4.1 Bioretention BMP Summary Fact Sheet

Description: Shallow storm water basin or landscaped area that utilizes engineered soils and vegetation to capture and treat runoff. Bioretention facilities are intended to provide water quality functions by filtering stormwater runoff and allowing vegetation uptake of nutrients. Treatment area consists of grass filter, sand bed, ponding area, organic/mulch or sod layer, planting soil, and vegetation. The primary processes that this BMP uses for pollutant removal are filtration and biological uptake.

IMPORTANT CONSIDERATIONS

DESIGN CRITERIA:

- An underdrain system must be designed so that runoff exits the facility within 48 hours assuming 50 percent of the underdrain capacity is lost due to clogging. The underdrain must not limit outflow more than the filter media. Infiltration calculations will be allowed if internal water storage is part of the design.
- Soil media and mulch or sod layer composition must be consistent with the specifications given in the details for these facilities.
- Diverse and native plant species designed for the hydric zone must be used.
- Pretreatment and energy dispersion must be provided.
- Provide sheet flow conditions into the facility (flow depth less than 1 inch and velocity less than 1 ft/s).
- Maximum contributing drainage area of 10 acres.
- Maximum contributing drainage of 5 acres per inflow point. Additional design effort to achieve sheet flow conditions for large inflows is necessary.
- Maximum ponding depth above the mulch for WQ_V and CP_V is 12 inches.
- Facility must not receive base flow and must be allowed to drain and reaerate between rainfall events.

ADVANTAGES/BENEFITS:

- Applicable to small drainage areas.
- Good for highly impervious areas.
- Can be planned as an aesthetic feature.

DISADVANTAGES/LIMITATIONS:

- Bioretention facilities are prone to failure due to piping through the soil media or inability of inflows to be dispersed and non-erosive.
- Facilities cannot be used without engineered soil material with appropriate phosphorus levels.
- Facilities cannot be used for watersheds with base flow and must be allowed to drain and reaerate between rainfall events.
- Sediment regulation is critical to sustain bioretention.
- Large commitment to establish and maintain vegetation.

MAINTENANCE CONSIDERATIONS:

- Inspect and repair/replace treatment area components.
- Adequate access must be provided for inspection/ maintenance.

STORMWATER MANAGEMENT SUITABILITY

L = Low **M** = Moderate **H** = High

H — **1-inch, 6- hr Water Quality (WQ_v) Control**

M — **1-yr, 24-hr Channel Protection (CP_v) Control**

L — **Peak Attenuation Control for 10-yr, 6-hr Storm**

L — **Peak Attenuation Control for 25-yr, 6-hr storm**

Bioretention facilities are highly effective in removing pollution from the 1-inch, 6-hr storm and can be designed to remove pollution for the 1-yr, 24-hr storm and a portion of peak attenuation for larger storm events.

IMPLEMENTATION CONSIDERATIONS

L — **Land Requirements**

M — **Capital Cost**

M — **Maintenance Cost**

M — **Clogging Issues with Orifices**

PRIMARY POLLUTANT REMOVAL PROCESSES

- Filtration
- Biological

WQ_V POLLUTANT REMOVAL RATES

Effectiveness	Design Detention Time *	Media Depth	Pollutant Removal Rates
Optimal Efficiency	1.3 days	4 feet	85% TSS 70% TP
Standard Efficiency	1.0 days	2 feet	85% TSS 60 % TP
TSS-Only Efficiency	**	2 feet	85% TSS 45% TP

* measured from the midpoint of the design storm
** based on depth of the water quality volume

4.1 Bioretention

4.1.1 General Description

Bioretention areas (also referred to bioretention filters, bioretention cells, and rain gardens) are structural storm water controls that capture and are able to temporarily store the water quality control volume (WQ_v) using solids and vegetation in landscaped areas to remove pollutants from storm water runoff. In addition, bioretention areas are able to temporarily store some or all of the channel protection volume (CP_v) and provide limited storage for peak attenuation for larger storm events.

Bioretention areas are engineered facilities in which runoff is conveyed as sheet flow to the “treatment area” which consists of a grass buffer strip, ponding area, organic, sod, or mulch layer, planting soil, and vegetation. An optional sand bed can also be included in the design to provide aeration and drainage of the planting soil. The filtered runoff is collected and returned to the conveyance system through an underdrain system. Some runoff collected in the bioretention area will infiltrate into the surrounding soil in areas with porous soils, the filter media and underdrain system may be designed assuming infiltration as per the infiltration requirements, specifications, and calculations specified in the Chapter 18 of the NCDENR Stormwater BMP Manual

There are numerous design applications, both on-line and off-line, for bioretention areas. On-line applications are where the entire contributing watershed flows through the facility and is typically applied to small watersheds such as single-family residential lots. Off-line applications employ a flow diversion structure intercepts of portion of the watershed flow into the facility and bypasses larger storm events. Typical off-line facilities are adjacent to parking lots, within larger pervious areas, and landscaped islands. Figures 4.1.1, 4.1.2, and 4.1.3 illustrate a number of examples of bioretention areas in both photographs and drawings.

Figure 4.1.1. Bioretention Area Examples

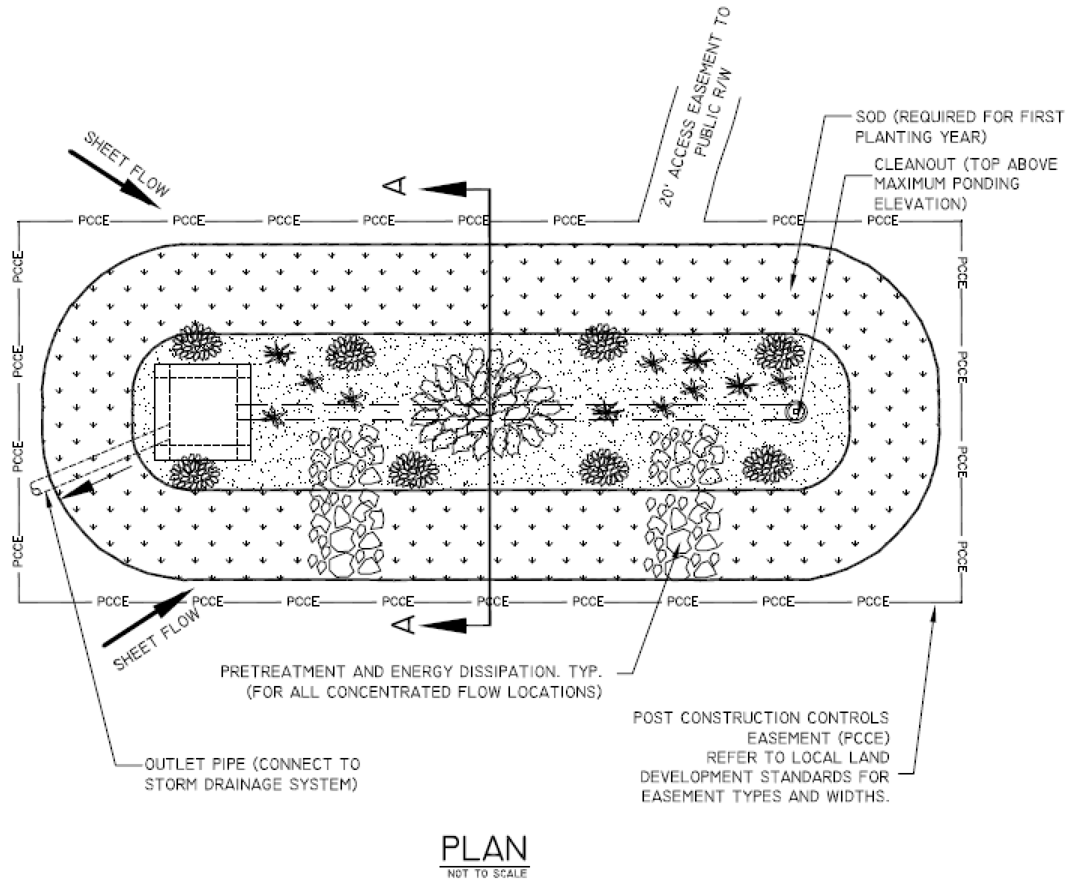
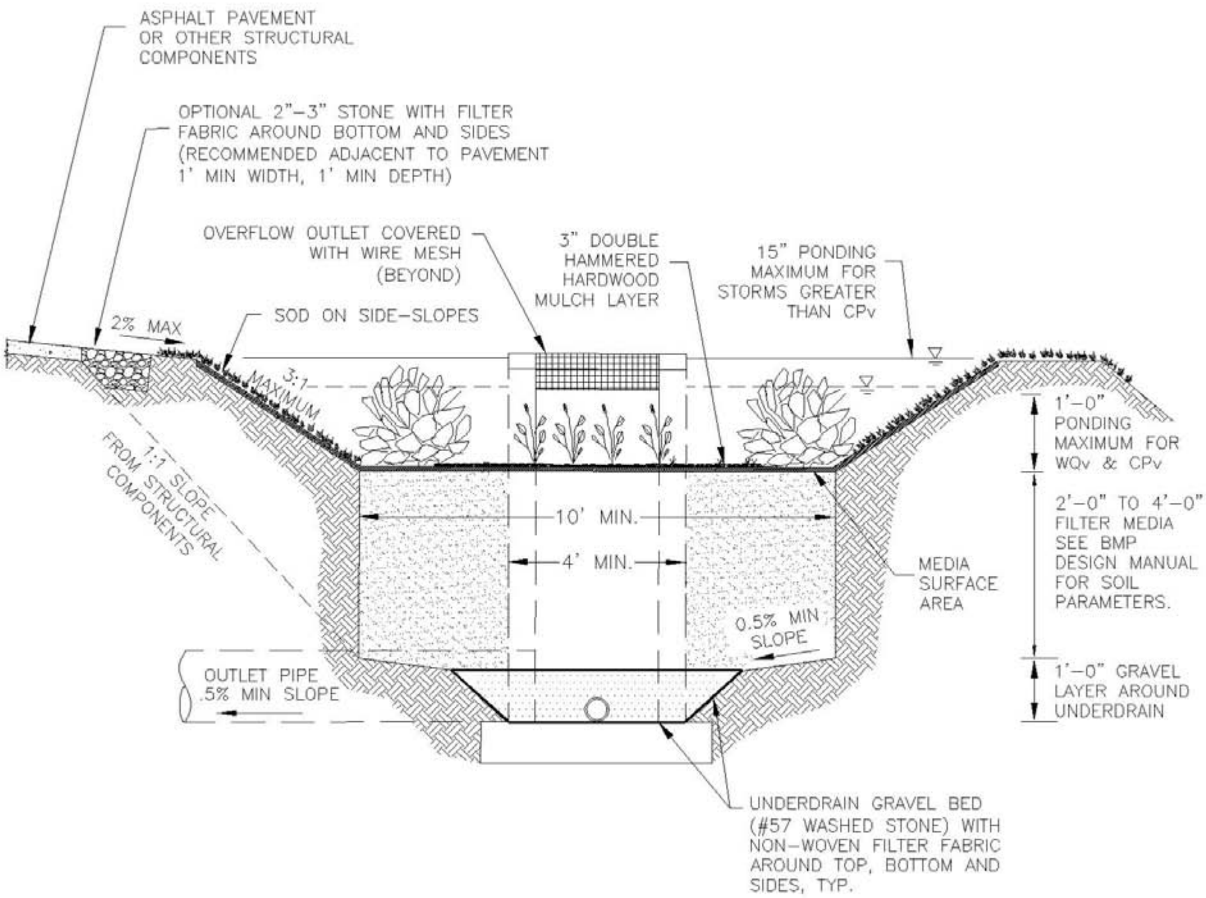


Figure 4.1.2 Plan View of a Typical Bioretention Area



SECTION A-A
NOT TO SCALE

Figure 4.1.3 Cross-section of a Typical Bioretention Area, Note: Sod may used as an alternative to mulch.

4.1.2 Storm Water Management Suitability

Bioretention areas are designed primarily for storm water quality, i.e. the removal of pollutants from storm water runoff. Bioretention can also provide runoff quantity control (peak attenuation control), particularly for smaller storm events. These facilities may sometimes be used to partially or completely meet channel protection requirements on smaller sites. However, bioretention areas may need to be used in conjunction with another structural control(s) to provide channel protection and peak attenuation. It is important to ensure that a bioretention area is designed to safely bypass high flows by either preventing the high flows from entering the facility or by ensuring that the high flows do not create erosive conditions if they enter the facility.

Water Quality Control (WQ_v)

Bioretention is an excellent storm water treatment practice due to the variety of pollutant removal mechanisms. Each of the components of the bioretention area is designed to perform a specific function.

Pretreatment devices such as grass filter strips or grass channels reduce incoming runoff velocity and filter some of the larger particulates from the runoff. The ponding area above the bioretention filter media provides for temporary storage of storm water runoff prior to its evaporation, infiltration, or uptake and provides additional settling capacity. The organic or mulch layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. The planting soil in the bioretention area acts as a filtration system, and clay in the soil provides adsorption sites for hydrocarbons, heavy metals, nutrients, and other pollutants. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants and serve to stabilize the surrounding soils. A gravel/sand bed can be placed around the underdrain to ensure positive drainage, to ensure aerobic conditions in the planting soil, and to provide a final polishing treatment media.

Channel Protection (CP_v)

For smaller sites, a bioretention area may be designed to capture the entire channel protection volume (CP_v) in either an off- or on-line configuration. Given that a bioretention area is typically designed to completely drain over 48 hours, the requirement of controlling the channel protection volume (1-year, 24-hour storm runoff volume) could be met. For larger sites where only the WQ_v is diverted to the bioretention area, another structural control must be used to control the required CP_v. A maximum ponding depth of 12 inches above the top of the basin floor is allowed when routing the WQ_v and CP_v and a maximum additional 3 inches of ponding depth is allowed for storm events larger than CP_v. Additional storage volume may be provided by creating a larger grassed area around the amended soil area, provided that the surface is stabilized for erosion control and the maximum ponding depths over the top of the basin floor are not exceeded.

Peak Attenuation Control

If designed with sufficient volume and appropriate outlet structures, peak attenuation control for the 10- and 25-year, 6-hour storms may be provided by the bioretention area. The 50-year, 6-hour storm event must also be routed through the bioretention area during the design. A maximum ponding depth of 15 inches above the top of the mulch is allowed when routing the 10-, 25-, and 50-year, 6-hour storm events. However, it is recommended that storms larger than the 1-year, 24-hour storm bypass bioretention areas to prevent channeling in the media.

4.1.3 Pollutant Removal Capabilities

Three bioretention designs have been developed for application in the Mecklenburg County area. The *optimal efficiency design* has the capability to remove 85% of the total suspended solids and 70% of the total phosphorus load. The *standard efficiency design* has the capability to remove 85% of the total suspended solids and 60% of the total phosphorus load. The *TSS-only efficiency design* has the capability to remove 85% of the total suspended solids and 45% of the total phosphorus load. Both the optimal efficiency and the standard efficiency designs assume urban post-development runoff conditions that has been observed in the Mecklenburg County area and that the facilities are sized, designed, constructed, and maintained in accordance with the appropriate recommended specifications contained in this manual. The design pollutant removal rates are derived from sampling data and computations completed for the development of this manual. In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or “treatment train” approach. Pollution removal rates are affected by the choice of design values. See Section 4.1.4 for a discussion of design values and appropriate pollution removal rates for specific designs. The *TSS-only efficiency design* is based on sizing criteria found in Chapter 12 of the NCDENR Stormwater BMP Manual.

4.1.4 Planning and Design Criteria

The following criteria are to be considered minimum standards for the design of a bioretention area. Items listed in Section 4.1.4.A through 4.1.4.I. are requirements and must be addressed in the design. Items listed in Section 4.1.4.J. are recommendations and are optional.

A: Design Requirements

Following is a list of design requirements that must be followed in the design of bioretention areas.

- Following are the design values that are required for the two bioretention area designs that are available for application in Mecklenburg County. The appropriate minimum design values and associated pollutant removal rates for each of the designs are given in Table 4.1.1.

Table 4.1.1 Design Values and Pollution Removal Rates

Threshold	Design Detention Time	Min. Media Depth	Pollution Removal Rate
Optimal Efficiency	1.3 days	4 feet	85% TSS 70% TP
Standard Efficiency	1.0 days	2 feet	85% TSS 60% TP
TSS-Only Efficiency	*	2 feet	85% TSS 45% TP

Note – TSS-Only design is based on depth of the water quality volume.

- Bioretention areas must have a contributing drainage area less than 10 acres.

- The maximum drainage area for each inflow location is 5 acres.

- Energy dispersion and pre-treatment is required for all major inflow locations, as defined in the following two bullets. Additional design effort may be required for inflows that receive large watershed areas because of the challenges associated with achieving sheet flow conditions for concentrated inflows for areas receiving more than 1 acre.

    - Energy dispersion devices dissipate the inflow energy so that the filter media is not damaged through erosion, displacement, etc. Energy dispersion devices must be provided for all concentrated flow locations such as pipes larger than 15 inches in diameter. Typical energy dispersion devices include level spreaders, riprap aprons, etc. that are designed so that sheet flow conditions are created. Sheet flow is defined as flow depths less than 1 inch with flow velocity less than 1 foot per second for the peak flow from the 1-yr 24-hr storm event.

    - Pre-treatment devices treat inflow for large particulates prior to entering the filter media. Pre-treatment devices such as grass buffers, swales, or forebays must be provided if the bioretention area is treating more than 1 acre of drainage. Pre-treatment devices are not required if a splitter device is provided. The following requirements are to be followed when using the above Pre-treatment devices:
      Grass Swales:
        - Length of the swale must be a minimum of 15 feet
        - Slope of the swale must be 2% of less
        - Swale capacity must be capable of handling all storm flows designed to past through the rain garden (trapezoidal cross-

sectional shape with side slopes flatter than 3:1 (h:v) and a minimum bottom width of 2 feet is required)

Forebay:

- Sized to be 0.2% times the size of the drainage area to the forebay
- Forebay can either be riprap or concrete

  - Any inlet receiving more than 1 acre of drainage must have a concrete or riprap forebay. It is recommended that the forebay surface area be sized to be 0.2% times the size of the drainage area to the forebay.

- There should be no woody vegetation at inflow locations.

- A gravel and perforated pipe underdrain system must be designed and installed to collect runoff that has filtered through the soil media. The underdrain system must not limit outflow more than the filter media and the underdrain system must be designed so that runoff exits the system within 48 hours. The underdrain system (pipe capacity and orifice capacity) must be designed assuming that 50 percent of the capacity is lost due to clogging. An internal water storage (IWS) system is allowed, provided that the filter media and underdrain system are designed per requirements, specifications and calculations for infiltration provided in Chapter 18 of the NCDENR Stormwater BMP Manual. If IWS is used, the WQv should infiltrate the soil within 48 hours.

- The underdrain system should be equipped with 6-inch minimum perforated Schedule 40 or stronger PVC pipe or double-wall HDPE pipe. Perforations shall be per AASHTO M278 for PVC pipe, AASHTO M252 for double-wall HDPE pipe, or be 3/8-inch in diameter spaced 3 inches on center along 4 longitudinal rows that are spaced 90° apart. The pipes may be installed with 0% grade or sloped with a maximum spacing of 10 feet on center.

- Underdrain pipes must be placed in the bottom of a 12-inch minimum gravel layer that is 4 feet in width (minimum). The gravel shall be #57 washed stone and must provide a minimum of 4 inches of cover over the pipe(s).

- Cleanouts of 6-inch solid PVC or double wall HDPE must be provided for every 50 linear feet of underdrain with two 45 degree couplings for a vertical stance, Cleanouts shall be provided at all bends, and ends of the system for maintenance purposes. The top of the cleanouts should extend 6 inches above extend above the maximum ponding elevation. At least one cleanout shall be installed as an emergency drain that is flush with the top of mulch and has a 6-inch threaded extension pipe. All cleanouts shall have a watertight, vandal-proof cap. The furthest cleanout from the outlet must have the minimum required filter media depth.

- A layer of filter fabric is placed between the amended soil and the gravel layer above the perforated pipe to limit piping of soil directly into the pipe. The gravel must be fully enclosed with filter fabric on the top, bottom and sides.

- The planting soil bed must be a least 2 feet in depth and up to 4 feet if larger vegetation is to be planted. Planting soils should meet the criteria as listed under Section H of this chapter.

- A separation distance of 2 feet should be maintained between the bottom of the bioretention area and the elevation of the seasonally high water table.

- If mulch is utilized, mulch layer composition must be doubled-hammered and screened hardwood mulch or chips; at least 6 months old. The layer must be at least 3 inches deep. Mulch cannot contain soil or fine organics, which have a tendency to create a barrier to infiltration thus the importance of making sure the mulch is screened.

- If Sod is utilized, sod layer must be washed or grown in primarily sand/sandy-loam soils with less than 6% clay content. Type of sod may vary but studies have shown 419 bermuda sod to be tolerable of bioretention conditions as well as full sun and/or dry conditions.

- A screen, wire mesh, or other suitable device must be installed to reduce the potential of the mulch layer being washed into the downstream storm drainage system and to reduce the potential for the outlet to be clogged.

- The storage area above the top of the mulch <u>must</u> be sized to hold the water quality control volume (WQ_v). The storage area above the filter media <u>may</u> be sized to hold the runoff volume for the channel protection volume (CP_v), Q_{10}, Q_{25}, and Q_{50} storms. The maximum ponding depth above the top of the mulch for WQ_v and CP_v is 12 inches. The maximum ponding depth above the top of the mulch for all storm events greater than the CP_v is 15 inches (including the 10-year, 6-hour; 25-year, 6-hour; and 50-year, 6-hour storm events).

- For the optimal efficiency and the standard efficiency designs, the planting soil filter bed must be sized using the following Darcy's Law equation with a filter bed drain time greater than 1.3 days for optimal efficiency design and 1.0 days for the standard efficiency design. Note that these design durations are measured relative to the center of the rainfall event (3 hours for the WQ_v), therefore, the value entered into the Darcy equation is either 1.425 days for the optimal efficiency design or 1.125 days for the standard efficiency design. A design coefficient of permeability (k) of 0.5 ft/day must be used to size bioretention areas.

$$\mathbf{A_f = (WQ_v)(d_f) / [(k)(h_f + d_f)(t_f)]}$$

where:

A_f	= surface area of filter media.(ft^2)
WQ_v	= water quality control volume (or total volume to be captured in ft^3)
d_f	= filter bed depth (2 ft standard, 4 ft optimal efficiency)
k	= design coefficient of permeability of filter media (0.5 ft/day)
h_f	= average height of water above filter bed (0.5 ft max)
t_f	= design filter bed drain time (days) (1.125 standard or 1.425 optimal efficiency)

- For the TSS-only efficiency design, the required area of the planting soil filter bed is equal to the WQv divided by the ponding depth. Additional volume may be provided to control all or a portion of the CPv and peak flows, provided that maximum ponding depths are not exceeded. The required planting soil filter bed area is computed using the following equation:

$$\mathbf{A_f = (WQ_v)/(h_f)}$$

where:

A_f	= surface area of ponding area directly above engineered media (ft^2)
WQ_v	= water quality control volume (or total volume to be captured in ft^3)
h_f	= Allow headwater depth for WQv in the bioretention area (ft)

- A bioretention area should not be placed into operation until the contributing drainage area is completely stabilized.

- The soil filter bed footprint (A_f) must be measured from the top of the soil media. Side slopes are excluded from A_f.

- All embankments shall be designed per the North Carolina Dam Safety Law of 1967, if applicable, and designed according to the requirements in Section 4.0.6 of this manual.

- Bioretention areas are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

- Sites with steeper slopes may require that bioretention areas be terraced. When terracing is needed, the rains gardens shall be separated by a solid embankment (underdrains may be connected). Refer to Section 4.0.6 for embankment specifications.

B. Pretreatment

Adequate pretreatment and inlet protection for bioretention areas is acheived when the following are provided: (a) grass filter strip below a level spreader, or grass channel, and (b) gravel curtain. Bioretention areas can be designed without pretreatment protection that meets design standards when site conditions preclude the use of pretreatment protection and based on a case-by-case review/approval by staff. Pretreatment is more important for bioretention facilities that have reduced the footprint sizes by routing computations to values less than given by the Darcy equation.

C. Liners

Some general rules for the use of liners (impermeable) in the design of bioretention areas include the following.

- Liners are also used to a large extent in urban areas where soils have been compacted greatly and conflicts with utilities may arise.
- If the bioretention area is located in contaminated soils liners will be used to prevent water migration into the contaminated soils.
- Liners may be appropriate when sensitive groundwater resources may be impacted by infiltrated storm water.
- Liners may be used to control runoff from hotspot land uses.

D. Outlet Structures

An outlet pipe must be provided from the underdrain system to the facility discharge. All connections and/or interface with catch basins/drop inlets shall be water tight to prevent leaks or soil piping. A rubber boot, hydraulic cement or industry approved sealant must be utilized for connecting underdrains or outlet pipes to structures.

E. Emergency Spillway

An overflow structure and nonerosive overflow channel must be provided to safely pass flows from the bioretention area that exceed the storage capacity to a stabilized downstream area or watercourse. The overflow should be set above the ponding limit for the WQ_v and other storm events (if any) that are meant to be controlled by the bioretention area.

The high flow overflow system within the bioretention area can consist of a yard drain catch basin (Figure 4.1.2), though any number of conventional systems could be used. The throat of the catch basin inlet is normally placed above the mulch layer, the maximum WQ_v stage, so that the WQ_v filters through the media and does not flow through the overflow structure. It should be designed as a domed grate or a covered weir structure to avoid clogging with floatation mulch and debris, and should be located away from inlets to avoid short circuiting of flow. It may also be placed into the side slope of the structure maintaining a neat contoured appearance.

F. Maintenance Access

Adequate access must be provided into all bioretention areas for inspection, maintenance, and landscaping upkeep. Access roads must have a minimum stabilized width of 12 feet (including a 10' offset from the high water elevation), maximum longitudinal grade of 15 percent, and maximum cross slope of 5 percent. A 20-foot wide maintenance access easement must be provided to ensure that the access remains in place.

G. Vegetation

Choose plants based on factors such as whether native or not, resistance to drought and inundation, cost, aesthetics, maintenance, etc. Planting recommendations for bioretention areas are as follows:

- Native plant species should be specified over non-native species.
- Vegetation should be selected based on a specified zone of hydric tolerance.
- A selection of trees with an understory of shrubs and herbaceous materials should be provided.

There can be up to three zones within a bioretention area depending on location and size (zones 4 – 6). Figure 4.1.4 presents the three zones. In these systems the lowest elevation supports plant species adapted to periodic or seasonal inundation. The middle elevation supports plants that like drier soil conditions, but can still tolerate irregular, occasional inundation by water. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. The objective is to have a system which resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth. For parking lots systems the bioretention area will most likely have a flat surface for storage, thus limiting the zones to one (Zone 4). In this case the plants are limited to those species adapted to periodic or seasonal inundation.

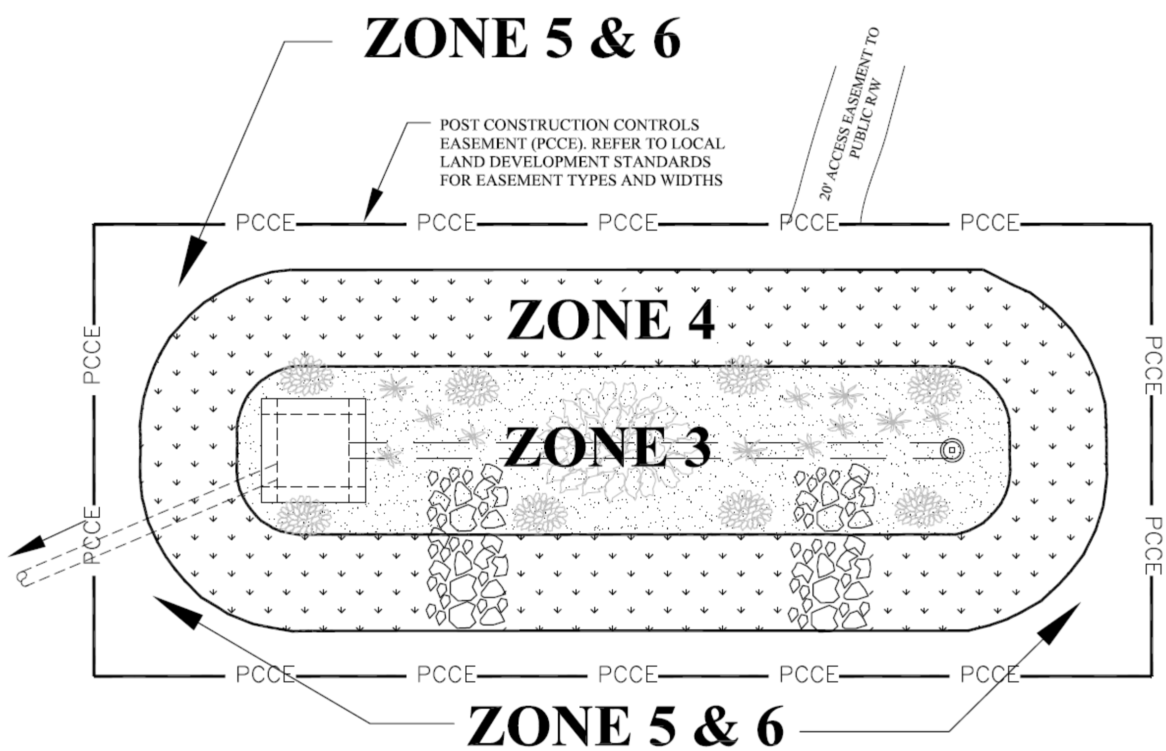


Figure 4.1.4 Bioretention Planting Zones

Plant material selection should include the factors discussed in Chapter 6 of this manual when utilizing mulch. Note: sod or variety of sod and mulch may be utilized with plant material.

- Trees should be planted in zones 5 and 6 only. Trees should not be planted in the standard bioretention design. Plant density and survival rate are very important for the proper functioning of bioretention areas. Thus diverse and native plant species designed for the hydric zone must be used.

- A dense and vigorous vegetative cover must be established over the contributing pervious drainage areas and side slopes of the bioretention area before runoff can be accepted into the facility.

- The bioretention area may be vegetated to resemble a terrestrial forest ecosystem with a, shrub layer and herbaceous ground cover. Three species of shrubs are recommended to be planted. Grass/Sod will be allowed for the bioretention area as an alternative to mulch and plants.

- Plants should be placed at regular intervals.

- After shrubs and herbaceous vegetation are established, the ground cover and mulch must be established.

H. Materials

Following are some detailed specifications/recommendations for materials that could be used in the construction of a bioretention facility.

No. 57 Aggregate	NCDOT Section 1005
Underdrain Pipe, PVC Plastic Pipe Schedule 40 Or HDPE n12.	NCDOT Section 1044
Mulch, 2x Shredded and Screened Hardwood Bark	NCDOT Section 1060
Geotextile	NCDOT Section 1056
Plant Materials	NCDOT Section 1670

Bioretention Soil Mixture

Bioretention soil mix should be developed by amending the existing soil or removing the existing soil and replacing it with the new planting mix. The material must be uniform in composition throughout, be free of stones, lumps, live plants and their roots, weed seeds, sticks, and other extraneous material.

The bioretention soil mixture must meet the following criteria:

PARAMETER	ACCEPTABLE VALUES	TESTING REQUIRED *	TEST METHODS
Sand Content (ASTM C-144 recommended)	80%	No	-
Organic Material (compost, sandy loam, and loamy sand)	20%	No	TMECC 05.07-A
Clay Content	Less than 6%	No	-
Phosphorus Index (total Phosphorus)	10 to 30 (12 to 36 ppm on a dry basis)	**Yes**	Mehlich 3 Extraction, Mehlich 2 Extraction (Mehlich 1 Extraction is acceptable but result must be multiplied by 1.7 for comparison)
pH	5.5 to 7.0	No	TMECC 04.11-A

Permeability	1 to 4 in/hr		No	ASTM D2434 (compacted to 20%)
Particle Size Analysis	Acceptable % Passing by Weight		Yes	ASTM D422
	Lower	Upper		
Sieve 2 inch (50 mm)	100	100		
Sieve No. 4 (4.75 mm)	98	100		
Sieve No. 8 (2.36 mm)	95	100		
Sieve No. 10 (2.0 mm)	86	100		
Sieve No. 16 (1.18 mm)	70	100		
Sieve No. 30 (600 um)	40	75		
Sieve No. 50 (300 um)	10	35		
Sieve No. 100 (150 um)	2	15		
Sieve No. 200 (75 um)	0	10		

* Even though testing is not required for all parameters, the inspector reserves the right to test suspect material and disapprove it for use if results show that parameters do not meet the acceptable values.

All bioretention areas must have a minimum of one test for soil mixture composition. A composite soil test is required to be performed on the soil planting media after it has been mixed and prior to its installation into the bioretention area to determine that the soil constituents meet the acceptable values in the table above. If the test results are outside of the acceptable limits, then the soil mixture must be removed and replaced with an acceptable soil mixture. Should the pH fall out of the acceptable range, it may be modified with lime or iron sulfate plus sulfur.

The bioretention soil mixture must be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches. No other materials or substances must be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The soil must be free of noxious weeds such as Bermuda grass, Quackgrass, Johnson grass, Mugwort, Nutsedge, Poison Ivy, Canadian Thistle, and/or Teathumb. The soil, mulch, and sand must be uniformly mixed and graded.

Mulch layer (if sod is not used)

The mulch layer composition must be doubled-hammered and screened hardwood mulch or chips. Mulch cannot contain soil or fine organics, which have a tendency to create a barrier to infiltration thus the importance of making sure the mulch is screened. The mulch layer should be well aged (stockpiled or stored for at least 6 months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. Grass clippings or pine straw should not be used as a mulch material.

Sod

The sod layer must be washed or grown in primarily sand/sandy-loam soils with less than 6% clay content. Type of sod may vary but studies have shown 419 bermuda sod to be tolerable of bioretention conditions as well as full sun and/or dry conditions.

Liner

Liner must be a composite liner consisting of a polypropylene geomembrane between two layers of 8-12-02 felt. The polypropylene geomembrane must have the following physical properties:

PROPERTY	TEST METHOD	CERTIFIED VALUE	TYPICAL VALUE
Gauge, nominal	-	45 (1.14)	45 (1.14)
Plies, reinforcing	-	1	1
Overall Thickness, minimum mils(mm)	ASTM D-571 Optical Method	41 (1.04)	44 (1.12)

Breaking strength-fabric, Minimum lbf (kN)	ASTM D-751 Method A	225 (1.0)	300 (1.34)
Low temperature flexibility ^{o}F (^{o}C)	ASTM D-2136 1.8-in. mandrel, 4 hour pass	-40 (-40)	-65 (-54)
Puncture resistance, minimum lbs (kN)	FTMS 101-C Method 2031	350 (1.56)	400 (1.78)
Tear strength, minimum lbf(kN)	ASTM D-5884	55 (0.24)	100 (0.45)
Dimensional stability % change, max.	ASTM D-1204 180^{o}F/82^{o}C 1 hour	1.0%	-0.5%
Hydrostatic resistance, minimum psi (MPa)	ASTM D-751 Method A, Procedure 1	350 (2.4)	400 (2.75)
Ply adhesion, minimum lbs/in (kN/m)	ASTM D-413 Machine Method, modified	20 (3.5)	30 (5.25)
Water absorption, maximum % weight change	ASTM D-471 30 days @ 70^{o}F/21^{o}C	<1.0%	<1.0%
UV resistance	ASTM G-26 Xenon Arc, 80^{o}C/4000 hours	Pass	Pass
ESCR (Environmental Stress Crack Resistance), min. hours with no failure	ASTM D-1693 3000 hours	Not affected by ESC	Not affected by ESC
Bonded seam strength, Minimum lbf (kN)	ASTM D-751 Modified	200 (0.89)	200 (0.89)
Peel adhesion, minimum lbs/in (kN/m)	ASTM D-413 Modified	20 (3.5) or FTB	20 (3.5) or FTB

I. Construction

The bioretention area must not be placed into operation until all contributing drainage areas are stabilized. The bioretention area must not be used as a sediment control facility unless the sediment is excavated to natural soil prior to the installation of the bioretention area. Following are some recommendations related to the construction of bioretention areas.

Excavation

It is very important to minimize compaction of both the base of the bioretention area and the required backfill. When possible, use excavation hoes to remove original soil. If the bioretention area is excavated using a loader, the contractor must use wide track or marsh track equipment, or light equipment with turf type tires. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high-pressure tires will cause excessive compaction resulting in reduced infiltration rates and is not acceptable. Compaction will significantly contribute to design failure.

If desired, two to three inches of sand can be rototilled into the base of the bioretention area before backfilling with the optional sand layer. Pump any ponded water before preparing (rototilling) base. When backfilling the topsoil over the sand layer, first place 3 to 4 inches of topsoil over the sand, then rototill the sand/topsoil to create a gradation zone. Backfill the remainder of the topsoil to the final grade.

Excavated material must be removed from the facility site. Facility walls and bottom must be free from protruding objects that could damage the liner. The bottom dimensions of the planting soil depth must be as shown on the Construction Drawings. The sidewalls of the facility must be roughened. The bottom of the facility must be graded flat.

Liner

If required, the liner must be placed on the sides and bottom of the facility.

Underdrain
Underdrain systems may be placed at a 0% slope or level bottom of the excavation. A watertight connection must be achieved where the underdrain pipe goes through the liner in accordance with polypropylene geomembrane manufacturer's specifications. Cleanouts of 6" solid PVC or HDPE pipe must be placed vertically using two 45 degree couplings as shown on the Construction Drawings in the bioretention area. The cleanouts must be connected to the perforated underdrain with a tee connection. The top of the cleanouts must extend 6" above the maximum ponding elevation. At least one cleanout shall be installed as an emergency drain that is flush with the top of mulch and has a 6-inch threaded extension pipe. All cleanouts must have watertight, vandal-proof caps. The underdrain must be backfilled with #57 washed stone and the stone completely covered with filter fabric, on the top, bottom, and sides.

Backfill
The Bioretention Soil Mixture must be placed in lifts of 12 inches. No heavy equipment is allowed in the basin area. Grading should be performed with light equipment such as a compact loader or a dozer/loader with marsh tracks having a ground pressure less than or equal to 5 psi. The Bioretention Soil Mixture must be saturated after each lift until water flows from the underdrain. Any sediment-laden water discharged from the underdrain must be filtered or removed from the outlet structure. If the Bioretention Soil Mixture becomes contaminated during the construction of the facility, the contaminated material must be removed and replaced with uncontaminated material.

Plant Installation (alternative to sod)
Mulch should be placed to a uniform thickness of 3 inches. Shredded and screened hardwood bark mulch is the only acceptable mulch. Mulch cannot contain soil or fine organics, which have a tendency to create a barrier to infiltration thus the importance of making sure the mulch is screened. Shredded mulch must be well aged (6-12 months) for acceptance.

Rootstock of all plant material must be kept moist during transport and on-site storage. For trees and shrubs, the plant root ball should be planted so 1/8th of the ball is above final grade surface. The diameter of the planting pit must be at least six inches larger than the diameter of the planting ball. Set and maintain the plant straight during the entire planting process. For perennials and bulbs, the plant must be placed in planting holes at the appropriate depths for the particular plants, with the root-side down. Thoroughly water ground bed cover after installation.

Trees must be braced using 2" by 2" stakes only as necessary and for the first growing season only. Stakes are to be equally spaced on the outside of the tree ball.

The planting soil specifications provide enough organic material to adequately supply nutrients from natural cycling. The primary function of the bioretention structure is to improve water quality. Adding fertilizers defeats, or at a minimum, impedes this goal. Do not add fertilizer.

J. Design Recommendations

In addition to the design requirements and parameters, following are some design recommendations that should be considered for bioretention area design. See Figures 4.1.2 and 4.1.3 for an overview of the various components of a bioretention area.

- In addition to the design detention times of 1.3 days for optimal efficiency design and 1.0 days for standard efficiency design, a maximum detention time should be considered to reduce the potential for problems associated with stagnant water. A maximum detention time of 48 hours for the WQ_v is preferred.

- When used in an off-line configuration, the water quality control volume (WQ_v) and possibly channel protection volume (CP_v) is diverted to the bioretention area through the use of a flow splitter. Storm water flows for larger storms can be diverted to other facilities for channel protection control and peak attenuation controls (see Chapter 5 for more discussion of off-line systems and design guidance for diversion structures and flow splitters).

- Bioretention area locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.

- A well-designed bioretention area should have a pretreatment facility such as a grass filter strip or grass channel that meets this Manual's design standards between the contributing drainage area and the ponding area.

- To prevent scour of bioretention sidewalls when using a level spreader inlet, it is recommended that the level spreader discharge at or below the ponding depth.

- A bioretention area design can also include some of the following:

  - Optional sand filter layer below the filter media to spread flow, filter runoff, and aid in aeration and drainage of the planting soil.

  - Stone diaphragm to meet the energy dispersion requirement at the beginning of the grass filter strip to reduce runoff velocities and spread flow into the grass filter.

  - Inflow diversion or an overflow structure should be used consisting of one of the following five main methods:

    - Use a flow diversion structure to divert larger storm events from the bioretention area.
    - Use a slotted curb and design the privately-maintained parking lot grades to divert the WQ_v into the facility. Bypass additional runoff to a downstream catch basin inlet. Requires temporary ponding into the parking lot.
    - Use of a short deflector weir (maximum height 6 inches) designed to divert the maximum water quality peak flow (WQ_v) from privately-maintained parking areas into the bioretention area.
    - An in-system overflow consisting of an overflow catch basin inlet and/or a pea gravel curtain drain overflow.

- Bioretention areas can be installed in lawns, parking lot islands, and unused lot areas.

- The minimum diameter of any outlet or overflow orifice is 4 inches unless a method is used to prevent clogging and is incorporated into the design.

- Recommended minimum dimensions of a bioretention area are 10 feet wide by 40 feet long. All designs except applications on single family residential lots should maintain a length to width ratio of at least 2:1.

- The sand bed (optional) should be 12 to 18 inches thick. Sand should be clean and have less than 6% silt or clay content.

- Stone for the curtain should be Number 57 Aggregate (NCDOT 1005).

- Consideration should be given to the potential for freezing of bioretention gardens placed in normally-shaded areas, which has been known to cause plant mortality and increased plant replacement costs.

4.1.5 Design Procedure

Step 1 - Using the BMP Selection Matrix presented at the beginning of Chapter 4, determine if the development site and conditions are appropriate for the use of a bioretention area.

Step 2 - Consider any special site-specific design conditions and check to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3 - Compute water quality volume (WQ_v) using equations 3.2 and 3.3 – $WQ_v = 1.0R_vA/12$.

Step 4 - Compute site hydrologic parameters using the SCS procedures and/or computer models that use the SCS procedures.

Step 5 - Compute water quality peak flow (WQ_p) using equation 3.4 for a modified curve number and the SCS hydrograph procedures with a 1-inch, 6-hr, balanced storm event. Estimate approximate storage for water quality volume using the Static method.

Step 6 - Compute protection volume (CP_v) using the SCS method and a 1-yr, 24-hr storm event. Estimate approximate storage volume for channel system stability using the Static method.

Step 7 - Size flow diversion structure, if needed, to divert the water quality volume to the bioretention area.

Step 8 - Design energy dispersion and pretreatment system. Energy dispersion can include a level spreader, or riprap aprons. Pretreatment can include a grass filter strip (on-line configuration) or grass channel (off-line), and stone diaphragm.

Step 9 - Determine the initial footprint area of the bioretention ponding/filter area.

The initial planting soil filter bed area in the *optimal efficiency* and *standard efficiency* designs is computed using the following equation based on Darcy's Law):

$$\mathbf{A_f = (WQ_v)(d_f) / [(k)(h_f + d_f)(t_f)]}$$

where:

A_f = surface area of ponding area (ft^2)
WQ_v = water quality control volume (or total volume to be captured – ft^3)
d_f = filter bed depth (2 ft standard, 4 ft optimal efficiency)
k = design coefficient of permeability of filter media (0.5 ft/day)
h_f = average height of water above filter bed (0.5 ft max)
t_f = design filter bed drain time (days)
(1.125 standard or 1.425 optimal efficiency)

If the WQ_v is being directed to the bioretention facility and larger storm events are being directed around the bioretention facility through the use of a flow diverter, then the flow routing procedure presented in Step 12 will be effective in reducing the initial bioretention footprint size provided by the above equation.

Step 9a - Determine the initial footprint area of the bioretention ponding/filter area.

For the TSS-only efficiency design, the required area of the planting soil filter bed is equal to the WQv divided by the ponding depth. Additional volume may be provided to control all or a portion of the CPv and peak flows, provided that maximum ponding depths are not exceeded. The required planting soil filter bed area is computed using the following equation:

$$\mathbf{A_f = (WQ_v)/(h_f)}$$

where:

A_f = surface area of ponding area directly above engineered media (ft^2)
WQ_v = water quality control volume (or total volume to be captured)
h_f = Allow headwater depth for water quality volume in the bioretention area (ft).

Step 10 - Set design elevations and dimensions of facility.

Step 11 - Derive stage-discharge and stage-storage relations for the bioretention area. Assume that discharge occurs for headwater depths at the elevation of the top of the filter media and higher. A zero discharge should be assumed at the elevation at the top of filter media.

Step 12 - Route flows through bioretention area and adjust design of facility to meet all design criteria. Initial footprint area can be reduced to values less than the Darcy equation results if design detention times are achieved and maximum ponding depths are not exceeded. This step is most effective where a flow diverter is included in the design to bypass storm events larger than the WQ_v around the bioretention facility.

Step 13 - Design conveyances to facility.

Step 14 - Size underdrain system.

Step 15 - Design emergency overflow. An overflow must be provided to bypass and/or convey larger flows to the downstream drainage system or stabilized watercourse. Nonerosive velocities need to be ensured at the outlet point.

Step 16 - Prepare vegetation and landscaping plan. A landscaping plan for the bioretention area should be prepared to indicate how it will be established with vegetation.

4.1.6 Inspection and Maintenance Requirements

Specific maintenance inspections and requirements are contained in each jurisdiction's Administrative Manual.

4.1.7 Design Procedure Form

Design Procedure Form: Bioretention Areas

BIORETENTION FEASIBILITY	**NOTES:**
1. Is the use of a bioretention area appropriate?	
2. Confirm design criteria and applicability.	
PRELIMINARY HYDROLOGIC CALCULATIONS	
3. Compute, WQ_v volume requirements Compute Runoff Coefficient, R_v Compute WQ_v Volume requirements	 Rv = ______ WQ_v = ______ acre-ft
4. Compute site hydrologic input parameters Development Conditions Area CN Adjusted CN Time of concentration	 Pre-developed Post-developed ______ acres ______ acres ______ ______ ______ ______ ______ hours ______ hours

5. Compute WQ_p peak flow Compute modified SCS curve number	WQ_p = ______ cfs CN = ______
6. Compute CP_v Compute S	S = ______
7. Size flow diversion structure	
BIORETENTION AREA DESIGN	
8. Pretreatment facility type and design parameters	______
9. Determine initial area of bioretention ponding/filter area.	A_f = ______ ft^2
10. Set design elevations and dimensions of facility	Length = ______ ft Width = ______ ft Elevation top of facility = ______ ft Other elevations = ______ ft = ______ ft = ______ ft
11. Develop stage-discharge and stage-storage	see table below
12. Route flows through bioretention area. Resize the footprint area, if desired. Step is most effective for facilities with flow diverters. Ensure detention time requirements and maximum ponding depth requirements are met.	
13. Design conveyance to facility	
14. Size underdrain system.	Length = ______ ft
15. Design emergency overflow.	Length of Weir (if used) = ______ ft
16. Prepare vegetation and landscaping plan.	Notes:

Elev	Area. (ft^2)	Volume. (ft^3)	Acc. Vol. (ft^3)	Q (cfs)

4.1.8 Bioretention Design Example #1

The following design example is for a bioretention area designed to control the 1-inch, 6-hour for water quality purposes, and pass the 1-year, 24-hour, 10-year and 25-year, 6-hour so that a downstream extended detention basin facility can provide channel protection and flood control following the design procedures given in section 4.1. In this design example, the channel protection volume (CP_V) is required to be held for a minimum of 24 hours from the center of the rainfall event (as is the requirement for projects within Mecklenburg County and the six Towns); however, the user should note that within the City of Charlotte, the channel protection volume (CP_V) is required to be held for a minimum of 48 hours from the center of the rainfall event. Figure 4.1.6 shows the site plan for the development data that will be used in the design example.

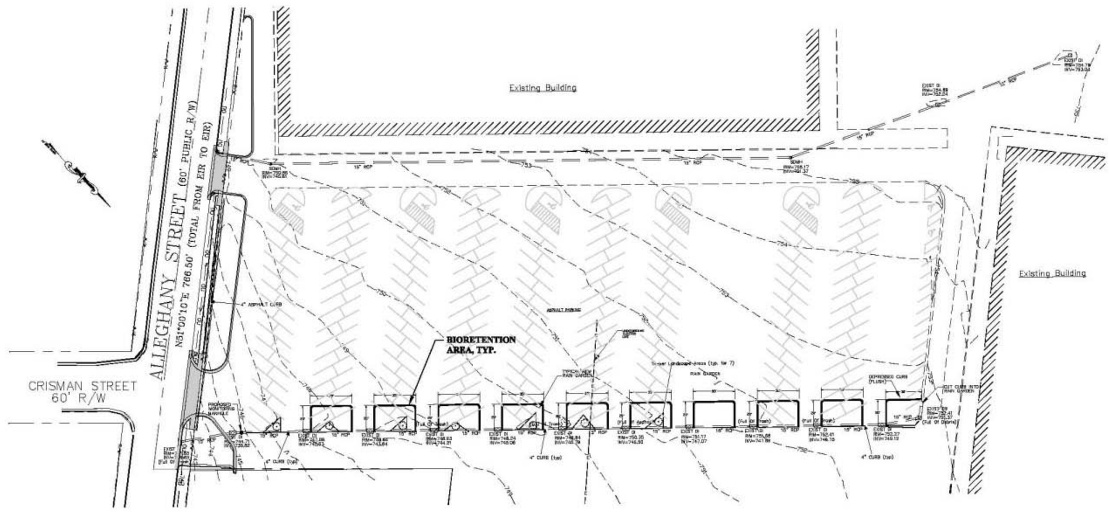


Figure 4.1.6 Example Site Plan for Bioretention Design

The following steps illustrate how to use the design procedures given in section 4.1 to design a bioretention area that will be acceptable for the design criteria given in this manual.

Step 1 BMP Feasibility

For the purposes of this design example, assume that a bioretention area is feasible.

Step 2 Confirm Design Criteria

The design criteria contained in Section 4.1 of the manual apply to this design.

Step 3 Compute Site Hydrologic Input Parameters

The size of the site is one acre and the proposed percent built-upon area is 85 percent. Using SCS hydrologic procedures and/or HEC-1 computer model the following data can be determined for the example development site.

Hydrologic Input Data

Condition	Area (acres)	CN	CN (adjusted) for 1-inch storm	t_c (hours)
Pre-developed	1.0	65	N/A	0.323
Post-developed	1.0	93.4	98.3	0.133

Results of Preliminary Hydrologic Calculations
(From Computer Model Results Using SCS Hydrologic Procedures)

Condition	$Q_{1\text{-inch}}$	$Q_{1\text{-year}}$	$Q_{10\text{-year}}$	$Q_{25\text{-year}}$	$Q_{50\text{-year}}$
Runoff	cfs	Cfs	cfs	cfs	cfs
Pre-developed	0.00	0.24	1.09	1.64	2.09
Post-developed	1.67	2.65	5.43	6.43	7.18

Step 4 Compute Water Quality Volume (WQ_v)

- Compute Runoff Coefficient, $R_{v,}$ using (Schueler's Method) Equation 3.1

  $R_v = 0.05 + 0.009(I) = 0.05 + (85.0)(0.009) = 0.82$

- Compute Water Quality Volume, WQ_v, using Equation 3.2

  $WQ_v = 1.0R_vA/12$ = (1.0 inches)(0.82)(1.0 acre)(1foot/12 inches) = 0.07 ac-ft

- Convert Water Quality Volume, WQ_v to inches of runoff using Equation 3.3

  $WQ_v = 1.0(R_v) = 1.0(0.82) = 0.82$ inches

Step 5 Compute Water Quality Peak Flow (WQ_p)

- Compute modified SCS curve number, CN, using Equation 3.4

  $CN = 1000/[10 + 5P + 10WQ_v – 10(WQ_v^2 + 1.25\ WQ_vP)^{0.5}]$
  $CN = 1000/[10 + 5(1.0) + 10(0.82) – 10\{(0.82^2 + 1.25(0.82 \times 1.0)\}^{0.5}] = 98.3$

- Compute WQ_p using SCS the hydrograph procedure documented in the Charlotte-Mecklenburg Storm Water Design Manual and the HEC-1 model or similar hydrologic model as approved by the review engineer. A 1-inch, 6-hour balanced storm event is required.

```
1***************************************                ***************************************
 *                                     *                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1) *                *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998              *                *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1               *                *         609 SECOND STREET           *
 *                                     *                *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   12APR07  TIME  18:40:19 *                *          (916) 756-1104             *
 *                                     *                *                                     *
 ***************************************                ***************************************


                              X     X  XXXXXXX   XXXXX        X
                              X     X  X        X     X      XX
                              X     X  X        X             X
                              XXXXXXX  XXXX     X     XXXXX   X
                              X     X  X        X             X
                              X     X  X        X     X       X
                              X     X  XXXXXXX   XXXXX       XXX


          THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.
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         THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
         THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
         NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
         DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
         KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                             HEC-1 INPUT                                            PAGE  1

          LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

            1           ID      MECKLENBURG COUNTY BMP DESIGN MANUAL
            2           ID      ANALYZED BY ABC ENGINEERING
            3           ID      DATE: OCTOBER 2006
                        *  **************************************************************************
                        *
                        *    TIME SPECIFICATION CARD
            4           IT      1       0       0     365
                        *  DIAGRAM
                        *    TIME INTERVAL CARD
            5           IN      5       0       0
                        *
                        *    OUTPUT CONTROL CARD
            6           IO      5       0       0
                        *

            7           KK    PRE1
                        * ***************************************************************************
                        * *************** 1-INCH, 6 HOUR STORM EVENT ********************************
                        * ***************************************************************************
            8           PI    .000    .003    .003    .003    .003    .003    .003    .004    .004    .004
            9           PI    .004    .004    .004    .004    .004    .005    .005    .005    .005    .006
           10           PI    .007    .007    .007    .008    .008    .009    .009    .010    .011    .012
           11           PI    .013    .019    .022    .025    .039    .050    .108    .188    .075    .043
           12           PI    .028    .023    .020    .014    .012    .011    .010    .009    .009    .008
           13           PI    .008    .007    .007    .007    .006    .005    .005    .005    .005    .005
           14           PI    .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
           15           PI    .003    .003    .003    .000
                        * ***************************************************************************
           16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
           17           KO      5       0       0       0      21
           18           BA   .0016
           19           LS      0    65.0       0
           20           UD   0.194

           21           KK   POST1
           22           KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
           23           KO      1       0       0       0      21
           24           BA   .0016
           25           LS      0    98.3       0
           26           UD   0.080
           27           ZZ
1*****************************************                                                ***************************************
 *                                       *                                                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                *   U.S. ARMY CORPS OF ENGINEERS     *
 *             JUN  1998                 *                                                *   HYDROLOGIC ENGINEERING CENTER    *
 *           VERSION 4.1                 *                                                *         609 SECOND STREET          *
 *                                       *                                                *      DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   12APR07  TIME  18:40:19   *                                                *          (916) 756-1104            *
 *                                       *                                                *                                     *
 *****************************************                                                ***************************************




                             CHARLOTTE-MECKELNBURG POST CONSTRUCTION DESIGN MANUAL
                             ANALYZED BY ABC ENGINEERING
                             DATE: OCTOBER 2006

   6 IO          OUTPUT CONTROL VARIABLES
                       IPRNT           5  PRINT CONTROL
                       IPLOT           0  PLOT CONTROL
                       QSCAL          0.  HYDROGRAPH PLOT SCALE

    IT           HYDROGRAPH TIME DATA
                        NMIN           1  MINUTES IN COMPUTATION INTERVAL
                       IDATE      1    0  STARTING DATE
                       ITIME        0000  STARTING TIME
                          NQ         365  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE      1    0  ENDING DATE
                      NDTIME        0604  ENDING TIME
                       ICENT          19  CENTURY MARK

                   COMPUTATION INTERVAL     .02 HOURS
                        TOTAL TIME BASE    6.07 HOURS

 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***


           *************
           *           *
  21 KK    *    POST1  *
           *           *
           *************

               SUBBASIN RUNOFF DATA

  24 BA          SUBBASIN CHARACTERISTICS
                       TAREA         .00  SUBBASIN AREA

                 PRECIPITATION DATA

   8 PB                STORM        1.00  BASIN TOTAL PRECIPITATION

  25 LS          SCS LOSS RATE
                       STRTL         .03  INITIAL ABSTRACTION
                      CRVNBR       98.30  CURVE NUMBER
                       RTIMP         .00  PERCENT IMPERVIOUS AREA

  26 UD          SCS DIMENSIONLESS UNITGRAPH
                        TLAG         .08  LAG

 ***********************************************************************************************************************************
```

```
    TOTAL RAINFALL =    1.00, TOTAL LOSS =     .18, TOTAL EXCESS =     .82

  PEAK FLOW     TIME                        MAXIMUM AVERAGE FLOW
                                   6-HR        24-HR       72-HR      6.07-HR
+   (CFS)       (HR)
                          (CFS)
+       2.      3.20                 0.          0.          0.           0.
                        (INCHES)   .812        .812        .812         .812
                         (AC-FT)     0.          0.          0.           0.

                         CUMULATIVE AREA =     .00 SQ MI

1
                                                    RUNOFF SUMMARY
                                            FLOW IN CUBIC FEET PER SECOND
                                         TIME IN HOURS,  AREA IN SQUARE MILES

                                          PEAK   TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD     BASIN    MAXIMUM    TIME OF
          OPERATION       STATION         FLOW    PEAK                                           AREA     STAGE     MAX STAGE
+                                                            6-HOUR     24-HOUR     72-HOUR

          HYDROGRAPH AT
+                            PRE1           0.     .00           0.          0.          0.        .00

          HYDROGRAPH AT
+                           POST1           2.    3.20           0.          0.          0.        .00


 *** NORMAL END OF HEC-1 ***
```

Note that the previous HEC-1 model output using the SCS method indicates that the runoff volume is 0.82 inches which matches the Schueler method runoff volume results using Equation 3-2.

Step 6a Compute Channel Protection Volume (CP_v)

- Compute maximum soil retention using SCS methods shown in the Charlotte-Mecklenburg Storm Water Design Manual. Note that the CN value used is the original site CN value, not the adjusted CN value used during the water quality runoff volume computation.

  $S = 1000/CN-10$
  $= 1000/93.4 – 10$
  $= 0.71$ inches

  Compute total runoff for the 1-year, 24-hour storm event. Total rainfall depth is 2.58 inches.

  $Q_d = (P-0.2S)^2/(P+0.8S)$
  $= [2.58 – (0.2)(0.71)]^2/[2.58 + (0.8)(0.71)]$
  $= 1.89$ inches

  Compute watershed runoff

  CP_v = (1.89 inches)(1 acres)(1 foot/12 inches) = 0.16 acre-feet

- **Estimate Approximate Storage Volume**

  All storm events will be diverted into the bioretention area. The maximum ponding depth for water quality and channel protection storm events must be less than or equal to 12 inches. In order to achieve the pollutant removal goals of the Post Construction Ordinance, the bioretention area must hold the Water Quality Volume (WQ_v) for 1.3 days above and within the filter media. Note that the detention time is measured relative to the center of rainfall (the 1-inch, 6-hour storm event center of rainfall is 3 hours, therefore, the time of interest is 1.3 days plus 3 hours; 34.2 hours or 1.425 days). The design requirements to meet the Post Construction Ordinance goals of 85 percent TSS and 70 percent TP removal include a filter media thickness of 4 feet.

For this example, the Channel Protection Volume (CP_v) is required to be held within the combination of bioretention and downstream extended detention basin for a minimum of 24 hours (48 hours in Charlotte). The "Static Method" can be used as an initial estimate and set the storage volume equal to the runoff volume, assumes that the storage volume fills instantaneously and empties through the outlet structures including the filter media, orifices, and weirs. In the case of the bioretention area, the outlet structure for the Water Quality Volume (WQ_v) is based on the filter media. The outlet structures for the Channel Protection Volume (CP_v) may be based on a combination of the bioretention filter media and an overflow weir and orifice structure of the bioretention area and the extended detention basin.

Using the Static Method, the bioretention area requires 0.07 acre-ft storage to hold the Water Quality Volume (WQ_v). The bioretention area and extended detention basin requires 0.16 acre-feet storage to hold the total Channel Protection Volume (CP_v). These values can be used as estimates to develop approximate storage volumes and grading plans, but routing computations must be performed to complete the design.

<u>Step 6b Compute Approximate Release Rates for Water Quality Volume (WQ_v) and Channel Protection Volume (CP_v)</u>

The following outlet hydraulic computations are performed using the Static Method. Routing computations must be performed to refine the design. The detailed outlet hydrograph analysis must show that a minimum of 5 percent of the runoff volume is held within the storage volume after the design duration time.

- Compute the release rate for water quality control (WQ_v).

  The water quality control volume (WQ_v) is to be released over a 1.3 day (31.2 hours) beyond the center of the design rainfall (3 hours) which results in a total control duration of 34.2 hours.

  Release rate = (0.07 ac-ft x 43560 ft^2/acre)/(34.2 hrs x 3,600 sec/hr) = 0.025 cfs

- Compute the release rate for channel protection volume control (CP_v).

  The channel protection volume (CP_v) is to be released over a 24-hour period beyond the center of the design rainfall (12 hours) which results in a total control duration of 36 hours.

  Release rate = (0.16 ac-ft x 43560 ft^2/acre)/(36 hrs x 3,600 sec/hr) = 0.054 cfs

<u>Step 7 Size Flow Diversion Structure</u>

This design example does not include a flow diversion structure (refer to Section 4.1.9 for example of flow diversion structure design.

<u>Step 8 Compute Pretreatment System Requirements</u>

The pretreatment requirement for a bioretention area is that the flow enters in a dispersed condition, which is defined to be a depth of less than 1-inch with a velocity less than 1 foot per second. The inflow for the storm event that enters the bioretention varies from 1.5 cfs for the 1-inch, 6-hour storm event to 5.9 cfs for the 25-year, 6-hour storm event. The energy dispersion design methods discussed in section 5.6 can be referenced to ensure that the inflow velocity and depth requirements are met.

Step 9 Compute Bioretention Area and Volume to Treat Water Quality Volume

- Size bioretention ponding area to contain Water Quality Volume
- Absolute minimum sizing allowed based on the depth of storage of the WQv above the media:

$$A_f = WQ_v/h_f$$
$$= (0.07 \text{ acre-ft})(43560 \text{ sf/ac})/1\text{ft}$$
$$= 3{,}049 \text{ sq ft}$$

where:
WQ_v = Water Quality Volume
h_f = Allow headwater depth for water quality volume in the bioretention area.

- Check the bioretention ponding/filter area based on Darcy's equation, use the greater surface area. A value of 0.25 inch/hour (0.5 foot/day) for the coefficient of permeability of the filter media is assumed.

$$A_f = (WQ_v)(d_f)/[(k)(h_f+d_f)(t_f)]$$

where:
A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (2.ft standard, 4 ft optimal efficiency)
k = design coefficient of permeability of filter media (0.5 ft/day)
h_f = average height of water above filter bed (0.5 ft max)
t_f = design filter bed drain time (days)
(1.125 standard or 1.425 optimal efficiency)

$$Af = \frac{(0.07 \text{ acre-ft})\ (43560 \text{ sf/ac})(4 \text{ ft}))}{[(0.5 \text{ ft/day})\ (0.5\text{ft}+4\text{ft})\ (1.425 \text{ days})]}$$

$$= 3{,}690 \text{ sq ft}$$

- Since the bioretention is being designed to remove 70% phosphorus, the surface area needs to be 3,690 sq ft. If treatment for phosphorus removal is not required, the minimum surface area would be 3,049 sq ft.

Step 10 Set Design Elevations and Dimensions of Facility

This step is completed for site-specific conditions and is not shown as part of this example.

Step 11a Develop Bioretention Storage-Elevation Table and Curve

Figure 4.1.6 shows the bioretention location on site, Figure 4.1.7 shows the plan view of the bioretention topography and Table 4.1.2 shows the storage-elevation data that was developed for this example.

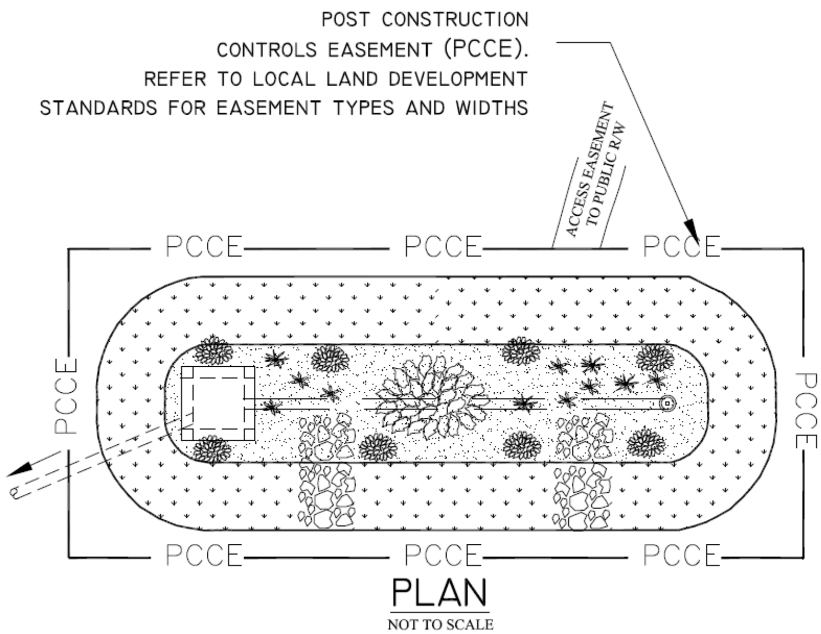

Figure 4.1.7 Plan View of Bioretention Topography (Not to Scale)

Table 4.1.2 Bioretention Storage-Elevation Data

Elevation	Area (sf)	Area (ac)	Avg. Area (ac)	Height (ft)	Inc vol (ac-ft)	Acc vol (ac-ft)
700	3690	0.085				0.000
700.5	4058	0.093	0.089	0.5	0.044	0.044
701	4449	0.102	0.098	0.5	0.049	0.093
701.5	4858	0.112	0.107	0.5	0.053	0.147
702.0	5285	0.121	0.116	0.5	0.058	0.205
702.5	5730	0.132	0.126	0.5	0.063	0.268
703.0	6194	0.142	0.137	0.5	0.068	0.337

Step 11b Develop Stage-Discharge for Bioretention Filter Media

The 1-inch, 6-hour storm event and portions of the more severe storm events will flow through the filter media. The outflow conditions for the filter media must be assessed in order to derive the relation for the stage-discharge and in order to perform routing computations. The routing must be performed for the storage area above the filter media, and not the storage area within the filter media. Therefore, all of the computations are based on elevation above the top of the filter media. Outflow when runoff is at the top of the filter media is ignored and assumed to be zero.

$$A_f = (WQ_v)(d_f)/[(k)(h_f+d_f)(t_f)]$$

$$WQ_v/t_f = Q_o = A_f\,(k)(h_f+d_f)/(d_f))(C_f)$$

where:

A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (ft)
k = coefficient of permeability of filter media (ft/day)

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

At elevation 701, top of water quality volume storage

Q_o = [(3,690 ft^2) (0.5 ft/day) (1ft+4ft)]/(4 ft)
= 2,767.5 cf/day
= 0.027 cfs

At elevation 700.5, the average water quality volume storage depth

Q_o = [(3,690 ft^2) (0.5 ft/day) (0.5ft+4ft)]/(4 ft)
= 2,075.6 cf/day
= 0.024 cfs

At elevation 700, top of filter media

Q_o = 0.00 cfs

<u>Step 12 Route Runoff Hydrographs through Bioretention</u>

Route all of the appropriate runoff hydrographs through the bioretention area with the following goals:

- 1-inch, 6-hour storm event through the filter media and ensure that 5 percent of the runoff volume remains in the facility after 1.3 days beyond the center of rainfall (1.425 days).
- Route storm events through the filter media and over flow structure with a maximum 12 inches of ponding depth for the 1-year, 24-hour storm and with a maximum 15 inches of ponding depth for the 10-, 25-, and 50-year, 6-hour storm events, which ensures that the filter media is not damaged due to inflow velocity and ensures that plants are not inundated with water for long periods of time.
- Hold 5 percent of the 1-year, 24-hour storm event within the bioretention and extended detention basin storage volume 24 hours after the center of rainfall (12 hours). Total detention time is 36 hours.
- Attenuate the 10- and 25-year, 6-hour storm events to pre-development levels.

The following HEC-1 file provides the results of the 1-inch, 6-hour storm event routing. Note, an iterative design process to reduce the bioretention footprint area is not performed for this design example because the storm events larger than the WQ_v are being diverted into the facility and the storage volume is being used to assist with meeting attenuation goals. (refer to Section 4.1.9 for a design example showing the iterative design example that results in a smaller footprint). The peak water surface elevation is shown to be 700.69 with the entire 1-inch storm event flowing through the filter media. Export of the hydrograph to a spreadsheet indicates that 27.6 percent of the 1-inch, 6-hour runoff hydrograph remains in the bioretention storage volume at 34.2 hours. The peak flow is attenuated from 1.67 cfs to 0.03 cfs.

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1***************************************                                          **************************************
 *                                      *                                         *                                    *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                         *    U.S. ARMY CORPS OF ENGINEERS    *
 *             JUN   1998               *                                         *    HYDROLOGIC ENGINEERING CENTER   *
 *           VERSION 4.1                *                                         *         609 SECOND STREET          *
 *                                      *                                         *      DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   05APR08  TIME  18:16:33  *                                         *          (916) 756-1104            *
 *                                      *                                         *                                    *
 ****************************************                                         **************************************

                                     X     X  XXXXXXX   XXXXX          X
                                     X     X  X        X     X        XX
                                     X     X  X        X               X
                                     XXXXXXX  XXXX     X       XXXXX   X
                                     X     X  X        X               X
                                     X     X  X        X     X         X
                                     X     X  XXXXXXX   XXXXX         XXX


         THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

         THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
         THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
         NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
         DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
         KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM
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1                                                    HEC-1 INPUT                                              PAGE  1

           LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

            1            ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
            2            ID       ANALYZED BY ABC ENGINEERING
            3            ID       DATE: OCTOBER 2006
                         *  ***************************************************************************
                         *
                         *     TIME SPECIFICATION CARD
            4            IT       2       0       0    1026
                         *  DIAGRAM
                         *     TIME INTERVAL CARD
            5            IN       5       0       0
                         *
                         *     OUTPUT CONTROL CARD
            6            IO       5       0       0
                         *

            7            KK     PRE1
                         * ****************************************************************************
                         * **************** 1-INCH, 6 HOUR STORM EVENT *********************************
                         * ****************************************************************************
            8            PI     .000    .003    .003    .003    .003    .003    .003    .004    .004    .004
            9            PI     .004    .004    .004    .004    .004    .005    .005    .005    .005    .006
           10            PI     .007    .007    .007    .008    .008    .009    .009    .010    .011    .012
           11            PI     .013    .019    .022    .025    .039    .050    .108    .188    .075    .043
           12            PI     .028    .023    .020    .014    .012    .011    .010    .009    .009    .008
           13            PI     .008    .007    .007    .007    .006    .005    .005    .005    .005    .005
           14            PI     .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
           15            PI     .003    .003    .003    .000
                         * ****************************************************************************
           16            KM    1-ACRE PRE-DEVELOPED CONDITIONS
           17            KO       5       0       0       0      21
           18            BA    .0016
           19            LS       0    65.0       0
           20            UD    0.194

           21            KK    POST1
           22            KM    1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
           23            KO       1       0       0       0      21
           24            BA    .0016
           25            LS       0    98.3       0
           26            UD    0.080

           27            KK   BIOROU
           28            KO       5       0       0       0      21
           29            KM    ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
           30            KM    NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
           31            RS       1    ELEV     700
           32            SA     .085    .093    .102    .112    .121    .132    .142
           33            SE      700   700.5     701   701.5     702   702.5     703
           34            SQ     0.00   0.024   0.027   0.029   0.032   0.035   0.037
           35            SE      700   700.5     701   701.5     702   702.5     703
           36            ZZ
1*****************************************                                              ****************************************
 *                                       *                                              *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                              *     U.S. ARMY CORPS OF ENGINEERS     *
 *              JUN   1998               *                                              *     HYDROLOGIC ENGINEERING CENTER    *
 *            VERSION 4.1                *                                              *          609 SECOND STREET           *
 *                                       *                                              *        DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   05APR08  TIME  18:16:33   *                                              *            (916) 756-1104            *
 *                                       *                                              *                                      *
 *****************************************                                              ****************************************

 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***


            *************
            *           *
   21 KK    *   POST1   *
            *           *
            *************

 *****************************************************************************************************************************

    TOTAL RAINFALL =    1.00, TOTAL LOSS =    .18, TOTAL EXCESS =    .82

                                                     RUNOFF SUMMARY
                                              FLOW IN CUBIC FEET PER SECOND
                                           TIME IN HOURS,  AREA IN SQUARE MILES

                                        PEAK    TIME OF    AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN     MAXIMUM     TIME OF
         OPERATION       STATION        FLOW     PEAK                                            AREA      STAGE     MAX STAGE
+                                                            6-HOUR      24-HOUR     72-HOUR

         HYDROGRAPH AT
+                          PRE1          0.      .00           0.          0.          0.        .00

         HYDROGRAPH AT
+                         POST1          2.     3.20           0.          0.          0.        .00

         ROUTED TO
+                        BIOROU          0.     3.90           0.          0.          0.        .00
+                                                                                                         700.69       6.17


 *** NORMAL END OF HEC-1 ***
```

The following HEC-1 file provides the results of the first step of the 1-year, 24-hour storm event routing. The designer has the two options. The first option is to set a spillway overflow elevation at the peak stage of the 1-inch, 6-hour storm event (700.69) and allow the additional runoff volume from the 1-year, 24-hour storm event to discharge through an overflow structure and control the majority of the CP_v in the downstream extended detention basin. The second option is to set a spillway overflow elevation above the peak stage of the 1-inch, 6-hour storm event and allow some or all of the additional runoff volume from the 1-year, 24-hour storm event to discharge through the filter media. For this example, the first option was selected because we felt that minimal benefit could be provided by storing the 1-year, 24-hour storm event in the bioretention area without exceeding the maximum 12 inch ponding depth. In order to estimate the benefit of the bioretention facility in controlling the 1-year, 24-hour storm event, the first iteration includes only the bioretention facility, as designed to control the 1-inch, 6-hour storm event with a 3.5 foot by 3.5 foot overflow structure set at elevation 700.70. The outlet structure configuration is illustrated in Figure 4.1.9.

```
1*****************************************                                                   ***************************************
 *                                       *                                                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *   U.S. ARMY CORPS OF ENGINEERS      *
 *              JUN   1998               *                                                   *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                                   *         609 SECOND STREET           *
 *                                       *                                                   *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   05APR08  TIME  19:58:19   *                                                   *          (916) 756-1104             *
 *                                       *                                                   *                                     *
 *****************************************                                                   ***************************************


                    X     X  XXXXXXX   XXXXX          X
                    X     X  X        X     X        XX
                    X     X  X        X               X
                    XXXXXXX  XXXX     X       XXXXX   X
                    X     X  X        X               X
                    X     X  X        X     X         X
                    X     X  XXXXXXX   XXXXX         XXX


 THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

 THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
 THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
 NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
 DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
 KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                        HEC-1 INPUT                                                       PAGE  1

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   2           ID       ANALYZED BY ABC ENGINEERING
   3           ID       DATE: OCTOBER 2006
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               *     TIME SPECIFICATION CARD
   4           IT       2       0       0    1080
               *  DIAGRAM
               *     TIME INTERVAL CARD
   5           IN       6       0       0
               *
               *     OUTPUT CONTROL CARD
   6           IO       5       0       0
               *

   7           KK    PRE1
   8           PB    2.58
               * *************************************************************************
               * ********* 6 MINUTE TIME INCREMENT,24-HOUR STORM EVENT **********************
               * *************************************************************************
   9           PI   .0000   .0010   .0010   .0010   .0011   .0010   .0011   .0010   .0011   .0011
  10           PI   .0011   .0011   .0011   .0011   .0012   .0011   .0012   .0011   .0012   .0012
  11           PI   .0012   .0012   .0012   .0013   .0012   .0012   .0013   .0012   .0013   .0013
  12           PI   .0013   .0013   .0013   .0013   .0014   .0013   .0014   .0014   .0013   .0014
  13           PI   .0014   .0014   .0014   .0015   .0015   .0015   .0015   .0015   .0015   .0016
  14           PI   .0016   .0016   .0016   .0017   .0017   .0016   .0018   .0017   .0017   .0018
  15           PI   .0018   .0018   .0018   .0019   .0019   .0018   .0020   .0019   .0019   .0020
  16           PI   .0020   .0020   .0020   .0021   .0021   .0021   .0021   .0021   .0021   .0022
  17           PI   .0022   .0022   .0024   .0024   .0026   .0026   .0028   .0029   .0029   .0030
  18           PI   .0032   .0032   .0032   .0032   .0032   .0032   .0033   .0034   .0036   .0038
  19           PI   .0039   .0041   .0044   .0046   .0048   .0051   .0054   .0058   .0062   .0066
  20           PI   .0070   .0077   .0086   .0096   .0106   .0115   .0238   .0476   .0764   .1371
  21           PI   .0951   .0190   .0166   .0144   .0122   .0098   .0084   .0080   .0074   .0068
  22           PI   .0064   .0060   .0056   .0054   .0052   .0048   .0046   .0044   .0042   .0040
  23           PI   .0038   .0037   .0036   .0035   .0034   .0034   .0033   .0033   .0032   .0031
  24           PI   .0030   .0030   .0029   .0028   .0027   .0027   .0026   .0026   .0025   .0024
  25           PI   .0023   .0023   .0022   .0023   .0022   .0022   .0022   .0021   .0021   .0021
  26           PI   .0021   .0020   .0020   .0020   .0019   .0020   .0019   .0019   .0018   .0018
  27           PI   .0018   .0018   .0017   .0018   .0017   .0017   .0016   .0017   .0016   .0016
  28           PI   .0015   .0016   .0015   .0015   .0015   .0014   .0014   .0014   .0013   .0014
  29           PI   .0013   .0013   .0013   .0013   .0013   .0012   .0013   .0013   .0012   .0013
  30           PI   .0012   .0013   .0012   .0013   .0012   .0012   .0013   .0012   .0012   .0012
  31           PI   .0012   .0012   .0012   .0012   .0012   .0011   .0012   .0012   .0011   .0012
  32           PI   .0011   .0012   .0011   .0012   .0011   .0011   .0012   .0011   .0011   .0011
  33           PI   .0011
  34           KM   1-ACRE PRE-DEVELOPED CONDITIONS
  35           KO       5       0       0       0      21
  36           BA   .0016
  37           LS       0    65.0       0
  38           UD   0.194
  39           KK   POST1
  40           KM   1-ACRE POST-DEVELOPED CONDITIONS - STANDARD SCS CURVE NUMBER
  41           KO       5       0       0       0      21
  42           BA   .0016
  43           LS       0    93.4       0
  44           UD   0.080

  45           KK   BIOROU
  46           KO       5       0       0       0      21
  47           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
  48           KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
```

```
          49           RS       1   ELEV     700
          50           SA    .085   .093    .097    .102    .112    .121    .132    .142
          51           SE     700  700.5  700.70     701   701.5     702   702.5     703
          52           SQ    0.00  0.024   0.025   6.863  29.796  61.693  90.475 102.269
          53           SE     700  700.5  700.70     701   701.5     702   702.5     703
          54           ZZ
1*****************************************                                                  **************************************
 *                                       *                                                  *                                    *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                  *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN    1998               *                                                  *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                  *         609 SECOND STREET           *
 *                                       *                                                  *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE    05APR08  TIME  19:58:19  *                                                  *           (916) 756-1104            *
 *                                       *                                                  *                                    *
 *****************************************                                                  **************************************


                                 CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                                 ANALYZED BY ABC ENGINEERING
                                 DATE: OCTOBER 2006

1
                                                            RUNOFF SUMMARY
                                                    FLOW IN CUBIC FEET PER SECOND
                                                 TIME IN HOURS,  AREA IN SQUARE MILES

                                            PEAK   TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD        BASIN     MAXIMUM     TIME OF
          OPERATION        STATION          FLOW     PEAK                                               AREA      STAGE     MAX STAGE
+                                                               6-HOUR      24-HOUR      72-HOUR

          HYDROGRAPH AT
+                             PRE1            0.    12.23           0.           0.           0.         .00

          HYDROGRAPH AT
+                            POST1            3.    12.07           0.           0.           0.         .00

          ROUTED TO
+                           BIOROU            2.    12.17           0.           0.           0.         .00
+                                                                                                                 700.78       12.17


 *** NORMAL END OF HEC-1 ***
```

The peak water surface elevation is shown to be 700.78 with a portion of the 1-year, 24-hour storm event flowing through the filter media and a portion of the 1-year, 24-hour storm event flow through the overflow structure. Detailed review of the TAPE 21 output indicates that the 1-year, 24-hour peak flow is 2.65 cfs which is attenuated to 1.85 cfs by routing through the bioretention filter media and overflow structure. Review of the outflow hydrograph indicates that 24.9 percent of the runoff volume has left the bioretention storage volume at 36 hours (24 hours after the center of rainfall). Figure 4.1.8 illustrates the inflow and outflow hydrographs. The goal of controlling the 1-year, 24-hour storm event for 24 hours has been met, without a downstream extended detention basin.

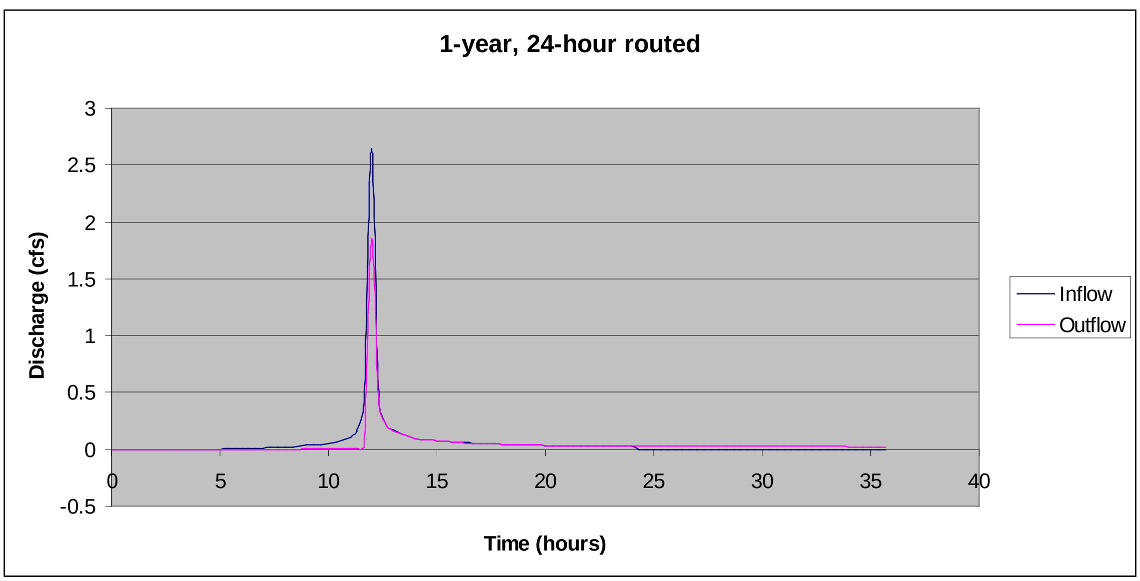

Figure 4.1.8 Bioretention Inflow and Outflow Hydrograph

Step 13 Design Conveyance System

Conveyance system design is not included in this design example. Standards for conveyance system design are covered in the Charlotte-Mecklenburg Storm Water Design Manual.

Step 14a Size Bioretention Underdrain System

The underdrain system must be designed to meet two design goals; the underdrain capacity must be greater than the filter media capacity, and the capacity must drain the runoff volume from the system within 48 hours. The design must assume that 50 percent of the underdrain system (perforations and pipe system capacity) is lost due to clogging.

Design specifications require the underdrain system to be a 6-inch perforated PVC pipe with 3/8-inch in diameter spaced 3 inches on center along 4 longitudinal rows that are spaced 90° apart. Minimum underdrain slope is 0.5 percent.

The length, slope, number of pipes, spacing, etc. is configured per design requirements. Based upon the required area for the bioretention BMP (3,690 ft^2) the approximate dimensions of the bioretention area is selected to be 37 feet wide by 100 feet in length (approximately 3,690 ft^2).

The design process uses a trial and error process to determine the proper underdrain capacity.
The capacity of the perforations and pipe (assuming 50 percent of the system is clogged) are computed. The computed underdrain capacity is checked relative to the filter media capacity to ensure that the filter media is the controlling outflow condition. The computed underdrain capacity if compared to the static outflow discharge that ensures the runoff within the system leaves within 48 hours.

Compute minimum drawdown discharge

Water quality volume	=	(0.07ac-ft)(43,560ft^3/ac ft)	= 3,049 ft^3
Drawdown	=	3,049 ft3/[(48 hours)(3,600sec/hour)]	
	=	0.018 cfs	

Compute perforation capacity

Since the maximum underdrain spacing is 10 feet on center and the bioretention area is 37 feet wide by 100 feet in length, three parallel underdrain pipes (6-inch diameter PVC) 100 feet in length were selected. For the calculations below, the length of pipe containing holes was reduced by 1 foot per cleanout to account for non-perforated fittings.

Number of perforations	=	(3 pipes)((100 - 3) ft/pipe)(4 rows/ft)(4 holes/row)	= 4,656 holes
50 percent of perforations	=	2,328 holes	
Capacity of one hole	=	$CA(2gh)^{0.5}$	
	=	$(0.6)(3.1416)[(3/8in)(1/24)]^2[(64.4)(4.5ft)]^{0.5}$	
	=	0.0078 cfs/hole	
Total capacity	=	(0.0078 cfs/hole)(2,328 holes)	= 18.16 cfs

The perforations capacity (18.16 cfs) is greater than the filter media capacity (0.024 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.018 cfs computed in this step). Therefore the design is acceptable.

Note that the headwater depth used to determine the filter media capacity is 0.5 feet, the average headwater depth above the filter media for the water quality storm event. The drawdown computation is also based on the water quality volume. The headwater depth for the perforations is also based on the same average headwater elevations, 0.5 feet above the filter media, or 4.5 feet above the perforations.

<u>Compute underdrain pipe capacity</u>
For 6-inch PVC underdrain pipe at 0.005 ft/ft slope

Capacity of pipe	=	$(1.49/n)(A)(A/P)^{0.67}(S)^{0.5}$
	=	$(1.49/0.013)(0.1963\ ft^2)(0.125\ ft)^{0.67}(0.005)^{0.5}$
	=	0.40 cfs
Capacity of pipe (50% clogged)	=	0.20 cfs

The perforations capacity (0.20 cfs) is greater than the filter media capacity at the average storage volume depth (0.024 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.018 cfs computed in this step). Therefore the design is acceptable.

Step 14b Calculate Q_{10} and Q_{25} Release Rate(s) and Water Surface Elevation(s) for Bioretention and Detention Basin

The next step of the design process is to design the bioretention facility and a detention basin to achieve the peak attenuation goals for the 10- and 25-year, 6-hour storm events (note that the previous step eliminated the need for an <u>extended</u> detention basin, therefore, the design process is now focused on designing a standard detention basin however, the benefits of the upstream bioretention facility are included in the design). This process is similar to previous examples in that the design is iterative. A stage-storage-discharge relation is developed assuming an outflow orifice and storage area. The appropriate storm events are routed through the storage volume, and the outflow peak discharge is compared to the pre-development peak discharge for the 10- and 25-year, 6-hour storm events; 1.10 and 1.64 cfs, respectively. In addition, the peak stage for the 10- and 25-year, 6-hour storm events must be less than 15 inches above the top of the filter media in the bioretention facility.

The following HEC-1 output files illustrate the results of the iterative process for the 10- and 25-year storm event. A 6.0 inch orifice that is installed at the base of the detention basin outlet structure (695.00) attenuates the post-developed peak discharge to appropriate values for the 10- and 25-year, 6-hour storm events. The TAPE21 file indicates that the pre-developed peak discharge for the 10-year, 6-hour storm event is 1.10 cfs and the post-developed peak discharge is 1.10 cfs with a detention basin peak stage of 696.62. The pre-developed peak discharge for the 25-year, 6-hour storm event is 1.64 cfs and the post-developed peak discharge is 1.28 cfs with a detention basin peak stage of 697.10. Intermediate steps are not presented.

```
1****************************************                                                ***************************************
 *                                       *                                                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                *    U.S. ARMY CORPS OF ENGINEERS     *
 *               JUN   1998              *                                                *    HYDROLOGIC ENGINEERING CENTER    *
 *             VERSION 4.1               *                                                *          609 SECOND STREET          *
 *                                       *                                                *       DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   05APR08  TIME  20:20:23   *                                                *           (916) 756-1104            *
 *                                       *                                                *                                     *
 ****************************************                                                ***************************************


                                                  X     X  XXXXXXX   XXXXX           X
                                                  X     X  X        X     X         XX
                                                  X     X  X        X                X
                                                  XXXXXXX  XXXX     X        XXXXX   X
                                                  X     X  X        X                X
                                                  X     X  X        X     X          X
                                                  X     X  XXXXXXX   XXXXX          XXX


            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                        HEC-1 INPUT                                                  PAGE  1

           LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

              1          ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
              2          ID       ANALYZED BY ABC ENGINEERING
```

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   3         ID      DATE: OCTOBER 2006
             *  ***************************************************************************
             *
             *    TIME SPECIFICATION CARD
   4         IT     2      0      0   1080
             *  DIAGRAM
             *    TIME INTERVAL CARD
   5         IN     5      0      0
             *
             *    OUTPUT CONTROL CARD
   6         IO     5      0      0
             *

   7         KK    PRE1
             * ****************************************************************************
             * **************** 10-YEAR, 6-HOUR STORM EVENT ******************************
             * ****************************************************************************
   8         PI   .000    .011    .011    .012    .012    .012    .012    .013    .013    .013
   9         PI   .014    .014    .015    .015    .016    .016    .017    .018    .018    .023
  10         PI   .024    .025    .026    .027    .029    .036    .039    .042    .045    .049
  11         PI   .054    .079    .089    .103    .161    .201    .395    .590    .275    .177
  12         PI   .112    .095    .084    .057    .051    .047    .043    .040    .038    .030
  13         PI   .028    .027    .025    .024    .023    .019    .018    .017    .017    .016
  14         PI   .016    .015    .015    .014    .014    .013    .013    .013    .012    .012
  15         PI   .012    .011    .011    .000
             * ****************************************************************************
  16         KM   1-ACRE PRE-DEVELOPED CONDITIONS
  17         KO     5      0      0      0     21
  18         BA   .0016
  19         LS     0   65.0      0
  20         UD   0.194

  21         KK   POST1
  22         KM   1-ACRE POST-DEVELOPED CONDITIONS - STANDARD SCS CURVE NUMBER
  23         KO     5      0      0      0     21
  24         BA   .0016
  25         LS     0   93.4      0
  26         UD   0.080

  27         KK  BIOROU
  28         KO     5      0      0      0     21
  29         KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
  30         KM   ROUTE THROUGH FILTER MEDIA UP TO 1-INCH STAGE
  31         KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
  32         RS     1   ELEV    700
  33         SA   .085    .093    .097    .102    .112    .121    .132    .142
  34         SE    700   700.5  700.70    701   701.5     702   702.5     703
  35         SQ   0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
  36         SE    700   700.5  700.70    701   701.5     702   702.5     703
  37         KK   EDROU
  38         KO     5      0      0      0     21
  39         KM   ROUTE BIORETENTION OUTFLOW THROUGH DETENTION BASIN
  40         KM   6-INCH ORIFICE
  41         RS     1   ELEV    695
  42         SA   .048    .053    .057    .062    .068    .073    .079
  43         SE    695   695.5     696   696.5     697   697.5     698
  44         SQ   0.00   0.473   0.819   1.057   1.251   1.418   1.568
  45         ZZ
1*****************************************                              ***************************************
 *                                       *                              *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                              *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                              *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                              *         609 SECOND STREET           *
 *                                       *                              *      DAVIS, CALIFORNIA 95616        *
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 *                                       *                              *                                     *
 *****************************************                              ***************************************

                        CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                        ANALYZED BY ABC ENGINEERING
                        DATE: OCTOBER 2006

1
                                               RUNOFF SUMMARY
                                        FLOW IN CUBIC FEET PER SECOND
                                     TIME IN HOURS,  AREA IN SQUARE MILES

                                   PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD       BASIN     MAXIMUM    TIME OF
        OPERATION       STATION    FLOW     PEAK                                               AREA      STAGE     MAX STAGE
+                                                      6-HOUR       24-HOUR      72-HOUR

        HYDROGRAPH AT
+                         PRE1       1.     3.40          0.           0.           0.         .00

        HYDROGRAPH AT
+                        POST1       5.     3.20          1.           0.           0.         .00

        ROUTED TO
+                       BIOROU       5.     3.27          0.           0.           0.         .00
+                                                                                                    700.91       3.27

        ROUTED TO
+                        EDROU       1.     3.63          0.           0.           0.         .00
+                                                                                                    696.62       3.67


 *** NORMAL END OF HEC-1 ***



1*****************************************                              ***************************************
 *                                       *                              *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                              *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                              *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                              *         609 SECOND STREET           *
 *                                       *                              *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   05APR08  TIME  20:22:53   *                              *          (916) 756-1104             *
 *                                       *                              *                                     *
 *****************************************                              ***************************************
```

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                    X     X  XXXXXXX   XXXXX          X
                    X     X  X        X     X        XX
                    X     X  X        X               X
                    XXXXXXX  XXXX     X       XXXXX   X
                    X     X  X        X               X
                    X     X  X        X     X         X
                    X     X  XXXXXXX   XXXXX         XXX


   THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

   THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
   THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
   NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
   DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
   KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                            HEC-1 INPUT                                                PAGE  1

         LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

           1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
           2           ID       ANALYZED BY ABC ENGINEERING
           3           ID       DATE: OCTOBER 2006
                       *  ******************************************************************************
                       *
                       *     TIME SPECIFICATION CARD
           4           IT       2       0       0    1080
                       *  DIAGRAM
                       *     TIME INTERVAL CARD
           5           IN       5       0       0
                       *
                       *     OUTPUT CONTROL CARD
           6           IO       5       0       0
                       *

           7           KK    PRE1
                       * ******************************************************************************
                       * ***************** 25-YEAR, 6-HOUR STORM EVENT ******************************
                       * ******************************************************************************
           8           PI    .000    .014    .014    .014    .015    .015    .015    .016    .016    .017
           9           PI    .017    .018    .018    .019    .019    .020    .021    .022    .023    .025
          10           PI    .027    .028    .029    .031    .033    .043    .046    .049    .053    .058
          11           PI    .064    .093    .104    .120    .189    .235    .466    .680    .324    .208
          12           PI    .131    .111    .098    .067    .061    .055    .051    .048    .045    .034
          13           PI    .032    .030    .029    .027    .026    .023    .022    .021    .021    .020
          14           PI    .019    .019    .018    .017    .017    .016    .016    .016    .015    .015
          15           PI    .014    .014    .014    .000
                       * ******************************************************************************
          16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
          17           KO       5       0       0       0      21
          18           BA   .0016
          19           LS       0    65.0       0
          20           UD   0.194

          21           KK   POST1
          22           KM   1-ACRE POST-DEVELOPED CONDITIONS - STANDARD SCS CURVE NUMBER
          23           KO       5       0       0       0      21
          24           BA   .0016
          25           LS       0    93.4       0
          26           UD   0.080

          27           KK  BIOROU
          28           KO       5       0       0       0      21
          29           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
          30           KM   ROUTE THROUGH FILTER MEDIA UP TO 1-INCH STAGE
          31           KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
          32           RS       1    ELEV     700
          33           SA    .085    .093    .097    .102    .112    .121    .132    .142
          34           SE     700   700.5  700.70     701   701.5     702   702.5     703
          35           SQ    0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
          36           SE     700   700.5  700.70     701   701.5     702   702.5     703
          37           KK   EDROU
          38           KO       5       0       0       0      21
          39           KM   ROUTE BIORETENTION OUTFLOW THROUGH DETENTION BASIN
          40           KM   4-INCH ORIFICE
          41           RS       1    ELEV     695
          42           SA    .048    .053    .057    .062    .068    .073    .079
          43           SE     695   695.5     696   696.5     697   697.5     698
          44           SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
          45           ZZ
1****************************************                                                  ****************************************
 *                                       *                                                 *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                 *   U.S. ARMY CORPS OF ENGINEERS       *
 *            JUN   1998                 *                                                 *   HYDROLOGIC ENGINEERING CENTER      *
 *          VERSION 4.1                  *                                                 *         609 SECOND STREET            *
 *                                       *                                                 *      DAVIS, CALIFORNIA 95616         *
 *  RUN DATE   05APR08  TIME  20:22:53   *                                                 *          (916) 756-1104              *
 *                                       *                                                 *                                      *
 ****************************************                                                  ****************************************
                              CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                              ANALYZED BY ABC ENGINEERING
                              DATE: OCTOBER 2006

                                                RUNOFF SUMMARY
                                           FLOW IN CUBIC FEET PER SECOND
                                        TIME IN HOURS,  AREA IN SQUARE MILES

                                        PEAK    TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN     MAXIMUM     TIME OF
         OPERATION        STATION       FLOW      PEAK                                            AREA       STAGE    MAX STAGE
+                                                              6-HOUR      24-HOUR      72-HOUR

         HYDROGRAPH AT
+                          PRE1           2.     3.37          0.           0.           0.       .00

         HYDROGRAPH AT
+                          POST1          6.     3.20          1.           0.           0.       .00
```

```
      ROUTED TO
+                  BIOROU        6.    3.27        1.        0.        0.       .00
+                                                                                    700.95      3.27

      ROUTED TO
+                   EDROU        1.    3.63        1.        0.        0.       .00
+                                                                                    697.10      3.67


 *** NORMAL END OF HEC-1 ***
```

The final step is to route the 50-year, 6-hour storm event through the bioretention area to ensure that the maximum 15 inches of headwater depth over the top of the filter media is not exceeded and that the detention basin passes the 50-year storm event with 6 inches of freeboard. The 3.5 foot by 3.5 foot open inlet is set at an elevation of 700.70, above the peak stage of the 1-inch storm event for the bioretention basin and a 20-foot emergency spillway weir is set at an elevation of 697.10, above the peak state of the 25-year storm event for the detention basin. The following HEC-1 output file illustrates the results.

```
1****************************************                                                 ****************************************
 *                                       *                                                 *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                 *   U.S. ARMY CORPS OF ENGINEERS       *
 *            JUN   1998                 *                                                 *   HYDROLOGIC ENGINEERING CENTER      *
 *         VERSION 4.1                   *                                                 *        609 SECOND STREET             *
 *                                       *                                                 *     DAVIS, CALIFORNIA 95616          *
 * RUN DATE   05APR08  TIME  19:55:11    *                                                 *         (916) 756-1104               *
 *                                       *                                                 *                                      *
 *****************************************                                                 ****************************************



                                                   X     X  XXXXXXX   XXXXX          X
                                                   X     X  X        X     X        XX
                                                   X     X  X        X               X
                                                   XXXXXXX  XXXX     X       XXXXX   X
                                                   X     X  X        X               X
                                                   X     X  X        X     X         X
                                                   X     X  XXXXXXX   XXXXX         XXX


            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                       HEC-1 INPUT                                            PAGE  1

          LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

            1           ID        CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
            2           ID        ANALYZED BY ABC ENGINEERING
            3           ID        DATE: OCTOBER 2006
                        *  ****************************************************************************
                        *
                        *     TIME SPECIFICATION CARD
            4           IT       2       0       0    1080
                        *  DIAGRAM
                        *     TIME INTERVAL CARD
            5           IN       5       0       0
                        *
                        *     OUTPUT CONTROL CARD
            6           IO       5       0       0
                        *

            7           KK    PRE1
                        * ****************************************************************************
                        * ***************** 50-YEAR, 6-HOUR STORM EVENT *******************************
                        * ****************************************************************************
            8           PI    .000    .016    .016    .016    .017    .017    .018    .018    .019    .019
            9           PI    .020    .020    .021    .022    .022    .023    .024    .025    .026    .031
           10           PI    .032    .033    .035    .037    .039    .049    .053    .056    .061    .066
           11           PI    .073    .103    .116    .133    .209    .260    .513    .749    .356    .231
           12           PI    .145    .124    .109    .077    .069    .063    .058    .054    .051    .040
           13           PI    .038    .036    .034    .033    .031    .026    .025    .024    .023    .023
           14           PI    .022    .021    .021    .020    .019    .019    .018    .018    .017    .017
           15           PI    .017    .016    .016    .000
                        * *****************************************************************************
           16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
           17           KO       5       0       0       0      21
           18           BA   .0016
           19           LS       0    65.0       0
           20           UD   0.194

           21           KK   POST1
           22           KM   1-ACRE POST-DEVELOPED CONDITIONS - STANDARD SCS CURVE NUMBER
           23           KO       5       0       0       0      21
           24           BA   .0016
           25           LS       0    93.4       0
           26           UD   0.080

           27           KK  BIOROU
           28           KO       5       0       0       0      21
           29           KM   ROUTE THROUGH THE BIORETENTION FACILITY
           30           KM   ROUTE THROUGH FILTER MEDIA UP TO 1-INCH STAGE
           31           KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
```

```
          32          RS       1    ELEV     700
          33          SA    .085    .093    .097    .102    .112    .121    .132    .142
          34          SE     700   700.5  700.70     701   701.5     702   702.5     703
          35          SQ    0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
          36          SE     700   700.5  700.70     701   701.5     702   702.5     703
          37          KK   EDROU
          38          KO       5       0       0       0      21
          39          KM   ROUTE BIORETENTION OUTFLOW THROUGH DETENTION BASIN
          40          KM   6-INCH ORIFICE AT 695, 20-FOOT EMERGENCY SPILLWAY AT 697.10
          41          RS       1    ELEV     695
          42          SA    .048    .053    .057    .062    .068    .069    .073    .079
          43          SE     695   695.5     696   696.5     697   697.1   697.5     698
          44          SQ    0.00   0.473   0.819   1.057   1.251   1.286  14.573  45.966
          45          ZZ
1*****************************************                                                     ***************************************
 *                                       *                                                     *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                     *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                     *   HYDROLOGIC ENGINEERING CENTER     *
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 *                                       *                                                     *                                     *
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                                CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                                ANALYZED BY ABC ENGINEERING
                                DATE: OCTOBER 2006


1
                                                                                RUNOFF SUMMARY
                                                                        FLOW IN CUBIC FEET PER SECOND
                                                                     TIME IN HOURS,  AREA IN SQUARE MILES

                                              PEAK     TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD       BASIN     MAXIMUM     TIME OF
          OPERATION       STATION             FLOW      PEAK                                              AREA       STAGE     MAX STAGE
+                                                                  6-HOUR     24-HOUR      72-HOUR

          HYDROGRAPH AT
+                            PRE1               2.      3.37            0.          0.          0.         .00

          HYDROGRAPH AT
+                           POST1               7.      3.20            1.          0.          0.         .00

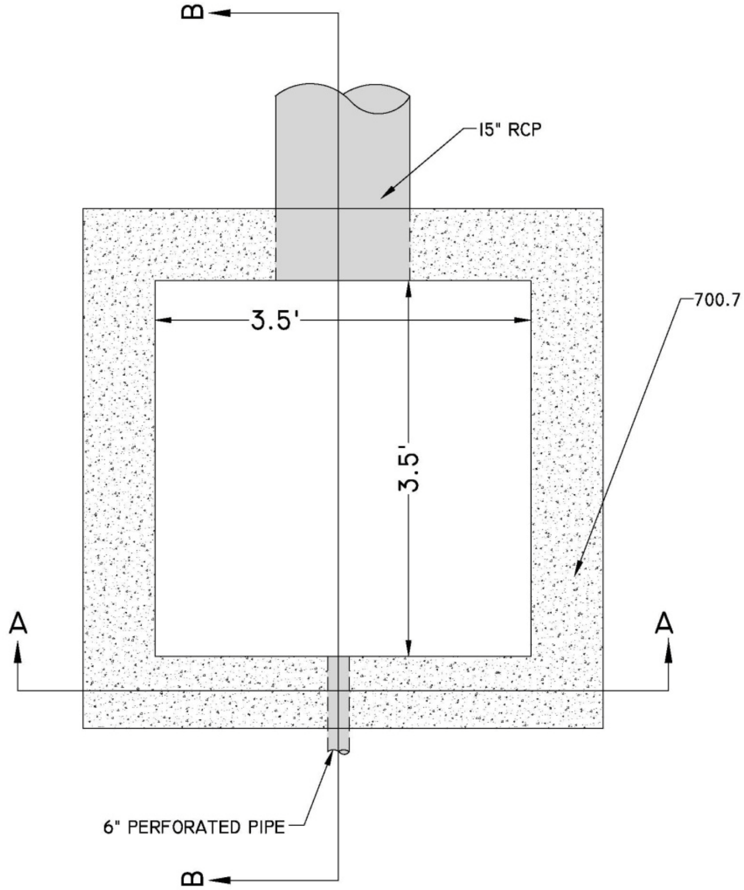
          ROUTED TO
+                          BIOROU               6.      3.23            1.          0.          0.         .00
+                                                                                                                  700.98       3.23

          ROUTED TO
+                           EDROU               3.      3.43            1.          0.          0.         .00
+                                                                                                                  697.16       3.43

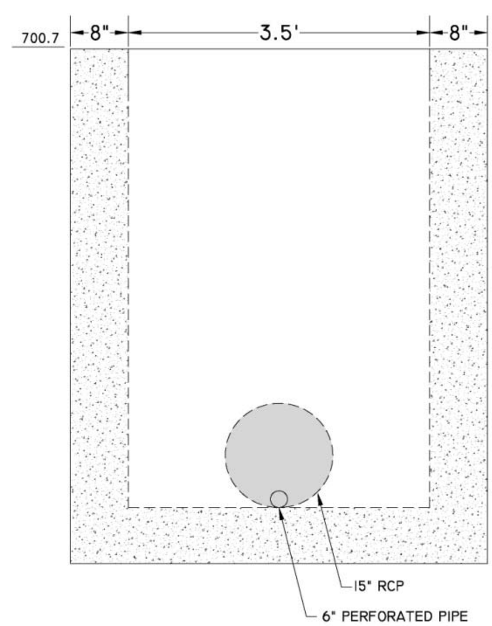

 *** NORMAL END OF HEC-1 ***
```

Table 4.1.3 Summary of Controls Provided

Control Element	Type/Size of Control	Peak Elev. (MSL)	Remarks
Water Quality (WQ_v)	Bioretention filter media at 700.0	700.69 (bio)	Entire 1-inch, 6-hour storm event is routed through bioretention filter media
Channel Protection (CP_v)	Bioretention filter media at 700.0 and 3.5 ft by 3.5 ft overflow at 700.70	700.78 (bio)	A portion 1-year, 24-hour storm event is routed through the bioretention filter media
Flood Protection Q_{10}	Detention basin 6.0-inch orifice at 695.0	700.91 (bio) 696.62 (det)	Same orifice control was designed for the 10- and 25-year storm events
Flood Protection Q_{25}	Detention basin 6.0-inch orifice at 695.0	700.95 (bio) 697.10 (det)	Same orifice control was designed for the 10- and 25-year storm events
Extreme Flood Protection Q_{50}	Bioretention – 3.5 ft by 3.5 ft overflow at 700.70 Detention basin – 20 foot weir at 697.10	700.98 (bio) 697.16 (det)	Peak stage in bioretention less than 15 inches for 50-year storm event



PLAN VIEW



SECTION A-A

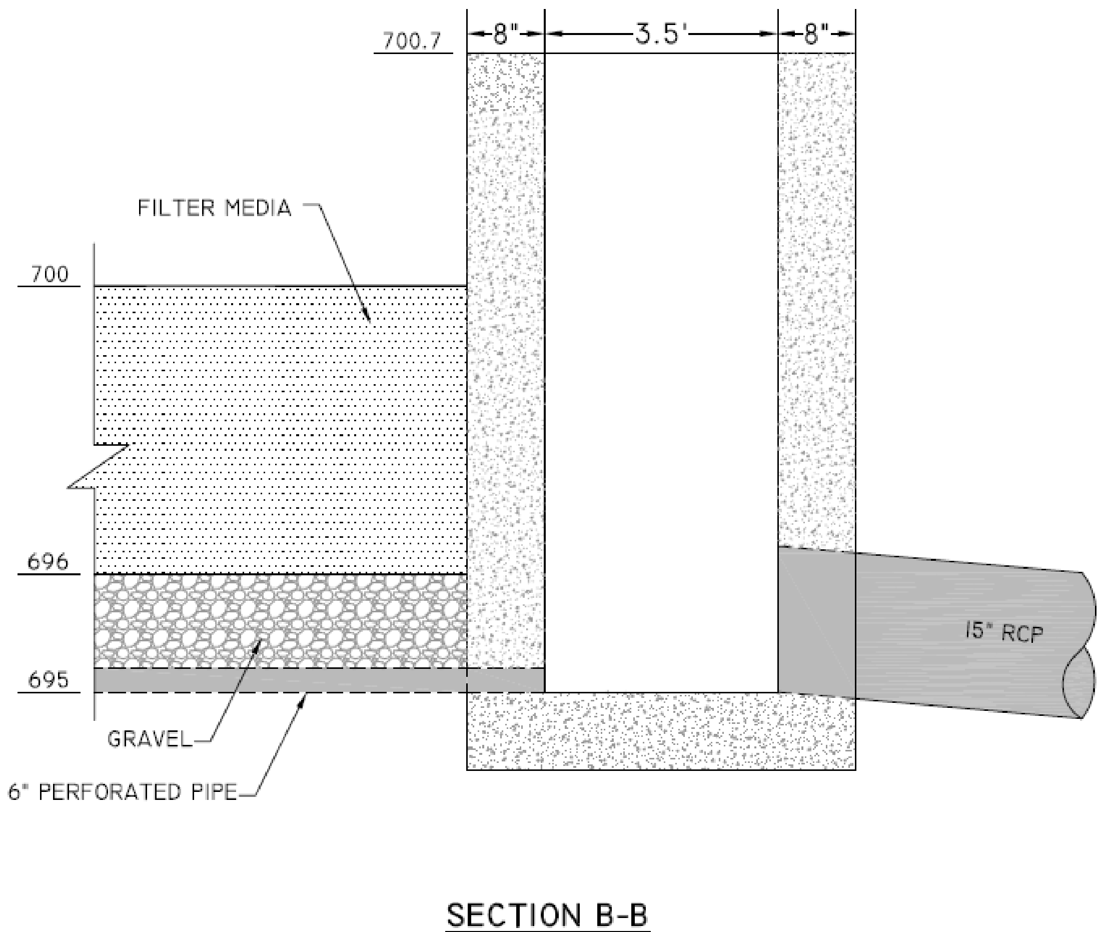


Figure 4.1.9 Schematic of Bioretention Outlet Structure

Step 15a Design Emergency Overflow

An emergency overflow structure is not designed in this example. Please refer to design methods shown in Chapter 5 - Outlet Structures.

Step 15b Assess Maintenance Access and Safety Features

A 12-foot wide stable maintenance access route must be provided. The access route must be contained within a 20-foot wide maintenance access easement from the BMP facility to public right-of-way.

Step 15c Investigate Potential Pond Hazard Classification

The bioretention area is constructed below the elevations of the surrounding topography, and therefore has no embankment and/or potential for embankment failure.

Step 16 Prepare Vegetation and Landscaping Plan

A landscaping plan for the bioretention area must be prepared to indicate how the bioretention area will be stabilized and established with vegetation. Diverse and native plant species designed for the hydric zone must be used. Plan must also include an invasive species prevention plan. Vegetation and landscaping plan must include plans for the first year of operation and full maturity (i.e. 3-year duration) as discussed in Chapter 6 – Vegetation and Landscaping.

4.1.9 Bioretention Design Example #2

The following design example is for a bioretention area designed to control the 1-inch, 6-hour storm event. The design also checks the partial benefit of routing a portion of the 1-year, 24-hour, 10-year, 6-hour, and 25-year, 6-hour storms through the bioretention facility by using a flow-splitter and following the design procedures given in section 4.1. In this design example, the channel protection volume (CP_V) is required to be held for a minimum of 24 hours from the center of the rainfall event (as is the requirement for projects within Mecklenburg County and the six Towns); however, the user should note that within the City of Charlotte, the channel protection volume (CP_V) is required to be held for a minimum of 48 hours from the center of the rainfall event. An extended detention facility is designed to intercept the flow that bypasses the bioretention facility and the flow that is routed through the bioretention facility to meet the 1-year, 24-hour, and 10- and 25-year, 6-hour storm event design goals. An optional step to reduce the bioretention footprint size to less than the value computed using the Darcy equation is also presented. Figure 4.1.10 shows the site plan for the development and base and hydrologic data that will be used in the design example.

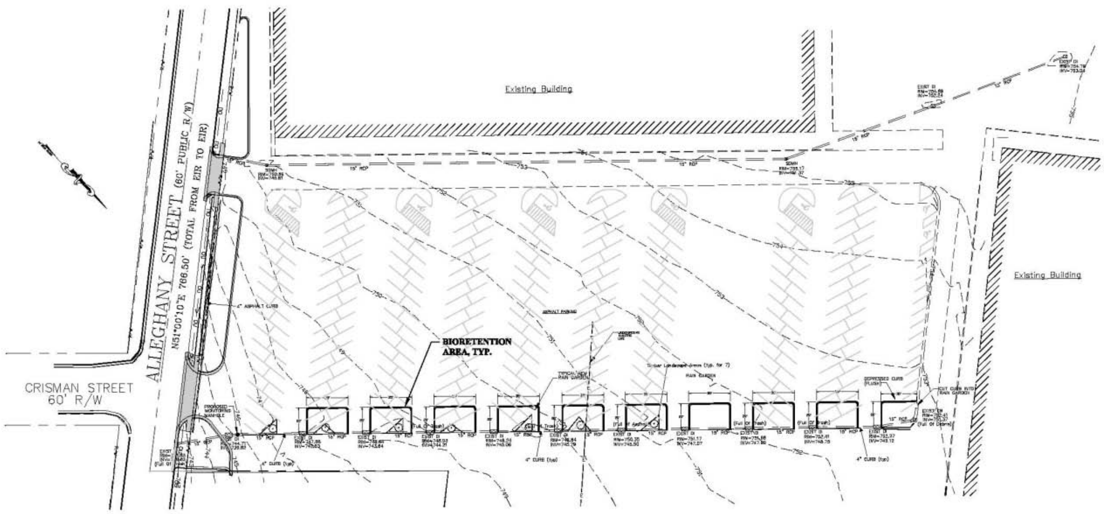


Figure 4.1.10 Example Site Plan for Bioretention Area Design

The following steps illustrate how to use the design procedures given in section 4.1 to design a bioretention and extended detention basin that will be acceptable for the design criteria given in this manual.

Step 1 BMP Feasibility

For the purposes of this design example, assume that a bioretention area is feasible.

Step 2 Confirm Design Criteria

The design criteria contained in Section 4.1 of the manual apply to this design.

Step 3 Compute Site Hydrologic Input Parameters

Using SCS hydrologic procedures and/or HEC-1 computer model the following data can be determined for the example development site.

Hydrologic Input Data

Condition	Area (acres)	CN	CN (adjusted) for 1-inch storm	t_c (hours)
Pre-developed	1.0	65	N/A	0.323
Post-developed	1.0	93.4	98.3	0.133

Results of Preliminary Hydrologic Calculations
(From Computer Model Results Using SCS Hydrologic Procedures)

Condition	$Q_{1\text{-inch}}$	$Q_{1\text{-year}}$	$Q_{10\text{-year}}$	$Q_{25\text{-year}}$	$Q_{50\text{-year}}$
Runoff	cfs	cfs	cfs	cfs	cfs
Pre-developed	0.00	0.24	1.09	1.64	2.09
Post-developed	1.67	2.65	5.43	6.43	7.18

Step 4 Compute Water Quality Volume (WQ_v)

The size of the site is one acre and the proposed imperviousness is 85 percent.

- Compute Runoff Coefficient, R_v, using (Schueler's Method) Equation 3.1

  $R_v = 0.05 + 0.009(I) = 0.05 + (85.0)(0.009) = 0.82$

- Compute Water Quality Volume, WQ_v, using Equation 3.2

  $WQ_v = 1.0R_vA/12 = (1.0 \text{ inches})(0.82)(1.0 \text{ acre})(1\text{foot}/12 \text{ inches}) = 0.07$ ac-ft

- Convert Water Quality Volume, WQ_v to inches of runoff using Equation 3.3

  $WQ_v = 1.0(R_v) = 1.0(0.82) = 0.82$ inches

Step 5 Compute Water Quality Peak Flow (WQ_p)

- Compute modified SCS curve number, CN, using Equation 3.4

  $CN = 1000/[10 + 5P + 10WQ_v – 10(WQ_v^2 + 1.25\, WQ_vP)^{0.5}]$
  $CN = 1000/[10 + 5(1.0) + 10(0.82) – 10\{(0.82^2 + 1.25(0.82 \times 1.0)\}^{0.5}] = 98.3$

- Compute WQ_p using SCS the hydrograph procedure documented in the Charlotte-Mecklenburg Storm Water Design Manual and the HEC-1 model. A 1-inch, 6-hour balanced storm event is required.

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1***************************************                               ***************************************
 *                                     *                               *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                             *    U.S. ARMY CORPS OF ENGINEERS     *
 *              JUN   1998              *                              *    HYDROLOGIC ENGINEERING CENTER    *
 *           VERSION 4.1                 *                             *         609 SECOND STREET           *
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 *                                     *                               *                                     *
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                                   X     X  X        X               X
                                   XXXXXXX  XXXX     X       XXXXX   X
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                                   X     X  X        X     X         X
                                   X     X  XXXXXXX   XXXXX         XXX


 THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

 THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
 THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
 NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
 DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
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        KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                          HEC-1 INPUT                                          PAGE  1

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           2           ID       ANALYZED BY ABC ENGINEERING
           3           ID       DATE: OCTOBER 2006
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                       *     TIME INTERVAL CARD
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                       *
                       *     OUTPUT CONTROL CARD
           6           IO       5       0       0
                       *

           7           KK    PRE1
                       * ******************************************************************************
                       * *************** 1-INCH, 6 HOUR STORM EVENT ********************************
                       * ******************************************************************************
           8           PI    .000    .003    .003    .003    .003    .003    .003    .004    .004    .004
           9           PI    .004    .004    .004    .004    .004    .005    .005    .005    .005    .006
          10           PI    .007    .007    .007    .008    .008    .009    .009    .010    .011    .012
          11           PI    .013    .019    .022    .025    .039    .050    .108    .188    .075    .043
          12           PI    .028    .023    .020    .014    .012    .011    .010    .009    .009    .008
          13           PI    .008    .007    .007    .007    .006    .005    .005    .005    .005    .005
          14           PI    .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
          15           PI    .003    .003    .003    .000

          16           KM    1-ACRE PRE-DEVELOPED CONDITIONS
          17           KO       5       0       0       0      21
          18           BA    .0016
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          20           UD    0.194

          21           KK    POST1
          22           KM    1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
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          24           BA    .0016
          25           LS       0    98.3       0
          26           UD    0.080
          27           ZZ
1****************************************                                   ***************************************
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 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                   *     U.S. ARMY CORPS OF ENGINEERS    *
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                             MECKLENBURG COUNTY BMP DESIGN MANUAL
                             ANALYZED BY ABC ENGINEERING
                             DATE: OCTOBER 2006

                       HYDROGRAPH AT STATION     POST1

    TOTAL RAINFALL =    1.00, TOTAL LOSS =     .18, TOTAL EXCESS =     .82

                                                RUNOFF SUMMARY
                                          FLOW IN CUBIC FEET PER SECOND
                                     TIME IN HOURS,  AREA IN SQUARE MILES

                                       PEAK   TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN     MAXIMUM     TIME OF
          OPERATION        STATION     FLOW    PEAK                                               AREA      STAGE     MAX STAGE
+                                                          6-HOUR     24-HOUR      72-HOUR

          HYDROGRAPH AT
+                            PRE1         0.     .00          0.          0.          0.         .00

          HYDROGRAPH AT
+                           POST1         2.    3.20          0.          0.          0.         .00


 *** NORMAL END OF HEC-1 ***
```

Note that the previous HEC-1 model output using the SCS method indicates that the runoff volume is 0.82 inches which matches the Schueler method runoff volume results using Equation 3-2.

Step 6a Compute Channel Protection Volume (CP$_v$)

- Compute maximum soil retention using SCS methods shown in the Charlotte-Mecklenburg Storm Water Design Manual. Note that the CN value used is the original site CN value, not the adjusted CN value used during the water quality runoff volume computation.

$S = 1000/CN - 10$
$= 1000/93.4 – 10$
$= 0.71$ inches

Compute total runoff for the 1-year, 24-hour storm event. Total rainfall depth is 2.58 inches.

$Q_d = (P-0.2S)^2/(P+0.8S)$
$= [2.58 – (0.2)(0.71)]^2/[2.58 + (0.8)(0.71)]$
$= 1.89$ inches

Compute watershed runoff

CP_v = (1.89 inches)(1 acres)(1 foot/12 inches) = 0.16 acre-feet

- **Estimate Approximate Storage Volume**

The entire Water Quality Volume (WQ_v) will be diverted into the bioretention area. For downstream BMP design, the runoff treated by the bioretention can be considered to be returned after routing through the bioretention storage volume and filter media. In order to achieve the pollutant removal goals of the Post Construction Ordinance, the bioretention must hold the Water Quality Volume for 1.3 days beyond the center of the rainfall event (1.3 days plus 3 hours is 1.425 days) above and within the filter media. The design requirements to meet 85 percent TSS and 70 percent TP removal goals of the Post-Construction Ordinance include a filter media thickness of 4 feet.

The Channel Protection Volume (CP_v) is required to be held within the combination of bioretention and extended detention dry storage volume for a minimum of 24 hours. The maximum ponding depth of the Water Quality Volume (WQ_V) and the Channel Protection Volume (CP_v) above the bioretention facility filter media is 12 inches (15 inches for storm events larger than the CP_v). The "Static Method" can be used as an initial estimate that sets the storage volume equal to the runoff volume, and assumes that the storage volume fills instantaneously and empties through the outlet structures including the filter media, orifices, and weirs. In the case of the bioretention area, the outlet structure for the Water Quality Volume (WQ_v) is based on the filter media. The outlet structure for the Channel Protection Volume (CP_v) may be based on a combination of the filter media and an overflow weir and orifice structure.

Using the Static Method, the bioretention area requires 0.07 acre-ft storage to hold the Water Quality Volume. The extended detention facility requires approximately 0.09 acre-feet (0.16 – 0.07; total Channel Protection Volume (CP_v) less the volume diverted to the bioretention area) to hold the Channel Protection Volume (CP_v). These values can be used as estimates to develop approximate storage volumes and grading plans, but routing computations must be performed to complete the design. The following computations provide a more accurate estimate of the storage volume and outlet hydraulic requirements for the extended detention to meet the Channel Protection Volume (CP_v) control and holding requirements.

Step 6b Compute Release Rates for Water Quality Control (WQ_v) and Channel Protection Volume (CP_v)

The following outlet hydraulic computations are performed using the Static Method. Routing computations must be performed to refine the design. The detailed outlet hydrograph analysis must show that a minimum of 5 percent of the runoff volume is held within the storage volume after the design duration time (where the requirement is 24 hours after the design duration time);

if the requirement is 48 hours, then the minimum would be 50% at 24 hours after the design duration time).

- Compute the release rate for water quality control.

  The water quality control volume (WQ_v) is to be released over a 1.3 day (31.2 hours) beyond the center of the design rainfall (3 hours) which results in a total control duration of 34.2 hours.

  Release rate = (0.07 ac-ft x 43560 ft^2/acre)/(34.2 hrs x 3,600 sec/hr) = 0.025 cfs

- Compute the release rate for channel protection volume. The channel protection volume (CP_v) is to be released over a 24-hour period beyond the center of the design storm (12 hours).

  Release rate = (0.09 ac-ft x 43560 ft^2/acre)/(36 hrs x 3,600 sec/hr) = 0.030 cfs

<u>Step 7 Compute Diversion Structure Geometry</u>

All flows up to the peak flow computed for the 1-inch, 6-hour storm event must be diverted into the bioretention area. Storm events larger than the 1-inch, 6-hour storm event should be directed away from the bioretention area into the extended detention basin. However, because of the hydraulic nature of the diversion structure, a portion of the larger storm events are diverted into the bioretention facility. The design must ensure that the portion of these larger events do not create a ponding depth greater than 12 inches above the bioretention filter media for the CP_V and do not create a ponding depth greater than 15 inches for storms larger than the CP_V.

For this facility, the contributing watershed is almost entirely impervious and contains a closed pipe system. Therefore, the diversion facility will intercept the contributing watershed in a pipe system and divert the low flows into the bioretention through a low flow orifice which is controlled by a weir which overtops for more intense or larger storm events. Figure 4.1.11 illustrates the diversion structure geometry.

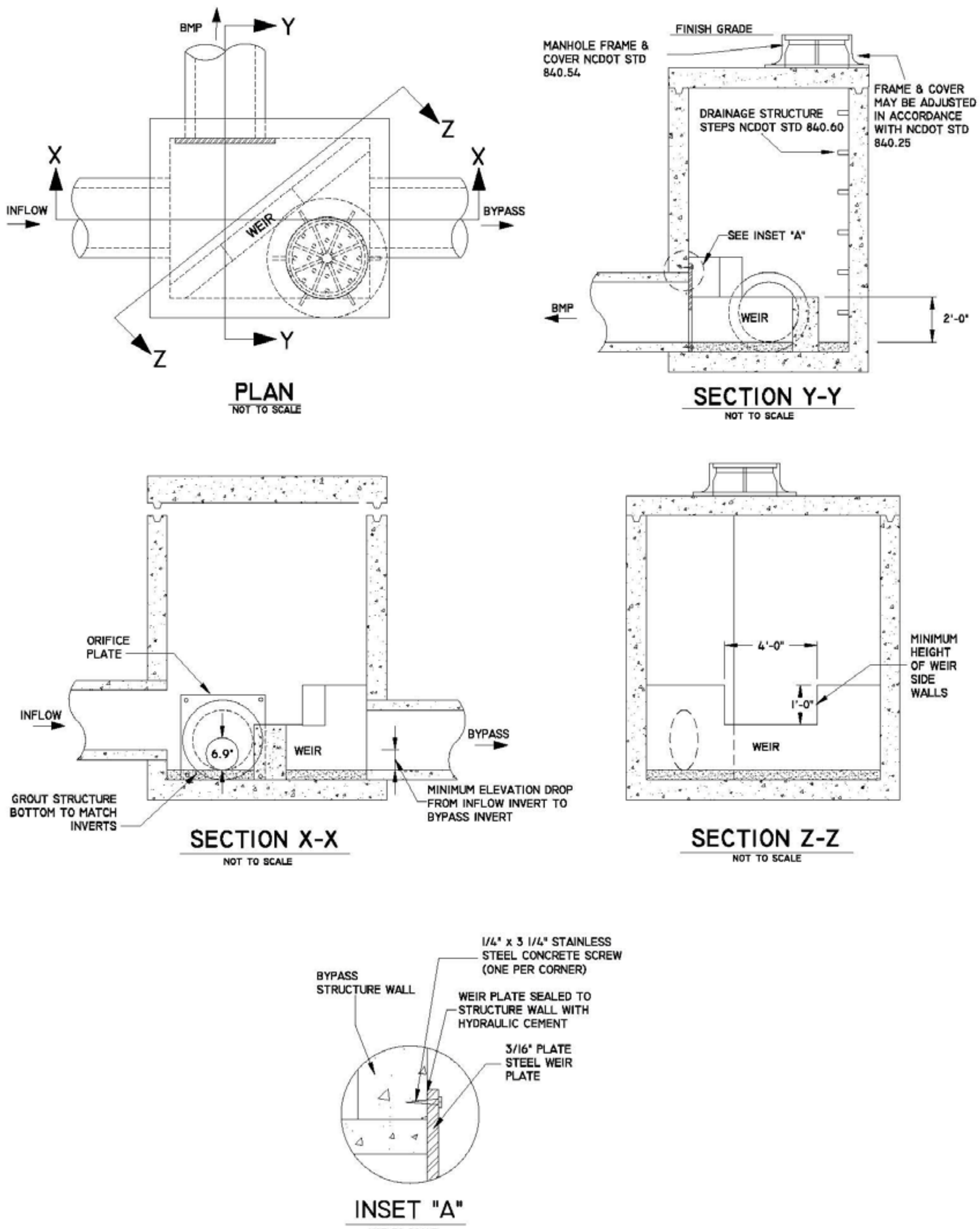

Figure 4.1.11 Diversion Structure Geometry

The first step is to assume a weir height of 2 feet and length of 4 feet and size a low flow orifice to pass the peak discharge for the 1-inch, 6-hour storm event with a headwater less than the weir height. Flow that overtops the weir will not enter the bioretention area and flow directly to the extended detention basin.

- Use orifice equation to compute cross-sectional area and diameter of orifice to divert flow to bioretention.
  - o $Q = CA(2gh)^{0.5}$, for Q = 1.67 cfs, h = 2.0 ft – ½ diameter of orifice, and C = discharge coefficient = 0.6

- o Try 6.9 inch orifice
- o Solve for A: $A = 1.67 \text{ cfs} / [0.6((2)(32.2 \text{ ft/s}^2)(2.0-(6.9/24)))^{0.5}] = 0.265 \text{ ft}^2$
- o With $A = \pi d^2/4$, d = 0.58ft = 6.9 inches
- o Use 6.9-inch orifice

Develop stage-discharge relations for a 6.9 inch orifice combined with a 2 foot high weir, 4 feet in length. Assumed invert of the 6.9 inch orifice is 700.

Elevation	Discharge into Bioretention (cfs)	Discharge into extended detention (cfs)	Total flow (cfs)
700.00	0.00	0.00	0.00
700.50	0.58	0.00	0.58
701.00	1.06	0.00	1.06
701.50	1.38	0.00	1.38
702.00	1.64	0.00	1.64
702.50	1.86	3.68	5.54
703.00	2.06	10.40	12.46
703.50	2.24	19.11	21.35
704.00	2.41	29.42	31.83
704.50	2.57	41.11	43.68
705.00	2.71	54.04	56.75

Check the design of the diversion structure with the HEC-1 model using the diversion computation process or by using level pool routings. An iterative process is typically necessary to ensure that all of the 1-inch, 6-hour storm event is being diverted to the bioretention and that an appropriate amount of the 1-year, 24-hour; 10-, 25-, and 50-year, 6-hour storm events are being bypassed. The bioretention must provide a safe overflow system for larger storm events such as the 1-year, 24-hour and 10, 25, and 50-year, 6-hour storm events with a maximum ponding depth in the bioretention facility of 12 inches for the 1-yr, 24-hr storm and a maximum ponding depth of 15 inches for all storms greater than the 1-year, 24-hour storm. The following table presents the results of the diversion design which were developed from a detailed HEC-1 output and TAPE21 files or DSS export files. The following HEC-1 output file presents the results of the analysis for the 1-year, 24-hour storm event.

Storm Event	Peak discharge (cfs)	Runoff volume (acre-feet)	Peak discharge into bioretention (cfs)	Runoff volume into bioretention (acre-feet)	Bypassed peak discharge (cfs)	Bypassed runoff volume (acre-feet)
1-inch, 6-hour	1.67	0.07	1.67	0.07	0.00	0.00
1-year, 24-hour	2.65	0.16	1.70	0.15	0.95	0.01
10-year, 6-hour	5.43	0.26	1.85	0.19	3.58	0.06
25-year, 6-hour	6.43	0.31	1.89	0.22	4.55	0.09
50-year, 6-hour	7.18	0.36	1.91	0.25	5.27	0.11

The diversion design was based on peak flow and ignored the benefit/impact of storage that could be associated with a diversion structure. A storage routing may be more appropriate, if significant storage is present within the diversion structure.

Note that the even though the larger peak flows are bypassing the bioretention area for the more severe storm events (10-, 25-, and 50-year, 6-hour), a high percentage of the runoff volume for those storm events is entering the bioretention area. The design of the bioretention area must account for the impact of these runoff volumes. The following HEC-1 illustrates the method by which the diversion structure is modeled and the method by which the portion of runoff from larger storm events is split and either routed through the bioretention facility or bypassed around the bioretention facility to the downstream extended detention basin.

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                               X     X  XXXXXXX   XXXXX          X
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                               X     X  X        X               X
                               XXXXXXX  XXXX     X       XXXXX   X
                               X     X  X        X               X
                               X     X  X        X     X         X
                               X     X  XXXXXXX   XXXXX         XXX


        THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

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        THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
        NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
        DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
        KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                        HEC-1 INPUT                                                PAGE  1

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          2          ID      ANALYZED BY ABC ENGINEERING
          3          ID      DATE: OCTOBER 2006
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                     *     TIME INTERVAL CARD
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                     *     OUTPUT CONTROL CARD
          6          IO       5       0       0
                     *

          7          KK    PRE1
                     * ****************************************************************************
                     * ***************** 1-YEAR, 24-HOUR STORM EVENT ******************************
                     * ********* 6 MINUTE TIME INCREMENT,24-HOUR STORM EVENT **********************
                     * ****************************************************************************
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         17          PI   .0022   .0022   .0024   .0024   .0026   .0026   .0028   .0029   .0029   .0030
         18          PI   .0032   .0032   .0032   .0032   .0032   .0032   .0033   .0034   .0036   .0038
         19          PI   .0039   .0041   .0044   .0046   .0048   .0051   .0054   .0058   .0062   .0066
         20          PI   .0070   .0077   .0086   .0096   .0106   .0115   .0238   .0476   .0764   .1371
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         28          PI   .0015   .0016   .0015   .0015   .0015   .0014   .0014   .0014   .0013   .0014
         29          PI   .0013   .0013   .0013   .0013   .0013   .0012   .0013   .0013   .0012   .0013
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         42          BA   .0016
         43          LS       0    93.4       0
         44          UD   0.080

         45          KK     DIV
         46          KO       5       0       0       0      21
         47          DT     BIO
         48          DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
         49          DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

         50          KK     BIO
         51          KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
         52          KO       5       0       0       0      21
         53          DR     BIO
         54          ZZ
```

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1****************************************                                                                  **************************************
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                                MECKLENBURG COUNTY BMP DESIGN MANUAL
                                ANALYZED BY ABC ENGINEERING
                                DATE: OCTOBER 2006

                                                       RUNOFF SUMMARY
                                               FLOW IN CUBIC FEET PER SECOND
                                            TIME IN HOURS,  AREA IN SQUARE MILES

                                             PEAK    TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD        BASIN     MAXIMUM    TIME OF
          OPERATION       STATION           FLOW     PEAK                                               AREA      STAGE     MAX STAGE
+                                                                6-HOUR     24-HOUR     72-HOUR

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+                           POST1             3.    12.07          0.          0.          0.          .00

          DIVERSION TO
+                             BIO             2.    12.07          0.          0.          0.          .00

          HYDROGRAPH AT
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          HYDROGRAPH AT
+                             BIO             2.    12.03          0.          0.          0.          .00


 *** NORMAL END OF HEC-1 ***
```

Step 8 Compute Pretreatment System Requirements

The pretreatment requirement for a bioretention area is that the flow enters in a dispersed condition, which is defined to be a depth of less than 1-inch with a velocity less than 1 foot per second. The inflow for the storm event that is diverted to the bioretention is 1.67 cfs for the 1-inch, 6-hour storm event. The energy dispersion design methods discussed in section 5.6 can be referenced to ensure that the inflow velocity and depth requirements are met.

The pretreatment requirement for an extended detention basin is a forebay that treats 0.2 inch/impervious area. (0.85 acres of impervious area)(0.2 inch)((1 foot/12 inches) = 0.014 ac-ft

Note: The forebay volume is included in the WQ_v and CP_v as part of the water quality and channel protection volume.

Step 9 Compute Bioretention Area and Volume to Treat Water Quality Volume

- Size bioretention ponding area to contain Water Quality Volume
- Absolute minimum sizing allowed based on the depth of storage of the WQv above the media:

$$
\begin{aligned}
A_f &= WQ_v/h_f \\
&= (0.07 \text{ acre-ft})(43560 \text{ sf/ac})/1\text{ft} \\
&= 3{,}049 \text{ sq ft}
\end{aligned}
$$

where:

WQ_v = Water Quality Volume

h_f = Allow headwater depth for water quality volume in the bioretention area.

- Check the bioretention ponding/filter area based on Darcy's equation, use the greater surface area. A value of 0.25 inch/hour (0.5 ft/day) for the design coefficient of permeability of the filter media is assumed.

$$A_f = (WQ_v)(d_f)/[(k)(h_f+d_f)(t_f)]$$

where:

A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (2 ft standard, 4 ft optimal efficiency)
k = design coefficient of permeability of filter media (0.5 ft/day)
h_f = average height of water above filter bed (0.5 ft max)
t_f = design filter bed drain time (days)
(1.125 standard or 1.425 optimal efficiency)

$$Af = \frac{(0.07\text{ acre-ft})(43560\text{ sf/ac})(4\text{ ft}))}{[0.5\text{ ft/day})(0.5\text{ft}+4\text{ft})(1.425\text{ days})]}$$

$$= 3{,}690\text{ sq ft}$$

- Since the bioretention is being designed to remove 70% phosphorus, the surface area needs to be 3,690 sq ft. If treatment for phosphorus removal is not required, the minimum surface area would be 3,049 sq ft.

Note that the following steps (Steps 10 through 14) assume that the designer does not desire to go through the iterative design process to reduce the bioretention footprint size. Optional steps 10 through 14 that assume the designer desires to reduce the footprint size are presented at the end of this example.

<u>Step 10 Set Design Elevations and Dimensions of Facility</u>

This step is completed for site-specific conditions and is not shown as part of this example.

<u>Step 11a Develop Bioretention Storage-Elevation Table and Curve</u>

Figure 4.1.10 shows the bioretention location on site, Figure 4.1.12 shows the plan view of the bioretention topography and Table 4.1.4 shows the storage-elevation data that was developed for this example.

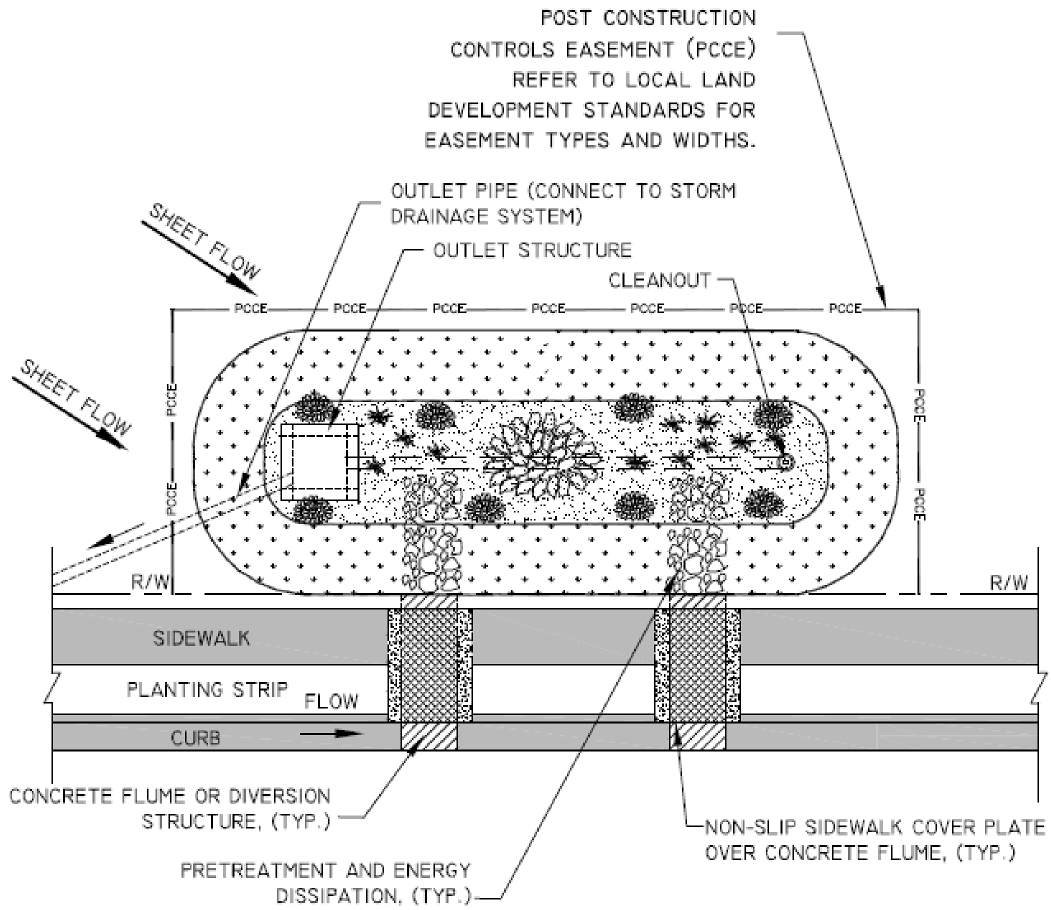

Figure 4.1.12 Plan View of Bioretention Topography (Not to Scale)

Table 4.1.4 Bioretention Storage-Elevation Data

Elevation	Area (sf)	Area (ac)	Avg. Area (ac)	Height (ft)	Inc. vol. (ac-ft)	Acc. vol. (ac-ft)
700	3690	0.085				0.000
700.5	4058	0.093	0.089	0.5	0.044	0.044
701	4449	0.102	0.098	0.5	0.049	0.093
701.5	4858	0.112	0.107	0.5	0.053	0.147
702.0	5285	0.121	0.116	0.5	0.058	0.205
702.5	5730	0.132	0.126	0.5	0.063	0.268
703.0	6194	0.142	0.137	0.5	0.068	0.337

Step 11b Develop Stage-Discharge for Bioretention Filter Media

The 1-inch, 6-hour storm event and portions of the more severe storm events will flow through the filter media. The outflow conditions for the filter media must be assessed in order to derive the relationship for the stage-discharge and in order to perform routing computations. The routing must be performed for the storage area above the filter media, and not the area within the filter media. Therefore, all of the computations are based on elevation above the top of the filter media. Outflow when runoff is at the top of the filter media is ignored and assumed to be zero.

$$A_f = (WQ_v)(d_f)/[(k)(h_f+d_f)(t_f)]$$

$$WQ_v/t_f = Q_o = A_f\,(k)(h_f+d_f)/(d_f))$$

where:

A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (ft)
k = coefficient of permeability of filter media (ft/day)
h_f = average height of water above filter bed (ft)

At elevation 701, top of water quality volume storage

Q_o = [(3,690 ft^2)(0.5 ft/day)(1ft+4ft)] / (4 ft)
= 2,306 cf/day
= 0.027 cfs

At elevation 700.5, the average water quality volume storage depth

Q_o = [(3,690 ft^2) (0.5 ft/day) (0.5ft+4ft)]/(4 ft)
= 2,075.6 cf/day
= 0.024 cfs

At elevation 700, top of filter media

Q_o = 0.00 cfs

Step 12 Route Runoff Hydrographs through Bioretention

Route all of the appropriate runoff hydrographs through the bioretention area with the following goals:

- 1-inch, 6-hour storm event through the filter media and ensure that 5 percent of the runoff volume remains in the facility after 1.3 days beyond the center of rainfall (1.425 days).
- Route storm events through the filter media and over flow structure to ensure a maximum 12 inches of ponding depth for the 1-year, 24-hour storm and to ensure a maximum 15 inches of ponding depth for the 10-, 25-, and 50-year, 6-hour storm events.
- Hold 5 percent of the 1-year, 24-hour storm event within a combination of the bioretention storage volume or downstream extended detention storage volume 24 hours after the center of rainfall (12 hours). Total detention time is 36 hours.
- Attenuate the 10- and 25-year, 6-hour storm events to pre-development levels.

The following HEC-1 file provides the results of the 1-inch, 6-hour storm event routing. The peak water surface elevation is shown to be 700.69 with the entire 1-inch storm event flowing through the filter media. Export of the hydrograph to a spreadsheet indicates that 27.8 percent of the 1-inch, 6-hour runoff hydrograph remains in the bioretention storage volume at 34.2 hours. The peak flow is attenuated from 1.67 cfs to 0.03 cfs. Because the entire 1-inch, 6-hour storm event is diverted into the bioretention facility, the routing results are the same as the routing results produced in the previous example (Section 4.1.8) which does not use a flow diversion structure but also directs the entire 1-inch, 6-hour storm event into the bioretention facility.

```
1***************************************                            ***************************************
 *                                      *                           *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                           *     U.S. ARMY CORPS OF ENGINEERS    *
 *             JUN   1998               *                           *     HYDROLOGIC ENGINEERING CENTER   *
 *          VERSION 4.1                 *                           *          609 SECOND STREET          *
 *                                      *                           *       DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   06APR08  TIME  18:13:38  *                           *           (916) 756-1104            *
 *                                      *                           *                                     *
 ***************************************                            ***************************************


                                  X     X  XXXXXXX   XXXXX          X
                                  X     X  X        X     X        XX
                                  X     X  X        X               X
                                  XXXXXXX  XXXX     X       XXXXX   X
                                  X     X  X        X               X
                                  X     X  X        X     X         X
                                  X     X  XXXXXXX   XXXXX         XXX


            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
```

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THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                              HEC-1 INPUT                                            PAGE  1

        LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

          1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
          2           ID       ANALYZED BY ABC ENGINEERING
          3           ID       DATE: APRIL 2008
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                      *
                      *    TIME SPECIFICATION CARD
          4           IT       2       0       0    1026
                      *  DIAGRAM
                      *    TIME INTERVAL CARD
          5           IN       5       0       0
                      *
                      *    OUTPUT CONTROL CARD
          6           IO       5       0       0
                      *

          7           KK    PRE1
                      * ****************************************************************************
                      * *************** 1-INCH, 6 HOUR STORM EVENT ********************************
                      * ****************************************************************************
          8           PI    .000    .003    .003    .003    .003    .003    .003    .004    .004    .004
          9           PI    .004    .004    .004    .004    .004    .005    .005    .005    .005    .006
         10           PI    .007    .007    .007    .008    .008    .009    .009    .010    .011    .012
         11           PI    .013    .019    .022    .025    .039    .050    .108    .188    .075    .043
         12           PI    .028    .023    .020    .014    .012    .011    .010    .009    .009    .008
         13           PI    .008    .007    .007    .007    .006    .005    .005    .005    .005    .005
         14           PI    .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
         15           PI    .003    .003    .003    .000
                      * ****************************************************************************
         16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
         17           KO       5       0       0       0      21
         18           BA   .0016
         19           LS       0    65.0       0
         20           UD   0.194

         21           KK   POST1
         22           KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
         23           KO       5       0       0       0      21
         24           BA   .0016
         25           LS       0    98.3       0
         26           UD   0.080

         27           KK     DIV
         28           KO       5       0       0       0      21
         29           DT     BIO
         30           DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
         31           DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

         32           KK     BIO
         33           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
         34           KO       5       0       0       0      21
         35           DR     BIO
         36           KK  BIOROU
         37           KO       5       0       0       0      21
         38           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
         39           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
         40           RS       1    ELEV     700
         41           SA    .085    .093    .102    .112    .121    .132    .142
         42           SE     700   700.5     701   701.5     702   702.5     703
         43           SQ    0.00   0.024   0.027   0.029   0.032   0.035   0.037
         44           SE     700   700.5     701   701.5     702   702.5     703

         45           KK   COMBO
         46           KO       5       0       0       0      21
         47           HC       2
         48           ZZ
1****************************************                                     ***************************************
 *                                       *                                     *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                     *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                     *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                     *         609 SECOND STREET           *
 *                                       *                                     *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   06APR08  TIME  18:13:38   *                                     *          (916) 756-1104             *
 *                                       *                                     *                                     *
 ****************************************                                     ***************************************


                              CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                              ANALYZED BY ABC ENGINEERING
                              DATE: APRIL 2008

                                                   RUNOFF SUMMARY
                                              FLOW IN CUBIC FEET PER SECOND
                                            TIME IN HOURS,  AREA IN SQUARE MILES

                                       PEAK   TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD        BASIN    MAXIMUM    TIME OF
          OPERATION        STATION     FLOW    PEAK                                                AREA     STAGE    MAX STAGE
+                                                          6-HOUR      24-HOUR      72-HOUR

          HYDROGRAPH AT
+                            PRE1        0.     .00           0.          0.           0.          .00

          HYDROGRAPH AT
+                           POST1        2.    3.20           0.          0.           0.          .00

          DIVERSION TO
+                             BIO        2.    3.20           0.          0.           0.          .00

          HYDROGRAPH AT
+                             DIV        0.    3.20           0.          0.           0.          .00

          HYDROGRAPH AT
+                             BIO        2.    3.20           0.          0.           0.          .00

          ROUTED TO
```

```
+                          BIOROU          0.    3.83          0.          0.          0.         .00
+                                                                                                          700.69        6.13

          2 COMBINED AT
+                           COMBO          0.    3.20          0.          0.          0.         .00


 *** NORMAL END OF HEC-1 ***
```

The following HEC-1 file provides the results of the first step of the 1-year, 24-hour storm event routing. The designer has the two options. The first option is to set a spillway overflow elevation at the peak stage of the 1-inch, 6-hour storm event (700.69) and allow the additional runoff volume from the split 1-year, 24-hour storm event (note that a portion of the 1-year, 24-hour storm event was diverted with the flow splitter to an extended detention basin) to discharge through an overflow structure. The second option is to set a spillway overflow elevation above the peak stage of the 1-inch, 6-hour storm event and allow the additional runoff volume from the 1-year, 24-hour storm event (again, note that the additional volume is not the entire 1-year, 24-hour volume due to the previous flow splitter operation) to discharge through the filter media. For this example, the first option and the same BMP hydraulic properties as the previous example (Section 4.1.8) were selected so that the relative benefits or impacts to the BMP designs due to the diversion can be compared with the design approach illustrated in Section 4.1.9.

The peak water surface elevation is shown to be 700.75 (previous example peak water surface elevation was 700.78) with a portion of the 1-year, 24-hour storm event bypassing the bioretention facility, a portion of the 1-year, 24-hour storm event flowing through the filter media and a portion of the 1-year, 24-hour storm event flowing through the overflow structure. Detailed review of the TAPE 21 output indicates that the 1-year, 24-hour peak flow is 2.65 cfs which is split to 0.95 cfs bypassing the bioretention and 1.70 cfs is directed to the bioretention facility. The 1.70 cfs is attenuated to 1.19 cfs (Example in Section 4.1.8 attenuated the entire 2.65 cfs to 1.85 cfs) by routing through the bioretention filter media and overflow structure. Review of the outflow hydrograph indicates that 24.8 percent (Example in Section 4.1.8 held 25.2 percent) of the runoff volume has left the bioretention storage volume and project site at 36 hours (24 hours after the center of rainfall). Therefore, the goal of controlling the 1-year, 24-hour storm event for 24 hours has been met, without a downstream extended detention basin.

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1*****************************************                                                          ***************************************
 *                                       *                                                          *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                          *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                          *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                          *         609 SECOND STREET           *
 *                                       *                                                          *      DAVIS, CALIFORNIA 95616        *
 * RUN DATE   07APR08  TIME  13:39:00    *                                                          *          (916) 756-1104             *
 *                                       *                                                          *                                     *
 *****************************************                                                          ***************************************



                                                  X     X  XXXXXXX   XXXXX          X
                                                  X     X  X        X     X        XX
                                                  X     X  X        X               X
                                                  XXXXXXX  XXXX     X        XXXXX  X
                                                  X     X  X        X               X
                                                  X     X  X        X     X         X
                                                  X     X  XXXXXXX   XXXXX         XXX


           THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

           THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
           THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
           NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
           DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
           KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                              HEC-1 INPUT                                                  PAGE  1

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              3           ID       DATE: OCTOBER 2006
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                          *  DIAGRAM
                          *     TIME INTERVAL CARD
              5           IN       6       0       0
                          *
                          *     OUTPUT CONTROL CARD
```

```
          6          IO      5      0      0
                     *

          7          KK    PRE1
                     * ****************************************************************************
                     * ***************** 1-YEAR, 24-HOUR STORM EVENT ******************************
                     * ********* 6 MINUTE TIME INCREMENT,24-HOUR STORM EVENT **********************
                     * ****************************************************************************
          8          PB    2.58
          9          PI   .0000   .0010   .0010   .0010   .0011   .0010   .0011   .0010   .0011   .0011
         10          PI   .0011   .0011   .0011   .0011   .0012   .0011   .0012   .0011   .0012   .0012
         11          PI   .0012   .0012   .0012   .0013   .0012   .0012   .0013   .0012   .0013   .0013
         12          PI   .0013   .0013   .0013   .0013   .0014   .0013   .0014   .0014   .0013   .0014
         13          PI   .0014   .0014   .0014   .0015   .0015   .0015   .0015   .0015   .0015   .0016
         14          PI   .0016   .0016   .0016   .0017   .0017   .0016   .0018   .0017   .0017   .0018
         15          PI   .0018   .0018   .0018   .0019   .0019   .0018   .0020   .0019   .0019   .0020
         16          PI   .0020   .0020   .0020   .0021   .0021   .0021   .0021   .0021   .0021   .0022
         17          PI   .0022   .0022   .0024   .0024   .0026   .0026   .0028   .0029   .0029   .0030
         18          PI   .0032   .0032   .0032   .0032   .0032   .0032   .0033   .0034   .0036   .0038
         19          PI   .0039   .0041   .0044   .0046   .0048   .0051   .0054   .0058   .0062   .0066
         20          PI   .0070   .0077   .0086   .0096   .0106   .0115   .0238   .0476   .0764   .1371
         21          PI   .0951   .0190   .0166   .0144   .0122   .0098   .0084   .0080   .0074   .0068
         22          PI   .0064   .0060   .0056   .0054   .0052   .0048   .0046   .0044   .0042   .0040
         23          PI   .0038   .0037   .0036   .0035   .0034   .0034   .0033   .0033   .0032   .0031
         24          PI   .0030   .0030   .0029   .0028   .0027   .0027   .0026   .0026   .0025   .0024
         25          PI   .0023   .0023   .0022   .0023   .0022   .0022   .0022   .0021   .0021   .0021
         26          PI   .0021   .0020   .0020   .0020   .0019   .0020   .0019   .0019   .0018   .0018
         27          PI   .0018   .0018   .0017   .0018   .0017   .0017   .0016   .0017   .0016   .0016
         28          PI   .0015   .0016   .0015   .0015   .0015   .0014   .0014   .0014   .0013   .0014
         29          PI   .0013   .0013   .0013   .0013   .0013   .0012   .0013   .0013   .0012   .0013
         30          PI   .0012   .0013   .0012   .0013   .0012   .0012   .0013   .0012   .0012   .0012
         31          PI   .0012   .0012   .0012   .0012   .0012   .0011   .0012   .0012   .0011   .0012
         32          PI   .0011   .0012   .0011   .0012   .0011   .0011   .0012   .0011   .0011   .0011
         33          PI   .0011
                     * *****************************************************************************
         34          KM   1-ACRE PRE-DEVELOPED CONDITIONS
         35          KO      5      0       0       0      21
         36          BA   .0016
         37          LS      0   65.0       0
         38          UD   0.194
         39          KK   POST1
         40          KM   1-ACRE POST-DEVELOPED CONDITIONS - SCS CURVE NUMBER
         41          KO      5      0       0       0      21
         42          BA   .0016
         43          LS      0   93.4       0
         44          UD   0.080

         45          KK     DIV
         46          KO      5      0       0       0      21
         47          DT     BIO
         48          DI   0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
         49          DQ   0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

         50          KK     BIO
         51          KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
         52          KO      5      0       0       0      21
         53          DR     BIO

         54          KK  BIOROU
         55          KO      5      0       0       0      21
         56          KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
         57          KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
         58          RS      1   ELEV     700
         59          SA   .085    .093    .097    .102    .112    .121    .132    .142
         60          SE    700   700.5  700.70     701   701.5     702   702.5     703
         61          SQ   0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
         62          SE    700   700.5  700.70     701   701.5     702   702.5     703

         63          KK   COMBO
         64          KO      5      0       0       0      21
         65          HC      2
         66          ZZ

1****************************************                                                ***************************************
 *                                       *                                                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                *         609 SECOND STREET           *
 *                                       *                                                *     DAVIS, CALIFORNIA 95616         *
 *  RUN DATE   07APR08  TIME  13:39:00   *                                                *         (916) 756-1104              *
 *                                       *                                                *                                     *
 ****************************************                                                 ***************************************


                           CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                           ANALYZED BY ABC ENGINEERING
                           DATE: OCTOBER 2006

1
                                                     RUNOFF SUMMARY
                                               FLOW IN CUBIC FEET PER SECOND
                                             TIME IN HOURS,  AREA IN SQUARE MILES

                                      PEAK    TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD       BASIN      MAXIMUM     TIME OF
          OPERATION       STATION     FLOW     PEAK                                              AREA       STAGE     MAX STAGE
+                                                          6-HOUR      24-HOUR      72-HOUR

          HYDROGRAPH AT
+                          PRE1         0.   12.23          0.           0.           0.          .00

          HYDROGRAPH AT
+                         POST1         3.   12.07          0.           0.           0.          .00

          DIVERSION TO
+                           BIO         2.   12.07          0.           0.           0.          .00

          HYDROGRAPH AT
+                           DIV         1.   12.07          0.           0.           0.          .00

          HYDROGRAPH AT
+                           BIO         2.   12.03          0.           0.           0.          .00

          ROUTED TO
+                        BIOROU         1.   12.20          0.           0.           0.          .00
```

```
+                                                                                            700.75       12.20

         2 COMBINED AT
+                            COMBO         1.   12.20          0.          0.          0.        .00


 *** NORMAL END OF HEC-1 ***
```

Step 13 Design Conveyance System

Conveyance system design is not included in this design example. Standards for conveyance system design are covered in the Charlotte-Mecklenburg Storm Water Design Manual.

Step 14a Size Bioretention Underdrain System

The underdrain system must be designed to meet two design goals; the underdrain capacity must be greater than the filter media capacity, and the capacity must drain the runoff volume from the system within 48 hours. The design must assume that 50 percent of the underdrain system (perforations and pipe system capacity) is lost due to clogging.

Design specifications require the underdrain system to be a 6-inch perforated PVC pipe with 3/8-inch perforations 3 inches on center along 4 longitudinal rows that are spaced 90° apart. Minimum underdrain slope is 0.5 percent.

The length, slope, number of pipes, spacing, etc. is configured per design requirements. Based upon the required area for the bioretention BMP (3,690 ft^2) the approximate dimensions of the bioretention area is selected to be 37 feet wide by 100 feet in length (approximately 3,690 ft^2).

The design process uses a trial and error process to determine the proper underdrain capacity. The capacity of the perforations and pipe (assuming 50 percent of the system is clogged) are computed. The computed underdrain capacity is checked relative to the filter media capacity to ensure that the filter media is the controlling outflow condition. The computed underdrain capacity if compared to the static outflow discharge that ensures the runoff within the system leaves within 48 hours.

Compute minimum drawdown discharge

Water quality volume = (0.07ac-ft)(43,560ft^3/ac ft) = 3,049 ft^3

Drawdown = 3,049 ft3/[(48 hours)(3,600sec/hour)]
= 0.018 cfs

Compute perforation capacity

Since the maximum underdrain spacing is 10 feet on center and the bioretention area is 37 feet wide by 100 feet in length, three parallel underdrain pipes (6-inch diameter PVC) 100 feet in length were selected. For the calculations below, the length of pipe containing holes was reduced by 1 foot per cleanout to account for non-perforated fittings.

Number of perforations = (3 pipes)((100 - 3) ft/pipe)(4 rows/ft)(4 holes/row) = 4,656 holes
50 percent of perforations = 2,328 holes
Capacity of one hole = $CA(2gh)^{0.5}$
= $(0.6)(3.1416)[(3/8in)(1/24)]^2[(64.4)(4.5ft)]^{0.5}$
= 0.0078 cfs/hole
Total capacity = (0.0078 cfs/hole)(2,328 holes) = 18.16 cfs

The perforations capacity (18.16 cfs) is greater than the filter media capacity (0.024 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.018 cfs computed in this step). Therefore the design is acceptable.

Note that the headwater depth used to determine the filter media capacity is 0.5 feet, the average headwater depth above the filter media for the water quality storm event. The drawdown computation is also based on the water quality volume. The headwater depth for the perforations is also based on the same average headwater elevations, 0.5 feet above the filter media, or 4.5 feet above the perforations.

Compute underdrain pipe capacity

For 6-inch PVC underdrain pipe at 0.005 ft/ft slope

Capacity of pipe	=	$(1.49/n)(A)(A/P)^{0.67}(S)^{0.5}$
	=	$(1.49/0.013)(0.1963\ ft^2)(0.125\ ft)^{0.67}(0.005)^{0.5}$
	=	0.40 cfs
Capacity of pipe (50% clogged)	=	0.20 cfs

The underdrain pipe capacity (0.20 cfs) is greater than the filter media capacity (0.024 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.018 cfs computed in this step). Therefore the design is acceptable.

Step 14b Calculate Q_{10} and Q_{25} (if required) Release Rate(s) and Water Surface Elevation(s)

The next step of the design process is to design the bioretention facility and a detention basin to achieve the peak attenuation goals for the 10- and 25-year, 6-hour storm events (note that the previous step eliminated the need for an extended detention basin, therefore, the design process is now focused on designing a standard detention basin however, the benefits of the upstream bioretention facility are included in the design). This process is similar to previous examples in that the design is iterative.

For this example, the same stage-storage-discharge relationship that was developed in the Example illustrated in Section 4.1.8 is used so that benefits or impacts of the diversion structure can be assessed. The appropriate storm events are routed through the storage volume, and the outflow peak discharge is compared to the pre-development peak discharge for the 10- and 25-year, 6-hour storm events; 1.10 and 1.64 cfs, respectively. In addition, the peak stage for the 10- and 25-year, 6-hour storm events must be less than 15 inches above the top of the filter media in the bioretention facility.

The following HEC-1 output files illustrate the results of the iterative process for the 10- and 25-year storm event. A 6.0 inch orifice that is installed at the base of the detention basin outlet structure (695.00) attenuates the post-developed to appropriate values for the 10- and 25-year, 6-hour storm events. The TAPE21 file indicates that the peak discharge for the 10-year, 6-hour storm event is 1.08 cfs with a peak stage of 696.57 (Example illustrated in Section 4.1.8 results in 1.10 cfs with a peak stage of 696.62). The peak discharge for the 25-year, 6-hour storm event is 1.27 cfs with a peak stage of 697.06 (Example illustrated in Section 4.1.8 results in 1.28 cfs with a peak stage of 697.10). Intermediate steps are not presented.

```
1*****************************************                                                         ***************************************
 *                                       *                                                         *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                         *   U.S. ARMY CORPS OF ENGINEERS      *
 *            JUN   1998                 *                                                         *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                         *         609 SECOND STREET           *
 *                                       *                                                         *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09APR08  TIME  13:33:14   *                                                         *          (916) 756-1104             *
 *                                       *                                                         *                                     *
 *****************************************                                                         ***************************************


                                                  X     X  XXXXXXX   XXXXX          X
                                                  X     X  X        X     X        XX
                                                  X     X  X        X               X
                                                  XXXXXXX  XXXX     X       XXXXX   X
                                                  X     X  X        X               X
                                                  X     X  X        X     X         X
                                                  X     X  XXXXXXX   XXXXX         XXX


          THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.
```

```
THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                            HEC-1 INPUT                                                     PAGE  1

       LINE         ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

         1          ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
         2          ID       ANALYZED BY ABC ENGINEERING
         3          ID       DATE: OCTOBER 2006
                    * **************************************************************************
                    *
                    *    TIME SPECIFICATION CARD
         4          IT      2       0       0    1080
                    * DIAGRAM
                    *    TIME INTERVAL CARD
         5          IN      5       0       0
                    *
                    *    OUTPUT CONTROL CARD
         6          IO      5       0       0
                    *

         7          KK    PRE1
                    * **************************************************************************
                    * ***************** 10-YEAR, 6-HOUR STORM EVENT *******************************
                    * **************************************************************************
         8          PI    .000    .011    .011    .012    .012    .012    .012    .013    .013    .013
         9          PI    .014    .014    .015    .015    .016    .016    .017    .018    .018    .023
        10          PI    .024    .025    .026    .027    .029    .036    .039    .042    .045    .049
        11          PI    .054    .079    .089    .103    .161    .201    .395    .590    .275    .177
        12          PI    .112    .095    .084    .057    .051    .047    .043    .040    .038    .030
        13          PI    .028    .027    .025    .024    .023    .019    .018    .017    .017    .016
        14          PI    .016    .015    .015    .014    .014    .013    .013    .013    .012    .012
        15          PI    .012    .011    .011    .000
                    * ***************************************************************************
        16          KM   1-ACRE PRE-DEVELOPED CONDITIONS
        17          KO      5       0       0       0      21
        18          BA   .0016
        19          LS      0    65.0       0
        20          UD   0.194

        21          KK   POST1
        22          KM   1-ACRE POST-DEVELOPED CONDITIONS - SCS CURVE NUMBER
        23          KO      5       0       0       0      21
        24          BA   .0016
        25          LS      0    93.4       0
        26          UD   0.080

        27          KK     DIV
        28          KO      5       0       0       0      21
        29          DT     BIO
        30          DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
        31          DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

        32          KK     BIO
        33          KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
        34          KO      5       0       0       0      21
        35          DR     BIO
        36          KK  BIOROU
        37          KO      5       0       0       0      21
        38          KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
        39          KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
        40          RS      1    ELEV     700
        41          SA    .085    .093    .097    .102    .112    .121    .132    .142
        42          SE     700   700.5  700.70     701   701.5     702   702.5     703
        43          SQ    0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
        44          SE     700   700.5  700.70     701   701.5     702   702.5     703

        45          KK   COMBO
        46          KM   COMBINE BIORETENTION OUTFLOW WITH FLOW THAT WAS DIVERTED
        47          HC      2

        48          KK   EDROU
        49          KO      5       0       0       0      21
        50          KM   ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
        51          KM   6-INCH ORIFICE
        52          RS      1    ELEV     695
        53          SA    .048    .053    .057    .062    .068    .073    .079
        54          SE     695   695.5     696   696.5     697   697.5     698
        55          SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
        56          ZZ
1****************************************                                              ***************************************
 *                                      *                                              *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                              *   U.S. ARMY CORPS OF ENGINEERS      *
 *            JUN   1998                *                                              *   HYDROLOGIC ENGINEERING CENTER     *
 *         VERSION 4.1                  *                                              *         609 SECOND STREET           *
 *                                      *                                              *      DAVIS, CALIFORNIA 95616        *
 * RUN DATE   09APR08  TIME  13:33:14   *                                              *          (916) 756-1104             *
 *                                      *                                              *                                     *
 ****************************************                                              ***************************************


                          CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                          ANALYZED BY ABC ENGINEERING
                          DATE: OCTOBER 2006

                                             RUNOFF SUMMARY
                                        FLOW IN CUBIC FEET PER SECOND
                                      TIME IN HOURS,  AREA IN SQUARE MILES

                                    PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN     MAXIMUM     TIME OF
         OPERATION       STATION    FLOW     PEAK                                             AREA      STAGE     MAX STAGE
+                                                       6-HOUR      24-HOUR       72-HOUR

         HYDROGRAPH AT
+                         PRE1        1.     3.40          0.          0.            0.        .00

         HYDROGRAPH AT
+                         POST1       5.     3.20          1.          0.            0.        .00
```

```
        DIVERSION TO
+                         BIO        2.    3.20          0.          0.          0.       .00

        HYDROGRAPH AT
+                         DIV        4.    3.20          0.          0.          0.       .00

        HYDROGRAPH AT
+                         BIO        2.    3.20          0.          0.          0.       .00

        ROUTED TO
+                      BIOROU        2.    3.33          0.          0.          0.       .00
+                                                                                                   700.78       3.33

        2 COMBINED AT
+                       COMBO        5.    3.23          0.          0.          0.       .00

        ROUTED TO
+                       EDROU        1.    3.63          0.          0.          0.       .00
+                                                                                                   696.57       3.67


 *** NORMAL END OF HEC-1 ***


1****************************************                                                   ***************************************
 *                                       *                                                  *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                  *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                  *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                                  *         609 SECOND STREET           *
 *                                       *                                                  *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09APR08  TIME  13:43:55   *                                                  *          (916) 756-1104             *
 *                                       *                                                  *                                     *
 ****************************************                                                   ***************************************


                                        X     X  XXXXXXX   XXXXX           X
                                        X     X  X        X     X         XX
                                        X     X  X        X                X
                                        XXXXXXX  XXXX     X        XXXXX   X
                                        X     X  X        X                X
                                        X     X  X        X     X          X
                                        X     X  XXXXXXX   XXXXX          XXX


           THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

           THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
           THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
           NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
           DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
           KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                    HEC-1 INPUT                                              PAGE  1

          LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

             1          ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
             2          ID       ANALYZED BY ABC ENGINEERING
             3          ID       DATE: OCTOBER 2006
                        *  ****************************************************************************
                        *
                        *     TIME SPECIFICATION CARD
             4          IT       2       0       0    1080
                        *  DIAGRAM
                        *     TIME INTERVAL CARD
             5          IN       5       0       0
                        *
                        *     OUTPUT CONTROL CARD
             6          IO       5       0       0
                        *

             7          KK    PRE1
                        * *****************************************************************************
                        * ***************** 25-YEAR, 6-HOUR STORM EVENT ******************************
                        * *****************************************************************************
             8          PI    .000    .014    .014    .014    .015    .015    .015    .016    .016    .017
             9          PI    .017    .018    .018    .019    .019    .020    .021    .022    .023    .025
            10          PI    .027    .028    .029    .031    .033    .043    .046    .049    .053    .058
            11          PI    .064    .093    .104    .120    .189    .235    .466    .680    .324    .208
            12          PI    .131    .111    .098    .067    .061    .055    .051    .048    .045    .034
            13          PI    .032    .030    .029    .027    .026    .023    .022    .021    .021    .020
            14          PI    .019    .019    .018    .017    .017    .016    .016    .016    .015    .015
            15          PI    .014    .014    .014    .000
                        * *****************************************************************************
            16          KM    1-ACRE PRE-DEVELOPED CONDITIONS
            17          KO       5       0       0       0      21
            18          BA   .0016
            19          LS       0    65.0       0
            20          UD   0.194

            21          KK   POST1
            22          KM    1-ACRE POST-DEVELOPED CONDITIONS - SCS CURVE NUMBER
            23          KO       5       0       0       0      21
            24          BA   .0016
            25          LS       0    93.4       0
            26          UD   0.080

            27          KK     DIV
            28          KO       5       0       0       0      21
            29          DT     BIO
            30          DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
            31          DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57
```

```
32          KK     BIO
33          KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
34          KO       5       0       0       0      21
35          DR     BIO
36          KK   BIOROU
37          KO       5       0       0       0      21
38          KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
39          KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
40          RS       1    ELEV     700
41          SA    .085    .093    .097    .102    .112    .121    .132    .142
42          SE     700   700.5  700.70     701   701.5     702   702.5     703
43          SQ    0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
44          SE     700   700.5  700.70     701   701.5     702   702.5     703

45          KK   COMBO
46          KM   COMBINE BIORETENTION OUTFLOW WITH FLOW THAT WAS DIVERTED
47          HC       2

48          KK   EDROU
49          KO       5       0       0       0      21
50          KM   ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
51          KM   6-INCH ORIFICE
52          RS       1    ELEV     695
53          SA    .048    .053    .057    .062    .068    .073    .079
54          SE     695   695.5     696   696.5     697   697.5     698
55          SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
56          ZZ
```

```
1*****************************************                                                    ***************************************
 *                                       *                                                    *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                    *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                    *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                    *         609 SECOND STREET           *
 *                                       *                                                    *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09APR08  TIME  13:43:55   *                                                    *          (916) 756-1104             *
 *                                       *                                                    *                                     *
 *****************************************                                                    ***************************************
```

```
                         CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                         ANALYZED BY ABC ENGINEERING
                         DATE: OCTOBER 2006
```

```
1
                                                     RUNOFF SUMMARY
                                              FLOW IN CUBIC FEET PER SECOND
                                           TIME IN HOURS,  AREA IN SQUARE MILES

                                     PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD        BASIN     MAXIMUM     TIME OF
          OPERATION       STATION    FLOW      PEAK                                              AREA      STAGE     MAX STAGE
+                                                          6-HOUR      24-HOUR      72-HOUR

          HYDROGRAPH AT
+                           PRE1       2.     3.37           0.           0.           0.         .00

          HYDROGRAPH AT
+                          POST1       6.     3.20           1.           0.           0.         .00

          DIVERSION TO
+                            BIO       2.     3.20           0.           0.           0.         .00

          HYDROGRAPH AT
+                            DIV       5.     3.20           0.           0.           0.         .00

          HYDROGRAPH AT
+                            BIO       2.     3.20           0.           0.           0.         .00

          ROUTED TO
+                         BIOROU       2.     3.27           0.           0.           0.         .00
+                                                                                                         700.78        3.27

          2 COMBINED AT
+                          COMBO       6.     3.20           1.           0.           0.         .00

          ROUTED TO
+                          EDROU       1.     3.63           1.           0.           0.         .00
+                                                                                                         697.06        3.67


 *** NORMAL END OF HEC-1 ***
```

The final step is to route the 50-year, 6-hour storm event through the bioretention area to ensure that the maximum 15 inches of headwater depth over the top of the filter media is exceeded and that the detention basin passes the 50-year storm event with 6 inches of freeboard. The 3.5 foot by 3.5 foot open inlet is set at an elevation of 700.70, above the peak stage of the 1-inch storm event for the bioretention basin and a 20-foot emergency spillway weir is set at an elevation of 697.10, above the peak state of the 25-year storm event for the detention basin. The following HEC-1 output file illustrates the results.

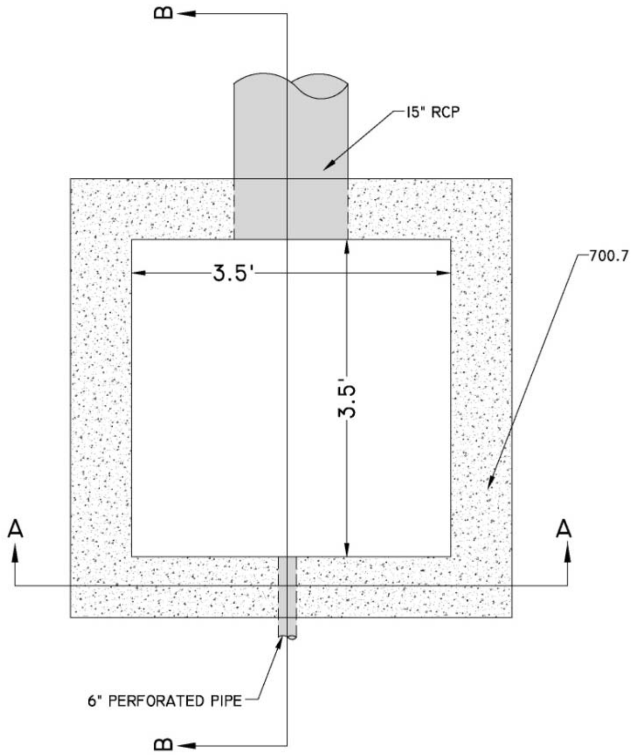
```
1*****************************************                                                    ***************************************
 *                                       *                                                    *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                    *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                    *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                    *         609 SECOND STREET           *
 *                                       *                                                    *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09APR08  TIME  14:29:32   *                                                    *          (916) 756-1104             *
 *                                       *                                                    *                                     *
 *****************************************                                                    ***************************************



                                          X     X  XXXXXXX   XXXXX          X
```

```
                                 X     X  X        X     X         XX
                                 X     X  X        X                X
                                 XXXXXXX  XXXX     X        XXXXX   X
                                 X     X  X        X                X
                                 X     X  X        X     X          X
                                 X     X  XXXXXXX   XXXXX          XXX


          THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

          THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
          THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
          NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
          DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
          KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                          HEC-1 INPUT                                        PAGE  1

        LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

          1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
          2           ID       ANALYZED BY ABC ENGINEERING
          3           ID       DATE: OCTOBER 2006
                      * ****************************************************************************
                      *
                      *    TIME SPECIFICATION CARD
          4           IT     2       0       0    1080
                      *  DIAGRAM
                      *    TIME INTERVAL CARD
          5           IN     5       0       0
                      *
                      *    OUTPUT CONTROL CARD
          6           IO     5       0       0
                      *

          7           KK   PRE1
                      * ****************************************************************************
                      * ***************** 50-YEAR, 6-HOUR STORM EVENT *******************************
                      * ****************************************************************************
          8           PI   .000    .016    .016    .016    .017    .017    .018    .018    .019    .019
          9           PI   .020    .020    .021    .022    .022    .023    .024    .025    .026    .031
         10           PI   .032    .033    .035    .037    .039    .049    .053    .056    .061    .066
         11           PI   .073    .103    .116    .133    .209    .260    .513    .749    .356    .231
         12           PI   .145    .124    .109    .077    .069    .063    .058    .054    .051    .040
         13           PI   .038    .036    .034    .033    .031    .026    .025    .024    .023    .023
         14           PI   .022    .021    .021    .020    .019    .019    .018    .018    .017    .017
         15           PI   .017    .016    .016    .000
                      * *****************************************************************************
         16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
         17           KO     5       0       0       0      21
         18           BA   .0016
         19           LS     0    65.0       0
         20           UD   0.194

         21           KK   POST1
         22           KM   1-ACRE POST-DEVELOPED CONDITIONS - SCS CURVE NUMBER
         23           KO     5       0       0       0      21
         24           BA   .0016
         25           LS     0    93.4       0
         26           UD   0.080

         27           KK    DIV
         28           KO     5       0       0       0      21
         29           DT    BIO
         30           DI   0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
         31           DQ   0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

         32           KK    BIO
         33           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
         34           KO     5       0       0       0      21
         35           DR    BIO
         36           KK  BIOROU
         37           KO     5       0       0       0      21
         38           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
         39           KM   OVERFLOW STRUCTURE SET AT ELEVATION 700.7
         40           RS     1    ELEV     700
         41           SA   .085    .093    .097    .102    .112    .121    .132    .142
         42           SE    700   700.5  700.70     701   701.5     702   702.5     703
         43           SQ   0.00   0.024   0.025   6.863  29.796  61.693  90.475 102.269
         44           SE    700   700.5  700.70     701   701.5     702   702.5     703

         45           KK   COMBO
         46           KM   COMBINE BIORETENTION OUTFLOW WITH FLOW THAT WAS DIVERTED
         47           HC     2

         48           KK   EDROU
         49           KO     5       0       0       0      21
         50           KM   ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
         51           KM   6-INCH ORIFICE
         52           RS     1    ELEV     695
         53           SA   .048    .053    .057    .062    .068    .073    .079
         54           SE    695   695.5     696   696.5     697   697.5     698
         55           SQ   0.00   0.473   0.819   1.057   1.251   1.418   1.568
         56           ZZ
1*****************************************                                            ***************************************
 *                                       *                                            *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                            *   U.S. ARMY CORPS OF ENGINEERS      *
 *              JUN   1998               *                                            *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                            *         609 SECOND STREET           *
 *                                       *                                            *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09APR08  TIME  14:29:32   *                                            *          (916) 756-1104             *
 *                                       *                                            *                                     *
 *****************************************                                            ***************************************


                               CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                               ANALYZED BY ABC ENGINEERING
                               DATE: OCTOBER 2006

1
                                                   RUNOFF SUMMARY
```

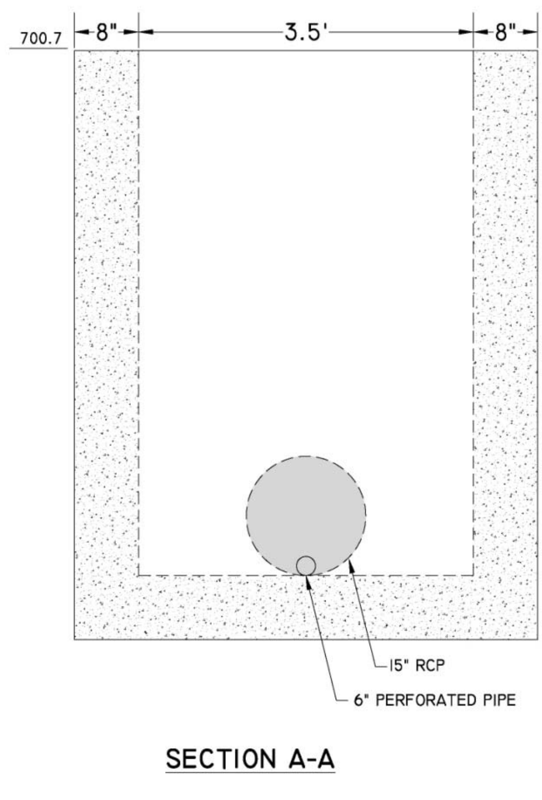
```
                                          FLOW IN CUBIC FEET PER SECOND
                                       TIME IN HOURS,  AREA IN SQUARE MILES

                                       PEAK   TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD       BASIN      MAXIMUM     TIME OF
          OPERATION       STATION      FLOW    PEAK                                              AREA        STAGE     MAX STAGE
+                                                           6-HOUR      24-HOUR     72-HOUR

          HYDROGRAPH AT
+                            PRE1        2.    3.37            0.          0.          0.         .00

          HYDROGRAPH AT
+                           POST1        7.    3.20            1.          0.          0.         .00

          DIVERSION TO
+                             BIO        2.    3.20            0.          0.          0.         .00

          HYDROGRAPH AT
+                             DIV        5.    3.20            0.          0.          0.         .00

          HYDROGRAPH AT
+                             BIO        2.    3.20            0.          0.          0.         .00

          ROUTED TO
+                          BIOROU        2.    3.27            0.          0.          0.         .00
+                                                                                                          700.78        3.27

          2 COMBINED AT
+                           COMBO        7.    3.20            1.          0.          0.         .00

          ROUTED TO
+                           EDROU        1.    3.63            1.          0.          0.         .00
+                                                                                                          697.42        3.67
 *** NORMAL END OF HEC-1 ***
```

Table 4.1.5 Summary of Controls Provided

Control Element	Type/Size of Control	Peak Elev. (MSL)	Remarks
Diversion Structure	6.9-inch orifice with 4-foot weir, 2 feet tall	N/A	Diverts 1-inch storm event into bioretention
Water Quality (WQ_v)	Bioretention filter media at 700.0	700.69 (bio)	Entire 1-inch, 6-hour storm event is routed through bioretention filter media
Channel Protection (CP_v)	Bioretention filter media at 700.0 and 3.5 ft by 3.5 ft overflow at 700.70	700.75 (bio)	A portion 1-year, 24-hour storm event is routed through the bioretention filter media
Flood Protection Q_{10}	Detention basin 6.0-inch orifice at 695.0	700.78 (bio) 696.57 (det)	Same orifice control was designed for the 10- and 25-year storm events
Flood Protection Q_{25}	Detention basin 6.0-inch orifice at 695.0	700.78 (bio) 697.06 (det)	Same orifice control was designed for the 10- and 25-year storm events
Extreme Flood Protection Q_{50}	Bioretention – 3.5 ft by 3.5 ft overflow at 700.70 Detention basin – 20 foot weir at 697.10	700.78 (bio) 697.42 (det)	Peak stage in bioretention less than 15 inches for 50-year storm event



PLAN VIEW



SECTION A-A

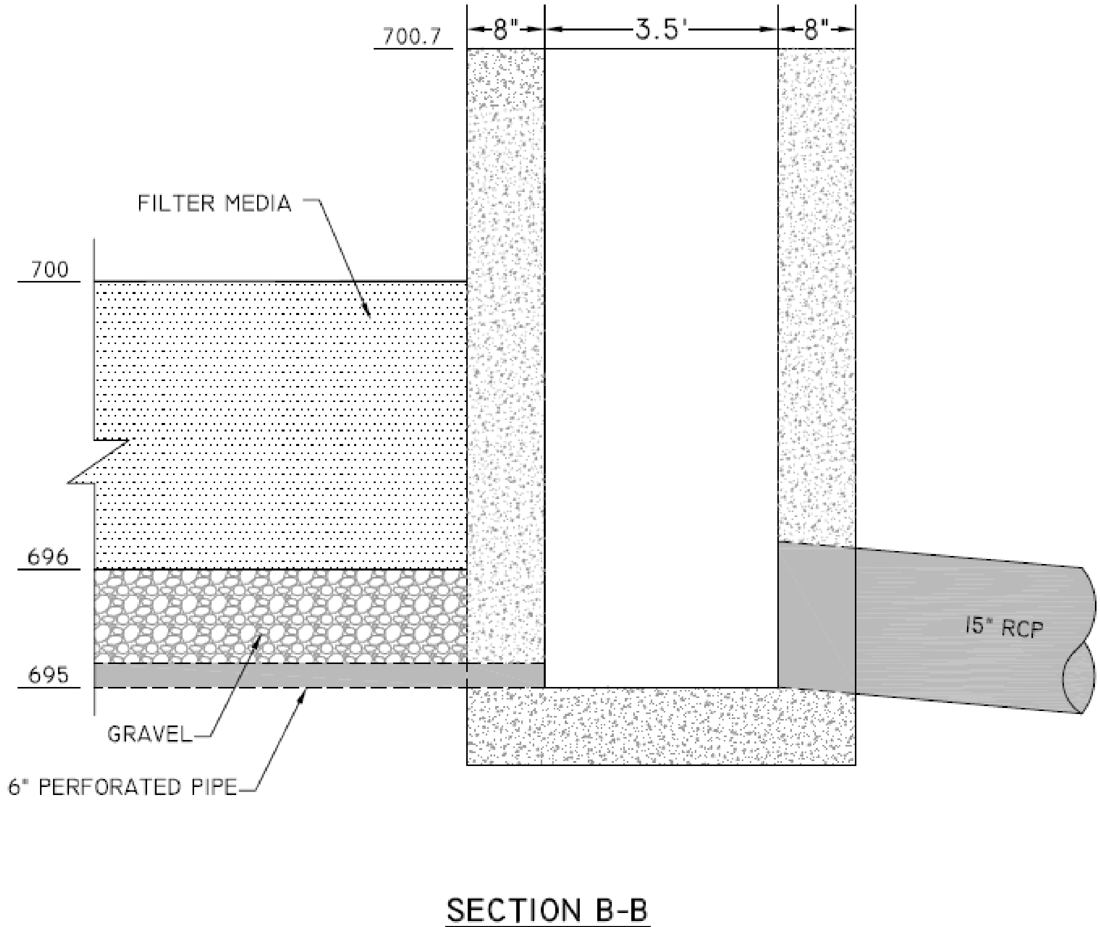


Figure 4.1.13 Schematic of Riser Detail

Step 10(Optional) Set Design Elevations and Dimensions of Facility

This step is completed for site-specific conditions and is not shown as part of this example. The design elevations and dimensions are adjusted through the iterative routing procedure, hydrologic/hydraulic computations and site conditions review.

Step 11a(Optional) Develop Bioretention Storage-Elevation Table and Curve

Figure 4.1.10 shows the bioretention location on site, Figure 4.1.14 shows the plan view of the bioretention topography and Table 4.1.6 shows the storage-elevation data that was developed for this example. Note that the stage-storage relations that is presented in the final stage-storage result from the iterative process. Intermediate trials and results are not presented.

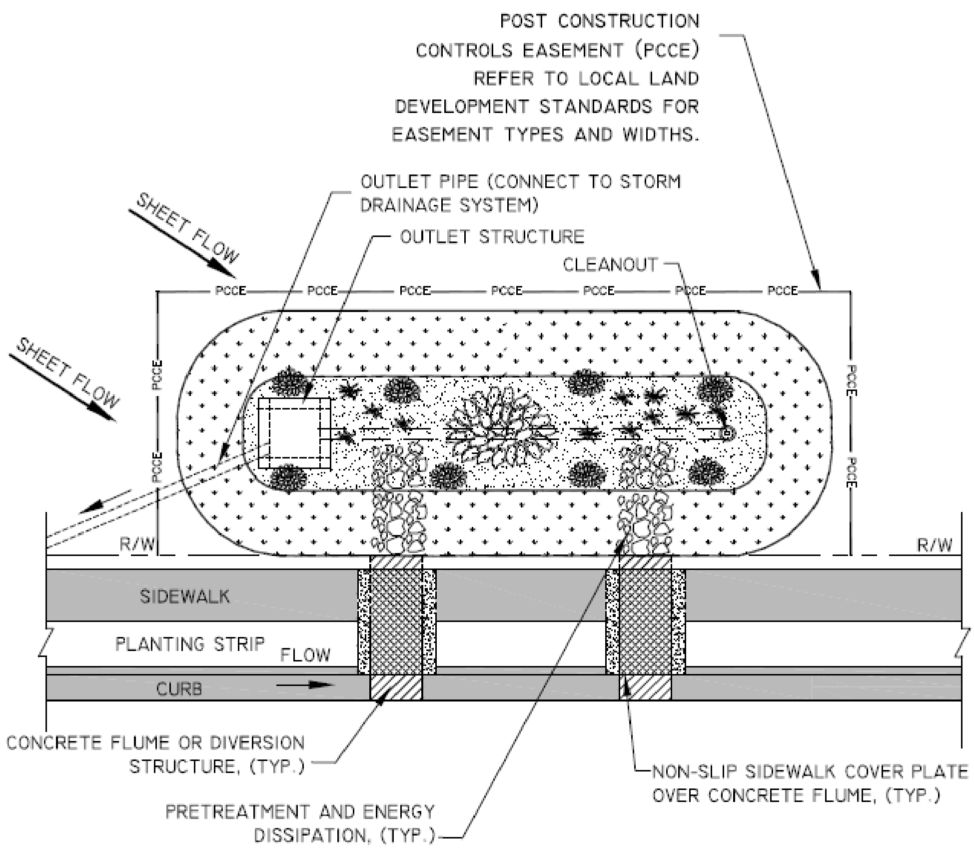


Figure 4.1.14 Plan View of Bioretention Topography (Not to Scale)

Table 4.1.6 Bioretention Storage-Elevation Data

Elevation	Area (sf)	Area (ac)	Avg. Area (ac)	Height (ft)	Inc. vol. (ac-ft)	Acc. vol. (ac-ft)
700	2809	0.064				0.000
700.5	3136	0.072	0.068	0.5	0.034	0.034
701	3481	0.080	0.076	0.5	0.038	0.072
701.5	3844	0.088	0.084	0.5	0.042	0.114
702.0	4225	0.097	0.093	0.5	0.046	0.160
702.5	4624	0.106	0.102	0.5	0.051	0.211
703.0	5041	0.116	0.111	0.5	0.055	0.267

Step 11b(Optional) Develop Stage-Discharge for Bioretention Filter Media

The 1-inch, 6-hour storm event and portions of the more severe storm events will flow through the filter media. The outflow conditions for the filter media must be assessed in order to derive the relation for the stage-discharge and in order to perform routing computations. The routing must be performed for the storage area above the filter media, and not the area within the filter media. Therefore, all of the computations are based on elevation above the top of the filter media. Outflow when runoff is at the top of the filter media is ignored and assumed to be zero. Note that the stage-discharge relations that is presented in the final stage-discharge result from the iterative process.

$$A_f = (WQ_v)(d_f)/[(k)(h_f+d_f)(t_f)]$$

$$WQ_v/t_f = Q_o = A_f\,(k)(h_f+d_f)/(d_f))$$

where:

A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (ft)
k = coefficient of permeability of filter media (ft/day)
h_f = average height of water above filter bed (ft)

At elevation 701, top of water quality volume storage

Q_o = [(2,809 ft^2)(0.5 ft/day)(1ft+4ft)] / (4 ft)
= 1,756 cf/day
= 0.020 cfs

At elevation 700.5, the average water quality volume storage depth

Q_o = [(2,809 ft^2) (0.5 ft/day) (0.5ft+4ft)]/(4 ft)
= 1,580 cf/day
= 0.018 cfs

At elevation 700, top of filter media

Q_o = 0.00 cfs

Step 12(Optional) Route Runoff Hydrographs through Bioretention

Route all of the appropriate runoff hydrographs through the bioretention area with the following goals:

- 1-inch, 6-hour storm event through the filter media and ensure that 5 percent of the runoff volume remains in the facility after 1.3 days beyond the center of rainfall (1.425 days).
- Route storm events through the filter media and over flow structure to ensure a maximum 12 inches of ponding depth for the 1-year, 24-hour storm and to ensure a maximum 15 inches of ponding depth for the 10-, 25-, and 50-year, 6-hour storm events.
- Hold 5 percent of the 1-year, 24-hour storm event within a combination of the bioretention storage volume or downstream extended detention storage volume 24 hours after the center of rainfall (12 hours). Total detention time is 36 hours.
- Attenuate the 10- and 25-year, 6-hour storm events to pre-development levels.

The following HEC-1 file provides the results of the 1-inch, 6-hour storm event routing. The iterative process reduces the bioretention footprint from 3,690 square feet to 2,809 square feet. The peak water surface elevation is shown to by 700.90 with almost the entire 1-inch storm event flowing through the filter media. Export of the hydrograph to a spreadsheet indicates that 34.1 percent of the 1-inch, 6-hour runoff hydrograph remains in the bioretention storage volume at 1.425 days (34.2 hours). The peak flow is attenuated from 1.67 cfs to 0.02 cfs. Later routings show that larger storm events can pass through the bioretention facility without exceeding one foot of depth on top of the filter media.

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1*****************************************                   ***************************************
 *                                       *                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                   *   U.S. ARMY CORPS OF ENGINEERS      *
 *            JUN   1998                 *                   *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                   *         609 SECOND STREET           *
 *                                       *                   *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   24AUG08  TIME  21:53:54   *                   *          (916) 756-1104             *
 *                                       *                   *                                     *
 *****************************************                   ***************************************


                    X     X  XXXXXXX   XXXXX          X
                    X     X  X        X     X        XX
                    X     X  X        X               X
                    XXXXXXX  XXXX     X       XXXXX   X
                    X     X  X        X               X
                    X     X  X        X     X         X
                    X     X  XXXXXXX   XXXXX         XXX


THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
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THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                         HEC-1 INPUT                                                    PAGE  1

        LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

          1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
          2           ID       ANALYZED BY ABC ENGINEERING
          3           ID       DATE: APRIL 2008
                      * ***************************************************************************
                      *
                      *    TIME SPECIFICATION CARD
          4           IT      2       0       0    1026
                      *  DIAGRAM
                      *    TIME INTERVAL CARD
          5           IN      5       0       0
                      *
                      *    OUTPUT CONTROL CARD
          6           IO      5       0       0
                      *

          7           KK    PRE1
                      * ***************************************************************************
                      * *************** 1-INCH, 6 HOUR STORM EVENT *********************************
                      * ***************************************************************************
          8           PI    .000    .003    .003    .003    .003    .003    .003    .004    .004    .004
          9           PI    .004    .004    .004    .004    .004    .005    .005    .005    .005    .006
         10           PI    .007    .007    .007    .008    .008    .009    .009    .010    .011    .012
         11           PI    .013    .019    .022    .025    .039    .050    .108    .188    .075    .043
         12           PI    .028    .023    .020    .014    .012    .011    .010    .009    .009    .008
         13           PI    .008    .007    .007    .007    .006    .005    .005    .005    .005    .005
         14           PI    .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
         15           PI    .003    .003    .003    .000
                      * ***************************************************************************
         16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
         17           KO      5       0       0       0      21
         18           BA   .0016
         19           LS      0    65.0       0
         20           UD   0.194

         21           KK   POST1
         22           KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
         23           KO      5       0       0       0      21
         24           BA   .0016
         25           LS      0    98.3       0
         26           UD   0.080

         27           KK     DIV
         28           KO      5       0       0       0      21
         29           DT     BIO
         30           DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
         31           DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

         32           KK     BIO
         33           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
         34           KO      5       0       0       0      21
         35           DR     BIO
         36           KK  BIOROU
         37           KO      5       0       0       0      21
         38           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
         39           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
         40           RS      1    ELEV     700
                      * SA  .085    .093    .102    .112    .121    .132    .142
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * SQ  0.00   0.024   0.027   0.029   0.032   0.035   0.037
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * KM TRIAL REDUCED SIZE
                      * SA  .077    .085    .094    .103    .112    .122    .133
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * SQ  0.00   0.022   0.024   0.027   0.029   0.032   0.034
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * KM TRIAL REDUCED SIZE
                      * SA  .057    .064    .072    .080    .088    .097    .106
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * SQ  0.00   0.016   0.018   0.020   0.022   0.024   0.025
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * KM TRIAL REDUCED SIZE
                      * SA  .069    .077    .085    .094    .103    .112    .122
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * SQ  0.00   0.020   0.022   0.024   0.026   0.028   0.031
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * KM TRIAL REDUCED SIZE
                      * SA  .067    .075    .083    .091    .100    .109    .119
                      * SE   700   700.5     701   701.5     702   702.5     703
                      * SQ  0.00   0.019   0.021   0.023   0.025   0.027   0.030
                      * SE   700   700.5     701   701.5     702   702.5     703
         41           KM   REDUCED SIZE
         42           SA    .064    .072    .080    .088    .097    .106    .116
         43           SE     700   700.5     701   701.5     702   702.5     703
         44           SQ    0.00   0.018   0.020   0.022   0.024   0.026   0.028
         45           SE     700   700.5     701   701.5     702   702.5     703

         46           KK   COMBO
         47           KO      5       0       0       0      21
         48           HC      2
         49           ZZ
1****************************************                                       ***************************************
 *                                       *                                       *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                       *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN  1998                 *                                       *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                       *         609 SECOND STREET           *
 *                                       *                                       *      DAVIS, CALIFORNIA 95616        *
 * RUN DATE   24AUG08  TIME  21:53:54    *                                       *           (916) 756-1104            *
 *                                       *                                       *                                     *
 ****************************************                                        ***************************************
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```
                                 CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                                 ANALYZED BY ABC ENGINEERING
                                 DATE: APRIL 2008
1
                                                            RUNOFF SUMMARY
                                                     FLOW IN CUBIC FEET PER SECOND
                                                 TIME IN HOURS,  AREA IN SQUARE MILES

                                            PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD          BASIN      MAXIMUM     TIME OF
           OPERATION          STATION       FLOW      PEAK                                                 AREA       STAGE     MAX STAGE
+                                                                6-HOUR       24-HOUR      72-HOUR

           HYDROGRAPH AT
+                                PRE1         0.       .00           0.           0.           0.          .00

           HYDROGRAPH AT
+                               POST1         2.      3.20           0.           0.           0.          .00

           DIVERSION TO
+                                 BIO         2.      3.20           0.           0.           0.          .00

           HYDROGRAPH AT
+                                 DIV         0.      3.20           0.           0.           0.          .00

           HYDROGRAPH AT
+                                 BIO         2.      3.20           0.           0.           0.          .00

           ROUTED TO
+                              BIOROU         0.      3.80           0.           0.           0.          .00
+                                                                                                                    700.90        6.17

           2 COMBINED AT
+                               COMBO         0.      3.20           0.           0.           0.          .00


 *** NORMAL END OF HEC-1 ***
```

The following HEC-1 file provides the results of the first step of the 1-year, 24-hour storm event routing. The designer has the two options. The first option is to set a spillway overflow elevation at the peak stage of the 1-inch, 6-hour storm event (700.90) and allow the additional runoff volume from the split 1-year, 24-hour storm event (note that a portion of the 1-year, 24-hour storm event was diverted with the flow splitter to an extended detention basin) to discharge through an overflow structure. The second option is to set a spillway overflow elevation above the peak stage of the 1-inch, 6-hour storm event and allow the additional runoff volume from the 1-year, 24-hour storm event (again, note that the additional volume is not the entire 1-year, 24-hour volume due to the previous flow splitter operation) to discharge through the filter media. For this example, the first option and the same BMP hydraulic properties as the previous example (Section 4.1.9) were selected so that the relative benefits or impacts to the BMP designs due reducing the bioretention footprint can be assessed. In addition, the designer desires to pass the larger storm events through the bioretention facility with less than a 15-inch ponding depth so hold any of the larger storm events with any additional attenuation and increase peak stage is not desirable. The stage-discharge, specifically related to the overflow discharge values are determined in later steps when routing the 10-, 25-, and 50-year storm events.

The peak water surface elevation is shown to be 700.96 (peak water surface elevation for the Darcy equation based approach was 700.75) with a portion of the 1-year, 24-hour storm event bypassing the bioretention facility, a portion of the 1-year, 24-hour storm event flowing through the filter media and a portion of the 1-year, 24-hour storm event flowing through the overflow structure. Detailed review of the TAPE 21 output indicates that the 1-year, 24-hour peak flow is 2.65 cfs which is split to 0.95 cfs bypassing the bioretention and 1.70 cfs is directed to the bioretention facility. The 1.70 cfs is attenuated to 1.29 cfs (the Darcy based design attenuates the 1.70 cfs to 1.19 cfs) by routing through the bioretention filter media and overflow structure. Review of the outflow hydrograph indicates that 28.1 percent (the Darcy based design held 24.8 percent) of the runoff volume has left the bioretention storage volume and project site at 36 hours (24 hours after the center of rainfall). Therefore, the goal of controlling the 1-year, 24-hour storm event for 24 hours has been met, without a downstream extended detention basin.

```
1*****************************************                                                      ***************************************
 *                                       *                                                      *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                      *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                      *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                                      *         609 SECOND STREET           *
 *                                       *                                                      *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   16SEP08  TIME  10:52:44   *                                                      *          (916) 756-1104             *
 *                                       *                                                      *                                     *
 *****************************************                                                      ***************************************
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                     X     X  XXXXXXX   XXXXX          X
                     X     X  X        X     X        XX
                     X     X  X        X               X
                     XXXXXXX  XXXX     X        XXXXX  X
                     X     X  X        X               X
                     X     X  X        X     X         X
                     X     X  XXXXXXX   XXXXX         XXX


THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                        HEC-1 INPUT                                            PAGE  1

 LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
   2           ID       ANALYZED BY ABC ENGINEERING
   3           ID       DATE: APRIL 2008
               *  ***************************************************************************
               *
               *    TIME SPECIFICATION CARD
   4           IT      2       0       0    1080
               *  DIAGRAM
               *    TIME INTERVAL CARD
   5           IN      6       0       0
               *
               *    OUTPUT CONTROL CARD
   6           IO      5       0       0
               *

   7           KK    PRE1
               * ***************** 1-YEAR, 24-HOUR STORM EVENT *******************************
               * ********* 6 MINUTE TIME INCREMENT,24-HOUR STORM EVENT ***********************
               * ****************************************************************************
   8           PB    2.58
   9           PI   .0000   .0010   .0010   .0010   .0011   .0010   .0011   .0010   .0011   .0011
  10           PI   .0011   .0011   .0011   .0011   .0012   .0011   .0012   .0011   .0012   .0012
  11           PI   .0012   .0012   .0012   .0013   .0012   .0012   .0013   .0012   .0013   .0013
  12           PI   .0013   .0013   .0013   .0013   .0014   .0013   .0014   .0014   .0013   .0014
  13           PI   .0014   .0014   .0014   .0015   .0015   .0015   .0015   .0015   .0015   .0016
  14           PI   .0016   .0016   .0016   .0017   .0017   .0016   .0018   .0017   .0017   .0018
  15           PI   .0018   .0018   .0018   .0019   .0019   .0018   .0020   .0019   .0019   .0020
  16           PI   .0020   .0020   .0020   .0021   .0021   .0021   .0021   .0021   .0021   .0022
  17           PI   .0022   .0022   .0024   .0024   .0026   .0026   .0028   .0029   .0029   .0030
  18           PI   .0032   .0032   .0032   .0032   .0032   .0032   .0033   .0034   .0036   .0038
  19           PI   .0039   .0041   .0044   .0046   .0048   .0051   .0054   .0058   .0062   .0066
  20           PI   .0070   .0077   .0086   .0096   .0106   .0115   .0238   .0476   .0764   .1371
  21           PI   .0951   .0190   .0166   .0144   .0122   .0098   .0084   .0080   .0074   .0068
  22           PI   .0064   .0060   .0056   .0054   .0052   .0048   .0046   .0044   .0042   .0040
  23           PI   .0038   .0037   .0036   .0035   .0034   .0034   .0033   .0033   .0032   .0031
  24           PI   .0030   .0030   .0029   .0028   .0027   .0027   .0026   .0026   .0025   .0024
  25           PI   .0023   .0023   .0022   .0023   .0022   .0022   .0022   .0021   .0021   .0021
  26           PI   .0021   .0020   .0020   .0020   .0019   .0020   .0019   .0019   .0018   .0018
  27           PI   .0018   .0018   .0017   .0018   .0017   .0017   .0016   .0017   .0016   .0016
  28           PI   .0015   .0016   .0015   .0015   .0015   .0014   .0014   .0014   .0013   .0014
  29           PI   .0013   .0013   .0013   .0013   .0013   .0012   .0013   .0013   .0012   .0013
  30           PI   .0012   .0013   .0012   .0013   .0012   .0012   .0013   .0012   .0012   .0012
  31           PI   .0012   .0012   .0012   .0012   .0012   .0011   .0012   .0012   .0011   .0012
  32           PI   .0011   .0012   .0011   .0012   .0011   .0011   .0012   .0011   .0011   .0011
  33           PI   .0011
               * *****************************************************************************
  34           KM   1-ACRE PRE-DEVELOPED CONDITIONS
  35           KO      5       0       0       0      21
  36           BA   .0016
  37           LS      0    65.0       0
  38           UD   0.194
  39           KK   POST1
  40           KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
  41           KO      5       0       0       0      21
  42           BA   .0016
  43           LS      0    93.4       0
  44           UD   0.080

  45           KK     DIV
  46           KO      5       0       0       0      21
  47           DT     BIO
  48           DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
  49           DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

  50           KK     BIO
  51           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
  52           KO      5       0       0       0      21
  53           DR     BIO

  54           KK  BIOROU
  55           KO      5       0       0       0      21
  56           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
  57           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
  58           RS      1    ELEV     700
               * SA  .085    .093    .102    .112    .121    .132    .142
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.024   0.027   0.029   0.032   0.035   0.037
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE
               * SA  .077    .085    .094    .103    .112    .122    .133
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.022   0.024   0.027   0.029   0.032   0.034
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE
               * SA  .057    .064    .072    .080    .088    .097    .106
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.016   0.018   0.020   0.022   0.024   0.025
               * SE   700   700.5     701   701.5     702   702.5     703
```

```
                    * KM TRIAL REDUCED SIZE
                    * SA  .069    .077    .085    .094    .103    .112    .122
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.020   0.022   0.024   0.026   0.028   0.031
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM TRIAL REDUCED SIZE
                    * SA  .067    .075    .083    .091    .100    .109    .119
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.019   0.021   0.023   0.025   0.027   0.030
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM TRIAL REDUCED SIZE
                    * SA  .064    .072    .080    .088    .097    .106    .116
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.018   0.020   0.022   0.024   0.026   0.028
                    * SE   700   700.5     701   701.5     702   702.5     703
         59         KM   REDUCED SIZE
         60         KM   ADD 7 BY 7 OVERFLOW STRUCTURE AT 700.90
         61         SA    .064    .072    .080    .088    .097
         62         SE     700   700.5     701   701.5     702
         63         SQ    0.00   0.018  0.0199   2.322   33.85
         64         SE     700   700.5   700.9     701   701.5

         65         KK   COMBO
         66         KO       5       0       0       0      21
         67         HC       2

         68         KK   EDROU
         69         KO       5       0       0       0      21
         70         KM   ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
         71         KM   6-INCH ORIFICE
         72         RS       1    ELEV     695
         73         SA    .048    .053    .057    .062    .068    .073    .079
         74         SE     695   695.5     696   696.5     697   697.5     698
         75         SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
         76         ZZ
1*****************************************                                                   ***************************************
 *                                       *                                                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *   U.S. ARMY CORPS OF ENGINEERS      *
 *            JUN   1998                 *                                                   *   HYDROLOGIC ENGINEERING CENTER     *
 *         VERSION 4.1                   *                                                   *         609 SECOND STREET           *
 *                                       *                                                   *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   16SEP08  TIME  10:52:44   *                                                   *          (916) 756-1104             *
 *                                       *                                                   *                                     *
 *****************************************                                                   ***************************************



                          CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                          ANALYZED BY ABC ENGINEERING
                          DATE: APRIL 2008

1
                                                     RUNOFF SUMMARY
                                              FLOW IN CUBIC FEET PER SECOND
                                           TIME IN HOURS,  AREA IN SQUARE MILES

                                   PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD       BASIN     MAXIMUM     TIME OF
          OPERATION       STATION  FLOW     PEAK                                               AREA      STAGE     MAX STAGE
+                                                        6-HOUR      24-HOUR      72-HOUR

          HYDROGRAPH AT
+                            PRE1      0.   12.23          0.           0.           0.        .00

          HYDROGRAPH AT
+                           POST1      3.   12.07          0.           0.           0.        .00

          DIVERSION TO
+                             BIO      2.   12.07          0.           0.           0.        .00

          HYDROGRAPH AT
+                             DIV      1.   12.07          0.           0.           0.        .00

          HYDROGRAPH AT
+                             BIO      2.   12.03          0.           0.           0.        .00

          ROUTED TO
+                          BIOROU      1.   12.20          0.           0.           0.        .00
+                                                                                                       700.96       12.20

          2 COMBINED AT
+                           COMBO      1.   12.20          0.           0.           0.        .00

          ROUTED TO
+                           EDROU      0.   12.43          0.           0.           0.        .00
+                                                                                                       695.46       12.43

 *** NORMAL END OF HEC-1 ***
```

<u>Step 13(Optional)   Design Conveyance System</u>

Conveyance system design is not included in this design example. Standards for conveyance system design are covered in the *Charlotte-Mecklenburg Storm Water Design Manual*.

<u>Step 14a(Optional)   Size Bioretention Underdrain System</u>

The underdrain system must be designed to meet two design goals; the underdrain capacity must be greater than the filter media capacity, and the capacity must drain the runoff volume from the system within 48 hours. The design must assume that 50 percent of the underdrain system (perforations and pipe system capacity) is lost due to clogging.

Design specifications require the underdrain system to be a 6-inch perforated PVC pipe with 3/8-inch perforations 3 inches on center along 4 longitudinal rows that are spaced 90° apart. Minimum underdrain slope is 0.5 percent.

The length, slope, number of pipes, spacing, etc. is configured per design requirements. Based upon the required area for the bioretention BMP (2,809 ft^2) the approximate dimensions of the bioretention area is selected to be 30 feet wide by 100 feet in length (approximately 2,809 ft^2).

The design process uses a trial and error process to determine the proper underdrain capacity. The capacity of the perforations and pipe (assuming 50 percent of the system is clogged) are computed. The computed underdrain capacity is checked relative to the filter media capacity to ensure that the filter media is the controlling outflow condition. The computed underdrain capacity if compared to the static outflow discharge that ensures the runoff within the system leaves within 48 hours.

Compute minimum drawdown discharge

Water quality volume	=	(0.07ac-ft)(43,560ft^3/ac ft)	= 3,049 ft^3
Drawdown	=	3,049 ft3/[(48 hours)(3,600sec/hour)]	
	=	0.018 cfs	

Compute perforation capacity

Since the maximum underdrain spacing is 10 feet on center and the bioretention area is 30 feet wide by 100 feet in length, two parallel underdrain pipes (6-inch diameter PVC) 100 feet in length were selected. For the calculations below, the length of pipe containing holes was reduced by 1 foot per cleanout to account for non-perforated fittings.

Number of perforations	=	(2 pipes)((100-3) ft/pipe)(4 rows/ft)(4 holes/row) = 3,104 holes	
50 percent of perforations	=	1,552 holes	
Capacity of one hole	=	$CA(2gh)^{0.5}$	
	=	$(0.6)(3.1416)[(3/8in)(1/24)]^2[(64.4)(4.5ft)]^{0.5}$	
	=	0.0078 cfs/hole	
Total capacity	=	(0.0078 cfs/hole)(792 holes)	= 12.11 cfs

The perforations capacity (12.11 cfs) is greater than the filter media capacity (0.020 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.018 cfs computed in this step). Therefore the design is acceptable.

Note that the headwater depth used to determine the filter media capacity is 0.5 feet, the average headwater depth above the filter media for the water quality storm event. The drawdown computation is also based on the water quality volume. The headwater depth for the perforations is also based on the same average headwater elevations, 0.5 feet above the filter media, or 4.5 feet above the perforations.

Compute underdrain pipe capacity

For 6-inch PVC underdrain pipe at 0.005 ft/ft slope

Capacity of pipe	=	$(1.49/n)(A)(A/P)^{0.67}(S)^{0.5}$
	=	$(1.49/0.013)(0.1963\ ft^2)(0.125\ ft)^{0.67}(0.005)^{0.5}$
	=	0.40 cfs
Capacity of pipe (50% clogged)	=	0.20 cfs

The underdrain pipe capacity (0.20 cfs) is greater than the filter media capacity (0.020 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.018 cfs computed in this step). Therefore the design is acceptable.

Step 14b(Optional) Calculate Q_{10} and Q_{25} (if required) Release Rate(s) and Water Surface Elevation(s)

The next step of the design process is to design the bioretention facility and a detention basin to achieve the peak attenuation goals for the 10- and 25-year, 60-hour storm events (note that the previous step eliminated the need for an extended detention basin, therefore, the design process is now focused on designing a standard detention basin however, the benefits of the upstream bioretention facility are included in the design). This process is similar to previous examples in that the design is iterative.

For this example, the same stage-storage-discharge relationship for the detention basin that was developed in the portion of this example using the Darcy equation to set the bioretention footprint sizes is used. This approach is taken so that benefits or impacts of the routing and subsequent bioretention footprint reduction can be assessed with regards to the detention basin size. The appropriate storm events are routed through the storage volume, and the outflow peak discharge is compared to the pre-development peak discharge for the 10- and 25-year, 6-hour storm events; 1.10 and 1.64 cfs, respectively. In addition, the peak stage for the 10- and 25-year, 6-hour storm events must be less than 15 inches above the top of the filter media in the bioretention facility. The bioretention overflow structure must be larger and allow more outflow with less headwater depth so that the maximum one foot ponding depth limitation is not exceeded.

The following HEC-1 output files illustrate the results of the iterative process for the 10- and 25-year storm event. A 6.0-inch orifice that is installed at the base of the detention basin outlet structure (695.00) attenuates the post-developed to appropriate values for the 10- and 25-year, 6-hour storm events. The TAPE21 file indicates that the peak discharge for the 10-year, 6-hour storm event is 1.09 cfs with a peak stage of 696.58 (results based on Darcy equation were 1.08 cfs with a peak stage of 696.57). The peak stage in the bioretention facility is 700.98. The peak discharge for the 25-year, 6-hour storm event is 1.27 cfs with a peak stage of 697.06 (results based on Darcy equation without footprint reduction using routing are the same; 1.27 cfs with a peak stage of 697.06). Intermediate steps are not presented.

```
1***************************************                                        **************************************
 *                                      *                                        *                                    *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                        *   U.S. ARMY CORPS OF ENGINEERS     *
 *              JUN   1998              *                                        *   HYDROLOGIC ENGINEERING CENTER    *
 *           VERSION 4.1                *                                        *       609 SECOND STREET            *
 *                                      *                                        *     DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   24SEP08  TIME  17:12:10  *                                        *         (916) 756-1104             *
 *                                      *                                        *                                    *
 ***************************************                                        **************************************


                              X     X  XXXXXXX   XXXXX          X
                              X     X  X        X     X        XX
                              X     X  X        X               X
                              XXXXXXX  XXXX     X       XXXXX   X
                              X     X  X        X               X
                              X     X  X        X     X         X
                              X     X  XXXXXXX   XXXXX         XXX


         THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

         THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
         THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
         NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
         DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
         KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                          HEC-1 INPUT                                          PAGE  1

         LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

           1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
           2           ID       ANALYZED BY ABC ENGINEERING
           3           ID       DATE: APRIL 2008
                       *  ***************************************************************************
                       *
                       *     TIME SPECIFICATION CARD
           4           IT       2       0       0    1026
                       *  DIAGRAM
                       *     TIME INTERVAL CARD
           5           IN       5       0       0
                       *
                       *     OUTPUT CONTROL CARD
           6           IO       5       0       0
                       *
```

```
    7          KK    PRE1
               * ****************************************************************************
               * **************** 10-YEAR, 6-HOUR STORM EVENT *******************************
               * ****************************************************************************
    8          PI    .000    .011    .011    .012    .012    .012    .012    .013    .013    .013
    9          PI    .014    .014    .015    .015    .016    .016    .017    .018    .018    .023
   10          PI    .024    .025    .026    .027    .029    .036    .039    .042    .045    .049
   11          PI    .054    .079    .089    .103    .161    .201    .395    .590    .275    .177
   12          PI    .112    .095    .084    .057    .051    .047    .043    .040    .038    .030
   13          PI    .028    .027    .025    .024    .023    .019    .018    .017    .017    .016
   14          PI    .016    .015    .015    .014    .014    .013    .013    .013    .012    .012
   15          PI    .012    .011    .011    .000
               * ****************************************************************************
   16          KM    1-ACRE PRE-DEVELOPED CONDITIONS
   17          KO       5       0       0       0      21
   18          BA   .0016
   19          LS       0    65.0       0
   20          UD   0.194

   21          KK   POST1
   22          KM    1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
   23          KO       5       0       0       0      21
   24          BA   .0016
   25          LS       0    93.4       0
   26          UD   0.080

   27          KK     DIV
   28          KO       5       0       0       0      21
   29          DT     BIO
   30          DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
   31          DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

   32          KK     BIO
   33          KM    RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
   34          KO       5       0       0       0      21
   35          DR     BIO
   36          KK  BIOROU
   37          KO       5       0       0       0      21
   38          KM    ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
   39          KM    NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
   40          RS       1    ELEV     700
               * SA  .085    .093    .102    .112    .121    .132    .142
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.024   0.027   0.029   0.032   0.035   0.037
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE
               * SA  .077    .085    .094    .103    .112    .122    .133
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.022   0.024   0.027   0.029   0.032   0.034
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE
               * SA  .057    .064    .072    .080    .088    .097    .106
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.016   0.018   0.020   0.022   0.024   0.025
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE
               * SA  .069    .077    .085    .094    .103    .112    .122
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.020   0.022   0.024   0.026   0.028   0.031
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE
               * SA  .067    .075    .083    .091    .100    .109    .119
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.019   0.021   0.023   0.025   0.027   0.030
               * SE   700   700.5     701   701.5     702   702.5     703
               * KM TRIAL REDUCED SIZE

               * SA  .064    .072    .080    .088    .097    .106    .116
               * SE   700   700.5     701   701.5     702   702.5     703
               * SQ  0.00   0.018   0.020   0.022   0.024   0.026   0.028
               * SE   700   700.5     701   701.5     702   702.5     703
   41          KM    REDUCED SIZE
   42          KM    ADD 7 BY 7 OVERFLOW STRUCTURE AT 700.90
   43          SA    .064    .072    .080    .088    .097
   44          SE     700   700.5     701   701.5     702
   45          SQ    0.00   0.018  0.0199   2.322   33.85
   46          SE     700   700.5   700.9     701   701.5

   47          KK   COMBO
   48          KO       5       0       0       0      21
   49          HC       2

   50          KK   EDROU
   51          KO       5       0       0       0      21
   52          KM    ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
   53          KM    6-INCH ORIFICE
   54          RS       1    ELEV     695
   55          SA    .048    .053    .057    .062    .068    .073    .079
   56          SE     695   695.5     696   696.5     697   697.5     698
   57          SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
   58          ZZ
1*****************************************                                            ***************************************
 *                                       *                                            *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                            *   U.S. ARMY CORPS OF ENGINEERS      *
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 *                                       *                                            *                                     *
 *****************************************                                            ***************************************

                        CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                        ANALYZED BY ABC ENGINEERING
                        DATE: APRIL 2008

                                              RUNOFF SUMMARY
                                        FLOW IN CUBIC FEET PER SECOND
                                     TIME IN HOURS,  AREA IN SQUARE MILES

                                 PEAK    TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD     BASIN     MAXIMUM     TIME OF
        OPERATION      STATION   FLOW     PEAK                                           AREA       STAGE     MAX STAGE
+                                                     6-HOUR     24-HOUR     72-HOUR
```

```
         HYDROGRAPH AT
+                          PRE1          1.    3.40           0.           0.           0.         .00

         HYDROGRAPH AT
+                         POST1          5.    3.20           1.           0.           0.         .00

         DIVERSION TO
+                           BIO          2.    3.20           0.           0.           0.         .00

         HYDROGRAPH AT
+                           DIV          4.    3.20           0.           0.           0.         .00

         HYDROGRAPH AT
+                           BIO          2.    3.20           0.           0.           0.         .00

         ROUTED TO
+                        BIOROU          2.    3.30           0.           0.           0.         .00
+                                                                                                          700.98        3.30

         2 COMBINED AT
+                         COMBO          5.    3.23           0.           0.           0.         .00

         ROUTED TO
+                         EDROU          1.    3.63           0.           0.           0.         .00
+                                                                                                          696.58        3.63


 *** NORMAL END OF HEC-1 ***


1*****************************************                                                   ***************************************
 *                                       *                                                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                   *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                   *         609 SECOND STREET           *
 *                                       *                                                   *      DAVIS, CALIFORNIA 95616        *
 * RUN DATE   24SEP08  TIME  17:24:12    *                                                   *          (916) 756-1104             *
 *                                       *                                                   *                                     *
 *****************************************                                                   ***************************************


                                                X     X  XXXXXXX   XXXXX          X
                                                X     X  X        X     X        XX
                                                X     X  X        X               X
                                                XXXXXXX  XXXX     X       XXXXX   X
                                                X     X  X        X               X
                                                X     X  X        X     X         X
                                                X     X  XXXXXXX   XXXXX         XXX


           THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

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           THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
           NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
           DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
           KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                                    HEC-1 INPUT                                                    PAGE  1

          LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

            1           ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
            2           ID       ANALYZED BY ABC ENGINEERING
            3           ID       DATE: APRIL 2008
                        *  ***************************************************************************
                        *
                        *     TIME SPECIFICATION CARD
            4           IT       2       0       0    1026
                        *  DIAGRAM
                        *     TIME INTERVAL CARD
            5           IN       5       0       0
                        *
                        *     OUTPUT CONTROL CARD
            6           IO       5       0       0
                        *

            7           KK    PRE1
                        * ****************************************************************************
                        * **************** 25-YEAR, 6-HOUR STORM EVENT ******************************
                        * ****************************************************************************
            8           PI    .000    .014    .014    .014    .015    .015    .015    .016    .016    .017
            9           PI    .017    .018    .018    .019    .019    .020    .021    .022    .023    .025
           10           PI    .027    .028    .029    .031    .033    .043    .046    .049    .053    .058
           11           PI    .064    .093    .104    .120    .189    .235    .466    .680    .324    .208
           12           PI    .131    .111    .098    .067    .061    .055    .051    .048    .045    .034
           13           PI    .032    .030    .029    .027    .026    .023    .022    .021    .021    .020
           14           PI    .019    .019    .018    .017    .017    .016    .016    .016    .015    .015
           15           PI    .014    .014    .014    .000
                        * ****************************************************************************
           16           KM   1-ACRE PRE-DEVELOPED CONDITIONS
           17           KO       5       0       0       0      21
           18           BA   .0016
           19           LS       0    65.0       0
           20           UD   0.194

           21           KK   POST1
           22           KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
           23           KO       5       0       0       0      21
           24           BA   .0016
           25           LS       0    93.4       0
           26           UD   0.080

           27           KK     DIV
           28           KO       5       0       0       0      21
```

```
        29          DT     BIO
        30          DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
        31          DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

        32          KK     BIO
        33          KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
        34          KO       5       0       0       0      21
        35          DR     BIO
        36          KK  BIOROU
        37          KO       5       0       0       0      21
        38          KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
        39          KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
        40          RS       1    ELEV     700
                    * SA  .085    .093    .102    .112    .121    .132    .142
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.024   0.027   0.029   0.032   0.035   0.037
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM REDUCED SIZE
                    * SA  .077    .085    .094    .103    .112    .122    .133
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.022   0.024   0.027   0.029   0.032   0.034
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM REDUCED SIZE
                    * SA  .057    .064    .072    .080    .088    .097    .106
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.016   0.018   0.020   0.022   0.024   0.025
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM REDUCED SIZE
                    * SA  .069    .077    .085    .094    .103    .112    .122
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.020   0.022   0.024   0.026   0.028   0.031
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM REDUCED SIZE
                    * SA  .067    .075    .083    .091    .100    .109    .119
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.019   0.021   0.023   0.025   0.027   0.030
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM REDUCED SIZE
                    * SA  .064    .072    .080    .088    .097    .106    .116
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.018   0.020   0.022   0.024   0.026   0.028
                    * SE   700   700.5     701   701.5     702   702.5     703
        41          KM   REDUCED SIZE
        42          KM   ADD 7 BY 7 OVERFLOW STRUCTURE AT 700.90
        43          SA    .064    .072    .080    .088    .097
        44          SE     700   700.5     701   701.5     702
        45          SQ    0.00   0.018  0.0199   2.322   33.85
        46          SE     700   700.5   700.9     701   701.5

        47          KK   COMBO
        48          KO       5       0       0       0      21
        49          HC       2

        50          KK   EDROU
        51          KO       5       0       0       0      21
        52          KM   ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
        53          KM   6-INCH ORIFICE
        54          RS       1    ELEV     695
        55          SA    .048    .053    .057    .062    .068    .073    .079
        56          SE     695   695.5     696   696.5     697   697.5     698
        57          SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
        58          ZZ
1*****************************************                                  ***************************************
 *                                       *                                  *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                  *   U.S. ARMY CORPS OF ENGINEERS      *
 *              JUN   1998               *                                  *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                 *                                  *         609 SECOND STREET           *
 *                                       *                                  *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   24SEP08  TIME  17:24:12   *                                  *           (916) 756-1104            *
 *                                       *                                  *                                     *
 *****************************************                                  ***************************************



                          CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                          ANALYZED BY ABC ENGINEERING
                          DATE: APRIL 2008
                                                  RUNOFF SUMMARY
                                             FLOW IN CUBIC FEET PER SECOND
                                          TIME IN HOURS,  AREA IN SQUARE MILES

                                         PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD        BASIN     MAXIMUM     TIME OF
         OPERATION        STATION        FLOW     PEAK                                                AREA      STAGE    MAX STAGE
+                                                              6-HOUR      24-HOUR     72-HOUR

         HYDROGRAPH AT
+                           PRE1           2.     3.37            0.          0.          0.          .00

         HYDROGRAPH AT
+                          POST1           6.     3.20            1.          0.          0.          .00

         DIVERSION TO
+                            BIO           2.     3.20            0.          0.          0.          .00

         HYDROGRAPH AT
+                            DIV           5.     3.20            0.          0.          0.          .00

         HYDROGRAPH AT
+                            BIO           2.     3.20            0.          0.          0.          .00

         ROUTED TO
+                         BIOROU           2.     3.27            0.          0.          0.          .00
+                                                                                                              700.98        3.27

         2 COMBINED AT
+                          COMBO           6.     3.20            1.          0.          0.          .00

         ROUTED TO
+                          EDROU           1.     3.63            1.          0.          0.          .00
+                                                                                                              697.06        3.63

 *** NORMAL END OF HEC-1 ***
```

The final step is to route the 50-year, 6-hour storm event through the bioretention area to ensure that the maximum 15 inches of headwater depth over the top of the filter media is exceeded and that the detention basin passes the 50-year storm event with 6 inches of freeboard. The 7 foot by 7 foot open inlet is set at an elevation of 700.90, above the peak stage of the 1-inch storm event for the bioretention basin and a 20-foot emergency spillway weir is set at an elevation of 697.10, above the peak state of the 25-year storm event for the detention basin. The following HEC-1 output file illustrates the results.

```
1***************************************                                          **************************************
 *                                      *                                         *                                    *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                         *   U.S. ARMY CORPS OF ENGINEERS     *
 *               JUN   1998             *                                         *   HYDROLOGIC ENGINEERING CENTER    *
 *            VERSION 4.1               *                                         *         609 SECOND STREET          *
 *                                      *                                         *      DAVIS, CALIFORNIA 95616       *
 * RUN DATE   15SEP08  TIME  18:38:27   *                                         *          (916) 756-1104            *
 *                                      *                                         *                                    *
 ****************************************                                          **************************************

                                        X     X  XXXXXXX   XXXXX          X
                                        X     X  X        X     X        XX
                                        X     X  X        X               X
                                        XXXXXXX  XXXX     X        XXXXX  X
                                        X     X  X        X               X
                                        X     X  X        X     X         X
                                        X     X  XXXXXXX   XXXXX         XXX


           THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

           THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
           THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
           NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
           DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
           KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


1                                          HEC-1 INPUT                                                  PAGE  1

           LINE         ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

             1          ID       CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
             2          ID       ANALYZED BY ABC ENGINEERING
             3          ID       DATE: APRIL 2008
                        *  ***************************************************************************
                        *
                        *     TIME SPECIFICATION CARD
             4          IT       2       0       0    1026
                        *  DIAGRAM
                        *     TIME INTERVAL CARD
             5          IN       5       0       0
                        *
                        *     OUTPUT CONTROL CARD
             6          IO       5       0       0
                        *

             7          KK    PRE1
                        * ****************************************************************************
                        * **************** 50-YEAR, 6-HOUR STORM EVENT ******************************
                        * ****************************************************************************
             8          PI    .000    .016    .016    .016    .017    .017    .018    .018    .019    .019
             9          PI    .020    .020    .021    .022    .022    .023    .024    .025    .026    .031
            10          PI    .032    .033    .035    .037    .039    .049    .053    .056    .061    .066
            11          PI    .073    .103    .116    .133    .209    .260    .513    .749    .356    .231
            12          PI    .145    .124    .109    .077    .069    .063    .058    .054    .051    .040
            13          PI    .038    .036    .034    .033    .031    .026    .025    .024    .023    .023
            14          PI    .022    .021    .021    .020    .019    .019    .018    .018    .017    .017
            15          PI    .017    .016    .016    .000
                        * ****************************************************************************
            16          KM   1-ACRE PRE-DEVELOPED CONDITIONS
            17          KO       5       0       0       0      21
            18          BA   .0016
            19          LS       0    65.0       0
            20          UD   0.194

            21          KK   POST1
            22          KM   1-ACRE POST-DEVELOPED CONDITIONS - ADJUSTED CURVE NUMBER
            23          KO       5       0       0       0      21
            24          BA   .0016
            25          LS       0    93.4       0
            26          UD   0.080

            27          KK     DIV
            28          KO       5       0       0       0      21
            29          DT     BIO
            30          DI    0.00    0.58    1.06    1.38    1.64    5.54   12.46   21.35   31.83   43.68
            31          DQ    0.00    0.58    1.06    1.38    1.64    1.86    2.06    2.24    2.41    2.57

            32          KK     BIO
            33          KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO BIORETENTION
            34          KO       5       0       0       0      21
            35          DR     BIO
            36          KK  BIOROU
            37          KO       5       0       0       0      21
            38          KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE BIORETENTION FACILITY
            39          KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
            40          RS       1    ELEV     700
                        * SA  .085    .093    .102    .112    .121    .132    .142
                        * SE   700   700.5     701   701.5     702   702.5     703
                        * SQ  0.00   0.024   0.027   0.029   0.032   0.035   0.037
                        * SE   700   700.5     701   701.5     702   702.5     703
                        * KM TRIAL REDUCED SIZE
                        * SA  .077    .085    .094    .103    .112    .122    .133
                        * SE   700   700.5     701   701.5     702   702.5     703
                        * SQ  0.00   0.022   0.024   0.027   0.029   0.032   0.034
                        * SE   700   700.5     701   701.5     702   702.5     703
```

```
                    * KM TRIAL REDUCED SIZE
                    * SA  .057    .064    .072    .080    .088    .097    .106
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.016   0.018   0.020   0.022   0.024   0.025
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM TRIAL REDUCED SIZE
                    * SA  .069    .077    .085    .094    .103    .112    .122
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.020   0.022   0.024   0.026   0.028   0.031
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM TRIAL REDUCED SIZE
                    * SA  .067    .075    .083    .091    .100    .109    .119
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.019   0.021   0.023   0.025   0.027   0.030
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * KM TRIAL REDUCED SIZE
                    * SA  .064    .072    .080    .088    .097    .106    .116
                    * SE   700   700.5     701   701.5     702   702.5     703
                    * SQ  0.00   0.018   0.020   0.022   0.024   0.026   0.028
                    * SE   700   700.5     701   701.5     702   702.5     703
             41     KM   REDUCED SIZE
             42     KM   ADD 7 BY 7 OVERFLOW STRUCTURE AT 700.90
             43     SA    .064    .072    .080    .088    .097
             44     SE     700   700.5     701   701.5     702
             45     SQ    0.00   0.018  0.0199   2.322   33.85
             46     SE     700   700.5   700.9     701   701.5

             47     KK   COMBO
             48     KO       5       0       0       0      21
             49     HC       2

             50     KK   EDROU
             51     KO       5       0       0       0      21
             52     KM   ROUTE BIORETENTION OUTFLOW AND BYPASSED DISCHARGE THROUGH DETENTION BASIN
             53     KM   6-INCH ORIFICE
             54     RS       1    ELEV     695
             55     SA    .048    .053    .057    .062    .068    .073    .079
             56     SE     695   695.5     696   696.5     697   697.5     698
             57     SQ    0.00   0.473   0.819   1.057   1.251   1.418   1.568
             58     ZZ
1*****************************************                                                   ***************************************
 *                                       *                                                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *   U.S. ARMY CORPS OF ENGINEERS      *
 *              JUN   1998               *                                                   *   HYDROLOGIC ENGINEERING CENTER     *
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 *                                       *                                                   *                                     *
 *****************************************                                                   ***************************************

                          CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                          ANALYZED BY ABC ENGINEERING
                          DATE: APRIL 2008

                                                        RUNOFF SUMMARY
                                                 FLOW IN CUBIC FEET PER SECOND
                                              TIME IN HOURS,  AREA IN SQUARE MILES

                                      PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD        BASIN      MAXIMUM     TIME OF
          OPERATION       STATION     FLOW     PEAK                                               AREA        STAGE     MAX STAGE
+                                                          6-HOUR      24-HOUR      72-HOUR

          HYDROGRAPH AT
+                            PRE1        2.    3.37          0.           0.           0.         .00

          HYDROGRAPH AT
+                           POST1        7.    3.20          1.           0.           0.         .00

          DIVERSION TO
+                             BIO        2.    3.20          0.           0.           0.         .00

          HYDROGRAPH AT
+                             DIV        5.    3.20          0.           0.           0.         .00

          HYDROGRAPH AT
+                             BIO        2.    3.20          0.           0.           0.         .00

          ROUTED TO
+                          BIOROU        2.    3.23          0.           0.           0.         .00
+                                                                                                           700.98        3.23

          2 COMBINED AT
+                           COMBO        7.    3.20          1.           0.           0.         .00

          ROUTED TO
+                           EDROU        1.    3.63          1.           0.           0.         .00
+                                                                                                           697.43        3.67


 *** NORMAL END OF HEC-1 ***
```
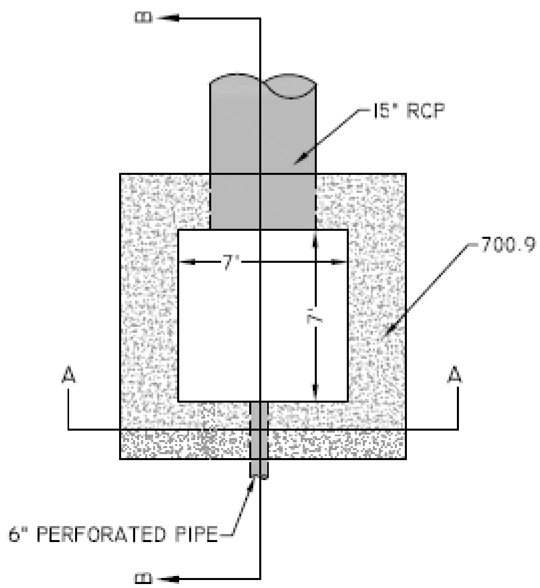
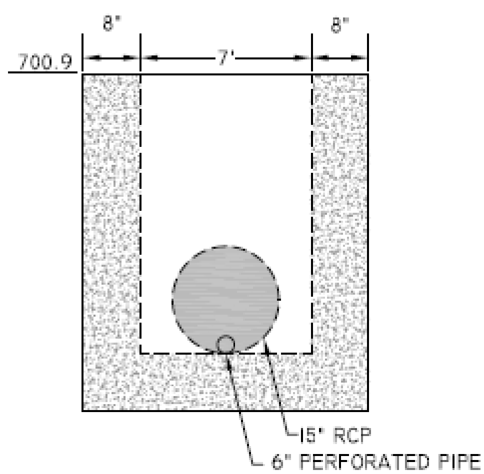

Table 4.1.7 Summary of Controls Provided

Control Element	Type/Size of Control	Peak Elev. (MSL)	Remarks
Diversion Structure	6.9-inch orifice with 4-foot weir, 2 feet tall	N/A	Diverts 1-inch storm event into bioretention
Water Quality (WQ_v)	Bioretention filter media at 700.0	700.90 (bio)	Entire 1-inch, 6-hour storm event is routed through bioretention filter media
Channel Protection (CP_v)	Bioretention filter media at 700.0 and 7.0 ft by 7.0 ft overflow at	700.96 (bio)	A portion 1-year, 24-hour storm event is routed through the

	700.90		bioretention filter media
Flood Protection Q_{10}	Detention basin 6.0-inch orifice at 695.0	700.98 (bio) 696.58 (det)	Same orifice control was designed for the 10- and 25-year storm events
Flood Protection Q_{25}	Detention basin 6.0-inch orifice at 695.0	700.98 (bio) 697.06 (det)	Same orifice control was designed for the 10- and 25-year storm events
Extreme Flood Protection Q_{50}	Bioretention – 7.0 ft by 7.0 ft overflow at 700.90 Detention basin – 20 foot weir at 697.10	700.98 (bio) 697.43(det)	Peak stage in bioretention less than 15 inches for 50-year storm event



PLAN VIEW



SECTION A-A

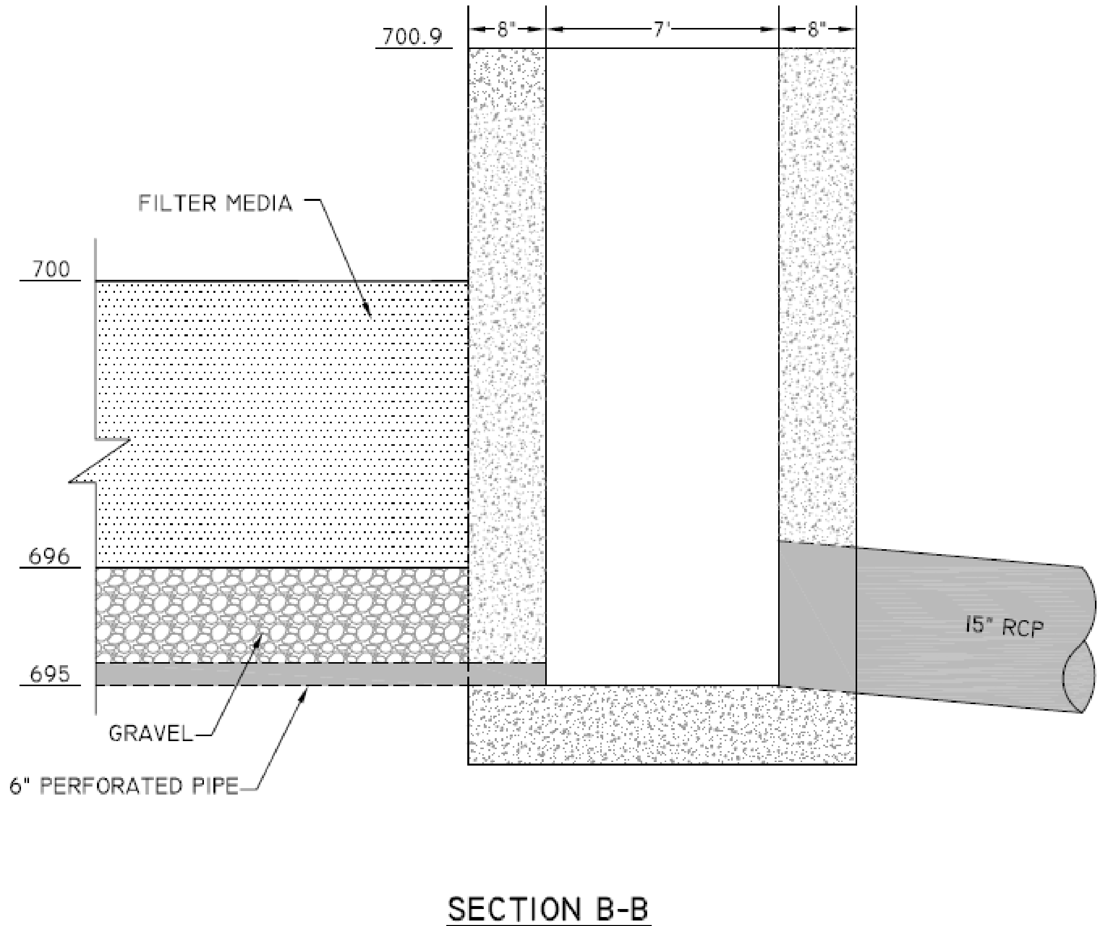


Figure 4.1.16 Schematic of Riser Detail

<u>Step 15a Design Emergency Overflow</u>

An emergency overflow structure is not designed in this example. Please refer to design methods shown in Chapter 5 - Outlet Structures.

<u>Step 15b Assess Maintenance Access and Safety Features</u>

A 12-foot wide stable maintenance access route must be provided. The access route must be contained within a 20-foot wide maintenance access easement from the BMP facility to public right-of-way.

<u>Step 15c Investigate Potential Pond Hazard Classification for the Dry Detention Basin</u>

The following table is copied from the North Carolina Department of Environment and Natural Resources (NCDENR) to assist the design with determining the potential hazard classification. The total height of proposed embankment is about three (3) feet (698.1 – 695.0). The receiving stream system is relative undeveloped with buildings with first floor elevations above the potential breach height, therefore potential for downstream development is minimal. Therefore, the designer feels that the embankment should be classified in a low hazard classification. Additional discussion with the appropriate NCDENR office may be necessary.

Hazard Classification	Description	Quantitative Guidelines
Low	Interruption of road service, low volume roads	Less than 25 vehicles per day
	Economic damage	Less than $30,000
Intermediate	Damage to highways, Interruption of service	25 to less than 250 vehicles per day
	Economic damage	$30,000 to less than $200,000
High	Loss of human life*	Probable loss of 1 or more human lives
	Economic damage	More than $200,000
	*Probable loss of human life due to breached roadway or bridge on or below the dam.	250 Vehicles per day at 1000 feet visibility 100 Vehicles per day at 500 feet visibility 25 Vehicles per day at 200 feet visibility

Step 16 Prepare Vegetation and Landscaping Plan

A landscaping plan for the bioretention area must be prepared to indicate how the bioretention area will be stabilized and established with vegetation. Diverse and native plant species designed for the hydric zone must be used. Plan must also include an invasive species prevention plan. Vegetation and landscaping plan must include plans for the first year of operation and full maturity (i.e. 3-year duration) as discussed in Chapter 6 – Vegetation and Landscaping.