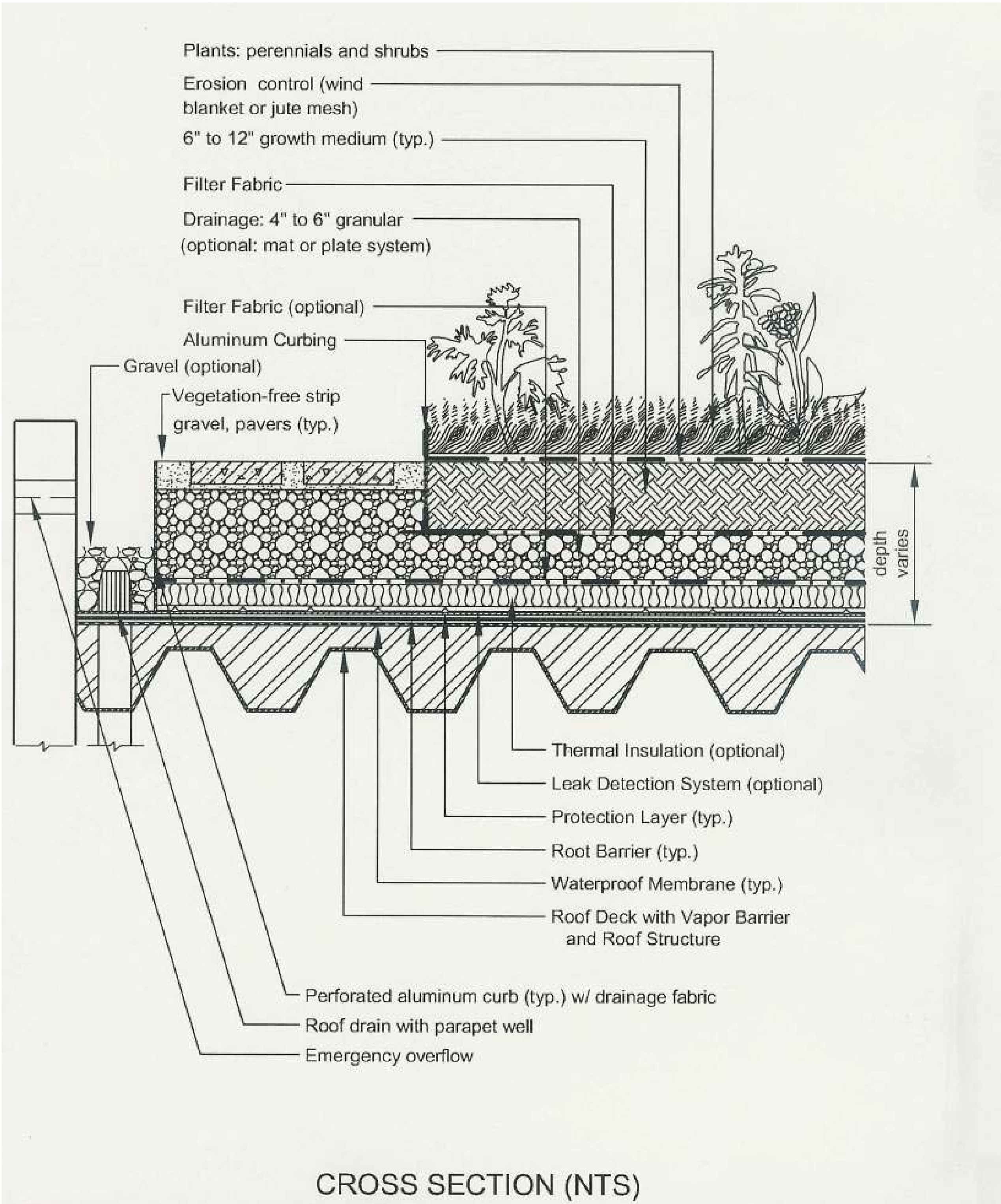
Figure 3 Photos of Vegetated Roof Cross-Sections
(source: B. Hunt, NCSU)

Figure 4. Typical Section –Extensive Vegetated Roof
(Source: Northern VA Regional Commission)



CROSS SECTION VIEW (NTS)

Figure 5. Typical Section- Intensive Vegetated Roof
(Source: Northern VA Regional Commission)



5 Physical Feasibility & Design Applications

Typical applications

Vegetated roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites. Vegetated roofs can be used on a variety of rooftops, including the following:

- Non-residential buildings (e.g. commercial, industrial, institutional and transportation uses)
- Multi-family residential buildings (e.g. condominiums or apartments)
- Mixed-use buildings

Local regulations may also permit the use of vegetated roofs on single family residential roofs.

Common Site Constraints

Structural Capacity of the Roof. When designing a vegetated roof, designers must not only consider the stormwater storage capacity of the vegetated roof, but also its structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive vegetated roof. As a result, a structural engineer, architect or other qualified professional should be involved with all vegetated roof designs to ensure that the building has enough structural capacity to support a vegetated roof.

Roof Pitch. Treatment volume (Tv) is maximized on relatively flat roofs (a pitch of 1 to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Vegetated roofs can be installed on rooftops with slopes up to 25% if baffles, grids, or strips are used to prevent slippage of the media. The effective treatment volume (Tv), however, diminishes on rooftops with steep pitches (Van Woert et al, 2005).

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane), and how construction materials will be stockpiled in the confined space.

Roof Type. Vegetated roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for vegetated rooftops due to pollutant leaching through the media (Clark et al, 2008).

Setbacks. Vegetated roofs should not be located near rooftop electrical and HVAC systems. A 2- foot wide vegetation-free zone is recommended along the perimeter of the roof, with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed to 1 foot for very small vegetated roof applications.

Retrofitting Green Roofs: Key feasibility factors to consider when evaluating a retrofit include the area, age and accessibility of the existing roof, and the capability of the building's owners to maintain it. Options for green roof retrofits are described in Profile Sheet RR-3 of Schueler et al (2007). The structural capacity of the existing rooftop can be a major constraint to a green roof retrofits.

Local Building Codes. Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the vegetated roof design should comply with the Kentucky Building Code with respect to roof drains and emergency overflow devices.

Construction Cost. When viewed strictly as stormwater treatment systems, vegetated roofs can cost between $12 and $25 per square foot, ranking them among the most costly stormwater practices available (Moran et al, 2004, Schueler et al 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency, higher rents due to green building scores, and increased roof longevity. These benefits over the life cycle of a vegetated roof may make it a more attractive investment. In addition, several communities may offer subsidies or financial incentives for installing vegetated roofs.

Risks of Leaky Roofs. Although well designed and installed green roofs have less problems with roof leaks than traditional roofs, there is a perception among property managers, insurers and product fabricators that this emerging technology could have a greater risk of problems. For an excellent discussion on how to properly manage risk in vegetated roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009).

6 Design Criteria

Overall Sizing

Vegetated roof areas should be sized to capture a portion of the Treatment Volume (Tv). The required size of a vegetated roof will depend on several factors, including the porosity and hydraulic conductivity of the growing media and the underlying drainage materials. Site designers and planners should consult with vegetated roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, the following equation can be used to determine the water quality treatment storage volume retained by a vegetated roof:

$$Tv = (RA * D * P)/12$$

Where, Tv = storage volume (cu. ft.)
RA = vegetated roof area (sq. ft.)
D = media depth (in.)
P = media porosity (usually 0.3, but consult manufacturer specifications

The resulting Tv can then be compared to the required Tv for the entire rooftop area (including all non-vegetated areas) to determine if it meets or exceeds the required Tv for Level 1 or Level 2 design, as shown in Table 8 above.

Guidance for selecting the appropriate post development CN for the vegetated roof for four different design storms is also provided in Table 9; in general, lower curve numbers are associated with more frequent design storms. In most cases, the maximum design storm is the 10-year event.

Structural Capacity of the Roof

Vegetated roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer should consult with a licensed structural engineer or architect to ensure that the building will be able to support the additional live and dead structural load and determine the maximum depth of the vegetated roof system and any needed structural reinforcement.

In most cases, fully-saturated extensive vegetated roofs have loads of about 15 to 25 lbs./sq. ft., which is fairly similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For an excellent discussion of vegetated roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*.

Functional Elements of a Vegetated Roof System

A vegetated roof is composed of up to eight different systems or layers, from bottom to top, that are combined together to protect the roof and maintain a vigorous cover. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary vegetated roofing systems, whereas in other cases, the designer or architect must assemble their own system, in which case they are advised to consult Weiler and Scholz- Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004)***.***

1. ***Deck Layer.*** The roof deck layer is the foundation of a vegetated roof. It and may be composed of concrete, wood, metal, plastic, gypsum or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the vegetated roof system. In general, concrete decks are preferred for vegetated roofs, although other materials can be used as long as the appropriate system components are matched to them.

2. ***Waterproofing Layer.*** All vegetated roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply, and liquid-applied methods (see Weiler and Scholz-Barth, 2009 and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the vegetated roof system.

3. ***Insulation Layer.*** Many vegetated rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal

roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems.

4. ***Root Barrier.*** The next layer of a vegetated roof system is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals that could leach into stormwater runoff should be avoided.

5. ***Drainage Layer and Drainage System.*** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The drainage layer should consist of synthetic or inorganic materials (e.g. gravel, recycled polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors and roof leader. The required depth of the drainage layer is governed by both the required stormwater storage capacity and the structural capacity of the rooftop. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.

6. ***Root-Permeable Filter Fabric.*** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it.

7. ***Growing Media.*** The next layer in an extensive vegetated roof is the growing media, which is typically 4 to 8 inches deep. The depth and composition of the media is described in the Filter Media Composition section in this Section.

8. ***Plant Cover.*** The top layer of a vegetated roof consists of non-native, slow-growing, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. A mix of base ground covers (usually *Sedum* species) and accent plants can be used to enhance the visual amenity value of a green roof.

Filter Media Composition

The recommended growing media for extensive vegetated roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials. The remaining media should contain no more than 20% organic matter, normally well-aged compost. The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media should have a maximum water retention capacity of around 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

The composition of growing media for intensive vegetated roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the vegetated roof planting plan, the growing media must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees.

Conveyance and Overflow

The drainage layer below the growth media should be designed to convey the 10-year storm without backing water up to into the growing media. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the vegetated roof surface. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging.

Vegetation and Surface Cover

A planting plan must be prepared for a vegetated roof by a landscape architect, botanist or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local development review authority.

Plant selection for vegetated rooftops is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most vegetated roof installations is a hardy, low-growing succulent, such as *Sedum, Delosperma, Talinum, Semperivum* or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006). Richmond lies within USDA Plant Hardiness Zone 6 (AHS, 2003). A list of some common vegetated roof plant species that work well in the Richmond watersheds can be found in Table 9 below.

- ❖ Plant choices can be much more diverse for deeper intensive vegetated roof systems. Herbs, forbs, grasses, shrubs and even trees can be used, but designers should understand they have higher watering, weeding and landscape maintenance requirements.
- ❖ The species and layout of the planting plan should reflect the location of building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and able to withstand heat, cold and high winds.

Table 9 Ground Covers for Vegetated Roofs in Richmond

Plant Hardiness Zone 6
Delosperma cooperi
Delosperma ecklonis var.latifolia
Hieracium villosum
Orostachys boehmeri
Sedum hispanicum
Sedum pluricaule var. ezawe
Sedum urvillei
Note: Landscape architects should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for definitive list of green roof plants, including accent plants.

- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on vegetated roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most vegetated roof plant species will *not* be native to Kentucky (which is contrast to *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of vegetated roof plant nurseries in the region, designers should order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract-grown.
- When appropriate species are selected, most vegetated roofs will not require supplemental irrigation, except for temporary irrigation during dry months as the vegetated roof is established. The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost.
- Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for vegetated roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming and weeding.
- The vegetated roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

Material Specifications

Standard specifications for North American vegetated roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The American Society for Testing and Materials (ASTM) has recently issued several overarching vegetated roof standards, which are described and referenced in Table 10 below.

Designers and reviewers should also fully understand manufacturer specifications for each system component listed, particularly if they choose to install proprietary "complete" vegetated roof systems or modules.

Table 10. Extensive Vegetated Roof Material Specifications

Material	Specification
Roof	Structural Capacity should conform to ASTM E-2397-014, *Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems*. In addition, use standard test methods ASTM E2398-014 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*, and ASTME 2399-014 for *Maximum Media Density for Dead Load Analysis*.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	1 to 2 inch layer of clean, washed granular material, such as ASTM D 448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with VUSBC.
Filter Fabric	Needled, non-woven, polypropylene geotextile. Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.
Growth Media	80% lightweight inorganic materials and 20% organic matter (e.g. well-aged compost). Media should have a maximum water retention capacity of around 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-014.
Plant Materials	Sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*.

7 Regional & Special Case Design Adaptations

Cold Climate and Winter Performance

Several design adaptations may be needed for vegetated roofs. The most important is to match the plant species to the appropriate plant hardiness zone. In areas with colder climates, vegetated roofs should be designed so the growing media is not subject to freeze-thaw, and provide greater structural capacity to account for winter snow loads.

Acid Rain

Much of Kentucky experiences acid rain, with rainfall pH ranging from 3.9 to 4.1. Research has shown that vegetated roof growing media can neutralize acid rain (Berhage et al, 2007), but it is not clear whether acid rain will impair plant growth or leach minerals from the growing media.

8 Construction

Construction Sequence

Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- ❖ Construct the roof deck with the appropriate slope and material.
- ❖ Install the waterproofing method, according to manufacturer's specifications.
- ❖ Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- ❖ Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- ❖ The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.
- ❖ The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- ❖ It generally takes 12 to 18 months to fully establish the vegetated roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).
- ❖ Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

Construction Inspection

Inspections during construction are needed to ensure that the vegetated roof is built in accordance with these specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during several steps of vegetated roof installation, as follows:

- ❖ During placement of the waterproofing layer, to ensure that it is properly installed and watertight;

- During placement of the drainage layer and drainage system;
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants, to ensure they conform to the planting plan;
- Before issuing use and occupancy approvals; and
- At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

9 Maintenance

Maintenance Inspections and Ongoing Operations

A vegetated roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see Table 11 below). In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first five years after the vegetated roof is installed.

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.

Written documentation between the local inspection authority and the property owner or manager should be required, in order to ensure adequate notification or authorization for access to conduct inspections.

Table 11. Typical Maintenance Activities Associated with Green Roofs

Activity	Schedule
• Water to promote plant growth and survival. • Inspect the vegetated roof and replace any dead or dying vegetation.	As Needed (Following Construction)
• Inspect the waterproof membrane for leaking or cracks. • Weeding to remove invasive plants. • Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.	Semi-Annually
• Annual fertilization (first five years).	Annually

E Manufactured BMP Systems

1 Description

There are two categories for this section. The first includes small structures for the purpose of collecting rainfall runoff for specific uses. Storage techniques may include cisterns, underground tanks, above-ground vertical storage tanks, rain barrels, rainwater harvesting or other similar systems. These techniques are for residential and small size commercial properties where the devices are placed for collecting water to provide additional sources to water plants, lawns, etc.

The second category is devoted to larger systems for non-residential designs. The rest of this document addresses those treatments.

The Manufactured BMP Systems mentioned in this standard are meant only to provide a frame of reference. The Richmond Planning Commission acknowledges that there may be additional Manufactured BMP Systems available that are not presented in this handbook. Presentation of the following products does not preclude the use of other available systems, nor does it constitute endorsement of any one system.

2 Definition

A Manufactured BMP system is a structural measure which is specifically designed and sized by the manufacturer to intercept stormwater runoff and prevent the transfer of pollutants downstream.

3 Purpose

Manufactured BMP systems are used solely for water quality enhancement in urban and ultra-urban areas where surface BMPs are not feasible. These are flow-through structures in that the design rate of flow into the structure is regulated by the inflow pipe or structure hydraulics as opposed to traditional BMPs designed to store the entire water quality volume. When the maximum design inflow is exceeded, the excess flow bypasses the structure or flows through the structure and bypasses the treatment with minimal turbulence and resuspension of previously trapped pollutants. Structures that rely on the inflow pipe to regulate the rate of flow into the treatment chamber typically cause stormwater to back up into the upstream conveyance system or associated storage facility. Depending on the type of structure and the configuration of the conveyance system, this excess flow will either bypass the treatment chamber or be attenuated and allowed to flow through the treatment chamber at the regulated rate.

Pollutant removal efficiencies presented in this standard are based upon currently available studies. Removal efficiencies are very variable, however, and highly dependant on storm size, influent pollutant concentrations, and rainfall intensity. Several monitoring studies are ongoing and many products may be modified to improve pollutant removal performance. Therefore, the removal efficiencies presented may be subject to change. As more of these products are built and additional monitoring studies track their performance over a wide range of rainfall events, the anticipated performance of these systems as water quality BMPs will become better established.

The discussion of each of the manufactured BMP systems presented in this standard includes the target pollutants for which the BMP was designed. Many of these systems were developed to remove a specific range of particulate pollutants, or total suspended solids (TSS), from stormwater runoff. Others, such as the filtering structures discussed below, were developed to capture a broad range of pollutants. The use of phosphorus as the target or "keystone" pollutant is recommended when using the performance-based water quality criteria to select a BMP. However, for stormwater "hot-spots", or areas from which a high concentration of urban pollutants can be expected, the primary pollutant of concern may be hydrocarbons (oil and grease), metals, or other compounds besides nutrients. Manufactured BMPs generally provide effective spill containment for material handling and transfer areas such as automobile fuel and service areas, and other urban hot-spots. Careful analysis of the proposed development project and intended uses help in selecting and appropriate BMP.

The manufactured BMP systems which have been evaluated at this time can be categorized as either:

- Hydrodynamic Structures - (Stormceptor, Vortechs Stormwater Treatment System, Downstream defender, BaySaver Separation System)
- Filtering Structures - (StormFilter, StormTreat System)

Hydrodynamic Structures

Hydrodynamic structures are those which rely on settling or separation of pollutants from the runoff. The hydrodynamic structures can be generally categorized as Chambered Separation Structures or Swirl Concentration Structures.

Chambered Separation Structures rely on settling of particles and, to a lesser degree, centrifugal forces to remove pollutants from stormwater. These structures contain an upper bypass chamber and a lower storage/separation chamber. Flow enters the structure in the upper bypass chamber and is channeled through a downpipe into the lower storage/separation, or treatment, chamber. The downpipe is configured such that when the rate of inflow into the structure exceeds its operating capacity, the flow simply "jumps" over the downpipe, bypassing the lower treatment chamber.

The outlet configuration of the downpipe forces the water to enter the lower treatment chamber in one direction, which encourages circular flow. This circular flow, as well as gravitational settling, traps the sediments and other particulate pollutants (as well as any pollutants which adsorb to the particulates) at the bottom of the chamber. The water leaves the treatment chamber through a return or riser pipe. The return or riser pipe extends below the water surface within the lower treatment chamber in order to prevent trapped floatables from exiting the structure. The hydraulic gradient of the structure prevents the inflow and the discharge from creating turbulent conditions within the lower treatment chamber. This feature helps prevent the resuspension of previously trapped particulate pollutants during high flow, or "bypass", storm events.

Swirl Separation Structures are characterized by an internal component that creates a swirling motion. This is typically accomplished by a tangential inflow location within a cylindrical chamber. The "swirl" technology is similar, if not identical to, the technology used in treating combined sewer overflows. The solids settle to the bottom and are trapped by the swirling flow path. Additional compartments or chambers act to trap oil and other floatables.

There is no bypass for larger flows prior to the treatment or swirl chamber. The larger flows simply pass through the structure untreated. However, due to the swirling motion within the structure, larger flows do not resuspend previously trapped particulates.

Filtering Structures

Filtering structures are characterized by a sedimentation chamber and a filtering chamber. The manufactured systems presented in this standard, the StormFilter and the StormTreat System, use very different configurations and filtering media. Both contain a primary settling chamber to remove heavy solids, floatables, oil, etc. The StormTreat System then directs the water through a series of screens and geotextile filters and into a containerized wetland system with soil and aquatic plants. The StormFilter, on the other hand, uses any one or combination of filter media cartridges. The filter media selected is typically based on the target pollutants to be removed or the desired efficiency. The number of cartridges is dependent on the project size, desired removal efficiency, and peak flow rates.

4 Conditions Where Practice Applies

Drainage Area

The sizing criteria for each manufactured BMP system should be obtained from the manufacturer to insure that the latest design and sizing criteria is used. In general, the flow-through configuration and treatment limitations will force drainage areas to remain relatively small.

Development Conditions

Manufactured BMP systems are ideal for use in ultra-urban areas since they are space efficient. Most of these systems can be placed under parking lots, or simply installed as a manhole junction box or inlet structure. Since other BMPs, such as sand filters and bioretention structures, are also suited for urban development, the designer must consider the type of pollutant load anticipated from the site, as well as other site factors, such as maintenance, aesthetics, etc., and select an appropriate BMP. In general, hydrodynamic and gross pollutant separate are recommended for the following:

- Pretreatment for other BMPs;
- Retrofit of existing development or Redevelopment; and
- Ultra-urban development areas.

Filtering structures are generally recommended for use in applications. In all cases, Manufactured BMP systems must be designed in accordance with the manufacturer's specifications.

5 Planning Considerations

The most significant feature of manufactured BMP systems is their small size and the ability to use them as retrofits underneath improved areas. (It should be noted that other BMPs, such as sand filters, can also be placed under improved areas.) The fact these BMPs are underground requires the designer to locate an acceptable outfall or improved drainage system for discharging runoff. The vertical elevation of the inflow and outflow pipe connections may be critical to the choice, or design, of the BMP.

Overflow

All of the manufactured BMP systems presented in this standard are flow-through structures that can be located on storm drainage systems that drain improved areas. Most manufactured systems, however, are designed to treat the first flush, or the water quality volume, of runoff. Therefore, an overflow, or bypass, is needed to divert flow that exceeds the design rate, or a storage facility is needed to store the appropriate volume of runoff for treatment. The discussion of each manufactured system will include the overflow or bypass provisions provided, or required.

6 Design Criteria

The design criteria for manufactured BMP systems should be obtained from the manufacturer. All designs should be reviewed by the manufacturer to insure that the system is appropriately designed and sized.

7 Maintenance and Inspections

All manufactured BMP systems require regular inspection and maintenance to maximize their effectiveness. The specific maintenance requirements and schedule should be prepared by the manufacturer and signed by the owner/operator. It should be noted that the frequency of maintenance is not only dependent on the type of manufactured system chosen, but also the pollutant load from the contributing drainage area. The frequency of maintenance required may vary from after any major storm, to once a month, to up to twice a year.

A maintenance log should be required to keep track of routine inspections and maintenance. A maintenance log can also help facility owners establish the effectiveness of certain “housekeeping” practices, such as street sweeping. Failure to maintain any stormwater BMP may result in reduced efficiency, resuspension or mixing of previously trapped pollutants, or clogging of the system.

Many suppliers of manufactured BMP systems recommend service contracts to ensure that maintenance occurs on a regular basis. Lack of maintenance is widely acknowledged to be the most prevalent cause of failure of both structural and non-structural BMPs.

Another consideration with manufactured BMP systems is the possible contamination and toxicity of trapped sediments, especially in areas considered to be stormwater hot-spots. Care must be taken in the disposal of sediment that may contain accumulations of heavy metals. Sediment testing is recommended prior to sediment removal to assure proper disposal. Experience in other jurisdictions has indicated reluctance on the part of waste water utility operators to accept the pump-out material from these structures. Landowners are encouraged to research the disposal options as part of the planning process prior to selecting the BMP.

F Roof Downspout System

1 Definition

A roof downspout system is an infiltration trench practice intended only for infiltrating rooftop runoff transported to the trench via roof downspout drains.

2 Purpose

The purpose of a roof downspout system is to provide water quality enhancement of rooftop runoff via infiltration of the water quality volume into the surrounding soils. This facility is not designed to infiltrate other surface water that could transport sediment or pollutants, such as from paved areas.

3 Conditions Where Practice Applies

Roof downspout systems may be used in any situation where disposing of rooftop runoff without direct connections to existing drainage systems or BMPs is acceptable and advantageous. Because of their small size, they are well suited for retrofitting in areas where runoff control of existing or new rooftop areas associated with building additions becomes necessary. As part of a low impact development strategy, roof downspout systems effectively disconnect the rooftop imperviousness from the drainage system which helps reduce the stormwater impact of the development. Use of roof downspout systems (or infiltration trenches in general) in residential areas should be used with caution due to concern for the potential lack of inspections and maintenance, and ultimate failure and abandonment of the facility.

4 Planning Considerations

The planning considerations for roof downspout systems are the same as those for infiltration trenches (see Section 7). The drainage area is limited to the rooftop areas of residential and/or commercial structures.

5 Design Criteria

This section provides recommendations and minimum criteria for the design of roof downspout systems intended to comply with the runoff quality requirements of the City of Richmond.

The design criteria for roof downspout systems are the same as those for infiltration trenches with the following exceptions and/or additions:

Distance from Structures

Roof downspout systems should be a minimum of 10 feet down-slope from any structure or property line, and 30 feet from any septic tank or drain field.

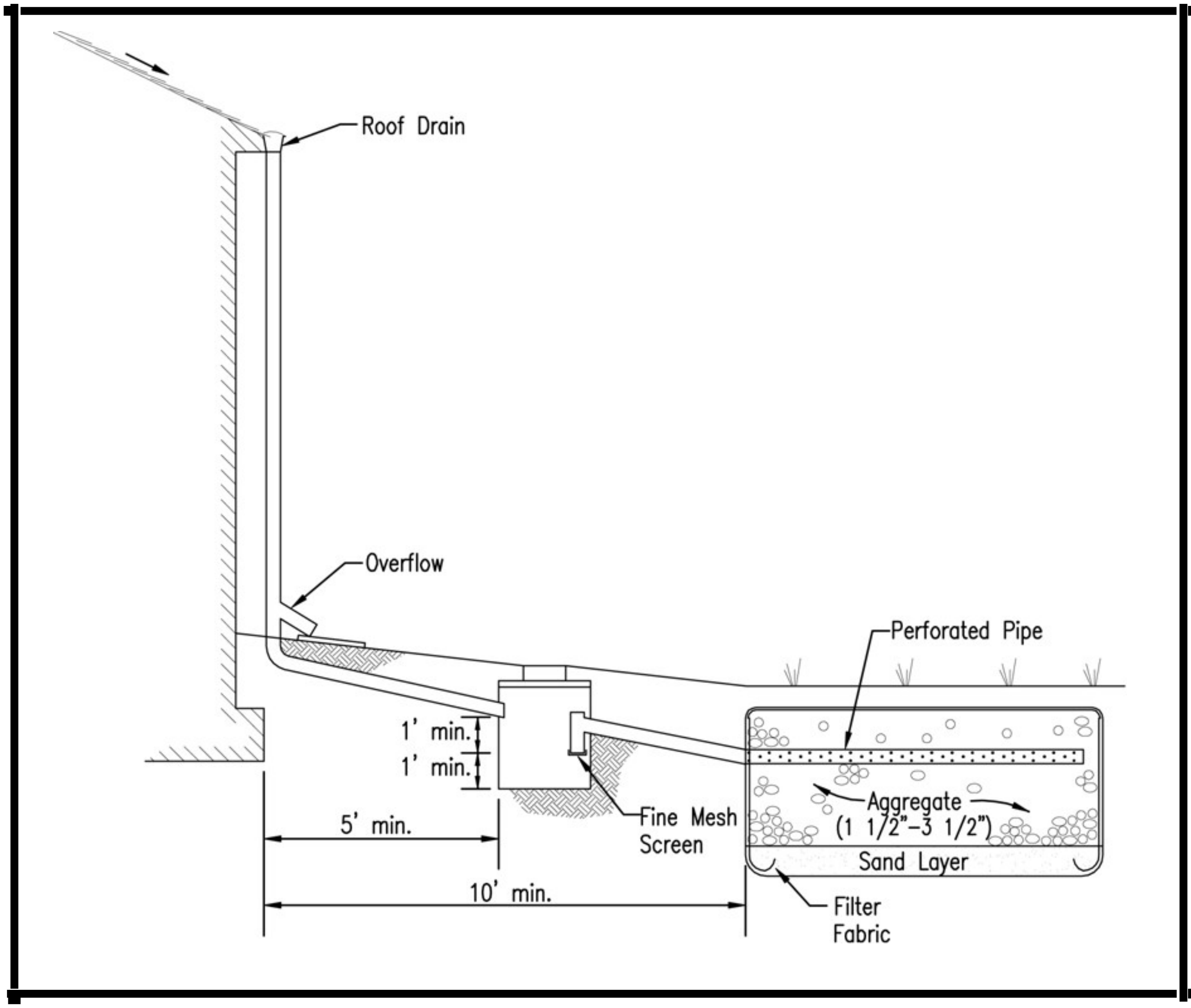
Runoff Pre-Treatment

Gutters should be fitted with mesh screens to prevent leaf litter and other debris from entering the system in areas where there is tree cover. The expected growth of newly planted trees should be considered. A pretreatment settling basin as shown in Figure 8 should be provided on all roof downspout systems.

Overflow

An overflow outlet should be provided on the downspout at the surface elevation to allow flow to bypass the infiltration facility when it is full or clogged (See Figure 6 below.) Adequate surface drainage away from the structure should be provided according to appropriate building codes.

Figure 6. Roof Downspout System with a Pretreatment Sump Basin



6 Construction Specifications

The construction specifications for roof downspout systems are the same as those for infiltration trenches (see Section 7).

7 Maintenance and Inspection Guidelines

Maintenance procedures are identical for those of an infiltration trench. Since these facilities are installed on individual buildings and other structures, provisions need to be made for their maintenance, especially when they are installed on single family dwellings. When flow is observed to be bypassing the facility, the system has clogged and should be evaluated for rehabilitation.

8 Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of a roof downspout system.

a Determine if the anticipated development conditions and rooftop areas are appropriate for a roof downspout system.
b. Determine if the soils (permeability, bedrock, water table, etc.) and topographic conditions (slopes, building foundations, etc.) are appropriate for a roof downspout system.
c. Locate the roof downspout system on the site within site topographic constraints.
d. Determine the roof area for each roof downspout system and calculate the required water quality volume.
e. Design the roof downspout system:
   - ❖ design infiltration rate, f_d = 0.5 f
   - ❖ max. Storage time T_{max} = 48 hours
   - ❖ max. Storage depth, d_{max}
   - ❖ stone backfill of clean aggregate (1.5" to 3.5" diameter) - KYTC No. 1 Open-
   - ❖ graded Course Aggregate
   - ❖ sand layer on trench bottom (8 inches
   - ❖ runoff pretreatment - concentrated input: gutter screens, settling basin
   - ❖ filter fabric on trench sides and top (not on trench bottom) keyed into trench
   - ❖ overflow channel or large storm bypass
   - ❖ observation well

f. Provide material specifications.
g. Provide sequence of construction.
h. Provide maintenance and inspection requirements.

G Vegetated Filter Strip

1 Definition

A vegetated filter strip is a densely vegetated strip of land engineered to accept runoff from upstream development as overland sheet flow. It may adopt any naturally vegetated form, from grassy meadow to small forest (See Figure 7 below).

2 Purpose

The purpose of a vegetated filter strip is to enhance the quality of stormwater runoff through filtration, sediment deposition, infiltration and absorption.

A vegetated filter strip may be used as a pretreatment BMP in conjunction with a primary BMP. This reduces the sediment and particulate pollutant load that could reach the primary BMP, which, in turn, reduces the BMP's maintenance costs and enhances its pollutant removal capabilities.

Vegetated filter strips rely on their flat cross-slope and dense vegetation to enhance water quality. Their flat cross-slope assures that runoff remains as sheet flow while filtering through the vegetation. There is limited ponding or storage associated with these BMPs, so they are ineffective for reducing peak discharges. Vegetated filter strips may lower runoff velocities and, sometimes, runoff volume. Typically, however, the volume reduction is not adequate for controlling stream channel erosion or flooding.

3 Conditions Where Practice Applies

<u>Drainage Area</u>

A vegetated filter strip should not receive large volumes of runoff since such flows tend to concentrate and form channels. Channels within a filter strip allow runoff to short-circuit the BMP, rendering it ineffective. Therefore, the contributing drainage area for a vegetated filter strip is based on the linear distance behind it that is maintained as sheet flow. Runoff is assumed to change from sheet flow to shallow concentrated flow after traveling 150 feet over pervious surfaces and 75 feet over impervious surfaces (Center for Watershed Protection, 1996). A level spreader may be used to convert shallow concentrated flow from larger areas back to sheet flow before it enters the filter strip. In any event, the contributing drainage area should never exceed five acres.

<u>Development Conditions</u>

Vegetated filter strips have historically been used and proven successful on agricultural lands, primarily due to their low runoff volumes. In urban settings, filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, small parking areas, and other small impervious areas. Filter strips should not be used to control large impervious areas.

Since vegetated filter strips should not be used to treat concentrated flows, they are suitable only for low to medium-density development (16-21% impervious), or as a pretreatment component for structural BMPs in higher density developments.

4 Planning Considerations

Site Conditions

The following site conditions should be considered when selecting a vegetated filter strip as a water quality BMP:

a Soils – Vegetated filter strips should be used with soils having an infiltration rate of 0.52 inches/hour; (sandy loam, loamy sand). Soils should be capable of sustaining adequate stands of vegetation with minimal fertilization.
b Topography – Topography should be relatively flat to maintain sheet flow conditions. Filter strips function best on slopes 5 percent or less.
c Depth of Water Table – A shallow or seasonally high groundwater table will inhibit the opportunity for infiltration. Therefore, the lowest elevation in the filter strip should be at least 2 feet above the water table.

If the soil's permeability and/or depth to water table are unsuitable for infiltration, the filter strip's primary function becomes the filtering and settling of pollutants. A modified design may be provided to allow ponding of the water quality volume at the filter's downstream end. The ponding area may be created by constructing a small permeable berm using a select soil mixture. The maximum ponding depth behind the berm should be 1 foot.

Water Quality Enhancement

Vegetated filter strips are occasionally installed as a standard feature in residential developments. To be used as a water quality BMP, however, filter strips must comply with certain design criteria. Vegetated filter strip designs should include specific construction, stabilization, and maintenance specifications. The most significant requirement is for runoff to be received as sheet flow. Certain enhancements may be necessary, such as added vegetation and grading specifications, or the use of level spreaders, to ensure that runoff enters the filter strip as sheet flow.

Sediment Control

A natural area that is designed to serve as a vegetated filter strip should not be used for temporary sediment control. Sediment deposition may have significant impacts on the existing vegetation. If a vegetated filter strip is proposed in a natural area marginally acceptable for use, due to topography or existing vegetation, then it may be appropriate to use the filter strip for temporary sediment control. However, when the project is completed, the sediment accumulation should be removed, the area should be regraded to create the proper design conditions (sheet flow), and the strip should be re-stabilized per the landscaping plan.

5 Design Criteria

This section provides recommendations and minimum design criteria for vegetated filter strips intended to enhance water quality. It is the designer's responsibility to decide which criteria are applicable to the each facility and to decide if any additional design elements are required. The designer must also provide for the long-term functioning of the BMP.

<u>Hydrology</u>

The hydrology of a filter strip's contributing drainage area shall be developed.

<u>Filter Strip Geometry</u>

Compliance with the following parameters will result in optimal filter strip performance (NVPDC):

a Length – The minimum length of a filter strip should be 25 feet, at a maximum slope of 2 percent. The length should increase by 4 feet for any 1 percent increase in slope. The optimum filter strip length is 80 to 100 feet.

b Width – The width of the filter strip (perpendicular to the slope) should be equal to the width of the contributing drainage area. When this is not practical, a level spreader should be used to reduce the flow width to that of the filter strip. The level spreader's width will determine the depth of flow and runoff velocity of the stormwater as it passes over the spreader lip and into the filter strip. A wide lip will distribute the flow over a longer level section, which reduces the potential for concentrated flow across the filter.

c Slope – The slope of the filter strip should be as flat as possible while allowing for drainage. Saturation may occur when extremely flat slopes are used.

<u>Level Spreader</u>

A level spreader should be provided at the upper edge of a vegetated filter strip when the width of the contributing drainage area is greater than that of the filter (see Figure 8). Runoff may be directed to the level spreader as sheet flow or concentrated flow. However, the design must ensure that runoff fills the spreader evenly and flows over the level lip as uniformly as possible. The level spreader should extend across the width of the filter, leaving only 10 feet open on each end.

<u>Pervious Berm</u>

To force ponding in a vegetated filter strip, a pervious berm may be installed. It should be constructed using a moderately permeable soil such as ASTM ML, SM, or SC. Soils meeting USDA sandy loam or loamy sand texture, with a minimum of 10 to 25% clay, may also be used. Additional loam should be used on the berm (± 25%) to help support vegetation. An armored overflow should be provided to allow larger storms to pass without overtopping the berm. Maximum ponding depth behind a pervious berm is 1 foot.

<u>Vegetation</u>

A filter strip should be densely vegetated with a mix of erosion resistant plant species that effectively bind the soil. Certain plant types are more suitable than others for urban stormwater control. The selection of plants should be based on their compatibility with climate conditions, soils, and topography and their ability to tolerate urban stresses from pollutants, variable soil moisture conditions and ponding fluctuations.

A filter strip should have at least two of the following vegetation types:

- ❖ deep-rooted grasses, ground covers, or vines
- ❖ deciduous and evergreen shrubs
- ❖ under- and over-story trees

Native plant species should be used if possible. Non-native plants may require more care to adapt to local hydrology, climate, exposure, soil and other conditions. Also, some non-native plants may become invasive, ultimately choking out the native plant population. This is especially true for non- native plants used for stabilization.

Newly constructed stormwater BMPs will be fully exposed for several years before the buffer vegetation becomes adequately established. Therefore, plants which require full shade, are susceptible to winter kill or are prone to wind damage should be avoided.

Plant materials should conform to the <u>American Standard for Nursery Stock</u>, current issue, as published by the American Association of Nurserymen. The botanical (scientific) name of the plant species should be according to the landscape industry standard nomenclature. All plant material specified should be suited for USDA Plant Hardiness Zones 6 or 7 (see Figure 9).

6 Construction Specifications

Overall, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable to construct a vegetated filter strip. The specifications should also satisfy all requirements of the local government.

<u>Sequence of Construction</u>

Vegetated filter strip construction should be coordinated with the overall project construction schedule. Rough grading of the filter strip should <u>not</u> be initiated until adequate erosion controls are in place.

<u>Soil Preparation</u>

Topsoil should be 8 inches thick, minimum. If grading is necessary, the topsoil should be removed and stockpiled. If the subsoil is either highly acidic or composed of heavy clays, ground dolomite limestone should be applied at an appropriate rate based on soil and slope conditions.

Subsoil should be tilled to a depth of at least 3 inches to adequately mix in soil additives and to permit bonding of the topsoil to the subsoil. If the existing topsoil is inadequate to support a densely vegetated filter strip, then suitable material should be imported. Proper specifications for imported topsoil should include the following:

a The USDA textural triangle classification.
b Requirements for organic matter content (not less than 1.5% by weight), pH (6 to 7.5), and soluble salt (not greater than 500 parts per million).
c Placement thickness and compaction. Topsoil should be uniformly distributed and compacted, and should have a minimum compacted depth of 6 to 8 inches.

7 Maintenance/Inspection Guidelines

Vegetated filter strips require regular maintenance. Field studies indicate that these BMPs usually have short life spans because of lack of maintenance, improper location, and poor vegetative cover.

The following maintenance and inspection guidelines are NOT all-inclusive. Specific facilities may require other measures not discussed here. It is the designer's responsibility to decide if additional measures are necessary.

Filter strips should be inspected regularly for gully erosion, density of vegetation, damage from foot or vehicular traffic, and evidence of concentrated flows circumventing the strip. The level spreader should also be inspected to verify that it is functioning as intended.

Inspections are critical during the first few years to ensure that the strip becomes adequately established. Maintenance is especially important during this time and should include watering, fertilizing, re-seeding or planting as needed.

Once a filter strip is well established and functioning properly, periodic maintenance, such as watering, fertilizing and spot repair, may still be necessary. However, fertilization efforts should be minimized. Natural selection allows certain species (usually native plants) to thrive while others decline. Excessive fertilization and watering to maintain individual plantings may prove costly, especially in abnormally dry or hot seasons. Overseeding and replanting should be limited to those species which have exhibited the ability to thrive.

To increase the functional longevity of a vegetated filter strip, the following practices are recommended:

- Regular removal of accumulated sediment,
- periodic reestablishment of vegetation in eroded areas or areas covered by accumulated sediment,
- periodic weeding of invasive species or weeds, and
- periodic pruning of woody vegetation to stimulate growth

Figure 7. Vegetated Filter Strip

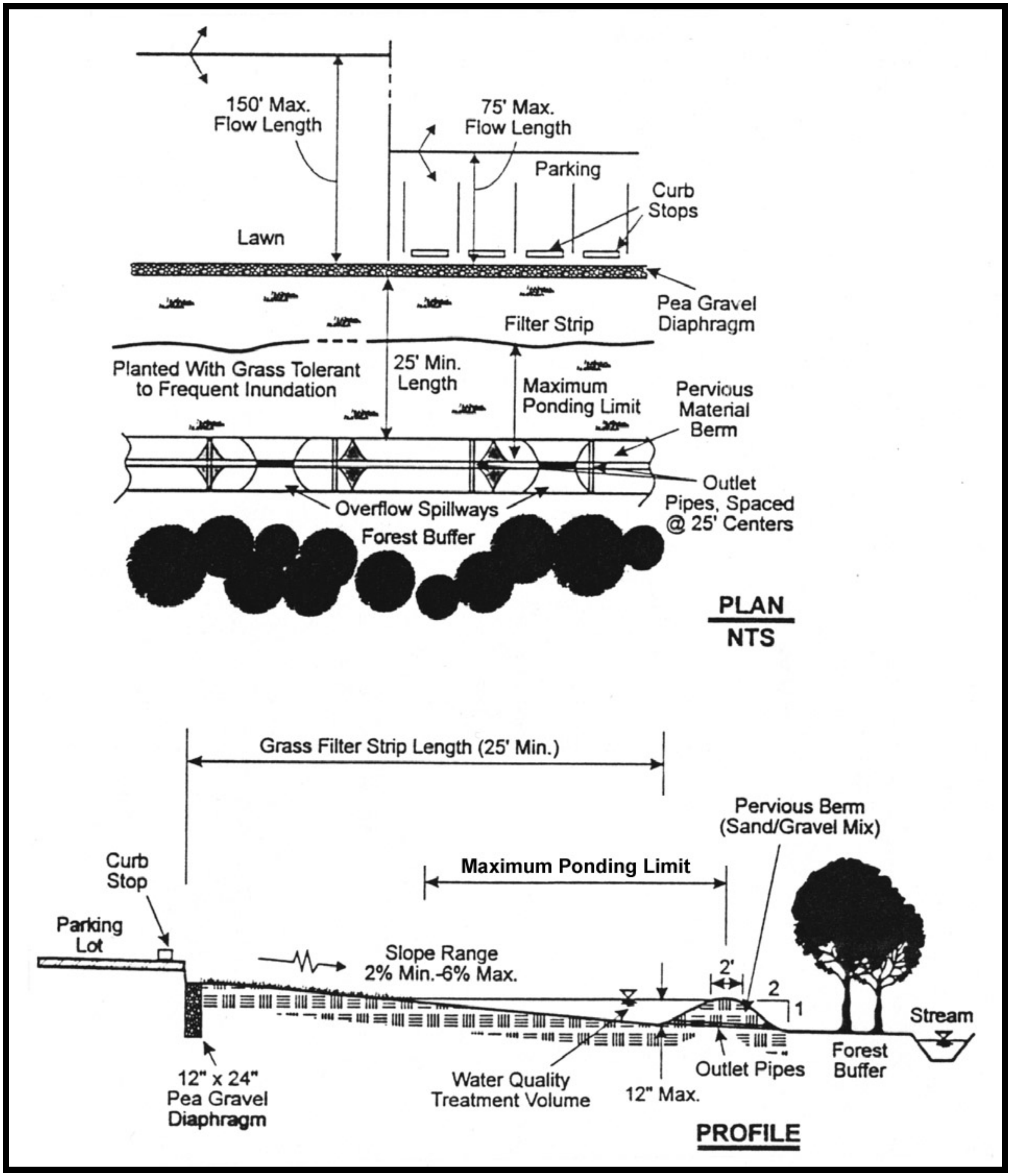


Figure 8. Level Spreader

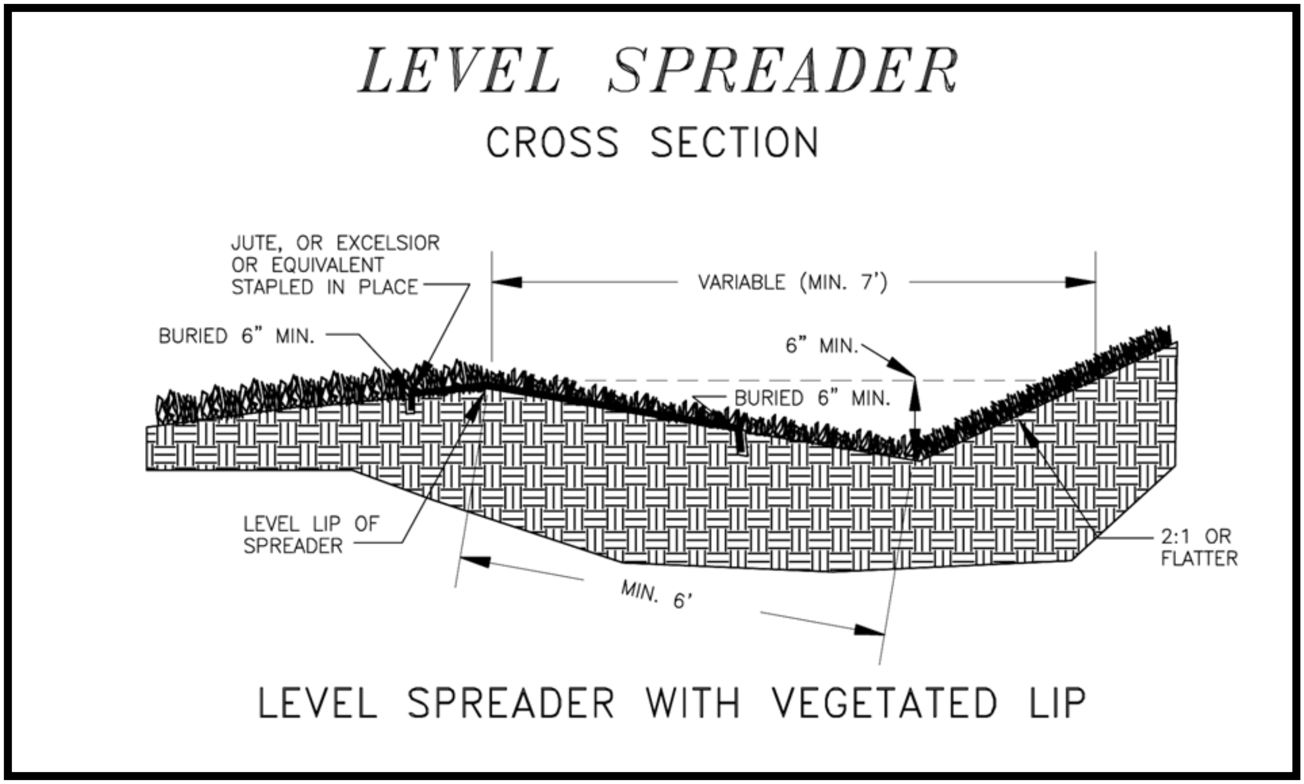
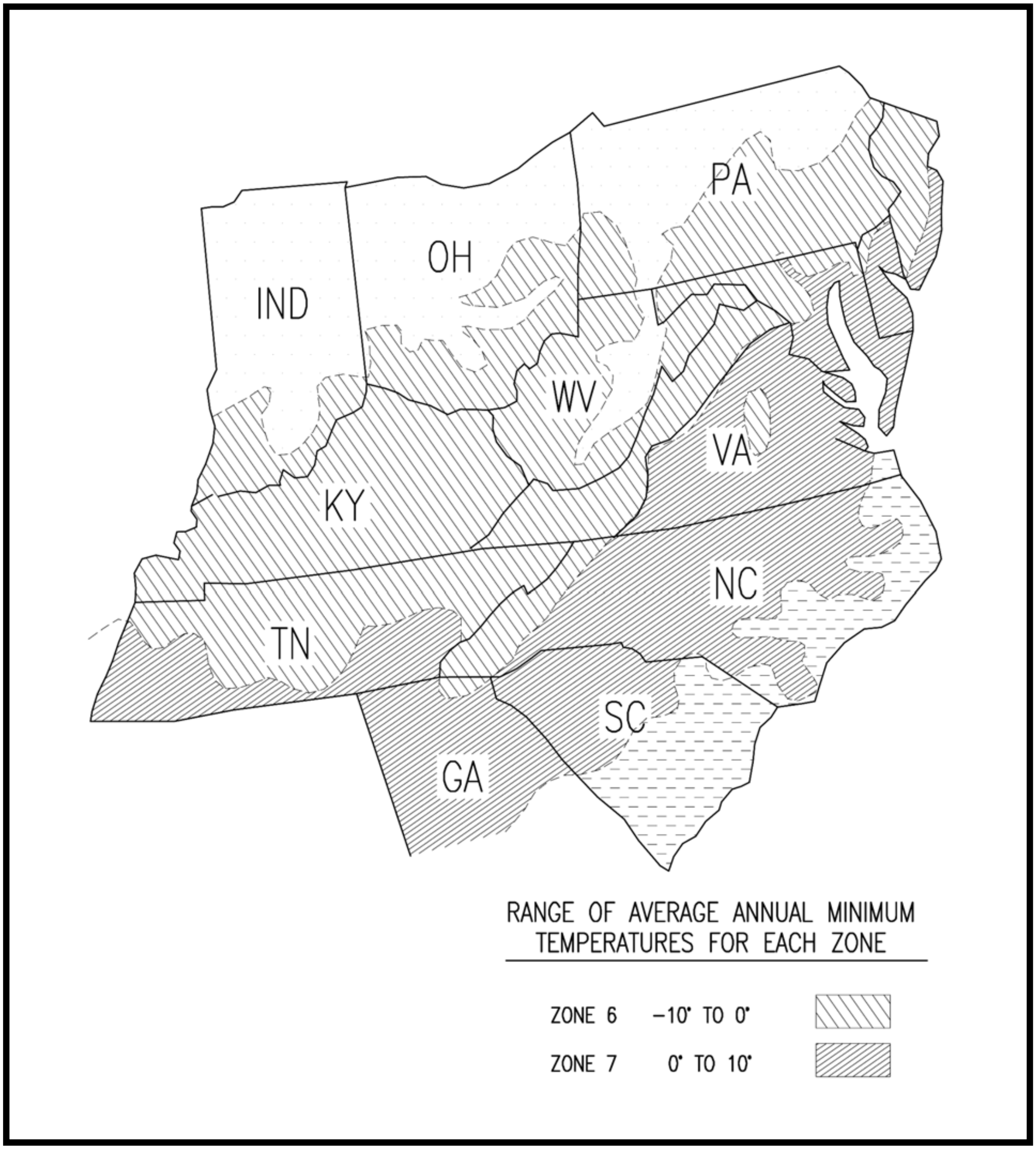


Figure 9. USDA Plant Hardiness Zones



H Grassed Swale

1 Definition

A grassed swale is a broad and shallow earthen channel vegetated with erosion resistant and flood- tolerant grasses. Check dams are strategically placed in the swale to encourage ponding behind them. Figure 10 below presents a grassed swale designed to hold small pockets of water behind each check dam. The water slowly drains through small openings in the chack dam and/or infiltrates into the ground. Slow channel velocities allow the vegetation to filter out sediments and other particulate pollutants from the runoff and increases the opportunity for infiltration and adsorption of soluble pollutants.

A water quality swale is a broad and shallow earthen channel vegetated with erosion resistant and flood tolerant grasses, and underlain by an engineered soil mixture. Figure 11 below presents a water quality swale with an engineered soils media directly under the swale, with an underdrain. This design may be used in areas where the soils are not conducive to infiltration, or in developments where the swale is constructed beside a roadway using fill or compacted soils.

2 Purpose

The purpose of grassed swales and water quality swales is to convey stormwater runoff at a non- erosive velocity in order to enhance its water quality through infiltration, sedimentation, and filtration. Check dams are used within the swale to slow the flow rate and create small, temporary ponding areas. A water quality swale is appropriate where greater pollutant removal efficiency is desired.

<u>Water Quality Enhancement</u>

Grassed swales and water quality swales remove pollution through sedimentation, infiltration, and filtration. Water quality swales are specifically engineered to filter stormwater through an underlying soil mixture while grass swales are designed to slow the velocity of flow to encourage settling and filtering through the grass lining. Vegetation filters out the sediments and other particulate pollutants from the runoff and increases the opportunity for infiltration and adsorption of soluble pollutants. The flow rate becomes a critical design element, since runoff must pass through the vegetation slowly for pollutant removal to occur. Monitoring of grassed swales has indicated low to moderate removal of soluble pollutants (phosphorous and nitrogen) and moderate to high removal of particulate pollutants.

<u>Flood Control</u>

Grassed swales and water quality swales will usually provide some peak attenuation depending on the storage volume created by the check dams. However, flood control should be considered a secondary function of grassed swales since the required storage volume for flood control is usually more than they can provide.

Channel Erosion Control

Grassed swales and water quality swales may also provide some benefits relative to channel erosion by reducing the peak rate of discharge from a drainage area. However, the holding capacity of a grassed swale designed for water quality purposes is limited.

Figure 10. Typical Grassed Swale Configuration

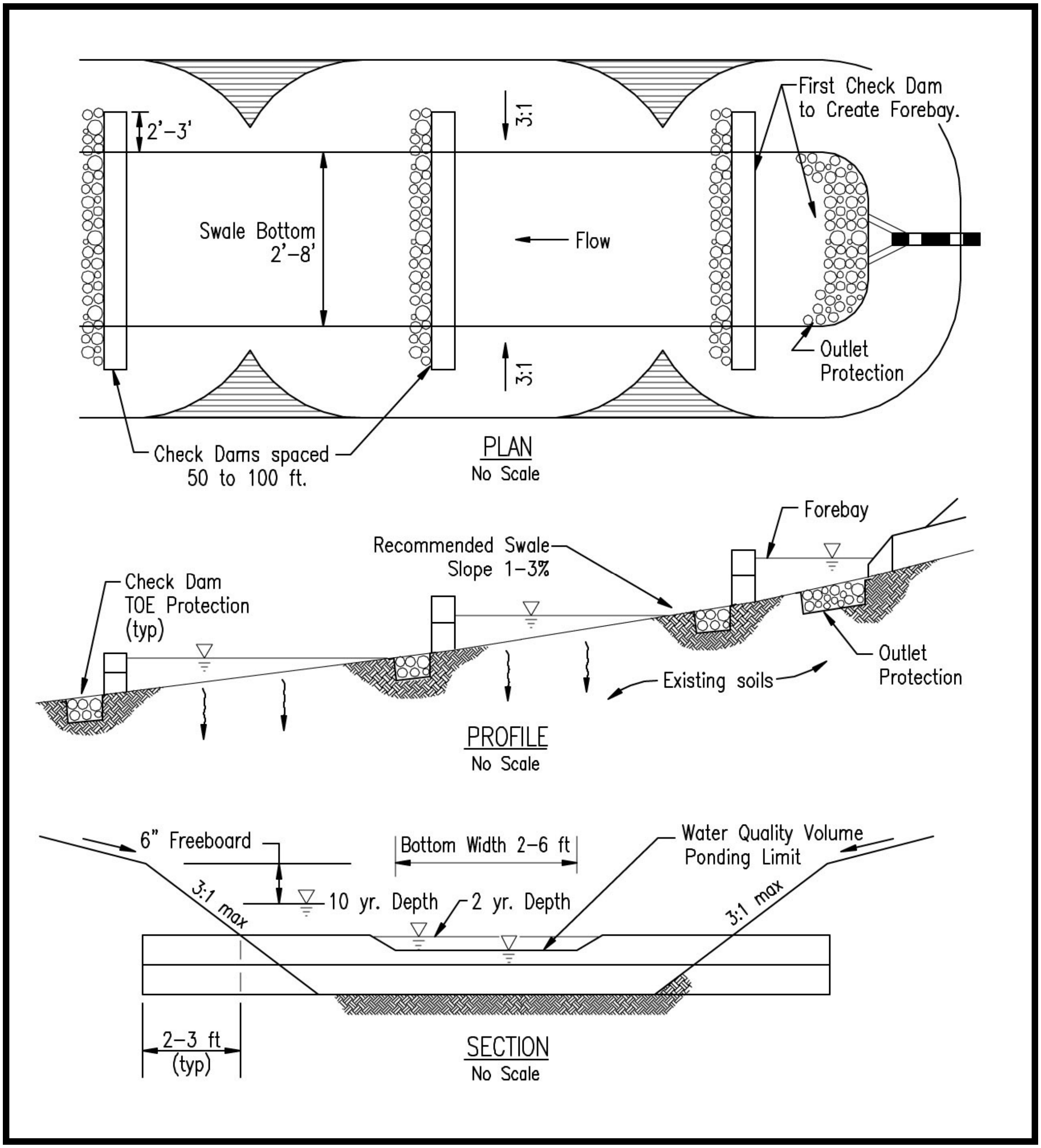
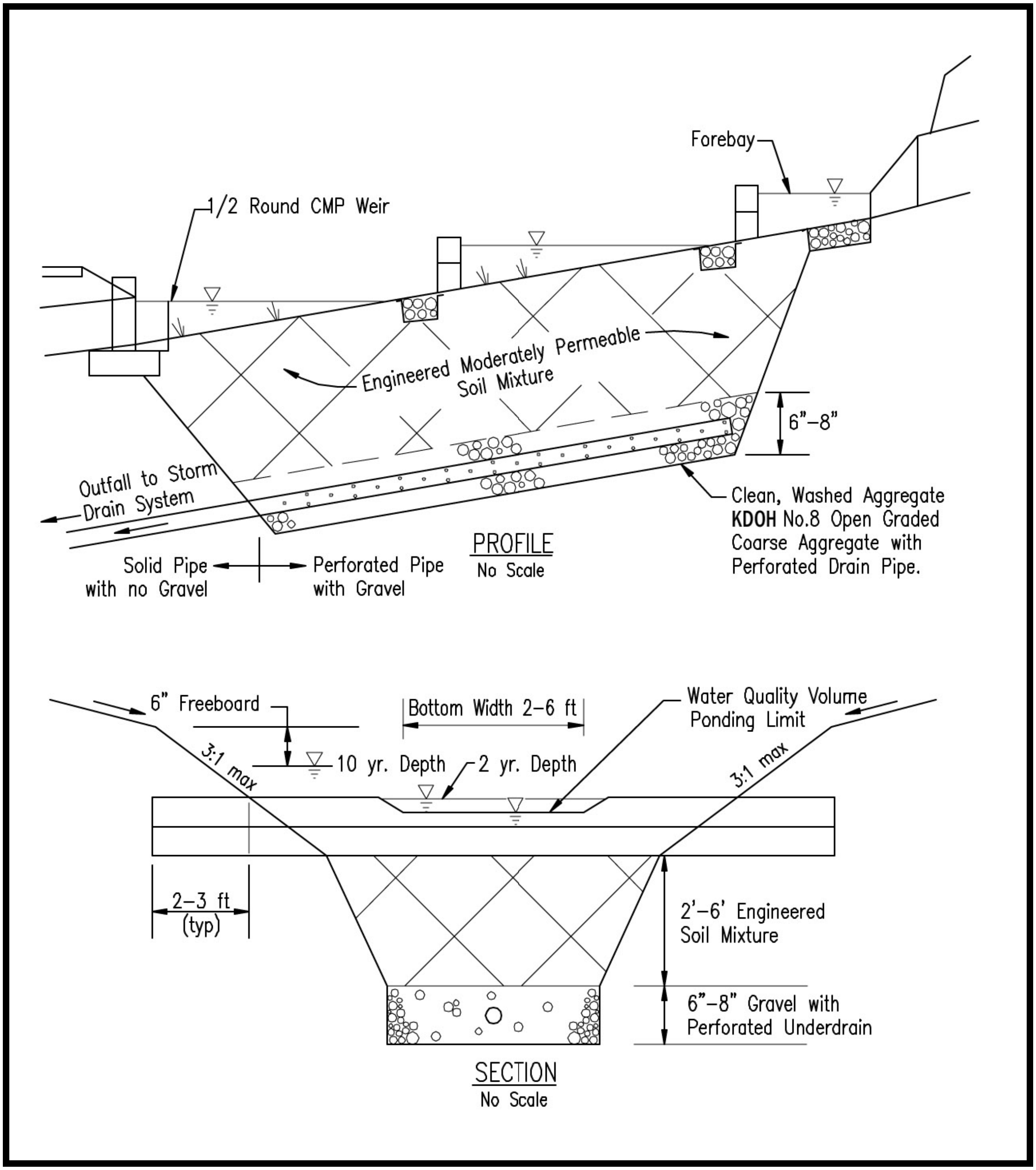


Figure 11. Typical Water Quality Swale Configuration



3 Condition Where Practice Applies

Drainage Area

Grassed swales and water quality swales engineered for enhancing water quality cannot effectively convey large flows. Therefore, their contributing drainage areas must be kept small. The dimensions (length, width, and overall geometry) and slope of the swale, and its ability to convey the 10-year storm at a non-erosive velocity will set the size of the contributing drainage area.

Development Conditions

Grassed swales are commonly used instead of curb and gutter drainage systems in low- to moderate- density (16 to 21% impervious) single-family residential developments. Since grassed swales do not function well with high volumes or velocities of stormwater, they have limited application in highly urbanized or other highly impervious areas. However, swales may be appropriate for use in these areas if they are constructed in series or as pretreatment facilities for other BMPs.

Grassed swales are usually located within the right-of-way when used to receive runoff from subdivision or rural roadways. They may also be installed within drainage easements along the side or rear of residential lots. Grassed swales can be strategically located within the landscape to intercept runoff from small impervious surfaces (small parking lots, rooftops, etc.) as a component of a subdivision-wide or development-wide BMP strategy.

Water quality swales are appropriate for the same development conditions as those listed for grassed swales with the addition of higher densities of development (16 - 37% impervious) due to the increased pollutant removal capability.

4 Planning Considerations

Site Conditions

The following items should be considered when selecting a grassed swale as a water quality BMP:

a Soils – Grassed swales can be used with soils having moderate infiltration rates of 0.27 inches per hour (silt loam) or greater. Besides permeability, soils should support a good stand of vegetative cover with minimal fertilization.

  Water quality swales can be used in areas of unsuitable soil conditions for infiltration since the engineered soil mixture and underdrain system is used in place of the insitu soils.

b Topography – The topography of the site should be relatively flat so that the swale can be constructed with a slope and cross-section that maintains low velocities and creates adequate storage behind the check dams.

c Depth to water table – A shallow or seasonally-high groundwater table will inhibit the opportunity for infiltration. Therefore, the bottom of the swale should be at least 2 feet above the water table.

Sediment Control

Grassed swales may be used for conveyance of stormwater runoff during the construction phase of development. However, the swales should be maintained as required by the local program requirements. Before final stabilization, sediment must be removed from the swales and the soil surface prepared for final stabilization. Tilling of the swale bottom may be needed to open the surface pores and re-establish the soil's permeability. Water quality swales should be constructed after a majority of the drainage area has been stabilized.

This section presents minimum criteria and recommendations for the design of grassed swales used to enhance water quality. It is the designer's responsibility to decide which criteria are applicable to the particular swale being designed and to decide if any additional design elements are required. The designer must also provide for the long-term functioning of the facility by choosing appropriate structural materials.

5 Design Criteria

The design of a water quality grassed swale includes calculations for traditional swale parameters (flow rate, maximum permissible velocities, etc.) along with storage volume calculations for the water quality volume.

Hydrology

The hydrology of a grassed swale's contributing drainage area shall be developed.

Swale Geometry

A grassed swale should have a trapezoidal cross-section to spread flows across its flat bottom. Triangular or parabolic shaped sections will concentrate the runoff and should be avoided. The side slopes of the swale should be no steeper than 3H:1V to simplify maintenance and to help prevent erosion.

Bottom Width

The bottom width of the swale should be 2 feet minimum and 6 feet maximum in order to maintain sheet flow across the bottom and to avoid concentration of low flows. The actual design width of the swale is determined by the maximum desirable flow depth, as discussed below.

Flow Depth

The flow depth for a water quality grassed swale should be approximately the same as the height of the grass. An average grass height for most conditions is 4 inches. Therefore, the maximum flow depth for the water quality volume should be 4 inches (Center for Watershed Protection, 1996).

Flow Velocity

The maximum velocity of the water quality volume through the grassed swale should be no greater than 1.5 feet per second. The maximum design velocity of the larger storms should be kept low enough so as to avoid resuspension of deposited sediments. The 2-year storm recommended maximum design velocity is 4 feet per second and the 10-year storm recommended maximum design velocity is 7 feet per second

Longitudinal Slope

The slope of the grassed swale should be as flat as possible, while maintaining positive drainage and uniform flow. The minimum constructable slope is between 0.75 and 1.0%. The maximum slope depends upon what is needed to maintain the desired flow velocities and to provide adequate storage for the water quality volume, while avoiding excessively deep water at the downstream end. Generally, a slope of between 1 and 3% is recommended. The slope should never exceed 5%

Swale length

Swale length is dependent on the swale's geometry and the ability to provide the required storage for the water quality volume.

Swale Capacity

The capacity of the grassed swale is a combined function of the flow volume (the water quality volume) and the physical properties of the swale such as longitudinal slope and bottom width. By using the Manning equation or channel flow nomographs, the depth of flow and velocity for any given set of values can be obtained. The Manning's 'n' value, or roughness coefficient, varies with the depth of flow and vegetative cover. An 'n' value of 0.15 is appropriate for flow depths of up to 4 inches (equal to the grass height). The n value decreases to a minimum of 0.03 for grass swales at a depth of approximately 12 inches (see Figure 13 below).

A grassed swale should have the capacity to convey the peak flows from the 10-year design storm without exceeding the maximum permissible velocities. (Note that a maximum velocity is specified for the 2-year and 10-year design storms to avoid resuspension of deposited sediments and other pollutants and to prevent scour of the channel bottom and side slopes.) The swale should pass the 10-year flow over the top of the check dams with 6 inches, minimum, of freeboard. As an alternative, a bypass structure may be engineered to divert flows from the larger storm events (runoff greater than the water quality volume) around the grassed swale. However, when the additional area and associated costs for a bypass structure and conveyance system are considered, it may be more economical to simply increase the bottom width of the grassed swale. It should then be designed to carry runoff from the 10-year frequency design storm at the required permissible velocity.

The longitudinal slope and the bottom width may be adjusted to achieve the maximum allowable velocity according to the Manning equation:

$$Q = \left[\frac{1.49}{n} r^{2/3} s^{1/2}\right] A$$

Where:
- Q = peak flow rate, cfs
- n = Manning's roughness coefficient
- r = hydraulic radius, ft. = A / wp
- s = longitudinal slope of the channel
- A = cross-sectional area of the channel, ft^2

The portion of the equation within the brackets represents the velocity of flow. The previous equation can be rewritten as:

$$Q = VA$$

Where:
- Q = peak flow rate, cfs
- V = flow velocity, ft/s = $\frac{1.49}{n} r^{2/3} s^{1/2}$
- A = cross-sectional area of the channel, ft^2.

Water Quality Volume

If a grassed swale is used as a conveyance channel, its purpose is to transport stormwater to the discharge point. However, the purpose of a water quality grassed swale is to slow the water as much as possible to encourage pollutant removal.

The use of check dams will create segments of the swale which will be inundated for a period of time. The required total storage volume behind the check dams is equal to the water quality volume for the contributing drainage area to that point. However, the maximum ponding depth behind the check dams should not exceed 18 inches. To ensure that this practice does not create nuisance conditions, an analysis of the subsoil should be conducted to verify its permeability.

Underlying Soil Bed - Water Quality Swales

An underlying engineered soil bed and underdrain system may be utilized in areas where the soils are not permeable and the swale would remain full of water for extended periods of time (creating nuisance conditions). This soil bed should consist of a moderately permeable soil material with a high level of organic matter: 50% sand, 20% leaf mulch, 30% top soil. The soil bed should be 30 inches deep and should be accompanied by a perforated pipe and gravel underdrain system.

In residential developments with marginal soils, it may be appropriate to provide a soil bed and underdrain system in all grassed swales to avoid possible safety and nuisance concerns.

Check Dams

The use of check dams in a grassed swale should be per the following criteria (see Figure 12 below):

a Height – A maximum height of 18 inches is recommended, and the dam height should not exceed one-half the height of the swale bank.
b Spacing – Spacing should be such that the slope of the swale and the height of the check dams combine to provide the required water quality volume behind the dams.
c Abutments – Check dams should be anchored into the swale wall a minimum of 2 to 3 feet on each side.
d Toe Protection – The check dam toe should be protected with riprap placed over a suitable geotextile fabric. The size (D_{50}) of the riprap should be based on the design flow in the swale. Class A1 Riprap is recommended.
e Overflow – A notch should be placed in the top of the check dam to allow the 2-year peak discharge to pass without coming into contact with the check dam abutments, or the abutments may be protected with a non-erodible material. Six inches of freeboard should be provided between the 10-year overflow and the top of the swale.
f Riprap check dams – Rip rap check dams should consist of a KYTC No. 1 Open-graded Coarse Aggregate core keyed into the ground a minimum of 6 inches, with a Class A riprap shell.
g Filter fabric – Filter fabric is required under riprap and gabion check dams.

h Driveway culvert weirs – Where a driveway culvert is encountered, a ½ round corrugated metal pipe weir bolted to the concrete driveway headwall may be utilized as a check dam, or a timber check dam placed at least one foot upstream of the culvert opening.

Outlets

Discharges from grassed swales must be conveyed at non-erosive velocities to either a stream or a stabilized channel to prevent scour at the outlet of the swale.

Inflow Points

Swale inflow points should be protected with erosion controls as needed (e.g., riprap, flow spreaders, energy dissipators, sediment forebays, etc.).

Vegetation

A dense cover of water-tolerant, erosion-resistant grass or other vegetation must be established. Grasses used in swales should have the following characteristics:

- a deep root system to resist scouring,
- a high stem density, with well-branched top growth,
- tolerance to flooding,
- resistance to being flattened by runoff, and
- an ability to recover growth following inundation.

Recommended grasses include, but are not limited to, the following: Kentucky-31 tall fescue, reed canary grass, redtop, and rough-stalked blue grass. Note that these grasses can be mixed.

The selection of an appropriate vegetative lining for a grassed swale is based on several factors including climate, soils, and topography.

Erosion control matting should be used to stabilize the soil before seed germination. This protects the swale from erosion during the germination process. In most cases, the use of sod is warranted to provide immediate stabilization on the swale bottom and/or side slopes. .

6 Construction Specifications

Specifications for the work should conform to the methods and procedures specified for earthwork, concrete, reinforcing steel, woodwork and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government.

<u>Sequence of Construction</u>

The construction of grassed swales should be coordinated with the overall project construction schedule. The swale may be excavated during the rough grading phase of the project to permit use of the excavated material as fill in earthwork areas. Otherwise, grassed swales should not be constructed or placed into service until the entire contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas may load the newly formed swale with a large volume of fine sediment. This could seriously impair the swale's natural infiltration ability.

The specifications for construction of a grassed swale should state the following:

- the earliest point in progress when storm drainage may be directed to the swale, and
- the means by which this delay in use will be accomplished.

Due to the wide variety of conditions encountered among projects, each project should be evaluated separately evaluated to decide how long to delay use of the swale.

<u>Excavation</u>

Initially, the swale should be excavated to within one foot of its final elevation. Excavation to the finished grade should be deferred until all disturbed areas in the watershed have been stabilized or protected. The final phase of excavation should remove all accumulated sediment. When final grading is completed, the swale bottom should be tilled with rotary tillers or disc harrows to provide a well-aerated, highly porous surface texture.

<u>Vegetation</u>

Establishing dense vegetative cover on the swale side slopes and floor is required. This cover will not only prevent erosion and sloughing, but will also provide a natural means to maintain relatively high infiltration rates.

<u>Materials</u>

a. Check dams – Check dams shall be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams shall be underlain by filter fabric.

   1 Wood - pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.
   2. Gabions - hexagonal triple twist mesh with PVC coated galvanized steel wire. The maximum linear dimension of the mesh opening shall not exceed 4.5 inches. The area of the mesh opening shall not exceed 10 square inches.

   Stone or riprap for gabions shall be sized according to Table 12 below. It shall consist of field stone or rough unhewn quarry stone. The stone shall be hard and angular and of a quality that will not disintegrate with exposure to water or weathering. The specific gravity of the individual stones shall be at least

2.5. Recycled concrete may be used if it has a density of at least 150 pounds per cubic foot and does not have any exposed steel or reinforcing bars.

3 Riprap - all riprap shall conform to KYTC Standards for open graded course aggregate.
4 Concrete - All concrete shall conform to KYTC or SCS specifications.

b. Underlying soil medium – The underlying soils should consist of the following:

1 Soil - USDA ML, SM, or SC.
2 Sand - ASTM C-33 fine aggregate concrete sand; KYTC fine aggregate, grading A or B.

c. Pea Gravel – Pea gravel should consist of washed ASTM M-43; KYTC No. 8 Open-graded Course Aggregate.

d Underdrain – An underdrain system below the swale bottom shall consist of the following:

1 Gravel - AASHTO #7, ASTM M-43, KYTC No. 3 Open-graded Course Aggregate.
2 PVC Pipe - AASHTO M-278, 4-inch rigid schedule 40, perforations of 3/8-inch diameter at 6-inch centers, 4 holes per row.
3 Filter fabric - shall be 4 – 6 oz nonwoven needle – punched geotextile.

Table 12. Stone or Riprap Sizes for Gabion Baskets

Basket Thickness		Stone Size (in.)
(in.)	(mm.)	
6	150	3 - 5
9	225	4 - 7
12	300	4 - 7
18	460	4 - 7
36	910	4 - 12

7 Maintenance and Inspection Guidelines

Maintenance of grassed swales includes upkeep of the vegetative cover and preservation of the swale's hydraulic properties. Individual land owners can usually carry out the suggested maintenance procedures for the swale or the portion of the swale on their property. To ensure continued long term maintenance, all affected landowners should be made aware of their maintenance responsibilities, and maintenance agreements should be included in land titles.

The following maintenance and inspection guidelines are not intended to be all-inclusive. Specific swales may require other measures not discussed here. It is the engineer's responsibility for determining if any additional items are necessary.

Vegetation

A dense and vigorous grass cover should be maintained in a grassed swale. This will be simplified if the proper grass type is selected in the design. Periodic mowing is required to keep the swale operating properly. Grass should never be cut to a height less than 3 inches. Ideally, a grass stand of 6 inches is most effective. Stabilization and reseeding of bare spots should be performed, as needed.

Check Dams

Properly constructed check dams should require very little maintenance since they are made of non- erodible materials. Periodic removal of sediment accumulated behind the check dams should be performed, as needed.

Debris and Litter Removal

The accumulation of debris (including trash, grass clippings, etc.) in the swale can alter the hydraulics of the design and lead to additional maintenance costs. Debris can also alter the flow path along the swale bottom causing low flows to concentrate and result in erosion of the swale bottom. As with any BMP, frequent inspections by the land owner will help prevent small problems from becoming larger.

Sediment Removal

The sediment that accumulates within the swale should be manually removed and the vegetation reestablished. If accumulated sediment has clogged the surface pores of the swale, reducing or eliminating the infiltration capacity, then the surface should be tilled and restabilized. Drilling or punching small holes into the surface layer can be used instead of tilling, if desired.

Figure 12. Typical Check Dam Configurations

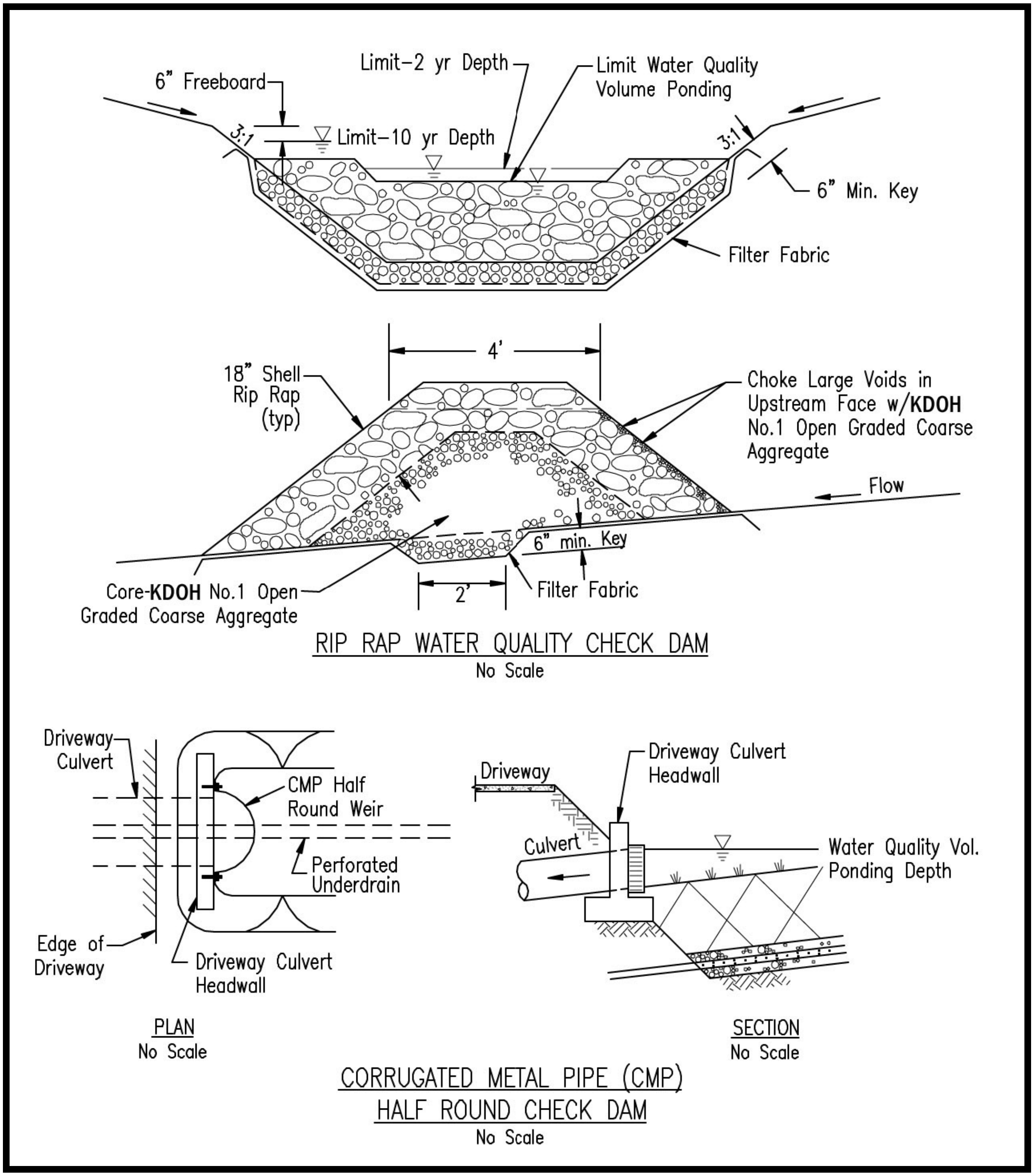
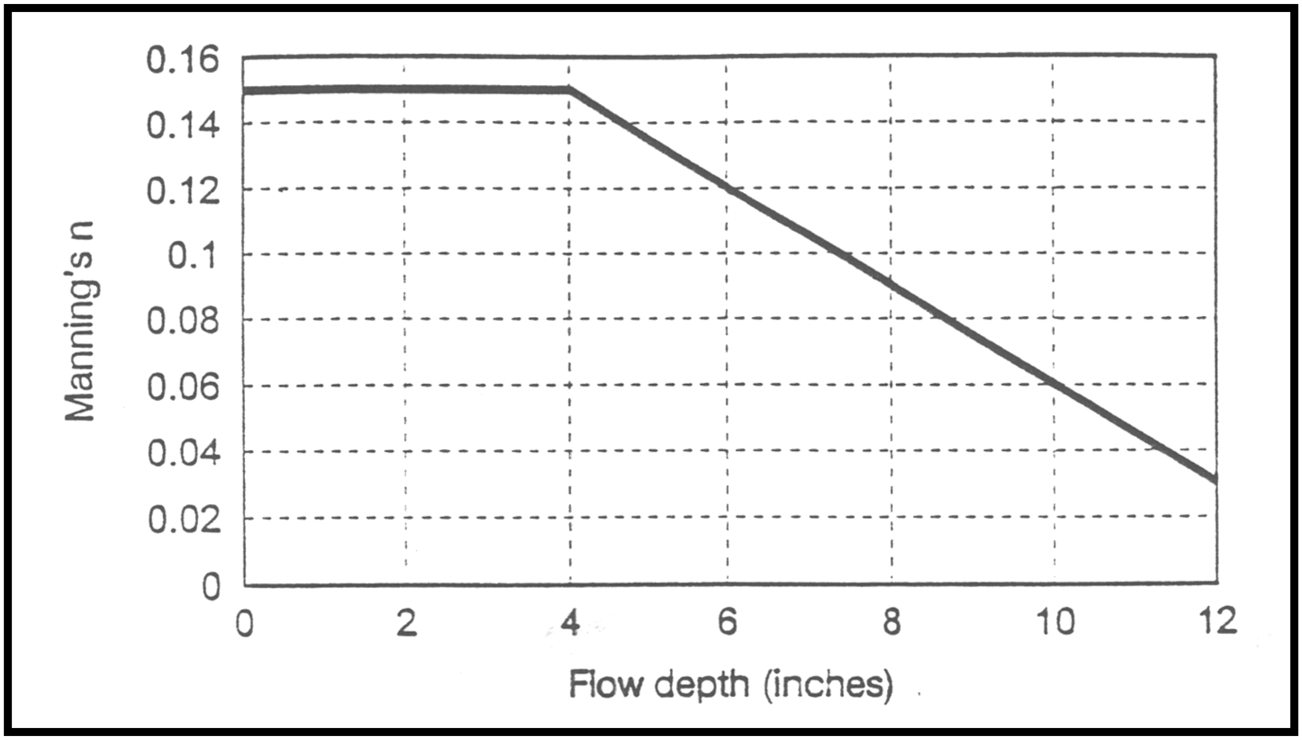


Figure 13. Manning's 'n' Values for Varying Depths of Flow



8 Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of a water quality grassed swale.

a Determine if the anticipated development conditions and drainage area are appropriate for a water quality grassed swale BMP.

b Determine if the soils (permeability, bedrock, etc.) and topographic conditions (slopes, existing utilities, and environmental restrictions) are appropriate for a grassed swale BMP.

c Determine any additional stormwater management requirements (channel erosion, flooding) for the project.

d Locate the grassed swale BMP(s) on the site.

e Determine the hydrology and calculate the 2-year and 10-year peak discharges (Part III) and the water quality volume for the contributing drainage area.

f Approximate the geometry of the grassed swale and evaluate water quality parameters: water quality depth of flow (recommended maximum of 4 inches), and storage volume behind check dams (water quality volume). Adjust swale geometry and re-evaluate as needed.

g Evaluate the grassed swale geometry for the 2-year design storm peak discharge velocity (4 feet per second), and capacity (check dam overflow), and the 10-year design storm peak discharge velocity (7 feet per second) and capacity (6 inches of freeboard). Adjust swale geometry and re-evaluate as needed.

h Establish specifications for appropriate permanent vegetation on the bottom and side slopes of the grassed swale.
i Establish specifications for sediment control.
j Establish construction sequence and construction specifications.
k. Establish maintenance and inspection requirements

I Infiltration Trench

1 Definition

An infiltration trench is a shallow, excavated trench backfilled with a coarse stone aggregate to create an underground reservoir. Stormwater runoff diverted into the trench gradually infiltrates into the surrounding soils from the bottom and sides of the trench. The trench can be either an open surface trench or an underground facility.

2 Purpose

Infiltration trenches are used primarily as water quality BMPs. Trenches are generally 2 to 10 feet deep and are backfilled with a coarse stone aggregate, allowing for temporary storage of storm runoff in the voids between the aggregate material. Stored runoff gradually infiltrates into the surrounding soil. The surface of the trench can be covered with grating and/or consist of stone, gabion, sand, or a grassed area with a surface inlet. Utilizing underground pipes within the trench can increase the temporary storage capacity of the trench and can sometimes provide enough storage for flooding and/or stream channel erosion control (see Figure 1 4 below).

3 Conditions Where Practice Applies

An infiltration trench may be used where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and where the water table is low enough to prevent pollution of groundwater.

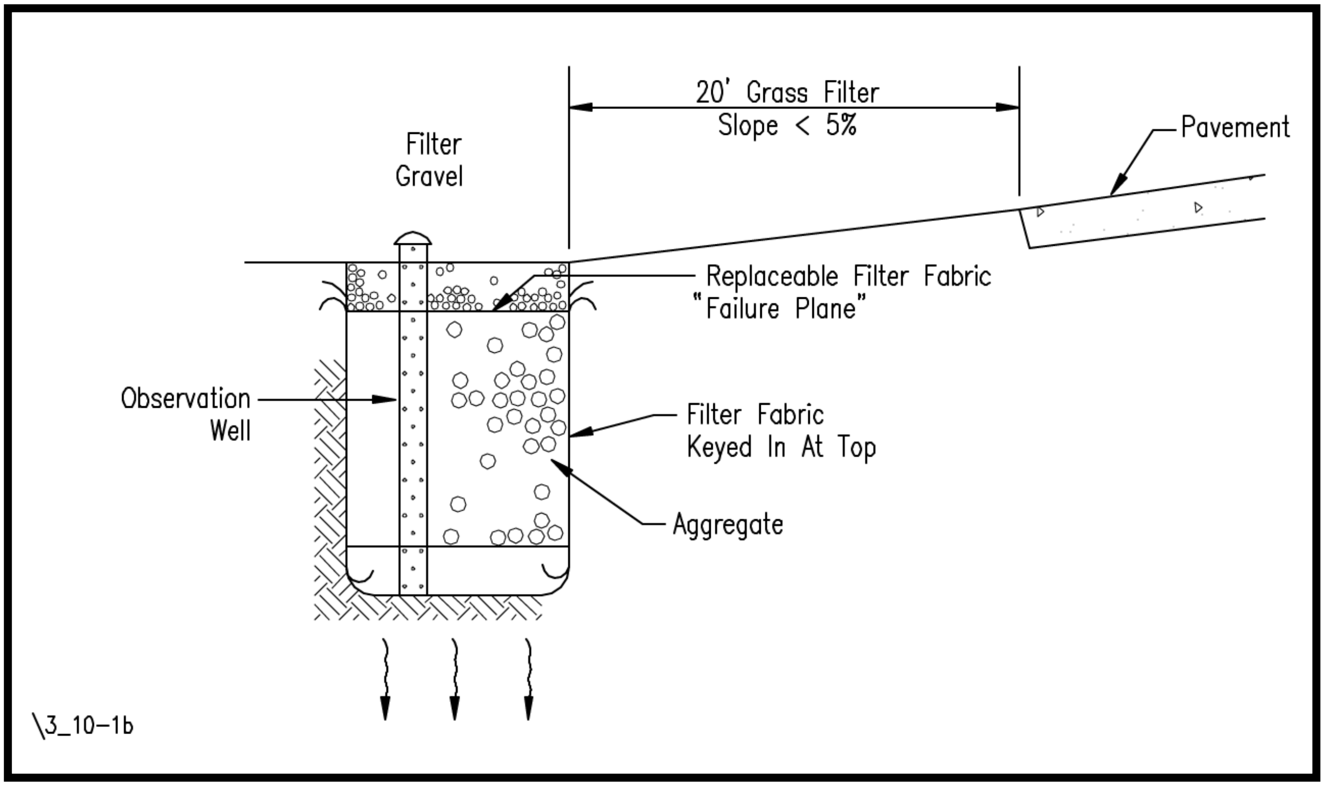
<u>Drainage Area</u>

Infiltration trenches are not practical for large drainage areas. Generally, the drainage area for infiltration trenches should be limited to 5 acres. Multiple trenches may be considered to control the runoff from a large site, but this also increases the associated maintenance responsibilities.

<u>Development Conditions</u>

Infiltration trenches are generally suited for low- to medium-density residential and commercial developments. They can be installed in multi-use areas, such as along parking lot perimeters, or in small areas that cannot readily support retention basins or similar structures. Unlike most BMPs, trenches can easily fit into the margin, perimeter, or other unused areas of developed sites, making them particularly suitable for retrofitting in existing developments or in conjunction with other BMPs. A trench may also be installed under a swale to increase the storage of the related infiltration system. In all cases, pretreatment of the stormwater runoff to remove course sediment and particulate pollutants prior to entering the infiltration trench should be provided.

Figure 14. Infiltration Trench - Section



4 Planning Considerations

Appropriate soil conditions and protection of groundwater are two important considerations when planning for an infiltration trench.

5 Design Criteria

The purpose of this section is to provide recommendations and minimum criteria for the design of infiltration trenches intended to comply with the runoff quality requirements of the Winchester Stormwater Management program.

<u>General</u>

Infiltration trenches are assumed to have rectangular cross-sections. Thus, the infiltration surface area (trench bottom) can be readily calculated from the trench geometry. The storage volume of the trench must be calculated using the void ratio of the backfill material that will be placed in it.

The same general criteria presented for the design of infiltration basins apply to trenches; the following information is provided for additional guidance.

Soils Investigation

A minimum of one soil boring log should be required for every 50 feet of trench length. A minimum of two soil boring logs should be required for each proposed trench location (Washington State DOE, 1992).

Topographic Conditions

Infiltration trenches should be located 20 feet down-slope and 100 feet up-slope from building foundations. An analysis should be completed to identify any possible adverse effects of seepage zones if there are nearby building foundations, basements, roads, parking lots or sloping sites. Developments on sloping sites often require the use of extensive cut and fill operations. The use of infiltration trenches on fill sites is not permitted.

Design Infiltration Rate

The design infiltration rate, f_d, should be set to equal one-half the infiltration rate obtained from the soil analysis. Therefore,

$$f_d = 0.5\, f$$

Maximum Storage Time and Trench Depth

All infiltration trenches should be designed to empty within 2 days following the occurrence of a storm event. Thus, a maximum allowable storage time, T_{max} , of 48 hours should be used.

The maximum depth for an infiltration trench may be defined as:

$$d_{max} = \frac{f_d T_{max}}{V_r}$$

where: d_{max} = maximum allowable depth of the facility, in ft;
f_d = design infiltration rate of the trench area soils, in ft/hr (f_d = 0.5f);
T_{max} = maximum allowable drain time = 48 hrs.;
V_r = void ratio of the stone reservoir expressed in terms of the percentage of porosity divided by 100 (0.4 typ.).

Refer to the KYTC's Road and Bridge Specifications, latest edition, for information and specifications for coarse aggregates. A void ratio of 0.40 is assumed for stone reservoirs using 1.5 to 3.5 inch stone - KYTC No. 1 Coarse-graded Aggregate.

The minimum surface area of the facility bottom may be defined as:

$$SA_{min} = \frac{Vol_{wq}}{f_d\, T_{max}}$$

where: $_{min}SA$ = minimum trench bottom surface area, in ft^2;
Vol_{wq} = water quality volume requirements, in ft^3;
f_d = design infiltration rate of the trench area soils, in ft/hr (f_d = 0.5f);
T_{max} = maximum allowable drain time = 48 hrs.

Runoff Pretreatment

Infiltration trenches should always be preceded by a pretreatment facility. Grease, oil, floatable organic materials, and settleable solids should be removed from the runoff before it enters the trench. Vegetated filters, sediment traps or forbays, water quality inlets (refer to Minimum Standard 14.10, Manufactured BMP Systems) are just a few of the available pretreatment strategies. To reduce both the frequency of turbulent flow-through and the associated scour and/or resuspension of residual material, infiltration trenches and associated pretreatment facilities should be installed off- line (MWCOG, 1992). Additional pretreatment arrangements are illustrated in Figure 3.10-3.

A grass strip or other type of vegetated buffer at least 20 feet wide should be maintained around trenches that accept surface runoff as sheet flow. The slope of the filter strip should be approximately 1% along its entire length and 0% across its width. A recent study by MWCOG (Galli, 1992) concluded that for areas receiving high suspended solid loads, a minimum filter length of 50 feet is desirable.

All trenches with surface inlets should be engineered to capture sediment from the runoff before it enters the stone reservoir. Any pretreatment facility design should be included in the design of the trench, complete with maintenance and inspection requirements.

Backfill Material

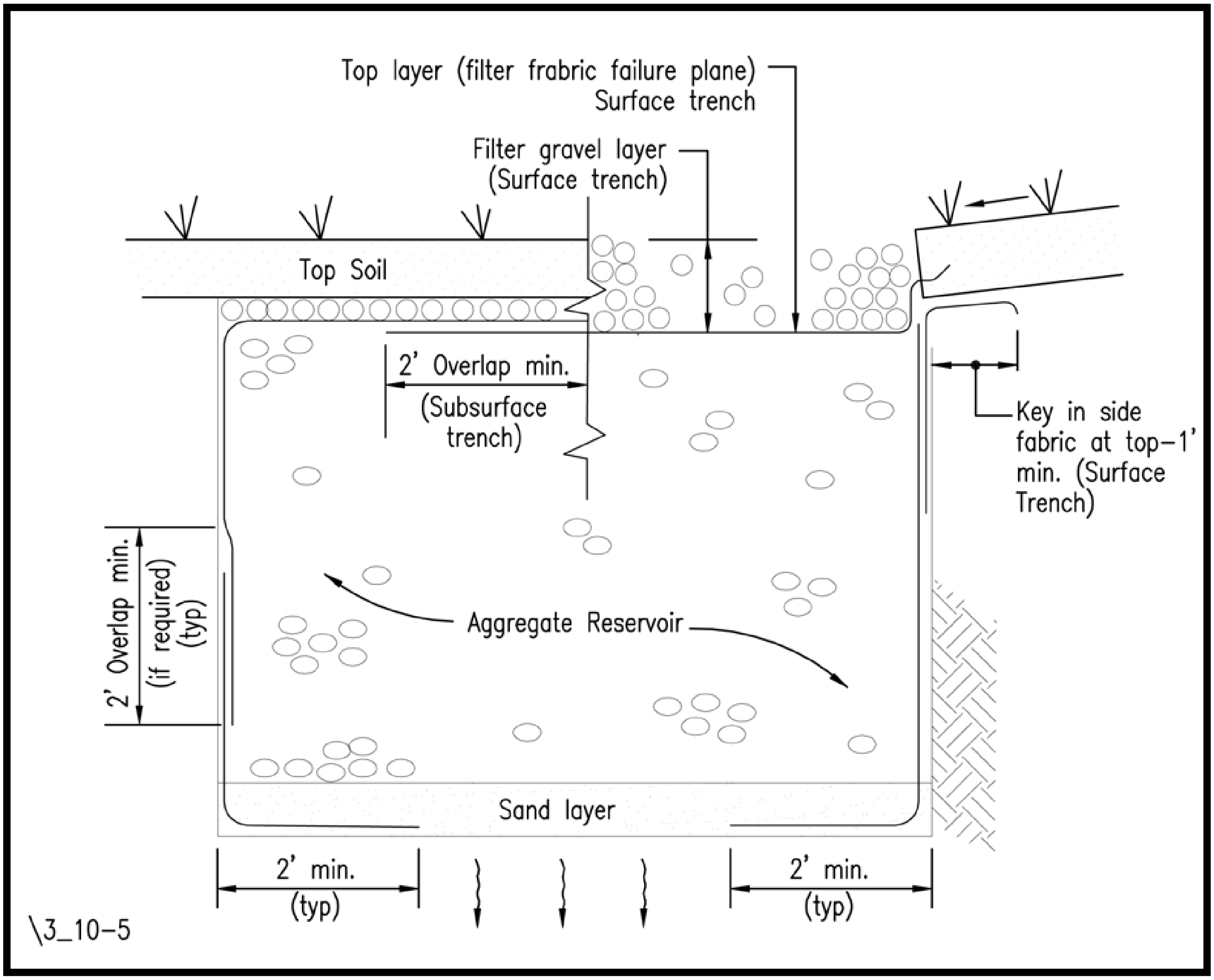
Backfill material for the infiltration trench should be clean aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches (i.e., KYTC No. 1 Open-graded Coarse Aggregate or equivalent). The aggregate should contain few aggregates smaller than the selected size. A void space for KYTC No. 1 aggregate is assumed to be 40 percent.

An 8 inch deep bottom sand layer (KYTC Fine Aggregate, Grading A or B) is required for all trenches to promote better drainage and reduce the risk of soil compaction when the trench is backfilled with stone (MWCOG, 1992).

Filter Fabric

The aggregate fill material should be surrounded with an engineering filter fabric as shown in Figure 15. For an aggregate surface trench, filter fabric should surround all of the aggregate fill material except the top one foot. A separate piece of fabric should be used for the top layer to act as a failure plane. This top piece can then be removed and replaced upon clogging. Note, however, that filter fabric should not be placed on the trench bottom.

Figure 15. Filter Fabric Placement



Overflow Channel

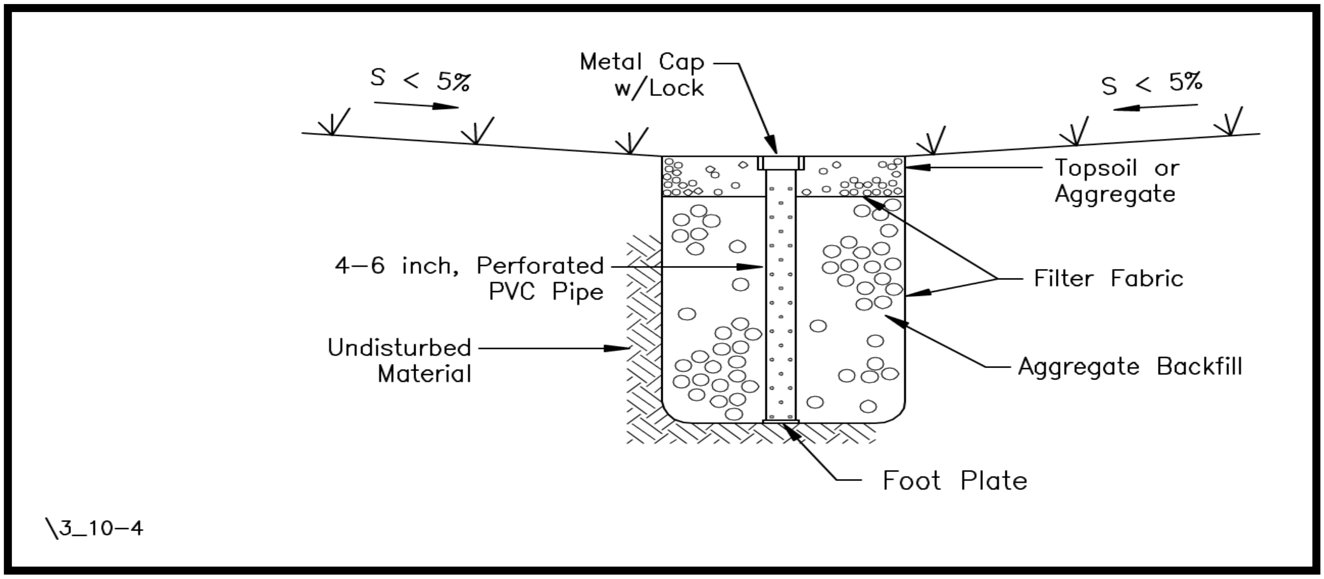
Usually, because of the small drainage areas controlled by an infiltration trench, an emergency spillway is not necessary. However, the overland flow path taken by the surface runoff, when the capacity of the trench is exceeded, should always be evaluated. A nonerosive overflow channel leading to a stabilized watercourse should be provided, as necessary, to insure that uncontrolled, erosive, concentrated flow does not develop.

Observation Well

An observation well should be installed for every 50 feet of infiltration trench length. The observation well will show how quickly the trench dewaters following a storm, as well as providing a means of determining when the filter fabric is clogged and maintenance is needed.

The observation well should consist of perforated PVC pipe, 4 to 6 inches in diameter. It should be installed in the center of the structure, flush with the ground elevation of the trench. Putting the observation well in a non-parking or traffic area to simplify inspections is best. The top of the well should be capped to discourage vandalism and tampering (See Figure 16).

Figure 16. Observation Well



6 Construction Specifications

Overall, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable. Further guidance can be found in the Soil Conservation Service's Engineering Field Manual. Specifications for the work should conform to the methods and procedures indicated for installing earthwork, concrete, reinforcing steel, pipe, water gates, metal work, woodwork and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government.

Construction of an infiltration trench should also be in conformance with the following:

Sequence of Construction
An infiltration trench should not be constructed or placed into service until all of the contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas within the drainage area may load the newly formed trench and/or pretreatment facility with a large volume of fine sediment.

The specifications for the construction of an infiltration trench should state the following: 1) the earliest point at which storm drainage may be directed to the trench, and 2) the means by which this delay in use is to be accomplished. Due to the wide variety of conditions encountered among development projects, each project should be evaluated separately to postpone trench use for as long as possible.

Trench Preparation

Trench excavation should be limited to the specific trench dimensions. Excavated materials should be placed away from the trench sides to avoid impacting the trench wall stability.

The trench should be excavated with a backhoe or similar device that allows the equipment to stand away from the trench bottom. This bottom surface should be scarified with the excavator bucket teeth on the final pass to eliminate any smearing or shearing of the soil surface. Similarly, the sand filter material should be placed on the trench bottom so that it does not compact or smear the soil surface. The sand must be deposited ahead of the loader so the equipment is always supported by a minimum of 8 inches of sand.

Large tree roots must be trimmed flush with the trench sides to prevent the fabric from puncturing or tearing during subsequent installation procedures. No voids between the filter fabric and the excavation walls should be present. If boulders or similar obstacles are removed from the excavated walls, natural soils should be placed in these voids before the filter fabric is installed. The side walls of the trench should be roughened where sheared and sealed by heavy equipment.

Vertically excavated walls may be difficult to maintain in areas where the soil moisture is high or where soft cohesive or cohesionless soils predominate. These conditions may require that the side slopes be laid back to maintain stability; trapezoidal rather than rectangular cross sections may result.

Fabric Laydown

The roll of filter fabric should be cut to the proper width before installation. The width should allow for perimeter irregularities plus a minimum 12-inch overlap at the top. When a fabric overlap is required elsewhere, the upstream section should overlap the downstream section by a minimum of 2 feet to ensure that the fabric conforms to the excavation surface during aggregate placement. Note that filter fabric should not be placed on the trench bottom.

Stone Aggregate Placement Compaction

The crushed stone aggregate should be placed in the trench in loose lifts of about 12 inches using a backhoe or front-end loader with a drop height near the bottom of the trench, and should be lightly compacted with plate compactors. Aggregate should not be dumped into the trench by a truck.

Backfill material for the infiltration trench should be clean, washed aggregate 1.5 to 3.5 inches in diameter (KYTC No. 1 Open-graded Coarse Aggregate or equivalent). The aggregate should contain few aggregates smaller than the selected size.

The 8 inch deep bottom sand layer should consist of KYTC Fine Aggregate, Grading A or B

Overlapping and Covering

Following the stone aggregate placement, the filter fabric should be folded over the stone aggregate to form a 12-inch minimum longitudinal overlap. The desired fill soil or stone aggregate should be placed over the lap at sufficient intervals to maintain the lap during subsequent backfilling.

Potential Contamination

Clean aggregate should not be mixed with natural or fill soils. All contaminated aggregate should be removed and replaced with clean aggregate.

Traffic Control

To prevent or reduce compaction of the soil, heavy equipment and traffic should not travel over the infiltration trench.

Observation Well

Observation wells should be provided as specified in the design criteria. The depth of the well at the time of installation should be clearly marked on the well cap.

7 Maintenance/Inspection Guidelines

The following maintenance and inspection guidelines are not intended to be all-inclusive. Specific facilities may require other measures not discussed here.

Inspection Schedule

The observation well and pretreatment facility should be monitored quarterly and after every large storm event. It is recommended that a log book be maintained showing the depth of water in the well at each observation in order to determine the rate at which the facility dewaters after runoff producing storm events. Once the performance characteristics of the structure have been verified, the monitoring schedule can be reduced to an annual basis, unless the performance data suggest that a more frequent schedule is required.

Sediment Control

Sediment buildup in the top foot of stone aggregate or the surface inlet should be monitored on the same schedule as the observation well. A monitoring well in the top foot of stone aggregate should be provided when the trench has a stone surface. Sediment deposited should not be allowed to build up to the point where it will reduce the infiltration rate into the trench.

It is recognized that infiltration facilities are subject to clogging. Once a trench facility has clogged, very little can be done to correct it, short of excavating the facility. Maintenance efforts, therefore, should focus on the measures used for pretreatment of runoff, in addition to the facility itself.

Vegetation Maintenance

Any vegetated buffers associated with an infiltration trench should be inspected regularly and maintained as needed. Regular maintenance of the buffer is necessary to promote dense turf with extensive root growth, which subsequently enhances runoff filtering, prevents erosion and sedimentation, and deters invasive weed growth. Bare spots should be immediately stabilized and revegetated. Fertilizers should be applied only as necessary and in limited amounts to avoid contributing to pollution problems which the infiltration basin helps to mitigate.

8 Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of an infiltration trench.

a Determine if the anticipated development conditions and drainage area are appropriate for an infiltration trench application.
b Determine if the soils (permeability, bedrock, water table, etc.) and topographic conditions (slopes, building foundations, etc.) are appropriate for an infiltration trench application.
c Locate the infiltration trench on the site within topographic constraints.
d Determine the drainage area for each infiltration trench and calculate the required water quality volume.
e Evaluate the hydrology of the contributing drainage area to determine peak rates of runoff.
f Design the infiltration trench:

- design infiltration rate, $f_d = 0.5\ f$
- max. storage time $T_{max} = 48$ hours
- max. storage depth, d_{max}
- stone backfill of clean aggregate (1.5" to 3.5") KYTC No. 1 Open-Graded Course
- Aggregate
- sand layer on trench bottom (8 inches)
- runoff pretreatment - concentrated input, sheet flow input
- vegetated buffer around trench to filter surface runoff
- filter fabric on trench sides and top (not on trench bottom) keyed into trench
- overflow channel or large storm bypass
- observation well

g Provide material specifications.
h Provide sequence of construction.
i Provide maintenance and inspection requirements.

J Bioretention Basin / Rain Gardens

1 Definition

The following information is drawn from the Prince George's County, Maryland Department of Environmental Protection Design Manual for Use of Bioretention in Stormwater Management (P.G. County, 1993) unless otherwise noted. This technology is also referred to as "Rain Gardens."

Figure 17 illustrates the Maryland bioretention (Rain Garden) concept as adapted for use in Richmond. There are seven major components to the bioretention area (Rain Garden): 1) the grass buffer strip; 2) the ponding area; 3) the surface mulch and planting soil; 4) the sand bed (optional); 5) the organic layer; 6) the plant material, and 7) the infiltration chambers. Each component is critical to sustaining a properly functioning BMP.

2 Purpose

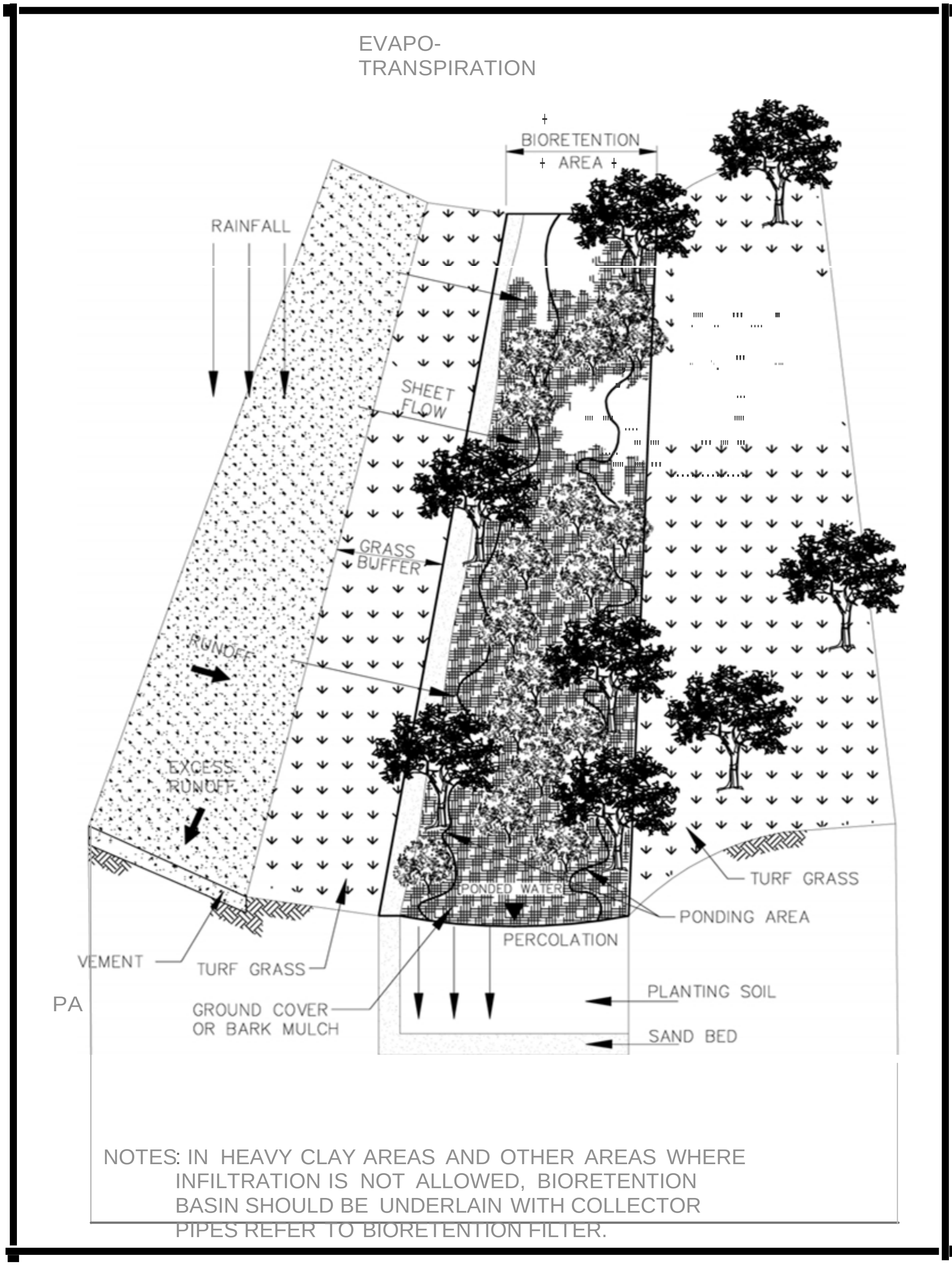
Bioretention basins are used primarily for water quality control. However, since they capture and infilter part of the stormwater from the drainage shed, they may provide partial or complete control of streambank erosion and partial protection from flooding (depending on the volume of water being captured and infiltered).

Bioretention facilities (Rain Gardens) are planting areas installed in shallow basins in which the stormwater runoff is treated by filtering through the bed components, biological and biochemical reactions within the soil matrix and around the root zones of the plants, and infiltration into the underlying soil strata. Properly constructed bioretention areas replicate the ecosystem of an upland forest floor through the use of specific shrubs, trees, ground covers, mulches and deep, rich soils. Since almost all bioretention basins are intended to be visual landscape amenities as well as stormwater BMPs, aesthetic considerations may be equally as important in their use as proper engineering. Bioretention design requires participation by a person with appropriate design skills and a working knowledge of indigenous horticultural practices, preferably a Landscape Architect.

<u>Water Quality Enhancement</u>

Bioretention basins enhance the quality of stormwater runoff through the processes of adsorption, filtration, volitization, ion exchange, microbial and decomposition prior to exfiltration into the surrounding soil mass. Microbial soil processes, evapotranspiration, and nutrient uptake in plants also come into play (Bitter and Bowers, 1995).

Figure 17 Bioretention B asin



The grass buffer strip filters particles from the runoff and reduces its velocity. The sand bed further slows the velocity of the runoff, spreads the runoff over the basin, filters part of the water, provides for positive drainage to prevent anaerobic conditions in the planting soil and enhances exfiltration from the basin. The ponding area functions as storage of runoff awaiting treatment and as a presettling basin for particulates that have not been filtered out by the grass buffer. The organic or mulch layer acts as a filter for pollutants in the runoff, protects the soil from eroding, and provides an environment for microorganisms to degrade petroleum-based solvents and other pollutants. The planting soil layer nurtures the plants with stored water and nutrients. Clay particles in the soil adsorb heavy metals, nutrients, hydrocarbons, and other pollutants. The plant species are selected based on their documented ability to cycle and assimilate nutrients, pollutants, and metals through the interactions among plants, soil, and the organic layer (ibid). By providing a variety of plants, monoculture susceptibilities to insect and disease infestation are avoided, and evapotranspiration is enhanced. The vented infiltration chambers provide unobstructed exfiltration through the open-bottomed cavities, decrease the ponding time above the basin, and aerate the filter media between storms through the open chamber cavities and vents to grade, preventing the development of anaerobic conditions. By providing a valve equipped drawdown drain to daylight, the basin can be converted into a soil media filter should exfiltration surface failures occur.

Perforated underdrain systems are recommended for facilities placed in residential areas and in all areas where the in-situ soils are questionable. Refer to 9A - Bioretention Filter.

The minimum width for a bioretention area is usually 10 feet, although widths as narrow as 4 feet may be used if the runoff arrives as dispersed sheet flow along the length of the facility from a properly sized vegetated strip. The minimum length should be 15 feet (for lengths greater than 20 feet, the length should be at least twice the width to allow dispersed sheet flow). As an infiltration BMP, the maximum ponding depth is restricted to six inches to restrict maximum ponding time to preclude development of anaerobic conditions in the planting soil (which will kill the plants) and to prevent the breeding of mosquitoes and other undesirable insects in the ponded water. The planting soil must have sufficient depth to provide appropriate moisture capacity, create space for the root systems, and provide resistance from windthrow (Minimum depth equal to the diameter of the largest plant root ball plus 4 inches).

Table 13 contains the target removal efficiencies once a mature plant community is created in the bioretention areas based on the volume of runoff to be captured and infiltered.

<u>Flood Control and Channel Erosion</u>

The amount of flood and channel erosion control provided by bioretention basins depends on the local rainfall frequency spectrum, the amount of pre-development (or pre-redevelopment) impervious cover, the amount of post-development impervious cover, and the volume of runoff captured and infiltered by the basin(s). The effect of the BMPs on peak flow rates from the drainage shed must be examined. As with other infiltration practices, bioretention basins tend to reverse the consequences of urban development by reducing peak flow rates and providing groundwater discharge.

Table 13 Pollutant Removal Efficiencies for Bioretention Basins

BMP Description	Target Phosphorus Removal Efficiency
Bioretention basin with capture and treatment volume equal to 0.5 inches of runoff from the impervious area.	50%
Bioretention basin with capture and treatment volume equal to 1.0 inches of runoff from the impervious area.	65%

3 Conditions Where Practice Applies

Bioretention basins are suitable for use on any project where the subsoil is sufficiently permeable to provide a reasonable rate of infiltration and where the water table is sufficiently lower than the design depth of the facility to prevent pollution of the groundwater. Bioretention basins are generally suited for almost all types of development, from single-family residential to fairly high density commercial projects. They are attractive for higher density projects because of their relatively high removal efficiency. Figures 18 through 21 illustrate several applications. Bioretention basins may also be installed in off-line pockets along the drainage swales adjacent to highways or other linear projects, as illustrated in Figure 22. For large applications, several bioretention basins are preferable to a single, massive basin.

Figure 18
Bioretention Basin at Edge of Parking Lot With Curb

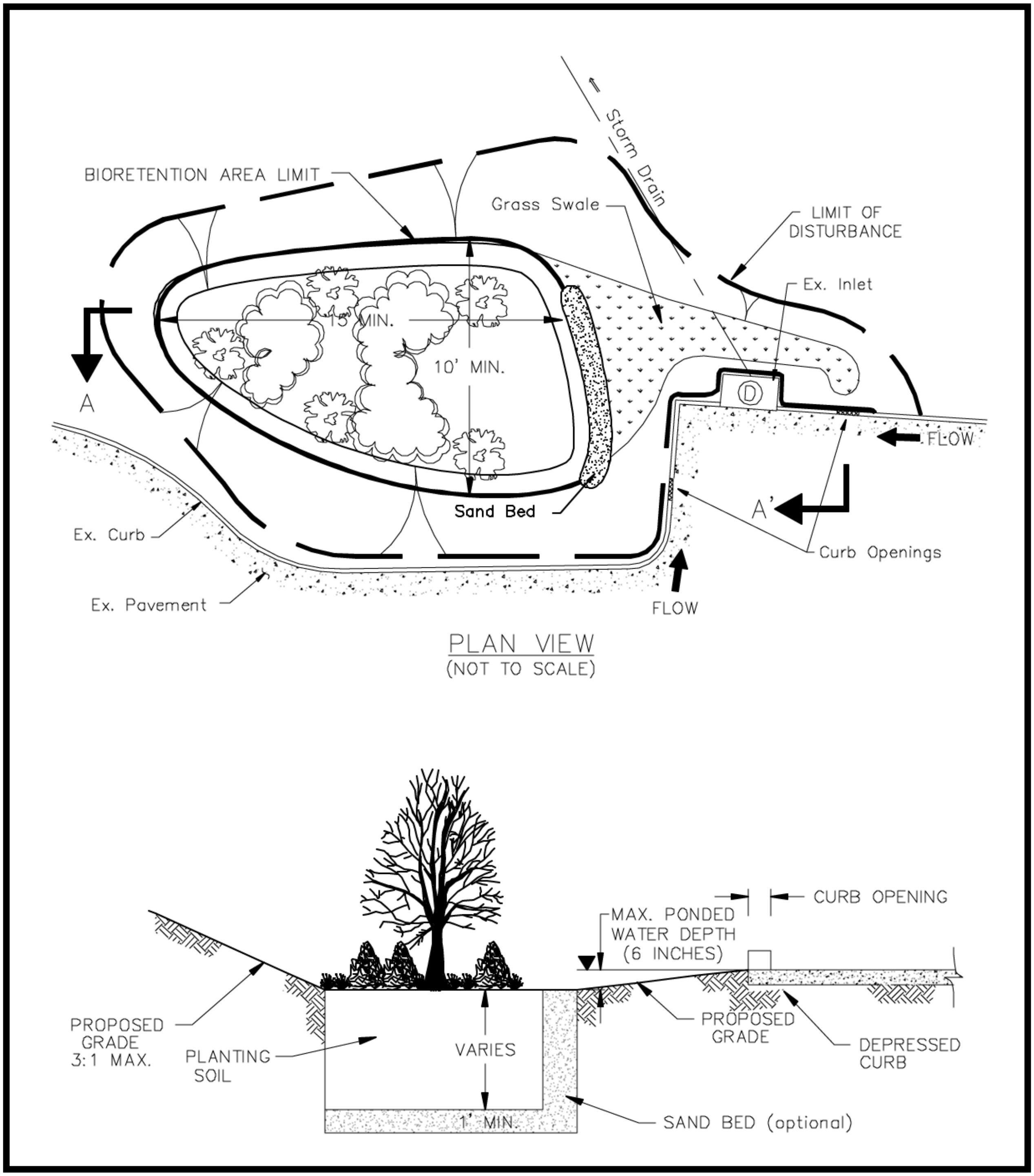


Figure 19
Bioretention Basin in a Planting Island in a Parking Lot

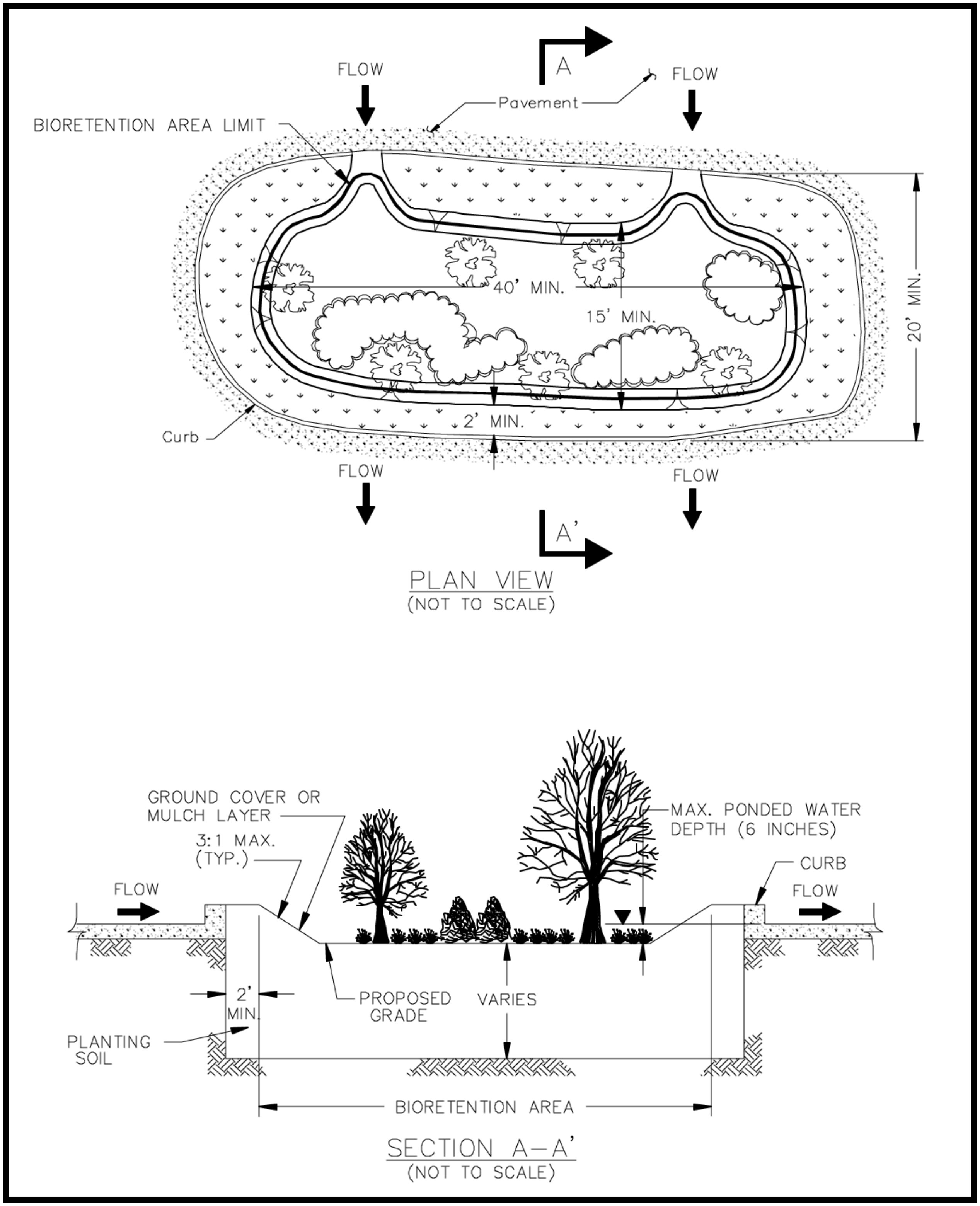


Figure 20

Bioretention Basin Adjacent to a Drainage Swale

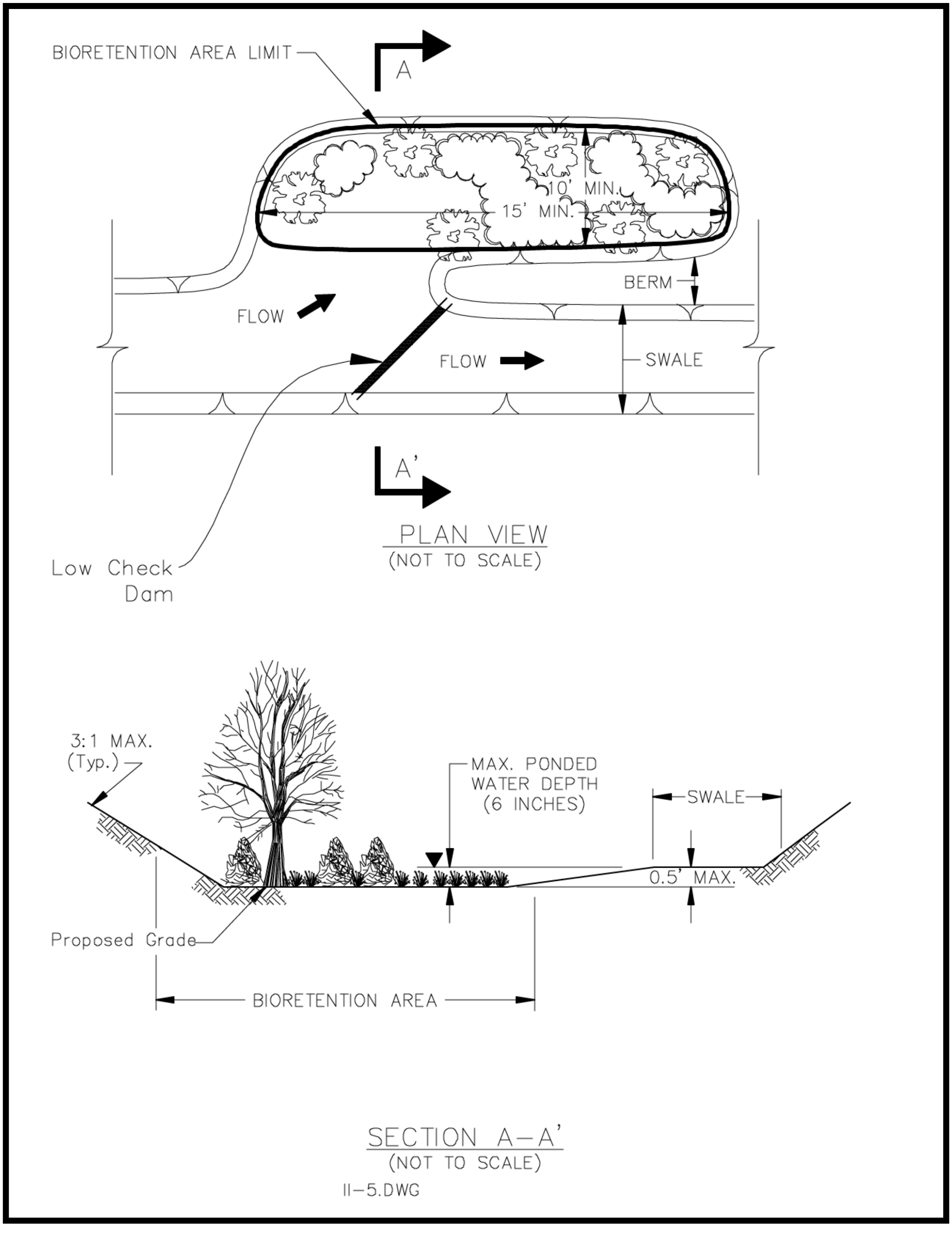
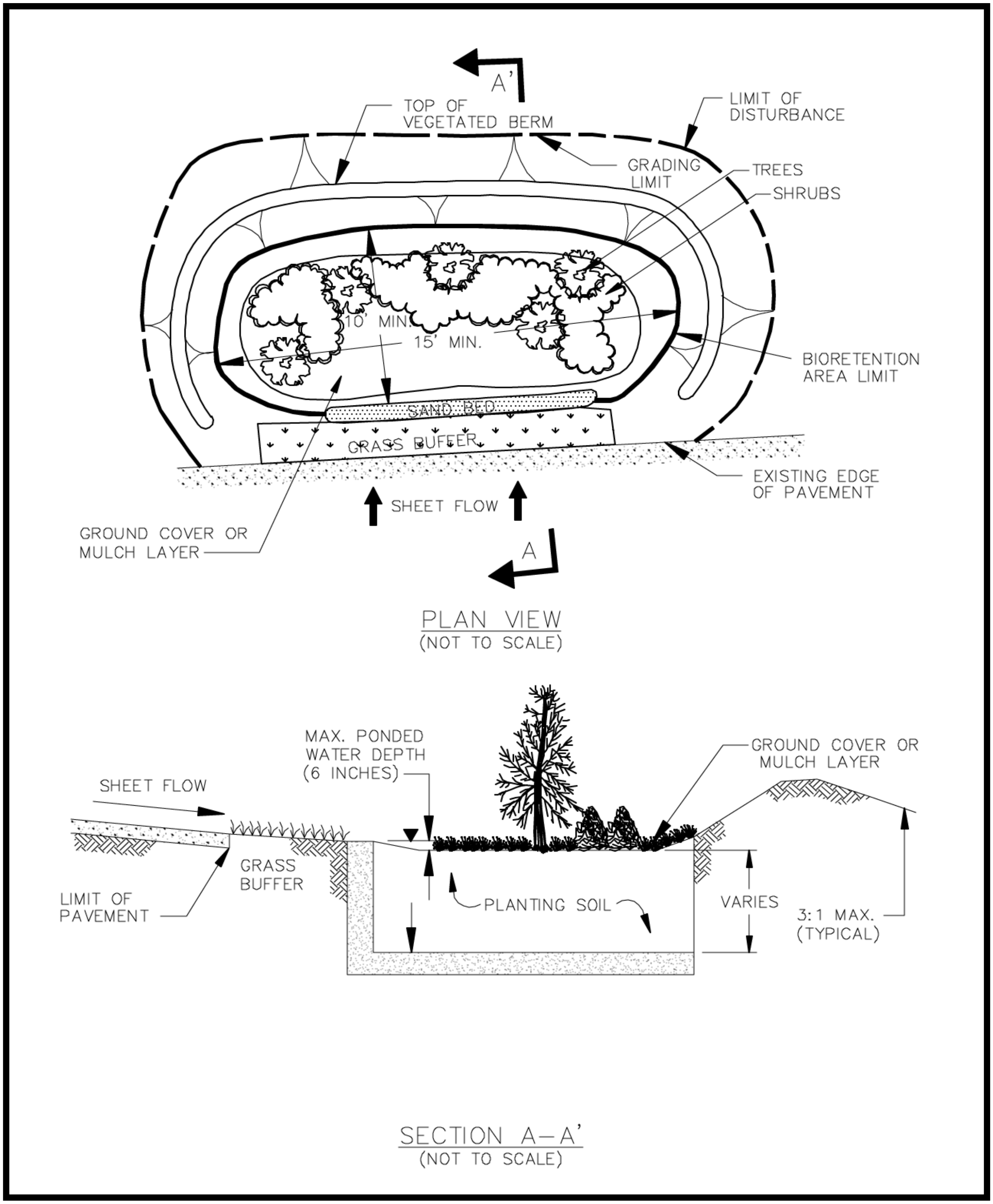


Figure 21
Bioretention Basin at Edge of Parking Lot Without Curbs



4 Planning Considerations

Site Conditions

In addition to site conditions affecting infiltration practices in general, the following apply specifically to bioretention basins. The application of individual bioretention basins will usually be limited to drainage areas from 0.25 to 1 acre. Generally, commercial or residential drainage areas exceeding 1 acre in size will discharge sheet flows greater than 5 cfs.

a Location Guidelines

Preferable locations for bioretention basins include 1) areas upland from inlets or outfalls that receive sheet flow from graded areas, and 2) areas of the site that will be excavated or cut. When available, areas of loamy sand soils should be used since these types of soils comprise the planting soils for bioretention basins. Locating the BMP in such natural locations would eliminate the cost of importing planting soils (see soil and organic specification under Design Considerations). BMP location should be integral with preliminary planning studies.

The following areas would be undesirable for bioretention basins: 1) areas that have mature trees which would have to be removed for construction of the bioretention basin, 2) areas that have existing slopes of 20% or greater, and 3) areas above or in close proximity to an unstable soil strata such as marine clay.

b Sizing Guidelines

For planning purposes, assume that the floor area of the bioretention basin will be a minimum of 2.5% of the impervious area draining to the basin if the first 0.6 inches of runoff is to be treated and a minimum of 4.0% of the impervious area on the drainage shed if the first 1.0 inches of runoff is to be treated. Derivation of these values is discussed below under Design Considerations. Note that small projects such as single family residences will likely default to the minimum 150 square foot area (10' X 15').

c Aesthetic Considerations

Aesthetic considerations of the bioretention basin must be considered early in the site planning process. While topography and hydraulic considerations may dictate the general placement of such facilities, overall aesthetics of the site and the bioretention basins must be integrated into the site plan and stormwater concept plan from their inception. Both the stormwater engineer and the Landscape Architect must participate during the layout of facilities and infrastructure to be placed on the site. Bioretention design must be an integral part of the site planning process

Sediment Control

Like other infiltration practices, provisions for long-term sediment control must be incorporated into the design, as well as precautions during on-site construction activities. Careful consideration must be given in advance of construction to the effects of work sequencing, techniques, and equipment employed on the future maintenance of the practice. Serious maintenance problems can be averted, or in large part, mitigated, by the adoption of relatively simple measures during construction.

a Construction Runoff

Bioretention basin BMPs should be constructed AFTER the site work is complete and stabilization measures have been implemented. If this is not possible, strict implementation of E&S protective measures must be installed and maintained in order to protect the bioretention facility from premature clogging and failure.

Like other infiltration BMPs, bioretention basins constructed prior to full site stabilization will become choked with sediment from upland construction operations, rendering them inoperable from the outset. Simply providing inlet protection or some other filtering mechanism during construction will not adequately control the sediment. One large storm may completely clog the bioretention basin, requiring complete reconstruction.

Experience with infiltration practices has also demonstrated that the bioretention basin site should NOT be used as the site of sedimentation basins during construction. Such use tends to clog the underlying strata and diminish their capacity to accept infiltration below that indicated in preconstruction soil studies.

Bioretention basins are landscape amenities and should be installed with other landscaping as the last stage of project construction.

A detailed sediment control design to protect the bioretention basin during its construction should be included with the facility design.

Experience with bioretention basins in Maryland has demonstrated that they must be protected until the drainage areas contributing to the practice have been adequately stabilized (P.G. Co., 1993).

The definition of the term “adequately stabilized” is critical to the success of the facility. At the conclusion of construction activity, the temporary erosion and sediment control measures are usually removed at the direction of the erosion and sediment control inspector when, at a minimum, stabilization measures such as seed and mulch are in place. This does not mean, however, that stabilization has actually occurred. Bioretention basins must be protected until stabilization of the upland site is functioning to control the sediment load from denuded areas. Provisions to bypass the stormwater away from the bioretention basin during the stabilization period should be implemented.

b Urban Runoff

A fully stabilized site will generate particulate pollutant load resulting from natural erosion, lawn and garden debris such as leaves, grass clippings, mulch, roadway sand, etc. Pretreatment of runoff to remove sediments prior to entering the bioretention basin is usually provided by a grass filter strip or grass channel. When runoff from sheet flow from such areas as parking lots, residential yards, etc., is involved, a grass filter strip, often enhanced with a pea gravel diaphragm, is usually employed. Table 14 provides sizing guidelines as a function of inflow approach length, land use, and slope. Minimum filter strip length (flow path) should be 10 feet.

TABLE 14
Pretreatment Filter Strip Sizing Guidance
(Source: Claytor and Schueler, 1996)

Parameter	Impervious Parking Lots				Residential Lawns				Notes
Maximum Inflow Approach Length (feet)	35		75		75		150		
Filter Strip Slope	≤ 2%	≥2%	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	Maximum = 6%
Filter Strip Minimum Length	10'	15'	20'	25'	10'	12'	15'	18'	

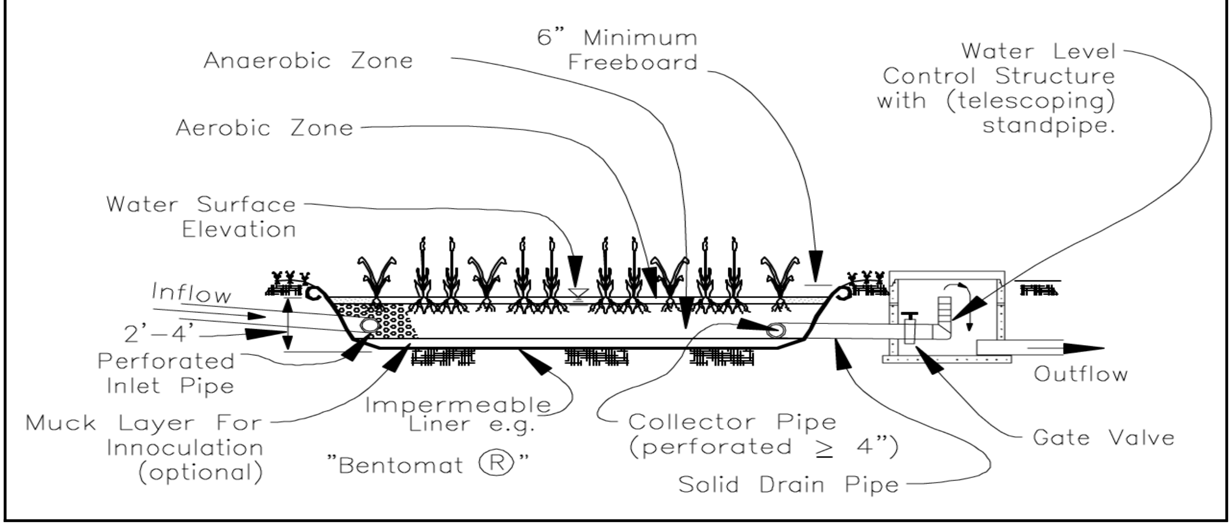
For applications where concentrated runoff enters the bioretention basin by surface flow, such as through a slotted curb opening, a grassed channel, often equipped with a pea gravel diaphragm to slow the velocity and spread out the flow entering the basin, is the usual pretreatment method. The length of the grassed channel depends on the drainage area, land use, and channel slope. Table 15 provides recommendations on sizing for grass channels leading into a bioretention basin for a one acre drainage area. The minimum grassed channel length should be 20 feet.

“Grassed filter strips, grassed channels, and side-slopes of the basin should be sodded with mature sod prior to placement of the bioretention basin into operation. Simply seeding these areas will likely result in conveyance of sediments into the basin and premature failure. Wrapping of the planting soil mixture up the side slopes beneath the sod is also recommended.”

TABLE 15
Pretreatment Grass Channel Sizing Guidance for a 1.0-Acre Drainage Area
(Source: Claytor and Schueler, 1996)

Parameter	≤ 33% Imperviou		Betwee n 34% and		≥ 67% Imperviou		Notes
Slope	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	Maximum slope = 4%
Grassed channel minimum length (feet)	25	40	30	45	35	50	Assumes a 2' wide bottom width

FIGURE 22
Upflow Inlet for Bioretention Basin
(Source: City of Alexandria)



When concentrated piped flow from impervious areas such as parking lots is routed to a bioretention basin, an energy absorbing and sedimentation structure in which the flow rises into the basin like a tide is usually advisable. Since sediments must usually be removed from such structures on a regular basis, they must be placed in locations where the extension booms on vacuum trucks may easily reach them. Figure 8-6 illustrates an upflow inlet structure for a bioretention basin. Maintenance requirements for pretreatment measures are discussed Maintenance/Inspection Guidelines.

5 General Design Criteria

The purpose of this section is to provide minimum criteria for the design of bioretention basin BMPs intended to comply with the Richmond Stormwater program's runoff quality requirements. Bioretention basins which capture and infilter the first 1 inch of runoff from impervious surfaces may also provide streambank erosion protection.

General

The design of bioretention basins should be in accordance with the Richmond Stormwater Manual Specifications as applicable as well as the additional criteria set forth below. The designer is not only responsible for selecting the appropriate components for the particular design but also for ensuring long-term operation.

Soils Investigation

As with infiltration basins (MS14.01), a minimum of one soil boring log should be required for each 5,000 square feet of bioretention basin area (plan view area) and in no case less than three soil boring logs per basin.

Topographic Conditions

Like other infiltration facilities, bioretention basins should be a minimum of 50 feet from any slope greater than 15 percent. A geotechnical report should address the impact of the basin upon the steep slope (especially in marine clay areas). Also, bioretention basins should be a minimum of 100 feet up-slope and 20 feet downslope from any buildings.

Basin Sizing Methodology

Bioretention basins are designed to exfilter the treatment quantity into the underlying soil strata, or into an underlying perforated underdrain system connected to a storm drain system or other outfall when the underlying soils, proximity to building foundation, or other such restrictions preclude the use of infiltration. When such an underdrain system is used, the facility is referred to as a Bioretention Filter - Minimum Standard.

Recent research at the University of Maryland has supported a reduction in overall depth of the planting soil to 2.5 feet. Generally, the soil depth can be designed to a minimum depth equal to the diameter of the largest plant root ball plus 4 inches. The recommended soil composition was revised to reduce the clay and increase the sand content (Refer to Soil Texture and Structure later in this standard). This revised soil composition also eliminated the 12" sand layer at the bottom of the facility. The researchers concluded that significant pollutant reductions are achieved in the mulch layer and the first 2 to 2.5 feet of soil.

The elevation of the overflow structure should be 0.5 feet above the mulch layer of the bioretention bed. When an underdrain system is used the overflow can be as much as 1.0 feet above the mulch layer.

The size of the bioretention facility is dictated by the amount of impervious surface in the contributing drainage area. For facilities capturing the first 0.5 inches of runoff from the impervious areas in the drainage shed, the surface area of the bioretention bed should be a minimum of 3% of the impervious area, or 1,300 square feet per impervious acre.

The minimum width and length is recommended at 10 feet and 15 feet respectively. (Widths as narrow as 4 feet may be used if the runoff arrives as dispersed sheet flow along the length of the facility from a properly sized vegetated strip).

The elevation of the overflow structure should be 0.5 feet above the mulch elevation of the bioretention bed.

Note that small projects such as single family residences may default to the minimum (10' x 15') 150 square foot area.

Runoff Pretreatment

Like other infiltration basins, bioretention basins must always be preceded by a pretreatment facility to remove grease, oil, floatable organic material, and settleable solids (see Urban Runoff section of Sediment Control under Planning Considerations above). Where space constraints allow, runoff should be filtered by a grass buffer strip and sand bed. The buffer strip and sand bed will reduce the amount of fine material entering the bioretention area and minimize the potential for clogging of the planting soil. The sand bed also increases the infiltration capacity and provides aeration for the plant roots in the bioretention area. For basins for which high sediment loadings are expected (treating largely pervious areas, etc.), the design can be modified to include a sediment forebay. Any pretreatment facility should be included in the design of the basin and should include maintenance and inspection requirements.

Drainage Considerations

The grading design must shape the site so that all runoff from impervious areas is routed through the bioretention basins. The basins must be sited so as to accept the design runoff quantity before bypassing any excess flow to the storm drainage system. Bioretention basin locations must therefore be integrated into the basic site design from its inception. Most of the Planning Considerations delineated above must come into play at this early stage in the design process. The overall site and impervious surfaces must be contoured to direct the runoff to the basins. Bioretention basins cannot usually be successfully integrated into a site design that does not take stormwater management into account from its inception. Elevations must be carefully worked out to assure that the desired amount runoff will flow into the basins and pool at no more that the maximum design depth. This requires a much higher degree of vertical control during construction that is normal with most landscaping work.

Preferably, bioretention basins should be placed “off-line,” i.e. the design should provide for runoff to be diverted into the basin until it fills with the treatment volume and then bypass the remaining flow around the BMP to the storm drainage system. The drainage system shall be designed to handle the 10-year, 24 hour storm). To prevent flood damage, however, the bioretention basin design must take into account how the runoff will be processed when larger events occur. This may require, at a minimum, that a vegetated emergency spillway be provided, and that a path for overland flow to an acceptable channel be incorporated into the design. The designer should provide for relief from the 25-year storm event.

Figure 8-2 illustrates an “off-line” application at the edge of a parking lot with curb and gutter. The inlet deflectors divert runoff into the bioretention basin until the basin fills and backs up. Subsequent runoff then bypasses to the adjacent, down gradient storm inlet. Figure 8-3 illustrates an “off-line” application in a planting island in a parking lot, while Figure 8-4 illustrates an “off-line application adjacent to a drainage swale (such highway drainage). Again, runoff flows into the bioretention basin until it fills, then bypasses down the swale. Placement of a flow diversion check dam in the swale will facilitate filling the basin. In some situations, an “off- line” configuration may not be practical or economical. Figure 18 and 21 illustrate applications where sheet flow enters the bioretention basin.

Figure 23 illustrates a grading plan for a bioretention basin. The grading plan was created for a double-cell bioretention area. There is a seven-foot buffer between cells which allow for the planting of upland trees. As indicated in the grading plan, sheet and gutter flow is diverted into the bioretention areas through openings in the curb. The elevation of the invert of the bioretention area is set by the curb opening elevation. The curb opening elevation is 0.5 ft. higher than the invert of the bioretention area, so water is allowed to pond to a maximum depth of one-half foot before runoff bypasses the bioretention area and flows into the storm drain system.

Precise grading of the basin is critical to capturing the water quality volume and operation of the facility. The plan should have a contour interval of no more than one-foot, and spot elevations should be shown throughout the basin. The perimeter contour elevation should contain the design storm without over topping anywhere except at the outflow structure.

<u>Planting Plan</u>

Selection of plantings must include coordination with overall site planning and aesthetic considerations for designing the bioretention plant community. Tables listing suitable species of trees, shrubs, and ground cover are provided at the end of this section. This listing is not intended to be all-inclusive due to the continual introduction of new horticultural varieties ans species in the nursery industry.

a Planting Concept

The use of plantings in bioretention areas is modeled from the properties of a terrestrial forest community ecosystem. The terrestrial forest community ecosystem is an upland community dominated by trees, typically with a mature canopy, having a distinct sub-canopy of understory trees, a shrub layer, and herbaceous layer. In addition, the terrestrial forest ecosystem typically has a well-developed soil horizon with an organic layer and a mesic moisture regime. A terrestrial forest community model for stormwater management was selected based upon a forest's documented ability to cycle and assimilate nutrients, pollutants, and metals through the interactions among plants, soil, and the organic layer. These three elements are the major elements of the bioretention concept.

Key elements of the terrestrial forest ecosystem that have been incorporated into bioretention design include species diversity, density, and morphology, and use of native plant species. Species diversity protects the system against collapse from insect and disease infestations and other urban stresses such as temperature and exposure. Typically, indigenous plant species demonstrate a greater ability of adapting and tolerating physical, climatic, and biological stresses.

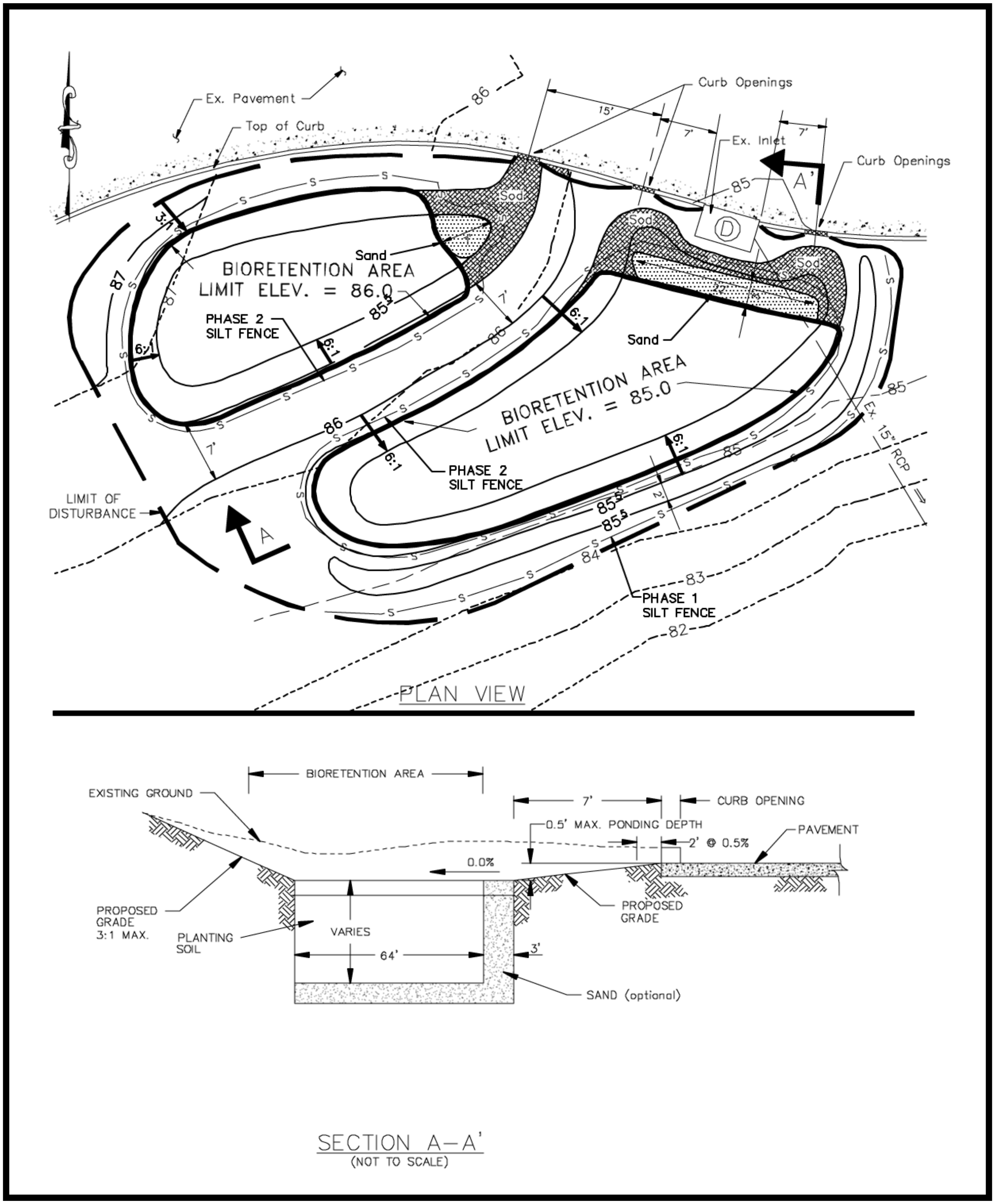
b Plant Species Selection

Plant species appropriate for use in bioretention areas are presented in Tables 8-5A through 8-5C, provided at the end of this section. These species have been selected based on the ability to tolerate urban stresses such as pollutants, variable soil moisture and ponding fluctuations. Important design considerations such as form, character, massing, texture, culture, growth habits/rates, maintenance requirements, hardiness, size, and type of root system are also included. A key factor in designating a species as suitable is its ability to tolerate the soil moisture regime and ponding fluctuations associated with bioretention. The plant indicator status (Reed, 1988) of listed species are predominantly facultative (i.e., they are adapted to stresses associated with both wet and dry conditions); however, facultative upland and wetland species have also been included. This is important because plants in bioretention areas will be exposed to varying levels of soil moisture and ponding throughout the year, ranging from high levels in the spring to potential drought conditions in the summer.

Recent research suggests an increase in the importance of the mulch layer and groundcover plant species in pollutant removal. The plant list in this standard will be expanded to include perennial flowering plants. A robust groundcover species with a thick mulch layer is recommended.

FIGURE 23

Grading Plan for Bioretention Basin



Designers considering species other than ones listed in Tables 8-5 should consult the following reference material on plant habitat requirements, and consider site conditions to ensure that alternative plant material will survive.

American Association of Nurserymen, Latest Edition. American Standard for Nursery Stock ASNI Z60, Washington, D.C.

Dirr, Michael A., 1975. Manual of Woody Landscape Plants, Stripes Publishing Company, Champagne, Illinois.

Hightshoe, G.L., 1988. Native Trees, Shrubs, and Vines for Urban and Rural America. Van Nostrand Reinhold, New York, New York.

Reed, P.B.Jr., 1988. National List of Species That Occur in Wetlands: Northeast. United
States Fish and Wildlife Service, St. Petersburg Florida.

Reasons for exclusion of certain plants from bioretention areas include inability to meet the criteria outlined in Tables 8-5 (pollutant and metals tolerance, soil moisture and structure, ponding fluctuations, morphology, etc.).

c Site and Ecological Considerations

Each site is unique and may contain factors that should be considered before selecting plant species. An example Plant Material Checklist is provided in Appendix 3E. The checklist has been developed to assist the designer in identifying critical factors about a site that may affect both the plant material layout and the species selection.

Selection of plant species should also be based on site conditions and ecological factors. Site considerations include microclimate (light, temperature, wind), the importance of aesthetics, overall site development design and the extent of maintenance requirements, and proposed or existing buildings. Of particular concern is the increase in reflection of solar radiation from buildings upon bioretention areas. Aesthetics are critical in projects of high visibility. Species that require regular maintenance (shed fruit or are prone to storm damage) should be restricted to areas of limited visibility and pedestrian and vehicular traffic.

Interactions with adjacent plant communities are also critical. Nearby existing vegetated areas dominated by non-native invasive species pose a threat to adjacent bioretention areas. Proposed bioretention area species should be evaluated for compatibility with adjacent plant communities. Invasive species typically develop into monocultures by out competing other species . Mechanisms to avoid encroachment of undesirable species include increased maintenance, providing a soil breach between the invasive community for those species that spread through rhizomes, and providing annual removal of seedlings from wind borne seed dispersal. Existing disease or insect infestations associated with existing site conditions or in the general area that may effect the bioretention plantings.

d Number of Species

A minimum of three species of trees and three species of shrubs should be selected to insure diversity. In addition to reducing the potential for monoculture mortality concerns, a diversity of trees and shrubs with differing rates of transpiration may ensure a more constant rate of evapotranspiration and nutrient and pollutant uptake throughout the growing season.

Herbaceous ground covers are important to prevent erosion of the mulch and the soil layers.

e Number and Size of Plants

The requisite number of plantings varies, and should be determined on an individual site basis. On average, 1000 trees and shrubs should be planted per acre. For example, a bioretention area measuring 15' x 40' would contain a combination of trees and shrubs totaling 14 individuals. The recommended minimum and maximum number of individual plants and spacing are given in Table 16. Two to three shrubs should be specified for each tree (2:1 to 3:1 ratio of shrubs to trees).

At installation, trees should be 1.0 inches minimum in caliper, and shrubs 3 to 4 feet in height or 18 to 24 inches in spread per ASNI Z60. Ground cover may be as seed or, preferably, plugs. The relatively mature size requirements for trees and shrubs are important to ensure that the installation f plants are readily contributing to the bioretention process (i.e., evapotranspiration, pollutant uptake).

TABLE 16
Recommended Tree and Shrub Spacing

	Tree Spacing (feet)	Shrub Spacing (feet)	Total Density (stems/acre)
Maximum	19	12	400
Average	12	8	1000
Minimum	11	7	1250

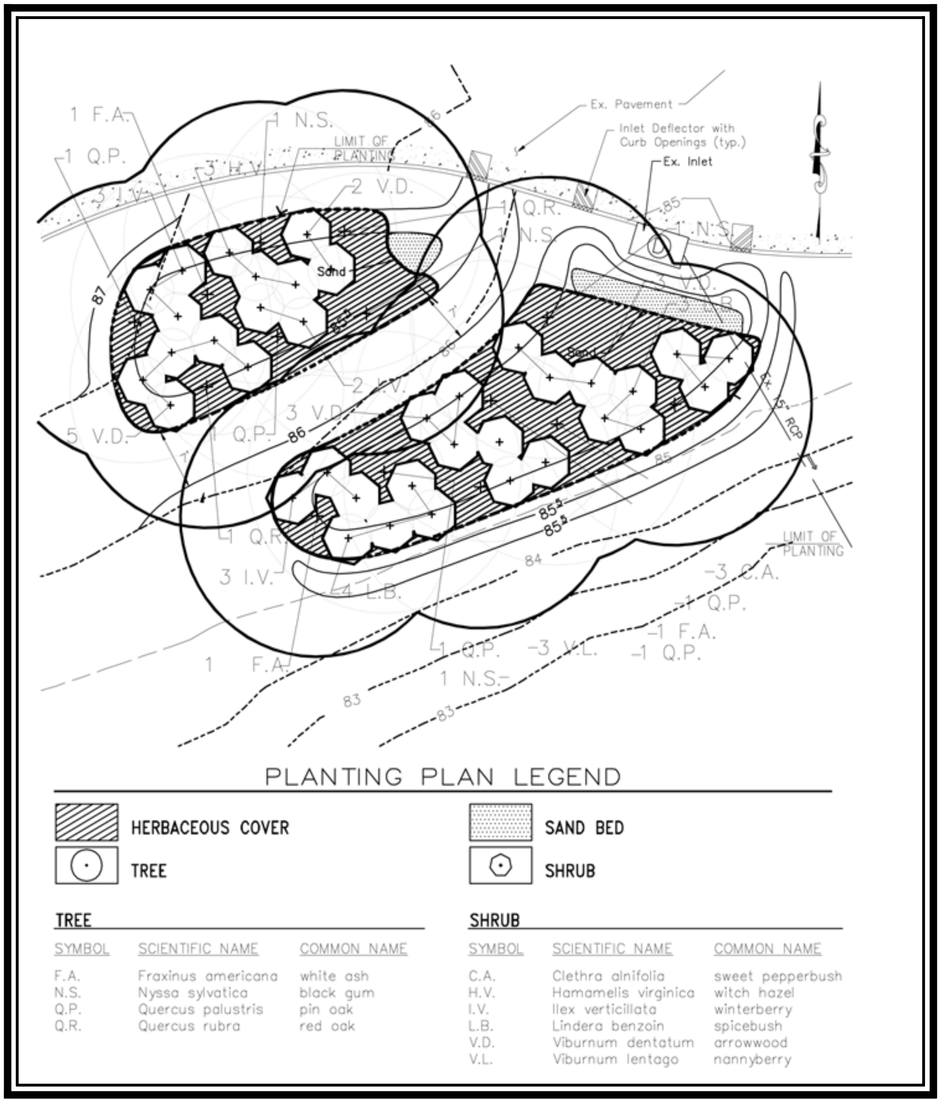
f Plant Layout

The layout of plant material can be a flexible process; however, the designer should follow some basic guidelines. As discussed above, the designer should first review the Plant Checklist (Appendix D). The checklist table can help expose any constraints that may limit the use of a particular species and/or where a species can be installed.

There are two guidelines that should apply to all bioretention areas. First, woody plant material should not be placed within the immediate areas of where flow will be entering the bioretention area.

Besides possibly concentrating flows, trees and shrubs can be damaged as a result of the flow. Secondly, it is recommended that trees be planted primarily on the perimeter of bioretention areas, to maximize the shading and sheltering of bioretention areas to create a microclimate which will limit the extreme exposure from summer solar radiation and winter freezes and winds. An example planting plan is shown in Figure 24.

FIGURE 24
Sample Planting Plan



<u>Mulch Layer Guidelines</u>

A mulch layer serves to prevent erosion and to protect the soil from excessive drying. Soil biota existing within the organic and soil layer are important in the filtering of nutrients and pollutants and assisting in maintaining soil fertility. Bioretention areas can be designed either with or without a mulch layer. If a herbaceous layer or ground cover (70 to 80% coverage) is provided, a mulch layer is not necessary. Areas should be mulched once trees and shrubs have been planted. Any ground cover specified as plugs may be installed once mulch has been applied.

The mulch layer recommended for bioretention may consist of either standard landscape fine shredded hardwood mulch or shredded hardwood chips. Both types of mulch are commercially available and provide excellent protection from erosion.

Mulch shall be free of weed seeds, soil, roots, or any other substance not consisting of either bole or branch wood and bark. The mulch shall be uniformly applied approximately 2 to 3 inches in depth. Mulch applied any deeper than three inches reduces proper oxygen and carbon dioxide cycling between the soil and the atmosphere.

Grass clippings are unsuitable for mulch, primarily due to the excessive quantities of nitrogen built up in the material. Adding large sources of nitrogen would limit the capability of bioretention areas to filter the nitrogen associated with runoff.

Plant Material Guidelines

a Plant Material Source

The plant material should conform to the current issue of the American Standard for Nursery Stock published by the American Association of Nurserymen. Plant material should be selected from certified nurseries that have been inspected by state or federal agencies. The botanical (scientific) name of the plant species should be in accordance with a standard nomenclature source such as Birr, 1975.

Some of the plant species listed in Tables 8-5, Recommended Plant Species For Use in Bioretention may be unavailable from standard nursery sources. These are typically species native to Kentucky and may not be commonly used in standard practices. Designers may need to contact nurseries specializing in native plants propagation.

b Installation

The success of bioretention areas is dependent on the proper installation specifications that are developed by the designer and subsequently followed by the contractor. The specifications include the procedures for installing the plants and the necessary steps taken before and after installation. Specifications designed for bioretention should include the following considerations:

- Sequence of Construction
- Contractors Responsibilities
- Planting Schedule and Specifications
- Maintenance
- Warranty

The sequence of construction describes site preparation activities such as grading, soil amendments, and any pre-planting structure installation. It also should address erosion and sediment control procedures. Erosion and sediment control practices should be in place until the entire bioretention area is completed. The contractors responsibilities should include all the specifications that directly effect the contractor in the performance of his or her work. The responsibilities include any penalties for unnecessarily delayed work, requests for changes to the design or contract, and exclusions from the contract specifications such as vandalism to the site, etc.

The planting schedule and specifications include type of material to be installed (e.g., ball and burlap, bare root, or containerized material), timing of installation, and post installation procedures. Balled and burlapped and containerized trees and shrubs should be planted during the following periods: March 15 through June 30 and September 15 through November 15. Ground cover excluding grasses and legumes can follow tree and shrub planting dates. Grasses and legumes typically should be planted in the spring of the year. The planting of trees and shrubs should be performed by following the planting specifications set forth in the Richmond specifications that provide guidelines that ensure the proper placement and installation of plant material. Designers may choose to use other specifications or to modify the jurisdiction specifications. However, any deviations from the jurisdiction specifications need to address the following:

- transport of plant material
- preparation of the planting pit
- installation of plant material
- stabilization seeding (if applicable)
- maintenance

An example of general planting specification for trees and shrubs and ground cover is given under Construction Specifications below.

c Warranties

Typically, a warranty is established as a part of any plant installation project. The warranty covers all components of the installation that the contractor is responsible for. The plant and mulch installation for bioretention should be performed by a professional landscape contractor. An example of standard guidelines for landscape contract work is provided below:

- The contractor shall maintain a one (1) calendar year 80% care and replacement warranty for all planting.

- The period of care and replacement shall begin after inspection and approval of the complete installation of all plants and continue for one calendar year.

- Plant replacements shall be in accordance with the maintenance schedule.
  Plant Growth and Soil Fertility

A discussion of plant growth and soil fertility development over time is important to for estimating the success and lifespan of bioretention areas. The physical, chemical, and biological factors influencing plant growth and development will vary over time as well as for each bioretention area. However, there are certain plant and soil processes that will be the same for all bioretention areas.

a Plant Growth

The role of plants in bioretention includes uptake of nutrients and pollutants and evapotranspiration of stormwater runoff. The plant material, especially ground covers, are expected to contribute to the evapotranspiration process within the first year of planting. However, trees and shrubs that have been recently planted demonstrate slower rates of growth for the first season due to the initial shock of transplanting. The relative rate of growth is expected to increase to normal rates after the second growth season.

The growth rate for plants in bioretention areas will follow a similar pattern to that of other tree and shrub plantings (reforestation projects, landscaping). For the first two years, the majority of tree and shrub growth occurs with the expansion of the plant root system. By the third or fourth year the growth of the stem and branch system dominates increasing the height and width of the plant. The comparative rate of growth between the root and stem and branch system remains relatively the same throughout the lifespan of the plant. The reproductive system (flowers, fruit) of the plants is initiated last.

The growth rates and time for ground covers to become acclimated to bioretention conditions is much faster than for trees and shrubs. The rate of growth of a typical ground cover can often exceed 100 percent in the first year. Ground covers are considered essentially mature after the first year of growth. The longevity of ground covers will be influenced by the soil fertility and chemistry as well as physical factors, such as shading and overcrowding from trees and shrubs and other ecological and physical factors.

Plants are expected to increase their contribution to the bioretention concept over time, assuming that growing conditions are suitable. The rate of plant growth is directly proportional to the environment in which the plant is established. Plants grown in optimal environments experience the greatest rates of growth. One of the primary factors determining this is soil fertility.

b Soil Fertility

Initially, soil in bioretention areas will lack a mature soil profile. It is expected that over time discrete soil zones referred to as horizons will develop. The development of a soil profile and the individual horizons is determined by the influence of the surrounding environment including physical, chemical, and biological processes. Two primary processes important to horizon development is microbial action and the percolation of runoff in the soil.

Horizons expected to develop in bioretention areas include an organic layer, followed by two horizons where active leaching (eluviation) and accumulation (illuvation) of minerals and other substances occur. The time frame for the development of soil horizons will vary greatly. As an average, soil horizons may develop within three to ten years. The exception to this is the formation of the organic layer often within the first or second year (Brady, 1984).

The evaluation of soil fertility in bioretention may be more dependent on the soil interactions relative to plant growth than horizon development. The soil specified for bioretention is important in filtering pollutants and nutrients as well as supply plants with water, nutrients, and support. Unlike plants that will become increasingly beneficial over time, the soil will begin to filter the storm water runoff immediately. It is expected that the ability to filter pollutants and nutrients may decrease over time, reducing the soil fertility accordingly. Substances from runoff such as salt and heavy metals eventually disrupt normal soil functions by lowering the cation exchange capacity (CEC). The CEC, the ability to allow for binding of particles by ion attraction, decreases to the point that the transfer of nutrients for plant uptake can not occur. However, the environmental factors influencing each bioretention area will vary enough that it is difficult to predict for the lifespan of soils. Findings from other stormwater management systems suggest an accumulation of substances eliminating soil fertility within five years. The monitoring of soil development in bioretention areas will help develop better predictions on soil fertility and development.

6 Construction Specifications

The construction of bioretention basins should be in accordance with the criteria set forth below. These specifications have been adapted from the Prince George's County, Maryland publication, Design Manual for Use of Bioretention in Stormwater Management.

Sequence of Construction

The sequence of various phases of basin construction must be coordinated with the overall project construction. As with other infiltration practices, rough excavation of the basin may be scheduled with the rough grading of the project to permit use of the excavated material as fill elsewhere on the site. However, the bioretention basin must not be constructed or placed in service until the entire contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas within the drainage area may otherwise load the newly formed basin with a large load of fine sediment, seriously impairing the natural infiltration ability of the basin floor. For these reasons, the locations of infiltration bioretention basins must NOT be used for sediment basins for erosion and sediment protection during site construction. The sequence of construction shall be as follows:

a Install Phase I erosion and sediment control measures for the site.

b Grade each site to elevations shown on plan. Initially, the basin floor may be excavated to within one foot of its final elevation. Excavation to finished grade shall be deferred until all disturbed areas within the watershed have been stabilized and protected. Construct curb openings, and/or remove and replace existing concrete as specified on the plan. Curb openings shall be blocked or other measures taken to prohibit drainage from entering construction area.

c Complete construction on the watershed and stabilize all areas draining to the Bioretention basin.

d Remove Phase I sediment control devices at direction of designated inspector.

e Install Phase II erosion and sediment control measures for bioretention area.

f Remove all accumulated sediment and excavate Bioretention Area to proposed depth. Use relatively light, tracked equipment to avoid compaction of the basin floor. After final grading is completed, deeply till the basin floor with rotary tillers or disc harrows that will provide a well-aerated, highly porous surface texture.

g Install the infiltration chambers, piping, manifolds, drains, vents, and infiltration stone in accordance in with the specifications and directions of the chamber manufacturer. Install a six-inch layer of washed, 1/4-inch pea gravel above the stone. Install a 1-foot layer of ASTM C-33 concrete sand on top of the pea gravel. Lightly compact with a landscaping roller.

h After confirmation that soil meets specs by performing the requisite gradation and chemical tests (see below), fill Bioretention Area with planting soil and sand, as shown in the plans and detailed in the specifications.

i Install vegetation and ground cover specified in the planting plan for Bioretention Area. Install mulch layer if called for in the design.

j Place sod, EC fabric, or non erosive lining (depending on inflow velocities) in the inlet channel and/or filter strips.

k Upon authorization from designated inspector, remove all sediment controls and stabilize all disturbed areas. Unblock curb openings, and provide drainage to the Bioretention Areas.

<u>Bioretention Area Soil Specifications</u>

a Planting Soil

The bioretention areas shall contain a planting soil mixture of 50% sand, 30% leaf compost (fully composted, NOT partially rotted leaves), and 20% topsoil. Topsoil shall be sandy loam or loamy sand of uniform composition, containing no more than 5% clay, free of stones, stumps, roots, or similar objects greater than one inch, brush, or any other material or substance which may be harmful to plant growth, or a hindrance to plant growth or maintenance.

The top soil shall be free of plants or plant parts of Bermuda grass, Quack grass, Johnson grass, Mugwort, Nutsedge, Poison Ivy, Canadian Thistle or others as specified. It shall not contain toxic substances harmful to plant growth.

The top soil shall be tested and meet the following criteria:

pH range:	5.0 - 7.0
Organic matter:	Greater than 1.5
Magnesium (Mg):	00+ Units Phosphorus (P_2O_5) 150+ Units
Potassium (K_2O):	120+ Units
Soluble salts:	not to exceed 900 ppm/.9 MMHOS/cm (soil) not to exceed 3,000 ppm/2.5 MMHOS/cm (organic mix)

The following testing frequencies shall apply to the above soil constituents:

pH, Organic Matter 1 test per 90 cubic yards, but no more than 1 test per Bioretention Area

Magnesium, Phosphorus, Potassium, Soluble Salts:

1 test per 500 cubic yards, but no less than 1 test per borrow source

One grain size analysis shall be performed per 90 cubic yards of planting soil, but no less than 1 test per Bioretention Area. Soil tests must be verified by a qualified professional.

b Mulch

A mulch layer shall be provided on top of the planting soil. An acceptable mulch layer shall include shredded hardwood or shredded wood chips or other similar product.

Of the approved mulch products all must be well aged, uniform in color, and free of foreign material including plant material.

c Sand

The sand for bioretention basins when utilized, shall be ASTM C-33 Concrete Sand and free of deleterious material.

d Compaction

Soil shall be placed in lifts less than 18 inches and lightly compacted (minimal compactive effort) by tamping or rolled with a hand-operated landscape roller.

Bioretention Area Planting Specifications

a Root stock of the plant material shall be kept moist during transport from the source to the job site and until planted.

b Walls of planting pit shall be dug so that they are vertical.

c The diameter of the planting pit must be a minimum of six inches (6") larger than the diameter of the ball of the tree.

d The planting pit shall be deep enough to allow 1/8 of the overall dimension of the root ball to be above grade. Loose soil at the bottom of the pit shall be tamped by hand.

e The appropriate amount of fertilizer is to be placed at the bottom of the pit (see below for fertilization rates).

f The plant shall be removed from the container and placed in the planting pit by lifting and carrying the plant by its' ball (never lift by branches or trunk).

g Set the plant straight and in the center of the pit so that approximately 1/8 of the diameter of the root ball is above the final grade.

H Backfill planting pit with existing soil.

i Make sure plant remains straight during backfilling procedure

j Never cover the top of the ball with soil. Mound soil around the exposed ball.

k Trees shall be braced by using 2" by 2" white oak stakes. Stakes shall be placed parallel to walkways and buildings. Stakes are to be equally spaced on the outside of the tree ball. Utilizing hose and wire the tree is braced to the stakes.

l Because of the high levels of nutrients in stormwater runoff to be treated, bioretention basin plants should not require chemical fertilization.

7 Maintenance/Inspection Guidelines

The following maintenance and inspection guidelines are not intended to be all inclusive. Specific Facilities may require additional measures not discussed here.

A schedule of recommended maintenance for bioretention areas is given in Table 17. The table gives general guidance regarding methods, frequency, and time of year for maintenance.

Planting Soil

Urban plant communities tend to become very acidic due to precipitation as well as the influences of storm water runoff. For this reason, it is recommended that the application of alkaline, such as limestone, be considered once to twice a year. Testing of the pH of the organic layer and soil, should precede the limestone application to determine the amount of limestone required.

Soil testing should be conducted annually so that the accumulation of toxins and heavy metals can be detected or prevented. Over a period of time, heavy metals and other toxic substances will tend to accumulate in the soil and the plants. Data from other environs such as forest buffers and grass swales suggest accumulation of toxins and heavy metals within five years of installation. However, there is no methodology to estimate the level of toxic materials in the bioretention areas since runoff, soil, and plant characteristics will vary from site to site.

As the toxic substances accumulate, the plant biologic functions may become impaired, and the plant may experience dwarfed growth followed by mortality. The biota within the soil can also become void and the natural soil chemistry may be altered. The preventative measures would include the removal of the contaminated soil. In some cases, removal and disposal of the entire soil base as well as the plant material may be required.

Mulch

Bioretention areas should be mulched once the planting of trees and shrubs has occurred. Any ground cover specified as plugs may be installed once the area has been mulched. Ground cover established by seeding and\or consisting of grass should not be covered with mulch.

Plant Materials

An important aspect of landscape architecture is to design areas that require little maintenance. Certain plant species involve maintenance problems due to dropping of fruit or other portions of the plant. Another problem includes plants, primarily trees that are susceptible to windthrow, which creates a potential hazard to people and property (parked cars). As a result, some plant species will be limited to use in low-traffic areas.

Ongoing monitoring and maintenance is vital to the overall success of bioretention areas. Annual maintenance will be required for plant material, mulch layer, and soil layer. A maintenance schedule should include all of the main considerations discussed below. The maintenance schedule usually includes maintenance as part of the construction phase of the project and for life of the design. A example maintenance schedule is shown in Table 17.

Maintenance requirements will vary depending on the importance of aesthetics. Soil and mulch layer maintenance will be most likely limited to correcting areas of erosion. Replacement of mulch layers may be necessary every two to three years. Mulch should be replaced in the spring. When the mulch layer is replaced, the previous layer should be removed first. Plant material upkeep will include addressing problems associated with disease or insect infestations, replacing dead plant material, and any necessary pruning.

Control of Sediments on the Drainage Shed

Care must be taken to protect the bioretention basin from excessive sediments from the drainage shed. Whenever additional land disturbing activity takes place in the area draining to the basin, effective erosion and sediment control measures must first be put in place to exclude sediments from the basin. Performance based special measures over and above those specified in the Virginia Erosion and Sediment Control Handbook, latest edition, may be required to assure that the bioretention basin is not damaged by such land disturbance. When sand or other street abrasives are used during the snow or icing conditions to provide traction on roadways or parking lots draining to bioretention basins, the pavement should be power/vacuum swept as soon as freezing weather abates to prevent damage to the basins.

TABLE 17
Example Maintenance Schedule for Bioretention Basin

Description	Method	Frequency	Time of the year
SOIL			
Inspect and Repair Erosion	Visual	Monthly	Monthly
ORGANIC LAYER			
Remulch any void areas	By hand	Whenever needed	Whenever needed
Remove previous mulch layer before applying new layer (optional)	By hand	Once every two to three years	Spring
Any additional mulch added (optional)	By hand	Once a year	Spring
PLANTS			
Removal and replacement of all dead and diseased vegetation considered beyond treatment	See planting specifications	Twice a year	3/15 to 4/30 and 10/1 to 11/30
Treat all diseased trees and shrubs	Mechanical or by hand	N/A	Varies, depends on insect or disease infestation
Watering of plant material shall take place at the end of each day for fourteen consecutive days after planting has been completed	By hand	Immediately after completion of project	N/A
Replace stakes after one year	By hand	Once a year	Only remove stakes In the spring
Replace any deficient stakes or wires	By hand	N/A	Whenever needed
Check for accumulated sediments	Visual	Monthly	Monthly

Table 18. Popular Native Plant Materials for Bioretention Basins

Perennials/Herbaceous	Shrubs	Trees
Virginia Wild Rye *(Elymus virginicus)*	Common Winterberry *(Ilex verticillatta)*	River Birch *(Betula nigra*)
Redtop Grass *(Agrostis alba)*	Inkberry *(Ilex glabra)*	Red Maple *(Acer rubrum)*
Swamp Milkweed *(Asclepias incarnata)*	Sweet Pepperbush *(Clethra ainifolia)*	Pin Oak *(Quercus palustris)*
Switchgrass *(Panicum virgatum)*	Wax Myrtle *(Myrica cerifera)*	Willow Oak *(Quercus phellos)*
Cardinal Flower *(Lobelia cardinalis)*	Virginia Sweetspire *(Itea virginica)*	Sweetgum *(Liquidambar styraciflua)*
Common Three Square *(Scirpus americanus)*	Swamp Azeala *(Azeala viscosum)*	Black Willow *(Salix nigra)*
Sensitive Fern *(Onoclea sensibilis)*	Button Bush *(Cephalanthus occidentalis)*	Grey Birch *(Betula populifolia)*
Blue Flag *(Iris versicolor)*	Black Haw *(Virburnum prunifolium))*	Black Gum *(Nyassa sylvatica)*
Woolgrass *(Scirpus cyperninus)*	Indigo Bush *(Amorpha fruticosa)*	Sycamore *(Platanus occidentalis)*
Indian Grass *(Sorghastrum nutans)*	Arrowwood *(Virburum dentatum)*	Green Ash *(Fraxinus pennsylvanica*
Marsh Marigold *(Caltha palustris)*		Sweetbay Magnolia* *(Magnolia virginiana)*
Joe Pye Weed *(Eupatorium purpureum)*		Atlantic White Cedar* *(Charnaecyparis thyoides)*
Turk's cap lily (*Lilium superbum*)		Bald Cypress* *(Taxodium distichum)*
Bee Balm *(Mornarda didyma)*		Grey Dogwood *(Cornus racernosa)*
Northern Sea Oats *(Chasmanthium latifolium)*		Smooth Alder *(Alnus serrulata))*
		Serviceberry *(Amelanchier canadensis)*
		Redbud (*Cercis candensis*)
		Box Elder *(Acer negundo)*
		Fringe Tree (*Chionanthus virginicus*)

Note: Prior to selection, please consult bioretention plant lists for more detailed information regarding inundation, drought and salt tolerance for each species.
* most applicable to the coastal plain

Bioretention Filter in multi-family residential setting.

Bioretention Basins in office setting parking lot.

K Infiltration Basin

1 Definition

An infiltration basin is a vegetated, open impoundment where incoming stormwater runoff is stored until it gradually infiltrates into the soil strata.

2 Purpose

Infiltration basins are used primarily for water quality enhancement. However, flooding and channel erosion control may also be achieved within an infiltration basin by utilizing a multi-stage riser and barrel spillway to provide controlled release of the required design storms above the water quality (infiltration) volume (refer to Figure 25).

3 Conditions Where Practice Applies

Infiltration basins may be used where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and where the water table is low enough to prevent pollution of groundwater.

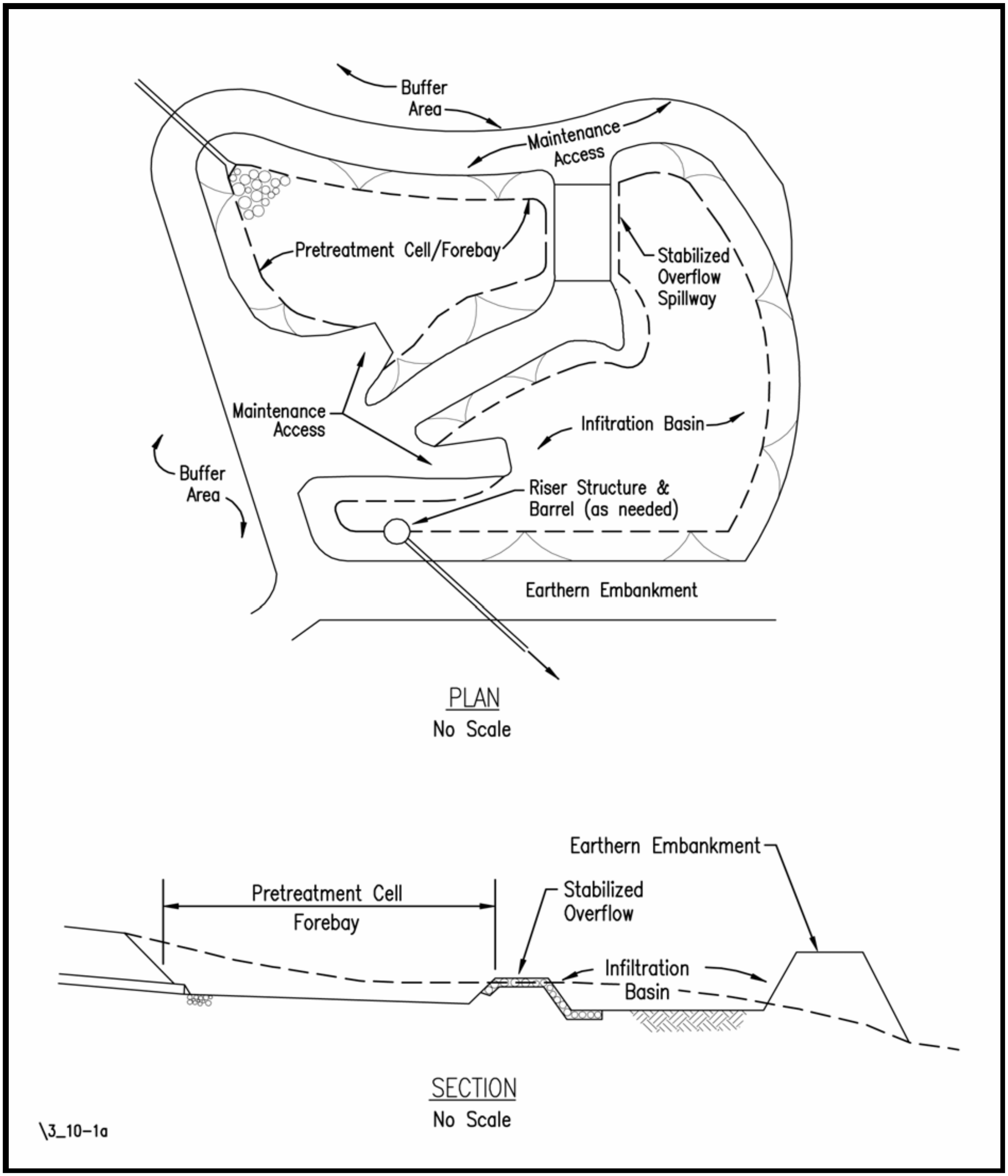
<u>Drainage Area</u>

Drainage areas served by infiltration basins should be limited to less than 50 acres. Drainage areas which are greater than 50 acres typically generate such large volumes of runoff that other detention or retention BMPs are more practical and cost-effective.

<u>Development Conditions</u>

Infiltration basins are generally suitable BMPs in low- to medium-density residential and commercial developments (38% to 66% impervious cover).

FIGURE 25
Infiltration Basin – Plan and Section



4 Planning Considerations

Appropriate soil conditions and protection of the groundwater are among the important considerations when planning an infiltration basin.

An infiltration basin has relatively large surface area requirements, when compared with an infiltration trench or dry well, and ranges from 3 to 12 feet in depth. The seasonal high groundwater table or bedrock should be located at least 2 to 4 feet below the bottom of the basin.

Maintenance

Like all stormwater BMPs, access to an infiltration basin should be considered in the planning stage. Access (as well as maneuvering room) should be provided to at least one side of the facility and the control structure or spillway. In addition, identifying a location and designing for on-site sediment disposal will greatly reduce long-term maintenance costs.

5 Design Criteria

The purpose of this section is to provide recommendations and minimum criteria for the design of infiltration basins intended to comply with the runoff quality requirements of the Owensboro/Daviess County Stormwater Management program.

General

The design of infiltration basins should be according to the detention basin standard of OMPC and this chapter, along with additional criteria set forth below. The designer is not only responsible for selecting the appropriate components for his or her particular design but also for ensuring their long-term operation by specifying appropriate structural materials.

The design of the overflow vegetated spillway must consider the frequency of flow. The spillway may require an armored bottom if it is to function during every storm which exceeds the water quality volume.

Hydrology and Hydraulics

Follow procedures outlined in the Stormwater Manual.

Soils Investigation

A minimum of one soil boring log should be required for each 5,000 square feet of infiltration basin area (plan view area) and under no circumstances should there be less than three soil boring logs per basin.

Topographic Conditions

Infiltration basins should be a minimum of 50 feet from any slope greater than 15%. If unavoidable, a geotechnical report should address the potential impact of infiltration on or near the steep slope. Developments on sloping sites often require extensive cut and fill operations. The use of infiltration basins on fill sites is not permitted. Also, infiltration basins should be a minimum of 100 feet up-slope and 20 feet down-slope from any buildings.

Design Infiltration Rate

The design infiltration rate, f_d, should be set to equal one-half the infiltration rate, f, determined from the soil analysis. Therefore:

$$f_d = 0.5\ f$$

Maximum Ponding Time and Depth

All infiltration basins should be designed to completely drain stored runoff within 2 days following the occurrence of a storm event. Thus, an allowable maximum ponding time, T_{max}, of 48 hours should be used. The maximum ponding depth for an infiltration basin is:

$$d_{max} = f_d T_{max}$$

where: d_{max} = maximum depth of the facility, in ft.
f_d = design infiltration rate of the basin area soils, in ft/hr (f_d = ½ f)
T_{max} = maximum allowable drain time = 48 hrs.

The ponding depth should not be so great as to contribute to the compaction of the soil surface. Depending on the specific soil characteristics, a maximum ponding depth of 2 feet is generally recommended (MWCOG, 1992).

The minimum surface area of the facility bottom is:

$$SA_{min} = \frac{Vol_{wq}}{f_d T_{max}}$$

where: SA_{min} = minimum basin bottom surface area, in ft^2;
Vol_{wq} = water quality volume requirements, in ft^3;
f_d = design infiltration rate of the basin area soils, in ft/hr;
T = maximum allowable drain time, in hours

Runoff Pretreatment

Infiltration basins should always be preceded by a pretreatment facility. Grease, oil, floatable organic materials, and settleable solids should be removed from the runoff before it enters the infiltration basin. Vegetated filters, sediment traps and/or forebays, water quality inlets (refer to Section B.3, Manufactured BMP Systems) are just a few of the available pretreatment strategies.

At a minimum, the layout and design of the basin should include a sediment forebay or pretreatment cell, as shown in Figure 25, to enhance and prolong the infiltration capacity. Any pretreatment facility should be included in the design of the basin and should include maintenance and inspection requirements. It is recommended that a grass strip or other vegetated buffer at least 20 feet wide be maintained around the basin to filter surface runoff.

Principal and Emergency Spillways

A diversion structure upstream of an off-line basin will regulate the rate of flow into the basin, but not the volume. Therefore, infiltration basins should have a spillway to convey flows from storm events which are larger than the design capacity. The primary outlet should be located above the required infiltration volume. Additionally, a riser and barrel system is advantageous for future conversion to an extended-detention or retention facility if the infiltration capacity of the soil becomes impaired.

An emergency spillway is recommended for all impounding structures, including infiltration basins. If a vegetated spillway is to be used as the primary outlet above the water quality volume, care should be taken to design for the increased frequency of use. This is especially critical between maintenance operations when the infiltration capacity is decreased due to sediment loads. If a spillway is to be used for all storms which generate more runoff than the water quality volume, then a nonerodible surface should be provided.

Fencing

Fencing may be provided where deemed necessary by the developer, land owner, or locality for the purposes of public safety or protection of vegetation.

6 Construction Specifications

In general, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable. Further guidance can be found in the Soil Conservation Service's Engineering Field Manual. Specifications for the work should conform to the methods and procedures indicated for installing earthwork, concrete, reinforcing steel, pipe, water gates, metal work, woodwork and masonry as they apply to the site and the purpose of the structure. The specifications should also satisfy all requirements of the local government.

Sequence of Construction

The sequence of various phases of basin construction should be coordinated with the overall project construction schedule. Rough excavation of the basin may be scheduled with the rough grading phase of the project to permit use of the material as fill in earthwork areas. Otherwise, infiltration measures should not be constructed or placed into service until the entire contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas within the drainage area may load the newly formed basin with a large volume of fine sediment. This could seriously impair the natural infiltration ability of the basin floor.

The specifications for construction of a basin should state the following: 1) the earliest point at which storm drainage may be directed to the basin, and 2) the means by which this delay in basin use is to be accomplished. Due to the wide variety of conditions encountered among projects, each project should be evaluated separately to postpone basin use for as long as possible.

Excavation

Initially, the basin floor should be excavated to within one foot of its final elevation. Excavation to the finished grade should be delayed until all disturbed areas in the watershed have been stabilized or protected. The final phase of excavation should remove all accumulated sediment. Relatively light, tracked-equipment is recommended for this operation to avoid compaction of the basin floor.

After the final grading is completed, the basin floor should be deeply tilled by means of rotary tillers or disc harrows to provide a well-aerated, highly porous surface texture.

Lining Material

Establishing dense vegetation on the basin side slopes and floor is recommended. A dense vegetative cover will not only prevent erosion and sloughing, but will also provide a natural means to maintain relatively high infiltration rates. Inflow points to the basin should also be protected with erosion controls (e.g., riprap, flow spreaders, energy dissipaters, etc.), as well as a sediment forebay.

7 Maintenance / Inspection Guidelines

The following maintenance and inspection guidelines are not intended to be all-inclusive. Specific facilities may require other measures not discussed here.

Inspection Schedule

When infiltration basins are first made functional they should be inspected monthly and after any large storm event. Thereafter, once the basin is functioning satisfactorily and without potential sediment problems, inspections may be made semi-annually and after any large storm events. All inspections should include investigation for potential sources of contamination.

Sediment Control

The basin should be designed to allow for maintenance. Access should be provided for vehicles to easily maintain the forebay (pre-settling basin) without disturbing vegetation or sediment any more than what is absolutely necessary.
Grass bottoms in infiltration basins seldom need replacement since grass serves as a good filter material. If silty water is allowed to trickle through the turf, most of the suspended material is strained out within a few yards of surface travel. Well-established turf on a basin floor will grow up through sediment deposits forming a porous turf and preventing the formation of an impenetrable layer. Grass planted on basin side slopes should also prevent erosion.

Vegetation Maintenance

Maintenance of the vegetation on the basin floor and side slopes is necessary to promote a dense turf with extensive root growth, which subsequently enhances infiltration, prevents erosion and sedimentation, and deters invasive weed growth. Bare spots should be immediately stabilized and revegetated.

The use of low-growing, stoloniferous grasses will permit long intervals between mowings. Mowing twice a year is generally satisfactory. Fertilizers should be applied only as necessary and in limited amounts to avoid contributing to pollution problems, including groundwater pollution, for which the infiltration basin helps mitigate.

8 Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of an infiltration basin.

a Determine if the anticipated development conditions and drainage area are appropriate for an infiltration basin application.

b Determine if the soils (permeability, bedrock, water table, embankment foundation, etc.) and topographic conditions (slopes, building foundations, etc.) are appropriate for an infiltration basin application.

c Locate the infiltration basin on the site within topographic constraints.

d Determine the drainage area to the infiltration basin and calculate the required water quality volume.

e Evaluate the hydrology of the contributing drainage area to determine peak rates of runoff.

f Design the infiltration basin:

- Design infiltration rate, fd = 0.5 f .
- Max. Storage time Tmax = 48 hours
- Max. Storage depth, dmax
- Runoff pretreatment - concentrated input, sheet flow input, sediment forebay
- Vegetated buffer around basin to filter surface runoff
- Vegetated emergency spillway and/or riser and barrel design
- Earthen Embankment design

g Provide material specifications.

h Provide sequence of construction.

i. Provide maintenance and inspection requirements

An Example of an Infiltration Basin

CHAPTER 9 – PERMITTING PROCESS

A Application for Land Subdivision

1. An Application for Land Subdivision is not required for residential development disturbing less than one (1) acre unless it is part of a larger common plan of development.
2. An Application for Land Subdivision is required for all other construction related disturbances greater than one (1) acre, any commercial development site, or industrial development site.

B Exemptions

The following activities are exempt from the requirements and from the procedures of this chapter:

1. Cemetery graves.
2. Emergencies posing an immediate danger to life or property, substantial flood or fire hazards.
3. Land disturbance activity less than 1 acre, which not a commercial development or located in or near a critical area.
4. Agricultural operations required to adopt and implement an individual agriculture water quality plan pursuant to the requirements set forth in the Kentucky Agriculture Water Quality Act (KRS Ch. 224).
5. Usual and customary site investigations, such as geotechnical explorations, clearing for surveying work, monitoring wells and archaeological explorations, which are undertaken prior to submittal of an application for preliminary subdivision plat.

Land Disturbance activities exempted as described above do not preclude the need for water quality protection. All land disturbances in Richmond shall have a plan in place for the protection of water quality.

Not exclusive. The approving agency may, on a project-by-project basis, exempt other land disturbance activities not specifically identified above.

C Application Submittals

The application submittal process for any disturbance greater than one (1) acre; or any commercial development or industrial development is illustrated in Appendix C and further described in the Project Submittal Checklist in Appendix B Form 2. Plan review follows the sequence below:

1. Meet with Planning and Zoning department atleast seven (7) days before any plat/plan is submitted to TAC to discuss review requirements.
2. Planning and Zoning Work Session (WS) review.
3. Planning and Zoning Business Session review.

Application submittal for any land disturbance of less than 1 acre that are not part of a common plan of development do not require Planning and Zoning Review. Planning and Zoning will specify Erosion Protection and Sediment Control (EPSC) measures within five (5) days of notification by Codes Enforcement. A Building Permit will not be issued until EPSC measures have been installed as specified by the City Inspector.

D Construction Guarantees

These are covered under Section 516 of the Development Ordinance.

E Permit Release

Projects will be closed once the City determines that final stabilization has been established, a copy of the Notice of Termination (NOT) has been received, and the City of Richmond's Storm Infrastructure Certification Form is complete (Appendix B Form 3).

F Relation to other laws

Neither this chapter nor any administrative decision made under it exempts the Permittee or any other person from procuring other required local, state, or federal permits or complying with the requirements and conditions of such other permit(s), or limits the right of any person to maintain, at any time, any appropriate action, at law or in equity, for relief or damages against the Permittee or any other person arising from the activity regulated by this chapter.

CHAPTER 10 – EROSION PROTECTION & SEDIMENT CONTROL

A Stormwater Pollution Prevention Plan (SWPPP)

1 SWPPPs shall be prepared by a licensed professional engineer, drawn to an appropriate scale and shall include sufficient information to evaluate the environmental characteristics of the affected areas, the potential impacts of the proposed grading on water resources, and measures proposed to minimize soil erosion and off-site sedimentation. The owner/developer/contractor shall perform all clearing, grading, drainage, construction, and development in strict accordance with the approved plan and this chapter.

2 The SWPPP shall include:

a. A site description that identifies sources of pollution to stormwater discharges associated with on-site construction activities.

1. Describe the function of the project

2. Sequential list of activities to be performed including at a minimum:

- ❖ Clearing and grubbing;
- ❖ Construction of erosion control devices;
- ❖ Installation of permanent and temporary stabilization measures;
- ❖ Grading;
- ❖ Utility installation;
- ❖ Building, parking lot, and site construction;
- ❖ Final grading, landscaping or stabilization;
- ❖ Implementation and maintenance of final erosion control structures;
- ❖ Removal of temporary erosion control devices;

b. Total area of site and total area of disturbance, including off-site borrow/fill areas

c. List water quality classification of receiving waters as defined by KDOW

d. Project site map/drawing

1. Vicinity map;

2. Property boundary of project;

3. A clear and definite location of surrounding area's watercourses including, streams, natural or artificial water storage areas, sinkholes, springs, wetlands, riparian zones, and other significant geographic features. Clearly delineate any vegetation to be saved.

4. Location of roads and other significant structures;

5. Anticipated drainage patterns and slopes after major grading activities, including impervious structures, discharge points (outfalls) with its associated flows, and specific limits of disturbance;

6. Location of areas that will be disturbed including fill and borrow areas. Include an additional project site map/drawing if borrow or fill areas are located off-site;

7. Location and types of BMPs for erosion protection and sediment control including provisions to preserve topsoil and limit disturbance;

8. Location of equipment and material storage areas necessary for the project;

9. Location Good Housekeeping protocols (e.g. waste management provisions, adequate material staging areas, concrete washout areas, spill prevention and response, etc.);

10. Location of potential pollutant sources;

11. A clear and definite delineation of any one hundred (100) year floodplain on or near the site;

12. Storm drainage system, including quantities of flow and site conditions around all points of surface water discharge from the site;

13. Provide an indication of scale used. Scale must be smaller than 1"=200' and must be a standard engineering scale, such as 30, 40, 50, 60, or 100.

e. Any BMPS may be selected provided that they are proven to be equally or more effective than the equivalent best management practices as contained in the *Kentucky Erosion Prevention and Sediment Control Manual and Field Guide* or the City of Richmond's minimum standards.

f. The SWPPP shall be signed by a professional engineer and certified in accordance with the signatory requirements in 401 KAR 5:065, Section 2(1).

g. A current copy of the SWPPP shall be readily available to the construction site from the date of project initiation (NOI) to the date of Notice of Termination (NOT).

h. All other requirements of a SWPPP Plan as defined in the current KPDES general permit for construction activities.

i. A site development construction project shall be considered in conformance with this chapter if soils have been prevented from being deposited onto adjacent properties, rights-of-ways, public storm drainage system, or wetland or watercourse for a storm event up to the maximum defined design criteria and any cleanup/maintenance observed to be needed is performed before the next storm event.

B Design and Maintenance Requirements

1. Ensure that BMPs selected minimize the amount of disturbance and time the disturbed area is exposed.

2. The design, testing, installation, and maintenance of erosion protection and sediment control operations and facilities shall adhere to the criteria, standards and specifications as set forth in the most recent version of the *Kentucky Erosion Prevention and Sediment Control Manual and Field Guide* or City of Richmond's minimum standards.

3. At a minimum, the following requirements shall be met:

    a. Cut and fill slopes shall be no greater than 2H:1V, unless approved by the approving agency.

    b. Clearing and grading, except that necessary to establish sediment control devices, shall not commence until sediment control devices have been installed.

    c. Erosion control methods shall include the following:

        1. Phasing of clearing and grading operations for all sites;

        2. Soil stabilization by seeding/mulching within 14 days of mass grading operations for borrow (excavation) and fill areas;

        3. Stabilizing soil stockpiles at the end of each workday;

        4. Installing diversion ditches or other techniques where upland runoff occurs past disturbed areas;

        5. Sediment control measures shall effectively minimize such discharges for storm events up to and including a 2-year, 24-hour event;

        6. All engineering calculation related to the design of erosion control methods shall be submitted with the SWPPP.

    d. Sediment control methods shall include installing retention facilities, sedimentation basins and traps, other similar facilities at the most downstream runoff location within the site.

    e. Waterway (creeks, ditches, etc.) protection shall include the installation of a temporary stream crossing, on-site storm water drainage system and stabilized outlets at all pipes.

    f. Prevention of mud and debris onto public roadways by construction equipment and vehicles shall include the installation of crushed stone construction entrances or an on-site tire washing station at the point of ingress and egress to the public roadway.

g. All BMPs shall be maintained in an effective, operating condition. A schedule of maintenance activities during and after construction of graded surfaces, EPSC facilities, and drainage structures shall be developed to ensure proper function of these devices.

h. Maintenance measures shall be performed before the next storm event.

C Inspection

1. Prior to commencing construction activities the permittee shall schedule a pre-construction meeting with the approving agency. The permittee shall provide a 7-day notice to approving agency prior to pre-construction meeting.

2. The permittee shall notify the approving agency 24 hours in advance of conducting inspections, except in the case of post-rainfall event inspections.

   a. At a minimum, the permittee shall conduct a self-inspection at the following stages:

      1. Completion of perimeter erosion and sediment controls.

      2. Completion of clearing and grading.

      3. Installation of temporary erosion controls.

      4. Completion of final grading and ground stabilization.

      5. Prior to the fiscal security release.

      6. Monthly after areas have been temporarily or permanently stabilized.

      7. Within 24 hours of a rain event 0.5 inches or greater and every 14 days, OR every 7 days.

   b. The Approving Agency may increase or decrease the number of required inspections as deemed necessary to ensure an effective SWPPP Plan and shall have the right to enter the property of the permittee without notice.

3. The permittee shall prepare an inspection report after each self-inspection and shall keep copies at the job site at all times, and may be required to fax or email the inspection report to the Approving Agency, if deemed necessary. At a minimum the inspection report shall include the date, time of day, name of the person conducting the inspection, company represented, scope of the inspection, major observations relating to the SWPPP and BMPs installed, appropriate photographs, and subsequent changes. The Approving Agency has the right to make regular inspections to ensure the validity of the inspection reports.

4. All inspections shall be provided to the City of Richmond in a digital format before a Certificate of Occupancy or Construction guarantee is released.

5. The permittee shall be self-policing and shall correct or remedy any EPSC measures that are not effective or functioning properly at all times during the various phases of construction. All updates to EPSC measures shall be accurately noted in the SWPPP.

6. The SWPPP must be updated throughout the construction project and available for on-site review.

CHAPTER 11 – POST-CONSTRUCTION STORMWATER MANAGEMENT MEASURES

A Site Performance Criteria

Unless judged by the City of Richmond to be exempt or granted a waiver, the following performance criteria shall be addressed for stormwater management at all sites:

1. All site designs shall establish stormwater management practices to control the peak flow rates of stormwater discharge associated with specified design storms and reduce the generation of stormwater. These practices should seek to utilize pervious areas for stormwater treatment and to infiltrate stormwater runoff from driveways, sidewalks, rooftops, parking lots, and landscaped areas to the maximum extent practical to provide treatment for both water quality and quantity. Stormwater management measures shall be required that are designed, built, and maintained to treat, filter, flocculate, infiltrate, screen, evapo-transpire, harvest and reuse stormwater runoff in order to manage stormwater runoff quality and quantity,

2. Areas of development and re-development that result in new or expanded discharge to high quality waters (HQW) shall include standards for runoff control that are considered sufficient by the City of Richmond to protect existing in-stream water uses and the level of water quality necessary to protect existing uses. HQW are listed in the 305(b) report on the KDOW website.

3. Certain industrial sites are required to prepare and implement a Stormwater Pollution Prevention Plan (SWPPP), and shall file a Notice of Intent (NOI) under the provisions of the National Pollutant Discharge Elimination System (NPDES) general permit. The SWPPP requirement applies to both existing and new industrial sites.

4. Stormwater discharges from land uses or activities with higher potential pollutant loadings, known as “hotspots”, may require the use of specific structural Stormwater Treatment Practices (STPs) and pollution prevention practices.

5. Hydraulic design calculations shall follow the procedures outlined in the City of Richmond Stormwater Policy Manual and incorporate the on-site stormwater quality runoff treatment standard accepted by the City of Richmond (Section C, below).

6. Structural and non-structural controls may be used to obtain permanent stormwater management over the life of the property’s use. Structural stormwater controls include, but are not limited to, grass swales, filter strips, infiltration basins, detention ponds, stormwater wetlands, natural filtration areas, sand filters, and rain gardens. Non-structural BMPs include, but are not limited to, open spaces, vegetated conveyances and buffers, natural infiltration, and low impact development.

B Post-Construction Exemptions

Post-construction stormwater management measures must be implemented at construction sites disturbing one or more acres of land or sites less than one acre that are from a common plan of development. The following activities may be exempt from the post-construction stormwater performance criteria in this chapter:

1. Any logging and agricultural activity that is consistent with an approved soil conservation plan or a timber management plan prepared or approved by the City of Richmond, as applicable.

2. Additions or modifications to existing single family structures

3. Developments that do not disturb more than one (1) acre of land, provided they are not part of a larger common development plan;

4. Repairs to any stormwater treatment practice deemed necessary by City of Richmond;

5. Any emergency project that is immediately necessary for the protection of life, property or natural resources;

6. Linear construction projects, such as pipeline or utility line installation, that do not result in the installation of any impervious cover, as determined by the City of Richmond shall minimize the number and width of stream crossings;

7. Any part of a land development that was approved by the City of Richmond prior to the effective date of this ordinance.

C Post-Construction Waivers

The minimum requirements for stormwater management may be waived in whole or in part upon written request of the applicant, provided that at least one of the following conditions described below applies. Waivers will not be granted due to monetary circumstances.

1. It can be demonstrated that the proposed development is not likely to impair attainment of the objectives of the Post-Construction Ordinance;

2. Provisions are made to manage stormwater by an off-site facility. The off-site facility is required to be in place, to be designed and adequately sized to provide a level of stormwater control that is equal to or greater than that which would be afforded by on-site practices and there is a legally obligated entity responsible for long-term operation and maintenance of the stormwater practice;

3. The City of Richmond finds that meeting the minimum on-site management requirements is not feasible due to the natural or existing physical characteristics of a site.

D Procedure for Exemptions and Waivers

Exemptions or waivers from stormwater management requirements shall not result in development or re-development that undermines the purpose of the Post Construction Ordinance. Written requests for exemptions (Section B, above) or waivers (Section C, above) shall be submitted to the Planning and Zoning Board and noted on their development or SWPPP for approval.

For any waiver request, the applicant must demonstrate to the satisfaction of the Planning and Zoning Board that the construction project will not result in the following impacts to downstream waterways:

- Deterioration of existing culverts, bridges, dams, and other structures;
- Degradation of biological functions or habitat;
- Accelerated streambank or streambed erosion or siltation;
- Increased threat of flood damage to public health, life, or property.

E Alternative Mitigation Measures

Where the City of Richmond waives all or part of the minimum stormwater management requirements, or where the waiver is based on the provision of adequate stormwater facilities provided downstream of the proposed development, the applicant may be required to provide one of the following mitigation options as determined by the City of Richmond:

- A monetary contribution may be required in-lieu of the stormwater management practices as established by the City of Richmond, and based on the cost estimate for the cubic feet of storage required for stormwater management of the development in question. All of the monetary contributions shall be credited to an appropriate capital improvements program project, and shall be made by the developer prior to the issuance of any Building Permit for the development.

- The purchase and donation of privately owned lands, or the grant of an easement to be dedicated for preservation and /or reforestation. These lands should be located adjacent to the stream corridor (25 feet from top of bank) in order to provide permanent buffer areas to protect water quality and aquatic habitat.

- The creation of a stormwater management facility or other drainage improvements on previously developed properties, public or private, that currently lack stormwater management facilities designed and constructed in accordance with the purposes and standards of the Post-Construction Ordinance

- In lieu of a monetary contribution, an applicant may obtain a waiver of the required stormwater management by entering into an agreement with the City of Richmond for the granting of an easement or the dedication of a sufficient amount of land by the applicant, to be used for the construction of an off-site stormwater management facility. It is preferred that the donated land is within the impacted watershed. The agreement shall be entered into by the applicant and the City of Richmond prior to the recording of plats or, if no record plat is required, prior to the issuance of the Building Permit.

- The developer may propose an alternative that provides an equivalent benefit to the City as other mitigation measures outlined above, although the City is not obligated to accept the proposal if, in its review, it does not consider the offer an equivalent measure.

F Stormwater Management Plan Approval

The Stormwater Management Plan must be submitted for approval as described in Chapter 2 and shall include all of the following required information:

1. Contact Information

The name, address, and telephone number of all persons having a legal interest in the property and the tax reference number and parcel number of the property or properties affected.

2. Topographic Base Map

A topographic base map of the site which extends a minimum of 100 feet beyond the limits of the proposed development and indicates existing surface water drainage including streams, ponds, culverts, ditches, and wetlands; current land use including all existing structures; locations of utilities, roads, and easements; and significant natural and manmade features not otherwise shown.

3. Calculations

Hydrologic and hydraulic design calculations for the pre-development and post-development conditions for the design storms required by this chapter shall be recorded in the City of Richmond's Stormwater Calculation Worksheet.

4. Soils Information

If a stormwater management control measure depends on the hydrologic properties of soils (e.g., infiltration basins), then steps should be taken by the design engineer to verify existing soils have sufficient permeability for the BMP to function as designed.

5. Maintenance and Repair Plan

The design and planning of all stormwater management facilities shall include detailed maintenance and repair procedures to ensure their continued function. These plans will identify the parts or components of a stormwater management facility that need to be maintained and the equipment and skills or training necessary. Provisions for the periodic review and evaluation of the effectiveness of the maintenance program and the need for revisions or additional maintenance procedures shall be included in the plan. Parties responsible for the operation and maintenance of a stormwater management facility shall document the installation and all maintenance and repairs to the facility, and shall retain the records for at least 3 years.

6. Landscaping Plan

The applicant must present a detailed plan for management of vegetation at the site after construction is finished, including who will be responsible for the maintenance of vegetation at the site and what practices will be employed to ensure that adequate vegetative cover is preserved.

7. Maintenance Easements

The applicant must execute a maintenance easement that shall be binding on all subsequent owners of land served by the stormwater management facility. The easement shall provide for access to the facility at reasonable times for periodic inspection by the City of Richmond, or their contractor or agent, and for regular or special assessments of property owners to ensure that the facility is maintained in proper working condition to meet design standards and any other provisions established by the Post-Construction Ordinance and this chapter. The easement shall be recorded by the City of Richmond in the land records.

8. Operations and Maintenance Agreement

Maintenance of all stormwater management facilities shall be ensured through the creation of a formal operation and maintenance agreement that must be approved by the City of Richmond and recorded into the land record prior to final plan approval. As part of the agreement, a schedule shall be developed for when and how often maintenance will occur to ensure proper function of the stormwater management facility. The agreement shall also include plans for annual inspections to verify proper performance of the facility between scheduled cleanouts and submittal of annual reports to the City of Richmond. See Appendix B Form 4 for the Operations and Maintenance Agreement.

9. EPSC Plans for Construction of Stormwater Management Measures

The applicant must prepare an erosion and sediment control plan for all construction activities related to implementing any on-site stormwater management practices.

10. Other Environmental Permits

The applicant shall assure that all other applicable environmental permits have been acquired for the site prior to approval of the final Stormwater Design Plan in a written and signed statement.

G Construction Inspection

Regular inspections of the stormwater management system during construction shall be conducted by the staff of the City of Richmond or certified by a professional engineer or inspector who has been approved by the jurisdictional stormwater authority. All inspections shall be documented and written reports prepared that contain the following information:

1. The date and location of the inspection;
2. Whether construction is in compliance with the approved Stormwater Management Plan;
3. Variations from the approved construction specifications;
4. Installation date of all stormwater measures since the previous inspection; and
5. Any violations that exist.

If any violations are found, the property owner shall be notified in writing of the nature of the violation and the required corrective actions. No added work shall proceed until any violations are corrected and all work previously completed has received approval by the City of Richmond.

H Performance Bond/Security

Procedures outlined in Section 516 of the Development Ordinance shall be followed for Construction Guarantees.

The City of Richmond will make a final inspection of the stormwater practice to ensure that it is in compliance with the approved plan and the provisions of this Chapter. Provisions for a partial pro-rata release of the performance security based on the completion of various development stages can be done at the discretion of the City of Richmond. After the final inspection, a completed Storm Sewer Infrastructure Construction and Functionality Certification Form must be turned in to the Planning and Zoning Department. As-built plans may be required before Certificate of Occupancy or Construction Guarantee is released.

CHAPTER 12 – IDDE PLAN

A Monitoring of Discharges

This section applies to all facilities that have stormwater discharges associated with industrial activity, including construction activity.

The City of Richmond shall be permitted to enter and inspect facilities subject to regulation under this Ordinance as often as may be necessary to determine compliance with this Ordinance. If a discharger has security measures in force which require proper identification and clearance before entry into its premises, the discharger shall make the necessary arrangements to allow access to representatives of the City of Richmond.

Facility operators shall allow the City of Richmond ready access to all parts of the premises for the purposes of inspection, sampling, examination and copying of records that must be kept under the conditions of a NPDES permit to discharge stormwater, and the performance of any additional duties as defined by state and federal law.

Upon notifying the owner or owner's representative, the City of Richmond shall have the right to immediate access to the property to set up on any permitted facility such devices as are necessary in the opinion of the City of Richmond to conduct monitoring and/or sampling of the facility's stormwater discharge and/or suspected illicit discharge.

The City of Richmond has the right to require the discharger to install monitoring equipment as necessary. The facility's sampling and monitoring equipment shall be maintained at all times in a safe and proper operating condition by the discharger at its own expense. All devices used to measure stormwater flow and quality shall be calibrated per manufacturer's specifications to ensure their accuracy.

Any temporary or permanent obstruction to safe and easy access to the facility to be inspected and/or sampled shall be promptly removed by the operator at the written or oral request of the City of Richmond and shall not be replaced. The costs of clearing such access shall be borne by the operator.

Unreasonable delays in allowing the City of Richmond to a permitted facility is a violation of any applicable stormwater discharge permit and of Ordinance No. 04-12. A person who is the operator of a facility with a NPDES permit to discharge stormwater associated with industrial activity commits an offense if the person denies the City of Richmond reasonable access to the permitted facility for the purpose of conducting any activity authorized or required by this Ordinance.

If the City of Richmond has been refused access to any part of the premises from which stormwater is discharged, and is able to demonstrate probable cause to believe that there may be a violation of this Ordinance, or that there is a need to inspect and/or sample as part of a routine inspection and sampling program designed to verify compliance with this Ordinance or any order issued hereunder, or to protect the overall public health, safety, and welfare of the community or environment, then the City of Richmond may seek issuance of a search warrant from any court of competent jurisdiction.

B BMP Requirements

The EPA has identified Best Management Practices (BMPs) for any activity, operation, or facility which may cause or contribute to pollution or contamination of stormwater, the stormwater system, or Waters of the U.S. The owner or operator of a commercial or industrial establishment shall provide, at their own expense, reasonable protection from accidental discharge of prohibited materials or other wastes into the municipal stormwater system or watercourses through the use of these structural and non-structural BMPs. Further, any person responsible for a property or premise, which is, or may be, the source of an illicit discharge, may be required to implement, at said person's expense, additional structural and non-structural BMPs to prevent the further discharge of pollutants to the municipal separate storm sewer system. Compliance with all terms and conditions of a valid NPDES permit authorizing the discharge of stormwater associated with industrial activity, to the extent practicable, shall be deemed in compliance with the provisions of this section. See City of Richmond’s stormwater website for additional information on stormwater BMPs.

C Maintenance

Every person owning property through which a watercourse passes, or such person's lessee, shall keep and maintain that part of the watercourse within the property free of trash, debris, and other obstacles that would pollute, contaminate, or significantly retard the flow of water through the watercourse. In addition, the owner or lessee shall maintain existing privately owned structures within or adjacent to a watercourse, so that such structures will not become a hazard to the use, function, or physical integrity of the watercourse.

CHAPTER 13 – DEFINITIONS

For the purposes of this Stormwater Manual, the following terms, phrases, words, and their derivatives shall have the definitions stated below.

1. **Accelerated Erosion** means erosion caused by development activities that exceeds the natural processes by which the surface of the land is worn away by the action of water, wind, or chemical action.
2. **Applicant** Is the property owner or agent of a property owner who submits an application to the city for a land disturbance activity pursuant to this manual.
3. **Approving Agency** The City of Richmond and their duly authorized designees are responsible for implementing all the provisions within current city ordinances.
4. **Bankful Elevation** The water level, or stage, at which the stream, river, or lake is at the top of its banks and any further rise would result in water moving into the floodplain (NOAA Glossary).
5. **Bedrock** is in place solid rock.
6. **Bench** A relatively level step excavated into earth material on which fill is to be placed.
7. **Best Management Practices (BMPs)** A technique or series of techniques, which are proven to be effective in controlling runoff, erosion, and sedimentation to prevent or reduce the discharge of pollutants to waters of the Commonwealth. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or water disposal, or drainage from raw materials storage.
8. **Borrow** Is earth material acquired from an off-site location for use in grading on a site.
9. **Buffer Zone** The area defined from bankful elevation extending toward a construction activity that shall be protected from disturbance.
10. **Building** means any structure, either temporary or permanent, having walls and a roof, designed for the shelter of any person, animal, or property, and occupying more than 100 square feet of area.
11. **Building Inspector** The person from the governing agency that reviews, approves, and provides inspection services related to building/structure activities.
12. **Certificate of Occupancy** Issued by the Building Inspector after final inspection of a constructed structure has been made and found to be in substantial compliance with all the requirements of this all applicable codes.
13. **Certificate of Stabilization** Is issued by the City after final inspection of a site has been made and found to be in substantial compliance with all requirements of this manual and governing ordinance.
14. **Channel** means a natural or artificial watercourse with a definite bed and banks that conducts continuously or periodically flowing water.
15. **City Inspector** is any person from the Approving Agency authorized to perform and enforce site inspections.
16. **Clearing and Grubbing** is the cutting and removal of trees, shrubs, bushes, windfalls and other vegetation including removal of stumps, roots, and other remains in the designated areas.
17. **Contractor** is the person who contracts with the permittee, landowner, developer, or another contractor (i.e. subcontractor) to undertake any or all the land disturbance activities covered by this chapter.

18 **Co-Permittee** is any person, other than the permittee, including but not limited to a developer or contractor who has or represents financial or operational control over the land disturbing activity.

19 **Critical areas** are within 25 ft of, and on a positive slope toward a "Water of the Commonwealth" (as defined in KRS 244.01-010(33)).

20 **Dedication** means the deliberate appropriation of property by its owner for general public use.

21 **Detention** means the temporary storage of storm runoff in a stormwater management practice with the goals of controlling peak discharge rates and providing gravity settling of pollutants.

22 **Detention Facility** means a detention basin or alternative structure designed for the purpose of temporary storage of stream flow or surface runoff and gradual release of stored water at controlled rates.

23 **Developer** is any person, firm, corporation, sole proprietorship, partnership, state agency, or political subdivision thereof engaged in the development or re-development of property.

24 **Development** 1) The improvement of property for any purpose involving building; 2) Subdivision, or the division of a tract or parcel of land in to 2 or more parcels; 3) the combination of any two or more lots, tracts, or parcels of property for any purpose; 4) the preparation of land for any of the above purposes.

25 **Drainage Easement** means a legal right granted by a landowner to a grantee allowing the use of private land for stormwater management purposes.

26 **Engineer** is a professional engineer licensed in the Commonwealth of Kentucky to practice in the field of civil works.

27 **Erosion** The wearing away of the ground surface as a result of the movement of wind, water, ice, and/or land disturbance activities.

28 **EPSC (Erosion Protection and Sediment Control)** is the prevention of soil erosion and control of solid material during land disturbing activities to prevent its transport out of the disturbed area by means of air, water, gravity, or ice through the selection of Best Management Practices (BMP).

29 **Erosion Control Inspector** is a person designated by the Approving Agency who has attended a Richmond sponsored or approved training course in EPSC.

30 **Fee in Lieu** means a payment of money in place of meeting all or part of the stormwater performance standards required by this ordinance.

31 ***Final Stabilization*** means that:

a. All soil disturbing activities at the site have been completed and either (1) a uniform perennial vegetative cover with a density of 70% of native background vegetation cover for the area has been established on all unpaved areas and areas not covered by permanent structures or equivalent stabilization measures (i.e. riprap, gabions, or geotextiles) have been employed.
b. For individual lots in residential construction, final stabilization means, the lot either has completed final stabilization as specified above by the homebuilder or the homebuilder has established temporary stabilization including perimeter controls for an individual lot prior to occupation of the home by the homeowner and informing the homeowner of the need for, and benefits of, final stabilization.

32 **Floodplain** is the 100-year floodplain which is that area adjoining a watercourse which could be inundated by a flood that has a one (1) percent chance of being equaled or exceeded in any given year and is delineated on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM).

33 **General Permit** A KPDES Storm Water General Permit for storm water discharges related to construction activities that disturb one acre or more. Coverage under this general storm water permit is obtained by filing a Notice of Intent (NOI) with the Kentucky Division of Water (KDOW) and receiving approval from said agency and developing a SWPPP.

34 **Grade** is the vertical location of the ground surface.

(1) *Existing grade* is the grade (contour of the land) prior to land disturbance.

(2) *Rough grade* is the stage at which the grade approximately conforms to the approved plan.

(3) *Finish grade* is the final grade of the site which conforms to the approved plan.

35 **Groundwater Management Area** means a geographically defined area that may be particularly sensitive in terms of groundwater quantity and /or quality by nature of the use or movement of groundwater, or the relationship between groundwater an surface water, and where special management measures are deemed necessary to protect groundwater and surface water resources.

36 **High quality waters or** HQW means those “waters of the Commonwealth” that have been categorized by the Kentucky Division of Water as high quality pursuant to the requirements of 401 KAR 10:030, Section 1(3).

37 **Hotspot** means an area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

38 **Impervious Cover** means those surfaces that cannot effectively infiltrate rainfall (e.g., building rooftops, pavement, sidewalks, driveways, etc).

39 **Impaired Waters** means those streams, rivers and lakes that currently do not meet their designated use classification and associated water quality standards under the Clean Water Act.

40 **Infill Development** means land development that occurs within designated areas based on local land use, watershed, and/or utility plans where the surrounding area is generally developed, and where the site or area is either vacant or has previously been used for another purpose.

41 **Industrial Stormwater Permit** means a National Pollutant Discharge Elimination System permit issued to a commercial industry or group of industries which regulates the pollutant levels associated with industrial stormwater discharges or specifies on-site pollution control strategies.

42 **Infiltration** means the process of percolating stormwater into the subsoil.

43 **Infiltration Facility** means any structure or device designed to infiltrate retained water to the subsurface. These facilities may be above grade or below grade.

44 **Land Development** means a human-made change to, or construction on, the land surface that changes its runoff characteristics.

45 **Land Disturbance Activity** means any land change that may result in soil erosion from wind, water and/or ice and the movement of sediments into or upon waters, lands, or rights-of-way within the city, including but not limited to building demolition, clearing and grubbing, grading, excavating, transporting and filling of land. Land disturbance activity does not include the following:

(1) Minor land disturbance activities including, but not limited to, underground utility repairs, replacement of existing utilities, home gardens, minor repairs, and maintenance work.

(2) Installation of fence, sign, telephone, and electric poles and other kinds of posts or poles.

(3) Emergency work to protect life, limb, or property and emergency repairs. If the land disturbing activity would have required an approved SWPPP except for the emergency, then the land area disturbed shall be shaped and stabilized in accordance with the requirements of this chapter.

46 **Landowner** means the legal or beneficial owner of land, including those holding the right to purchase or lease the land, or any other person holding proprietary rights in the land.

47 **Maintenance Agreement** means a legally recorded document that acts as a property deed restriction, and which provides for long-term maintenance of stormwater management practices.

48 **Municipal Separate Storm Sewer System (MS4)** means publicly-owned facilities by which stormwater is collected and /or conveyed, including but not limited to any roads with drainage systems, municipal streets, gutters, curbs, catch basins, inlets, piped storm drain, pumping facilities, retention and detention basins, natural and human-made or altered drainage ditches/channels, reservoirs and other drainage structures.

49 **Non-Structural Measure** means a stormwater control and treatment technique that used natural processes, restoration or enhancement of natural systems, or design approaches to control runoff and/or reduce pollutant levels. Such measures are used in lieu of or to supplement structural practices on a land development site. Non-structural measures include, but are not limited to: minimization and/or disconnection of impervious surfaces; development design that reduces the rate and volume of runoff; restoration or enhancement of natural areas such as riparian areas, wetlands, and forests; and on-lot practices such as rain barrels, cisterns, and vegetated areas that intercept roof and driveway runoff.

50 **Nonpoint Source Pollution** means pollution from any source other than from any discernible, confined, and discrete conveyances, and shall include, but not be limited to, pollutants from agricultural, silvicultural, mining, construction, subsurface disposal and urban runoff sources.

51 **Notice of Intent (NOI)** means submission of the NOI to KDOW acts as the notice that the identified party intends to be authorized by a KPDES permit issued for stormwater discharges associated with construction activity.

52 **Notice of Termination (NOT)** is submitted to KDOW to terminate your KPDES permit coverage for stormwater discharges associated with construction activity.

53 **Offset Fee** means a monetary compensation paid to a local government for failure to meet pollutant load reduction targets.

54 **Off-Site Facility** means a stormwater management measure located outside the subject property boundary described in the permit application for land development activity.

55 **On-Site Facility** means a stormwater management measure located within the subject property boundary described in the permit application for land development activity.

56 **Ordinance Enforcement Board** shall consist of five (5) members, appointed by the mayor of Richmond, subject to the approval of the City Commission. The Code Enforcement Board shall hear and decide all appeals related to this Ordinance and enforce this ordinance pursuant to the provisions of KRS 65.8821.

57 **Outfall** the point of discharge to any watercourse from a public or private stormwater drainage system (piped or un-piped) as defined in the KPDES statewide general permit for MS4s (KYG20).

58 **Owner** the owner, mortgagee or person, firm or corporation in control of a piece of land; or any other person authorized to act as the agent for the owner; any person who submits a stormwater management concept or design plan for approval, or requests issuance of a permit, when required, authorizing land development to commence; and any person responsible for complying with an approved stormwater management design plan.

59 **Permittee** the applicant in whose name a valid Land Disturbance Permit is duly issued pursuant to this chapter and his/her agents, employees, and others acting under his/her direction.

60 **Planning and Zoning Director** is appointed by the City Commission and is the person in charge of the daily administration of the City of Richmond's Development Ordinance.

61 **Pollutant** means and includes dredged spoil, solid waste, incinerator residue, sewage, sewage sludge, garbage, chemical, biological or radioactive materials, heat, wrecked or discarded equipment, rock, sand, soil, industrial, municipal or agricultural waste, and any substance resulting from the development, processing, or recovery of any natural resource which may be discharged into water.

62 **Private Development/Redevelopment** means developments that are not the responsibility of the state or local municipality to provide maintenance on including storm sewers, stormwater facilities, and roads.

63 **Public Development/Redevelopment** means developments that are the responsibility of the state or local municipality to provide maintenance on including storm sewers, stormwater facilities, and roads.

64 **Public Works Director** is the City of Richmond Public Works Department Director and City Engineer.

65 **Redevelopment** means any construction, alteration or improvement involving land disturbance performed in areas where existing land use is high density commercial, industrial, institutional or multi-family residential.

66 **Responsible Party** means any individual, partnership, firm, company or any other legal entity that is named on a stormwater maintenance agreement as responsible for long-term operation and maintenance of one or more stormwater BMPs.

67 **Retention Facility** is a temporary or permanent natural or manmade structure that provides for the storage of storm water runoff by means of a permanent pool of water.

68 **Riparian Buffer** see Buffer Zone.

69 **Runoff** is rainfall, snowmelt, or irrigation water flowing over the ground surface.

70 **Sediment** means soils or other surficial materials transported or deposited by the action of wind, water, ice, or gravity as a product of erosion.

71 **Sedimentation** the process or action of deposition sediment that is determined to have been caused by erosion.

72 **Site** means the entire area of land on which the land disturbance activity is proposed in the land disturbance permit application.

73 **Site Plan** is a plan or set of plans showing the details of any land disturbance activity of a site including but not limited to the construction of: structures, open and enclosed drainage facilities, stormwater management facilities, parking lots, driveways, curbs, pavements, sidewalks, bike paths, recreational facilities, ground covers, plantings, and landscaping.

74 **Slope** the incline of a ground surface expressed as a ratio of horizontal distance to vertical distance.

75 **Soil** naturally occurring surficial deposits overlying bedrock.

76 **Stop Work Order** means an order issued which requires that all construction activity on a site be stopped.

77 **Stormwater Management** means the use of structural or non-structural practices that are designed to reduce stormwater runoff pollutant loads, discharge volumes, peak flow discharge rates and detrimental changes in stream temperature that affect water quality and habitat.

78 **Stormwater Procedures Manual** a compilation of rules, design criteria, guidelines and standards adopted by the City of Richmond as being proven methods of controlling construction related surface runoff, erosion and sedimentation.

79 **Stormwater Pollution Prevention Plan (SWPPP)** means a site-specific, written document that: (1) identifies potential sources of stormwater pollution at the construction site; (2) describes practices to reduce pollutants in stormwater discharges from the construction site; and identifies procedures the operator will implement to comply with the terms and conditions of a construction general permit.

80 **Stormwater Retrofit** means a stormwater BMP designed for an existing development site that previously had either no stormwater BMP in place or a practice inadequate to meet the stormwater management requirements of the site.

81 **Stormwater Runoff** means stormwater run-off, snow melt run-off, and surface run-off and drainage.

82 **Stormwater Treatment Practices (STPs)** means measures, either structural or nonstructural, that are determined to be the most effective, practical means of preventing or reducing point source or nonpoint source pollution inputs to stormwater runoff and water bodies.

83 **Stream Buffer** means an area of land at or near a stream bank, wetland, or waterbody that has intrinsic water quality value due to the ecological and biological processes it performs or is otherwise sensitive to changes which may result in significant degradation to water quality.

84 **Stripping** any activity which removes or significantly disturbs the vegetative surface cover including clearing, grubbing of stumps and root mat, and topsoil removal.

85 **Structure** anything manufactured, constructed or erected which is normally attached to or positioned on land, including buildings, portable structures, earthen structures, roads, parking lots, and paved storage.

86 **Topsoil** the upper layer of soil.

87 **Utility** is the owner/operator of any underground facility including an underground line, facility, system, and its appurtenances used to produce, store, convey, transmit, or distribute communications, data, electricity, power, heat, gas, oil, petroleum products, potable water, stormwater, steam, sewage and other similar substances.

88 **Water Pollution** means the alteration of the physical, thermal, chemical, biological, or radioactive properties of the waters of the Commonwealth in such a manner, condition, or quantity that will be detrimental to the public health or welfare, to animal or aquatic life or marine life, to the use of such waters as present or future sources of public water supply or to the use of such waters for recreational, commercial, industrial, agricultural, or other legitimate purposes.

89 **Watercourse** means a channel, which gathers or carries surface water.

90 **Watershed** is a region draining to a specific river, river system, or body of water.

91 **Wetlands** a lowland area such as a marsh, that is saturated with moisture, as defined in Sec. 404, Federal Water Pollution Control Act Amendments of 1987.

References

1 References

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Knox County, Tennessee. *Knox County Stormwater Management Manual Volume 2, Technical Guidance*. 2006.

Atlanta Regional Council (ARC). *Georgia Stormwater Management Manual Volume 2 Technical Handbook.* 2001.

Washington State Department of Ecology. *Stormwater Management Manual for Western Washington.* 2000.

City of Richmond
Planning and Zoning
(859) 623-1000
239 West Main Street
Richmond, KY 40475

Storm Water Calculation Worksheet

Project/Applicant name: ____

Pre-Development Area

Total area of lot/parcel ___________ acres   One (1) acre contains 43,560 sq/ft
Total area of lot/parcel ___________ sq/ft

Land-Disturbing Activity is any activity that results in movement of earth, or a change in the existing soil cover (both vegetative and non-vegetative) and/or the existing soil topography. Land disturbing activities include, but are not limited to clearing, grading, filling, excavation, and compaction associated with stabilization of structures and road construction.

LAND DISTURBING ACTIVITY, STABILIZATION, VOLUME OF CUT/FILL

Impervious surface is a hard surface that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development. A hard surface area which causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to roof tops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, packed earthen materials, or other surfaces which similarly impede the natural infiltration of storm water.

STORM WATER CALCULATIONS – IMPERVIOUS SURFACE

NEW/PROPOSED

Total New/ Proposed ____________sq/ft

Percentage Impervious Area __________%

EXISTING

Total Existing ____________sq/ft

Percentage Impervious Area __________%

Calculate the total area to be cleared, graded, filled, excavated, and/or compacted for proposed development project. Include in this calculation the area to be cleared for:

Indicate Total Volumes of Proposed:
Cut______________ (cu/yd)   Fill ______________ (cu/yd)

Storm Water Detention/Retention Design

(Attach separate sheets to show cross-sections and details) Ref. Attachments: YES NO

Total Storage Required: __________ cu.ft. Dimensions: ___________________

Material: ______________________ Type: ________________________

Comments: ____

Outlet Structure Design

(Attach separate sheet to show outlet structure detail) Ref. Attachments: YES NO

Material: ________________

2 Yr Inlet: _________(size) ______ (elev.) Storage: ___________cu.ft.

25 Yr Inlet: ________(size) ______ (elev.) Storage: ___________cu.ft.

100 Yr Inlet: _______(size) ______ (elev.) Storage: ___________cu.ft.

Outlet: ____________(size) ______ (elev.) ____________ (material)

* Attach plat/plan sheet showing entire site development with storm sewer system improvements to be installed on development with catch basins, man holes, junction boxes, outlet structures, proposed contours, existing contours, easements, structure details, and etc. that pertain to the installation and maintenance of the completed storm sewer system.

ENGINEER & APPLICANT SIGNATURE

By signing the Storm Water Calculation Worksheet, I as the engineer attest that the information provided herein was calculated by me and is true and correct to the best of my knowledge.

____
(FIRM NAME)

(WET STAMP)

____________________________________ ____________
(ENGINEER SIGNATURE) (DATE)

By signing the Storm Water Calculation Worksheet, I as the applicant/owner attest that the information provided herein is true and correct to the best of my knowledge. I also certify that this application is being made with the full knowledge and consent of all owners to install the aforementioned improvements to the affected property as stated in this application.

____________________________________ __________________
(LANDOWNER OR AUTHORIZED SIGNATURE) (DATE)

____
(LANDOWNER OR AUTHORIZED PRINTED NAME)

City of Richmond
Planning and Zoning
(859) 623-1000
239 West Main Street
Richmond, KY 40475

City of Richmond Planning & Zoning – Project Submittal Checklist

The following briefly outlines the Planning and Zoning (P&Z) plat/plan approval process submittal schedule of approval for engineers, surveyors, owners, and developers.

1. Meet with the Planning and Zoning Director at least seven (7) days before any plat/plan is submitted to discuss requirements. (See D.O. Sec. 502.5)

Submission Deadline: **Date**:________________ **Time: 12:00 p.m.**
Technical Advisory Committee: Date:________________ Time: 1:30 p.m.

2. Submit plat/plans for Technical Advisory Committee (T.A.C.)
   - ☐ Completed and signed application. (found online)
   - ☐ Completed plat checklist. (found online or Appendix "A" in the development ordinance)
   - ☐ Minimum of Fifteen (15) full scale copies of plat/plan.
   - ☐ Minimum of three (3) full scale copies of SWPPP, BMP Plan, or Erosion Sediment Control Plan
   - ☐ Storm Calculation Worksheet completed with supporting attachments.
   - ☐ Stormwater Management Plan, as applicable
3. T.A.C. meeting with utility providers. Must have a knowledgeable representative present to answer questions and concerns pertaining to plat/plan. Plats pulled from review at T.A.C. will be resubmitted starting with step two (2).
4. Engineer/surveyor will receive a list of comments/corrections from the T.A.C. meeting by the following Friday. If not received via e-mail or fax it is the responsibility of the engineer/surveyor to contact the P&Z Office.

Submission Deadline: **Date**:________________ **Time: 12:00 p.m.**
Planning & Zoning Work Session: Date:________________ Time: 5:30p.m.

5. Submit for Work Session meeting with the Planning and Zoning Commissioners.
   - ☐ All comments/corrections from T.A.C. meeting have been completed and shown on plat/plans.
   - ☐ Application fee and engineering review fees are due.
   - ☐ Minimum of Fifteen (15) copies of plat/plan. Contact the P&Z office for approval to reduce the scale of plans in an effort to conserve paper. If plans can be rescaled a minimum of three (3) full scale copies are required with twelve at the reduced scale.
   - ☐ Minimum of three (3) full scale copies of SWPPP, BMP Plan, or Erosion Sediment Control Plan
   - ☐ Stormwater Management Plan, as applicable
6. Work Session Meeting: Must have a knowledgeable representative present to answer questions and concerns pertaining to plat/plan. Plats/plans pulled from review will be resubmitted starting with step five (5). If more than one (1) month has lapsed or major design changes have occurred plats/plans will be required to follow steps starting with step two (2).

7. Engineer/surveyor will receive a list of comments/corrections from the W.S. meeting by noon the following day. If not received via e-mail or fax it is the responsibility of the engineer/surveyor to contact the P&Z Office.

Submission Deadline:	**Date**:________________	**Time: 12:00 p.m.**
P&Z Business Session:	**Date:________________**	**Time: 5:30p.m.**

8. Submit for Business Session with the P&Z Commissioners.
   - □ All comments/corrections from the W.S. meeting have been completed and shown on plat/plans.
   - □ Minimum of Fifteen (15) copies of plat/plan. Contact the P&Z office for approval to reduce the scale of plans in an effort to conserve paper. If plans can be rescaled a minimum of three (3) full scale copies are required with twelve at the reduced scale.
   - □ Minimum of three (3) full scale copies of SWPPP, BMP Plan, or Erosion Sediment Control Plan
   - □ Stormwater Management Plan, as applicable
   - □ Geo-referenced digital compliant to the City's GIS digital requirements.
9. Business Session Meeting: Must have a knowledgeable representative present to answer questions and concerns pertaining to plat/plan. All previous comments/corrections should be complete. Plats/plans will only be approved contingent upon signatures at this point. Plats/plans that fail to meet this requirement will be resubmitted the following month for Work Session review and follow the guidelines starting with step five (5).

* The Planning and Zoning office will require one (2) full size copy of any plat/plan with signature approvals and one (1) geo-referenced digital, compliant with the City's GIS digital requirements.

Development Ordinance Quick Reference Guide

406.4 Dimensional Requirements (Setback & easements by zone)
406.5 Allowable Land Uses (Permitted & conditional use by zone)
409K Landscaping (Design requirements and buffer regulations)
411 Parking Regulations
412 Signs (Application available online)
414 Outdoor Lighting
514 Public Utilities/Facilities (Water, gas, sanitary sewer, & stormwater)
516 Construction Guarantees (Bonds, Issuance of Temporary C.O. Agreements)
517 Schedule of Fees, Charges, & Expenses
Ordinance 12-51 Post Construction Stormwater Runoff
Ordinance 12-52 Erosion Prevention and Sediment Control Requirements
Ordinance 12-53 Erosion Prevention and Sediment Control Requirements for lots less than one acre and not part of a larger common plan of development.
Ordinance 12-54 Prohibition, Elimination, and Control of Illicit Discharges to the Storm Sewer System

Planning & Zoning Web Site: http://planning.richmond.ky.us/
See the application page online for supporting documents.
See the information section for:
City's Development Ordinance
Comprehensive Plan
Plat Details for development and erosion control

City of Richmond
Storm Infrastructure Certification Form

Business/Development Name: ____
Site Address: ____
Description of Detention Area: ____
____

Contact Information:
Owner: ____________________________ Developer: _______________________
Company: __________________________ Company: ________________________
Address: ___________________________ Address: _________________________
Phone#: ____________________________ Phone#: __________________________

Responsible Party for Detention Area, Construction, and Maintenance:
Name: ____
Address: ____
Phone#: ____

Professional Engineer:
Company: ____
Name: ____
Address: ____
Phone#: ____

With this form:
*Attach hard copy of signed and wet stamped construction drawings for storm water infrastructure proposed for this development.
* Attach a digital copy of construction plat that shall be properly geo-referenced onto the City of Richmond Geographic Information System (GIS).
* Engineer to provide daily construction reports and a full set of digital and hard copy as-built.

Site Approval Date: _____________________ Construction Start Date: ______________
Infrastructure Completion Date: ______________________
Follow Up Inspection Date: __________________________
(approx. 3yrs after completion date)

I certify under penalty of law that the storm water infrastructure and permanent stormwater management measures installed on this project were constructed within substantial compliance to the engineering design and construction documents designed by ________________________ PE license #___________ date __________.

I have notified the party responsible for operation and maintenance of the permanent stormwater management measures, and explained the duties and responsibilities that are associated with their proper operation. They have signed all required agreements for operation and maintenance of the permanent stormwater management measures.

I furthermore certify that the installed infrastructure including permanent stormwater management measures functions as represented in the design and hydraulic calculations provided to the City of Richmond for this project.

_____________________________ (Certifying Engineer)

________ Date

(Wet Stamp of Certifying Engineer)

Document Preparation Date: November, 2012

STORMWATER MANAGEMENT/BMP FACILITIES OPERATION AND MAINTENANCE AGREEMENT

THIS AGREEMENT, made and entered into this ___ day of ____________, 20___, by and between (Insert Full Name of Owner)____hereinafter called the "Landowner", and City of Richmond, hereinafter called the "City". WITNESSETH, that WHEREAS, the Landowner is the owner of certain real property described as (Madison County tax Map/Parcel Identification Number) ____ as recorded by deed in the land records of Madison County, Kentucky, Deed Book __________ Page __________, hereinafter called the "Property".

WHEREAS, the Landowner is proceeding to build on and develop the property; and

WHEREAS, the Site Plan/Subdivision Plan known as ___________________________________ (Name of Plan/Development), hereinafter called the "Plan", which is expressly made a part hereof, as approved or to be approved by the City, provides for detention and/or treatment of stormwater within the confines of the property; and

WHEREAS, the City and the Landowner, its successors and assigns, including any homeowners association, agree that the health, safety, and welfare of the residents of Richmond, Kentucky require that on-site stormwater management/BMP facilities be constructed and maintained on the Property; and

WHEREAS, the City requires that on-site stormwater management/BMP facilities as shown on the Plan be constructed and adequately maintained by the Landowner, its successors and assigns, including any homeowners association.

NOW, THEREFORE, in consideration of the foregoing premises, the mutual covenants contained herein, and the following terms and conditions, the parties hereto agree as follows:

1. The on-site stormwater management/BMP facilities shall be constructed by the Landowner, its successors and assigns, in accordance with the plans and specifications identified in the Plan.
2. The Landowner, its successors and assigns, including any homeowners association, shall adequately maintain the stormwater management/BMP facilities. This includes all pipes and channels built to convey stormwater to the facility, as well as all structures,

improvements, and vegetation provided to control the quantity and quality of the stormwater. Adequate maintenance is herein defined as good working condition so that these facilities are performing their design functions. The Annual Inspection Report is to be used to establish if the working condition of the facility is acceptable to the City.

3. The Landowner, its successors and assigns, shall inspect the stormwater management/BMP facility and submit an inspection report annually. The purpose of the inspection is to assure safe and proper functioning of the facilities. The inspection shall cover the entire facilities, berms, outlet structure, pond areas, access roads, etc. Deficiencies shall be noted in the inspection report.
4. The Landowner, its successors and assigns, hereby grant permission to the City, its authorized agents and employees, to enter upon the Property and to inspect the stormwater management/BMP facilities whenever the City deems necessary. The purpose of inspection is to follow-up on reported deficiencies and/or to respond to citizen complaints. The City shall provide the Landowner, its successors and assigns, copies of the inspection findings and a directive to commence with the repairs if necessary.
5. In the event the Landowner, its successors and assigns, fails to maintain the stormwater management/BMP facilities in good working condition acceptable to the City, the City may enter upon the Property and take <u>whatever steps necessary</u> to correct deficiencies identified in the inspection report and to charge the costs of such repairs to the Landowner, its successors and assigns. This provision shall not be construed to allow the City to erect any structure of permanent nature on the land of the Landowner outside of the easement for the stormwater management/BMP facilities. It is expressly understood and agreed that the City is under no obligation to routinely maintain or repair said facilities, and in no event shall this Agreement be construed to impose any such obligation on the City.
6. The Landowner, its successors and assigns, will perform the work necessary to keep these facilities in good working order as appropriate. In the event a maintenance schedule for the stormwater management/BMP facilities (including sediment removal) is outlined on the approved plans, the schedule will be followed.
7. In the event the City pursuant to this Agreement, performs work of any nature, or expends any funds in performance of said work for labor, use of equipment, supplies, materials, and the like, the Landowner, its successors and assigns, shall reimburse the

City upon demand, within thirty (30) days of receipt thereof for all actual costs incurred by the City hereunder.

8. This Agreement imposes no liability of any kind whatsoever on the City and the Landowner agrees to hold the City harmless from any liability in the event the stormwater management/BMP facilities fail to operate properly.
9. This Agreement shall be recorded among the land records of Madison County, Kentucky, and shall constitute a covenant running with the land, and shall be binding on the Landowner, its administrators, executors, assigns, heirs and any other successors in interests, including any homeowners association.

WITNESS the following signatures and seals:

____
Company/Corporation/Partnership Name (Seal)

By: ____

____
(Type Name)

____
(Type Title)

STATE OF KENTUCKY

COUNTY OF MADISON

The foregoing Agreement was acknowledged before me this ____ day of _________, 20___, by

____.

____
NOTARY PUBLIC

My Commission Expires: ____________

CITY OF RICHMOND, KENTUCKY

By: ____

____
(Name)

____
(Title)

STATE OF KENTUCKY

COUNTY OF MADISON

The foregoing Agreement was acknowledged before me this ____ day of _________, 20___, by

____.

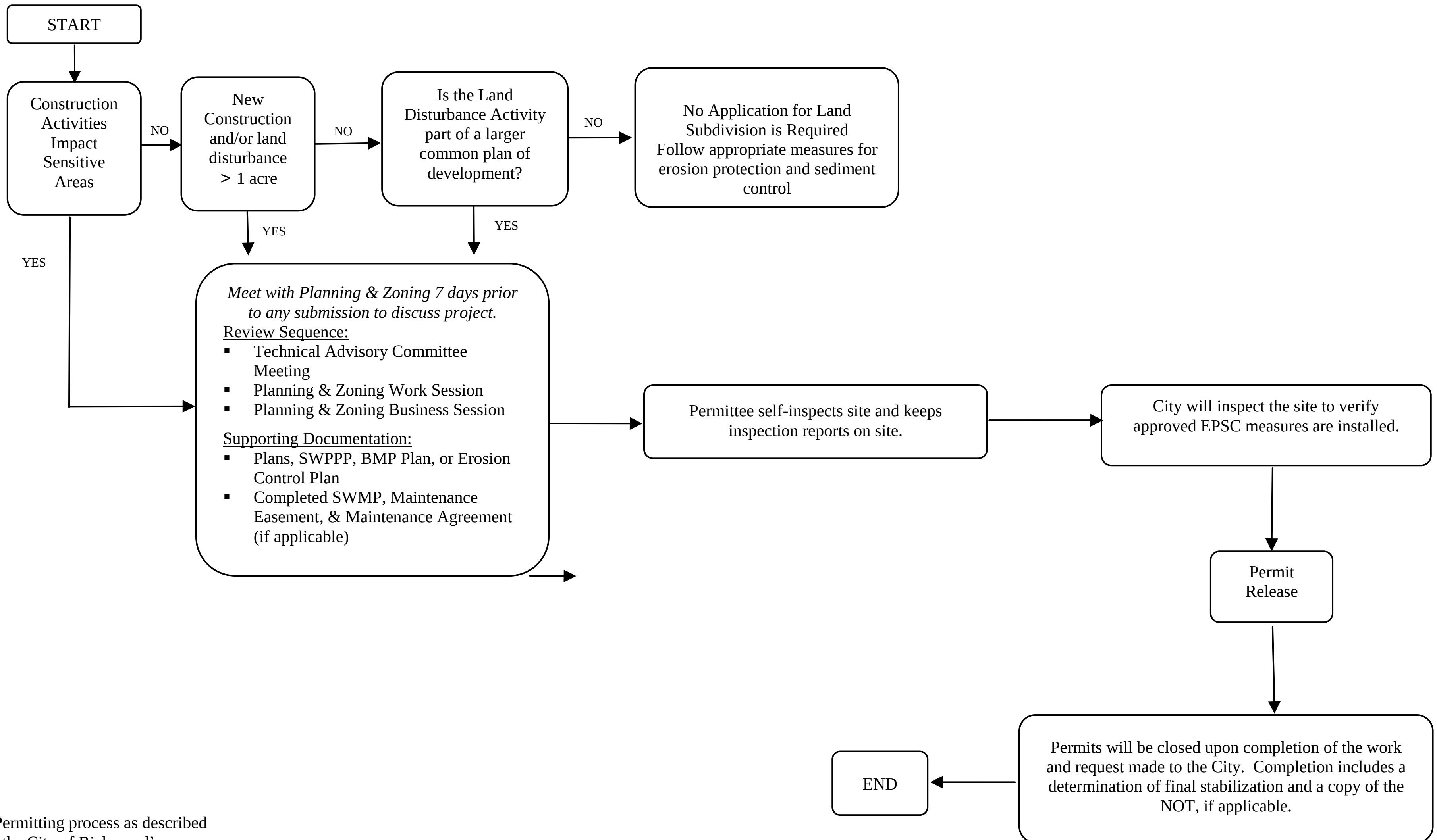
____
NOTARY PUBLIC

My Commission Expires: _____________

Approved as to Form:

____________________________________ ____________
City Attorney Date

LAND DISTURBANCE PERMITTING PROCESS*



*****Permitting process as described in the City of Richmond's Stormwater Procedures Manual and enforced by City Ordinances.

Permeable Pavement Inspection and Maintenance Checklist

Site Name:____

Location:____

Site Status:____

Date:______________________ Time:______________________

Inspector:____

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Item	Inspected (Yes or No)	Maintenance Needed (Yes or No)	Comments / Description
1. Pavement Area (Monthly)			
Pavement area free of debris			
Inlets and outlets unobstructed			
Is water standing after a storm event*			
Any evidence of clogged pores that require vacuum-sweeping			
Access to pervious pavement (egress and ingress routes) safe and efficient			
2. Vegetation			
Any evidence of eroding material coming into or from pervious pavement areas **			
Any noticeable irrigation needs			
Fallen leaves/plant debris collecting in paving area			
Grass height over 4 inches			
Vegetation health affected by oil/grease from vehicles **			

* After major storms
** Annually

Other **			
3. Hazards (Monthly)			
Obstructions or debris affecting overflows / emergency spillways			
Load-bearing capability of pavement intact			

Comments:

____

____

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

Actions to be Taken:

____

____

____

____

____

The next routine inspection is scheduled for approximately: ___________________
(date)

* After major storms
** Annually

Greenroof Inspections and Maintenance Checklist

Site Name:______________________________

Location:______________________________

Site Status:______________________________

Date:______________ Time:______________

Inspector:______________________________

Greenroof Type: Extensive Roof Cover ☐ Intensive Roof Garden ☐

Inspection Items	Inspected (Yes or No)	Maintenance Needed (Yes or No)	Comments / Description
1. Debris Removal (Monthly)			
Gutter inlets blocked by plant debris/trash or plant growth hindered by debris			
2. Vegetation (Monthly)			
Any evidence of additional irrigation needs? *			
Fallen leaves/debris interfering with plant health			
Any dead plants to be replaced			
Any need for weeding/ mowing/trimming *			
3. Soil Substrate/Growing Medium (Annual)			
Any evidence of wind or water erosion			
4. Structural Components (Annual)			
Any evidence of structural deterioration			
Load-bearing walls in good condition			
Spalling or cracking of structural parts			

* Monthly during growing season

Access/maintenance routes maintained and free of debris			
Other (After Major Storms)			
Any locations of standing water that may harbor insect infestations			

Comments:

____

____

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Actions to be Taken: **Due Date:**

____

____

____

____

____

The next routine inspection is scheduled for approximately: ___________________
(date)

* Monthly during growing season

Operation and Maintenance Inspection Report for Enhanced Swales, Grass Channels, Open Channels and Filter Strips

Site Name:______________________________

Location:______________________________

Site Status:______________________________

Date:______________ Time:______________

Inspector:______________________________

Maintenance Item	Inspected (Yes or No)	Maintenance Needed (Yes or No)	Comments / Description
1. Debris Cleanout (Monthly)			
Facility and adjacent area clear of debris			
Inlets and outlets clear of debris			
Any dumping of yard wastes into facility			
Has litter (branches, etc) been removed			
2. Vegetation (Monthly)			
Adjacent areas stabilized			
Grass mowed			
Plant height not less than design water depth			
Any evidence of erosion			
Is plant composition according to approved plans			
Any unauthorized or inappropriate plantings			
Any dead or diseased plants			
Any evidence of plant stress from inadequate watering			
3. Oil and Grease (As applicable to BMP) (Monthly)			
Any evidence of filter clogging			

4. Dewatering (Monthly)			
Facility dewaters between storms			
5. Check Dams/Energy Dissipators (Annually, After major storms)			
Any evidence of sedimentation buildup			
Does sedimentation require removal (i.e. > 50% full)			
Any evidence of erosion at downstream toe of drop structures			
6. Sediment Deposition (Annually)			
Swale clean of sediments			
Sediments should not be > than 20% of swale design depth			
7. Outlets/overflow spillway (Annually, After major storms)			
General condition			
Any evidence of erosion			
Any evidence of blockages			
8. Integrity of Facility			
Has facility been blocked or filled inappropriately			

Comments:

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

If any of the above Inspection Items are checked “yes” for “Maintenance Needed”, list maintenance actions below:

Maintenance Actions to be Taken:

____

____

____

The next routine inspection is scheduled for approximately ____________________
(date)

Infiltration Trench Operation, Maintenance, and Management Inspection Checklist

Site Name:____

Location:____

Site Status:____

Date:_____________________________ Time:_____________________________

Inspector:____

Maintenance Item	Inspected (Yes or No)	Maintenance Needed (Yes or No)	Comments / Description
1. Debris Cleanout (Monthly)			
Trench surface clear of debris			
Inflow pipes clear of debris			
Inlet area clear of debris			
Overflow spillway clear of debris			
2. Sediment Traps or Forebays (Annual)			
Obviously trapping sediment			
Greater than 50% of storage volume remaining			
3. Dewatering (Monthly)			
Trench dewaters between storms			
4. Sediment Cleanout of Trench (Annual)			
Evidence of sedimentation in trench			
Does sedimentation currently require removal			
5. Inlets (Annual)			
Good condition			
Any evidence of erosion			

6. Outlet/Overflow Spillway (Annual)			
Good Condition, no need for repair			
Any evidence of erosion			
7. Aggregate Repairs (Annual)			
Surface of aggregate clean			
Top layer of stone in need of replacement			
Trench in need of rehabilitation			

Comments:

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

If any of the above Inspection Items are checked "yes" for "Maintenance Needed", list maintenance actions below:

Maintenance Actions to be Taken:

____

____

____

The next routine inspection is scheduled for approximately ____________________
(date)

Sand/Organic Filter Operation, Maintenance, and Management Inspection Checklist

Site Name:________________________________

Location:________________________________

Site Status:________________________________

Date:________________ Time:________________

Inspector:________________________________

Inspection Frequency Key: A=annual; M=monthly; S=after major storms.

Maintenance Item	Inspected (Yes or No)	Maintenance Needed (Yes or No	Comments / Description
1. Debris Cleanout (Monthly)			
Contributing areas cleanout of debris			
Filtration facility clean of debris			
Inlet and outlets clear debris			
2. Oil and Grease (Monthly)			
No evidence of filter surface clogging			
Activities in drainage area minimize oil and grease entry			
3. Vegetation (Monthly)			
Contributing drainage area stabilized			
No evidence of erosion			
Area mowed and clipping removed			
4. Water Retention Where Required (Monthly)			
Water holding chambers at normal pool			
No evidence of leakage			
5. Sediment Deposition (Annual)			

Filter chamber free of sediments			
Sedimentation chamber not more than half full of sediments			
6. Structural Components (Annual)			
No evidence of structural deterioration			
Any grates are in good condition			
No evidence of spalling or cracking of structural parts			
7. Outlets/Overflow Spillway (Annual)			
Good condition (no need for repair)			
No evidence of erosion (if draining into a natural channel)			
8. Overall Function of Facility (Annual)			
Evidence of flow bypassing facility			
No noticeable odors outside of facility			

Comments:

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

If any of the above Inspection Items are checked "yes" for "Maintenance Needed", list maintenance actions below:

Maintenance Actions to be Taken:

____

____

____

The next routine inspection is scheduled for approximately ____________________
(date)

Stormwater Pond Operation, Maintenance, and Management Inspection Checklist

Site Name:____

Location:____

Site Status:____

Date:_____________________ Time:_____________________

Inspector:____

.

Maintenance Item	Inspected (Yes or No)	Maintenance Needed (Yes or No	Comments / Description
Embankment and emergency spillway (Annual, After Major Storms)			
1. Vegetation and ground cover adequate			
2. Embankment erosion			
3. Animal burrows			
4. Unauthorized planting			
5. Cracking, bulging or sliding of dam			
a. Upstream & downstream face			
b. At or beyond toe (downstream/upstream)			
c. Emergency spillway			
6. Pond, toe & chimney drains clear and functioning			
7. Seeps/leaks on downstream face			
8. Slope protection or riprap failure			
9. Vertical/horizontal Alignment of top of Dam “As-Built”			

10. Emergency spillway clear of obstructions and debris			
11. Other (specify)			
Riser and principal spillway (Annual)			
1. Flow office obstructed			
2. Low flow trash rack			
3. Weir trash rack maintenance			
4. Excessive sediment accumulation insider riser			
5. Condition of riser and barrels a. cracks or displacement			
b. Minor spalling (<1”)			
c. Major spalling (rebars exposed)			
d. Joint failures			
e. Water tightness			
6. Metal pipe condition			
7. Control valve a. Operational/exercised			
b. Chained and locked			
8. Pond drain valve a. Operational/exercised			
b. Chained and locked			
9. Outfall channels functioning			
10. Other (specify)			
Permanent Pool (Wet Ponds)		**(Monthly)**	
1. Undesirable vegetative growth			
2. Floating or floatable debris removal required			
3. Visible pollution			

4. Shoreline problem			
5. Other (specify)			
Sediment Forebays			
1. Sedimentation noted			
2. Sediment cleanout when depth <50% design depth			
Dry Pond Areas			
1. Vegetation adequate			
2. Undesirable vegetative growth			
3. Undesirable woody vegetation			
4. Low flow channels clear of obstructions			
5. Standing water or wet spots			
6. Sediment and/or trash accumulation			
7. Other (specify)			
Condition of Outfall into Ponds (Annual, After Major Storms)			
1. Riprap failures			
2. Slope erosion			
3. Storm drain pipes			
4. Endwalls / Headwalls			
5. Other (Specify)			
Other (Monthly)			
1. Encroachment on pond or easement area			
2. Complaints from residents			
3. Aesthetics a. Grass growing required			
b. Graffiti removal needed			

c. Other (specify)			
4. Any public hazards (specify)			
Constructed Wetland Area (Annual)			
1. Vegetation healthy and growing			
2. Evidence of invasive species			
3. Excessive sedimentation in Wetland Area			

Comments:

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

If any of the above Inspection Items are checked "yes" for "Maintenance Needed", list maintenance actions below:

Maintenance Actions to be Taken:

____

____

____

The next routine inspection is scheduled for approximately ____________________
(date)

Constructed Wetlands Inspections and Maintenance Checklist

Site Name:______________________________

Location:______________________________

Site Status:______________________________

Date:______________ Time:______________

Inspector:______________________________

Inspection Item	Inspected (Yes or No)	Maintenance Needed (Yes or No	Comments / Description
Embankment and emergency spillway (Monthly, After major storm)			
Vegetation healthy			
Erosion on embankment			
Animal burrows in embankment			
Cracking, sliding, bulging of dam			
Drains blocked or not functioning			
Leaks or seeps on embankment			
Emergency spillway obstructed			
Erosion in/around emergency spillway			
Other			
Riser and principal spillway (Annually)			
Low-flow orifice functional*			
Trash rack (Debris removal needed? Corrosion?)*			
Sediment buildup in riser			
Concrete/Masonry condition (Cracks,displacement, spalling?)			
Metal pipe in good condition			
Control valve operation			
Pond drain valve operation			

*After major storm

Outfall channels function, not eroding			
Other (describe)			
Sediment Forebays (Annually)			
Sedimentation description			
Sediment cleanout needed (over 50 percent full)*			
Constructed Wetland Ponding Areas (Monthly)			
Wetland vegetation present and healthy			
Vegetation removal needed			
Floatable debris			
Shoreline problem			
Erosion at outfalls into pond			
Headwalls in good condition			
Hazards (Monthly)			
Have there been complaints from residents			
Public hazards noted			

Comments:

____

____

____

Overall Condition of Facility ☐ **Acceptable** ☐ **Unacceptable**

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed: **Due Date**

____

____

____

The next routine inspection is scheduled for approximately: ____________________
(date)

*After major storm