4.8 Sand Filters BMP Summary Fact Sheets

Description: Multi-chamber structure designed to treat storm water runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and, typically, an underdrain collection system. It can be configured as either a surface or subsurface facility. In sand filter systems, storm water pollutants are removed primarily through filtration with some additional treatment from gravitational settling and adsorption.

IMPORTANT CONSIDERATIONS

DESIGN CRITERIA:

- A sediment chamber that contains 20 percent of the water quality volume is required as a pretreatment device.
- The underdrain system must be designed so that runoff exits the facility within design duration assuming 50 percent of the underdrain capacity is lost due to clogging.
- Maximum contributing drainage area is 10 acres.
- No runoff should enter the filter's sand bed until the upstream drainage area is completely stabilized.
- The filtration media surface must be sized using Darcy's equation with an average filtration rate of 1.75 inches/hour.
- Maximum ponding depth for water quality storm is 24 inches with an additional 36 inches for more severe storm events.
- The filter media must be designed to drain and re-aerate between storm events.
- The top of the filter media must be flat.

ADVANTAGES/BENEFITS:

- Normally used in highly impervious areas.
- Good retrofit capability.
- Can be located underground with limited surface space.
- Larger units can be used to partially attenuate runoff peaks.

DISADVANTAGES/LIMITATIONS:

- High maintenance burden.
- Typically needs to be combined with other controls to provide water quantity control.
- Not recommended for areas with high sediment content in storm water or clay/silt runoff areas.
- Relatively costly.
- Possible odor problems.
- Infiltration and internal water storage techniques are allowed.

MAINTENANCE CONSIDERATIONS:

- Inspect for clogging – rake debris screen and first inch of sand.
- Remove sediment from forebay/chamber when more than 1 foot of storage is lost.
- Sediment, topsoil, and 3 inches of filter material must be removed after the allowable drawdown time is exceeded by 25 percent.
- Entire filter material and underdrain system must be replaced if removal of 3 inches of media does not restore filtration rate.

STORMWATER MANAGEMENT SUITABILITY

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

H **1-inch, 6-hr Water Quality Protection**

M **1-yr, 24-hr Channel Protection Volume**

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

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

Sand filter facilities are highly effective in controlling pollution removal for the 1-inch, 6-hour storm and can be designed to control the volume of the 1-yr, 24-hr storm and a portion of peak attenuation for larger storm events.

IMPLEMENTATION CONSIDERATIONS

L **Land Requirements**

H **Capital Cost**

H **Maintenance Cost**

H **Maintenance Considerations**

PRIMARY POLLUTANT REMOVAL PROCESSES

- Filtration

POLLUTANT REMOVAL RATES

Effectiveness	Detention Time	Media Depth	Max. PIndex	Pollutant Removal Rates
Optimal Efficiency	2.0 days	2.5 feet	50 ppm	85% TSS 70% TP
Standard Efficiency	1.0 days	2.0 feet	50 ppm	70% TSS 35% TP
TSS-only Efficiency	2.0 days	2.5 feet	N/A	85% TSS

4.8 Sand Filters

4.8.1 General Description

Sand filters are structural storm water controls that capture and temporarily store storm water runoff and pass it through a filter bed of sand. Most sand filter systems consist of two-chambers. The first chamber, the sediment forebay, removes floatables and heavy sediments. The second chamber, the filtration chamber, removes additional pollutants and finer sediments by filtering the runoff through a sand bed. The filtered runoff is collected by an underdrain and discharged. Sand filters can be used on development sites where the use of other controls may be precluded.

There are two primary sand filter types, the surface sand filter and the underground sand filter:

Surface Sand Filter – The surface sand filter is a ground level open air facility that consists of a sediment forebay and a filter bed chamber. Surface sand filters can be designed as an excavation, with earthen embankments, or as a concrete or block structure. A surface sand filter facility consists of a two-chamber open-air structure, which is located at ground-level. The first chamber is the sediment chamber while the second chamber houses the sand filter bed. Flow enters the sedimentation chamber where settling of larger sediment particles occurs. Runoff is then discharged from the sedimentation chamber through a perforated standpipe into the filtration chamber. After passing through the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. Figure 4.8.1 and 4.8.2 illustrate a typical surface sand filter.

Underground Sand Filter – The underground sand filter is located in a vault, and is intended primarily for extremely space limited and high density areas. The underground sand filter is a two-chamber system with an optional third chamber for peak or volume attenuation and to collect and combine the filtered runoff with overflow runoff. The initial chamber is a sedimentation chamber that temporarily stores runoff and utilizes the storage area to capture sediment. The sedimentation chamber is separated from the sand filter chamber by a submerged wall that protects the filter bed from oil, trash, and large particle sediment. The filter bed should be a minimum of 2.0 feet or 2.5 feet deep depending upon design selected, and may have a protective screen of gravel or permeable geotextile to limit clogging. The sand filter chamber also includes an underdrain system with inspection and clean out wells. Perforated drain pipes under the sand filter bed extend into the downstream system or the optional third chamber that collects filtered runoff. Flows beyond the filter capacity are diverted through an overflow weir.

Underground sand filters are typically constructed on-line, but can be constructed off-line. For off-line construction, the overflow between the second and third chambers may not be required. The underground vault must be tested for water tightness prior to placement of filter layers. Figure 4.8.5 illustrates a typical underground sand filter.

Figure 4.8.1 Surface Sand Filter

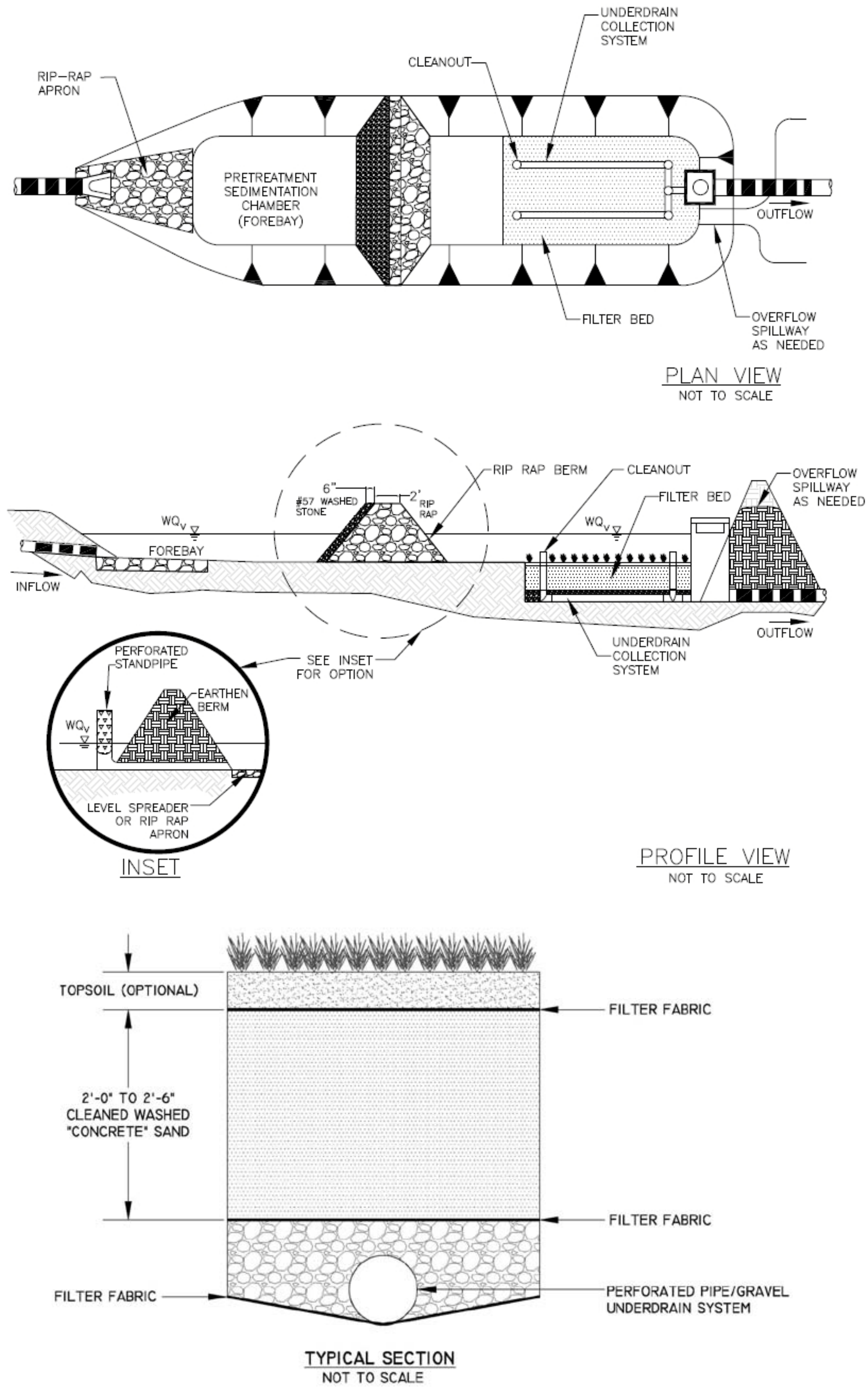

Figure 4.8.2 Schematic of Surface Sand Filter

Source: Center for Watershed Protection

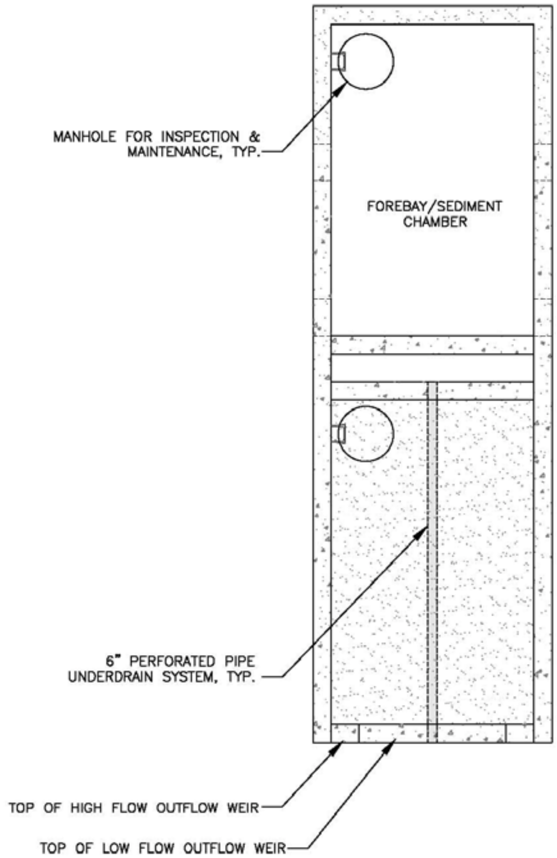

Figure 4.8.3 Schematic of Underground Sand Filter
Source: Center for Watershed Protection

4.8.2 Storm Water Management Suitability

Sand filter systems are designed primarily for storm water quality and will typically need to be used in conjunction with another structural control to provide downstream channel protection and peak discharge control. Under certain circumstances, filters can provide runoff quantity control, particularly for smaller storm events and large filters. It is important to ensure that a sand filter facility 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)

In sand filter systems, storm water pollutants are removed through a combination of gravitational settling, filtration, and adsorption. The filtration process removes suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants. Surface sand filters with a grass cover have opportunities for bacterial decomposition as well as vegetation uptake of pollutants, particularly nutrients.

Channel Protection (CP_v)

For smaller sites, a sand filter may be designed to capture the entire channel protection volume CP_v in either an off- or on-line configuration. Given that a sand filter system is typically designed to completely drain over 1 to 2 days, the requirement of controlling the 1-year, 24-hour storm runoff volume could be met. For larger sites or where only the WQ_v is diverted to the sand filter facility, another structural control must be used to provide CP_v volume control.

Peak Attenuation Control (Q_p)

In most cases, another structural control must be used in conjunction with a sand filter system to reduce the post-development peak flow to pre-development levels (detention) if needed. However, if designed with sufficient volume (stage), the peak attenuation control for the 10- and/or 25-year, 6-hour storms may be controlled by the sand filter facility.

Sand filter facilities must provide flow diversion or be designed to safely pass extreme storm flows and protect the filter bed and facility. A maximum ponding depth of 5 feet above the filter media must be maintained during all storm events greater than the 1-inch, 6-hour storm event, up to the 50-year, 6-hour storm.

4.8.3 Pollutant Removal Capabilities

Three sand filter 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 70% of the total suspended solids and 35% of the total phosphorus load. The *TSS-only design* has the capability to remove 85% of the total suspended solids and 0% of the total phosphorus loads. All of these 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. See section 4.8.4 for a discussion of design variables and appropriate pollutant removal rates for specific designs.

4.8.4 Planning and Design Criteria

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

A. Design Requirements

Following is a list of design requirements that must be followed in the design of sand filters.

- Following are the design values that are required for the three sand filter designs that are available for application in Mecklenburg County. The appropriate minimum design values and associated pollutant removal rates for each of the design are given in Table 4.8.1.

Table 4.8.1 Design Values and Pollution Removal Rates

Threshold	Minimum Detention Time	Minimum Media Depth	Maximum PIndex	Pollution Removal Rate
Optimal Efficiency	2.0 days	2.5 feet	50 ppm	85% TSS 70% TP
Standard Efficiency	1.0 days	2 feet	50 ppm	70% TSS 35% TP
TSS-only Efficiency	2.0 days	2.5 feet	N/A	85% TSS

- A sediment chamber is required as a pretreatment device for all sand filters. The sedimentation chamber storage area must be sized to hold 20 percent of the water quality volume.

- For above ground sand filters, the sedimentation chamber bottom elevation must be above the top of the filter media elevation.

- Sand filters require a sand filter media with a gravel and perforated pipe underdrain system. The underdrain system must not limit outflow more than the filter media and must be designed so that runoff exits the facility within the design duration. The underdrain system (pipe capacity and orifice capacity) must be designed assuming that 50 percent of the capacity is lost due to clogging.

- The underdrain collection 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 shall have a minimum slope of 0.5% and a maximum spacing of 10 feet on center.

- 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.

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

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

- The top of the sand filter media must be protected. Washed sod, filter fabric with number 2 stone on top, or a 1-inch thick debris screen should be used to prevent large floatables from clogging the system.

- The maximum contributing drainage area for a surface sand filter is 10 acres. The maximum drainage area for a perimeter sand filter is 2 acres. The maximum drainage area for an underground sand filter is 5 acres.

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

- No runoff should enter the filter's sand bed until the upstream drainage area is completely stabilized and site construction if completed. Any disturbed areas within the drainage area must be identified and stabilized. Filtration controls must only be constructed after the construction site is stabilized.

- The filtration media surface area should be sized using Darcy's equation using an average filtration rate of 1.75 inches/hour.

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

where:

A_f = surface area of sand filter media (ft^2)

WQ_v = water quality control volume (ft^3)
d_f = filter bed depth (2.0' or 2.5' per design)
k = coefficient of permeability of filter media (3.5 ft/day)
h_f = average height of water above filter bed (1.0' maximum)
t_f = design filter bed drain time (days)

- Maximum ponding depth for the water quality storm event is 24 inches with an additional 36 inches for more severe storm events.

- 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

- The top of a sand filter must be flat.

- For underground sand filters, the minimum distance from the top of sand to the inside top of the structure is 5 feet.

B. Physical Specifications/Geometry

Figure 4.8.4 illustrates the various components of a sand filter.

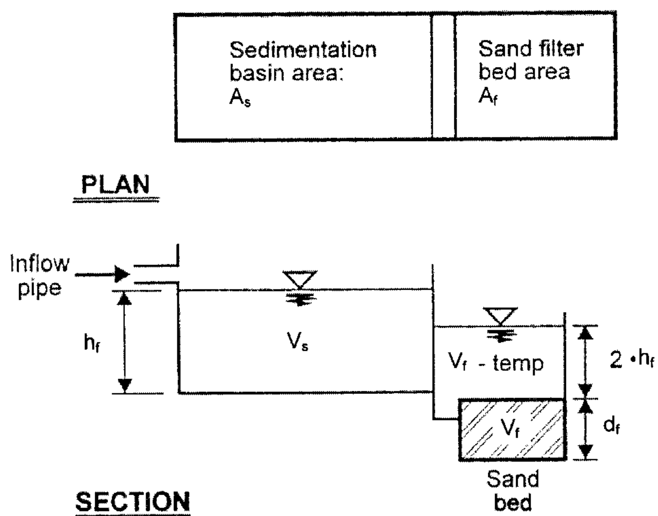

Figure 4.8.4 Surface Sand Filter Volumes
Source: Claytor and Schueler, 1996

The filter media consists of a 2.0 to 2.5 feet layer of clean washed medium sand (meeting ASTM C33 concrete sand specifications) on top of the gravel and underdrain system. A 1-inch thick debris screen must be placed on top of the sand filter media to prevent large floatables from clogging the system. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. A proper fabric selection with equal pore-openings is critical. Figure 4.8.5 illustrates a typical media cross section.

The structure of the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media.

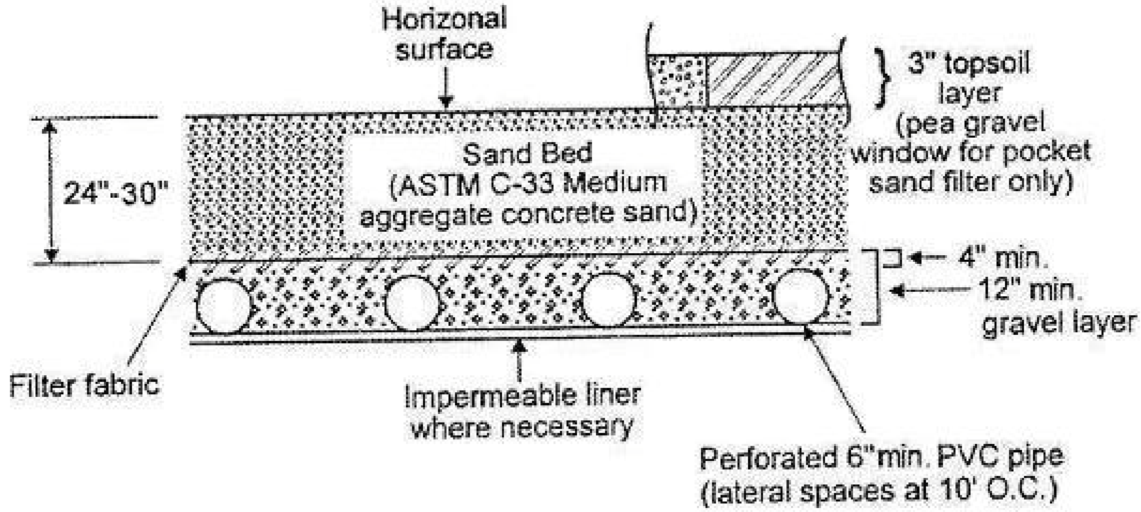

Figure 4.8.5 Typical Sand Filter Media Cross Sections
Source: Claytor and Schueler, 1996

C: Pretreatment/Inlets

- Pretreatment of runoff in a sand filter system is provided by the sedimentation chamber.
- Inlets to surface sand filters must be provided with energy dissipators. Exit velocities from the sedimentation chamber must be sheet flow to prevent filter media erosion.
- Figure 4.8.9 shows a typical inlet pipe from the sedimentation basin to the filter media basin for the surface sand filter.

D. Outlet Structures

Outlet pipe must be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways). If all storms are being routed through the outlet, outlet protection may be required.

E. Emergency Spillway

An emergency or bypass spillway must be included in the sand filter to safely pass flows that exceed the design storm flows. The spillway prevents filter water levels from overtopping the internal baffle walls or embankments in a manner that can cause structural damage to the filter media or other surrounding features.

F. Maintenance Access

Adequate access must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. Access grates to the filter bed must be included in a perimeter and underground sand filter design. The access location must be spaced so that all underground locations are within 25 feet from surface access. Facility designs must enable maintenance personnel to easily replace upper layers of the filter media. See appropriate jurisdiction's land development standards manual for the width of the required easement (PCCE or SDE).

G. Safety Features

Surface sand filter facilities can be fenced to restrict access from non-approved personnel.

H. Landscaping

Surface filters can be designed with a grass cover to aid in pollutant removal and prevent clogging. The grass must be capable of withstanding frequent periods of inundation and drought.

I. Design Recommendations

In addition to the design requirements and variables, following are some design recommendations that should be considered for sand filter design.

- Sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or high clay/silt sediment loads must not use a sand filter unless additional pretreatment is considered to reduce the potential clogging and failure of the filter bed.

- Surface sand filters are generally used in an off-line configuration where the water quality volume (WQ_v) is diverted to the filter facility through the use of a flow diversion structure and flow splitter. In many cases, storm water flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.

- Perimeter sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.

- For a surface sand filter, a 2-foot separation is recommended between the bottom of the sand filter and the elevation of the seasonally high water table.

4.8.5 Design Procedures

Following are the design procedures to be used for the design of sand filters.

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 sand filter facility.

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.

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

Step 7 Size flow diversion structure, if needed, to divert the water quality volume to the sand filter.

Step 8 Compute the release rates for the water quality control and channel protection volume control.

Step 9 Compute pretreatment volume (if included in the design). The sedimentation chamber should be sized to contain 20 percent of the WQ_v.

Step 10 Size filtration basin chamber

The filter area is sized using the following equation (based on Darcy's Law):

$$A_r = (WQ_v)(d_f) / [(k)(h_r + d_f)(t_f)]$$

where:

A_r = surface area of filter bed (ft^2)
WQ_v = Water Quality Protection Volume (or total Volume to be infiltrated)
d_f = filter bed depth (designer selects either 24 inches or 30 inches)
k = coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for sand)
h_f = average height of water above filter bed (ft) (1/2 h_{max}, which varies based on site but h_{max} is typically ≤ 1 foot)
t_f = design filter bed drain time (days) (designer selects either 27 or 51 hours, which is 24 or 48 hours beyond the center of the water quality storm event, 3 hours)

Set preliminary dimensions of filtration basin chamber and sedimentation chamber.

Step 11 Derive stage-discharge and stage-storage relations for the sand filter. 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 of the top of filter media.

Step 12 Route flows through sand filter facility and adjust design of facility to meet all design criteria.

Step 13 Design inlets, pretreatment facilities, underdrain system, and outlet structures

Step 14 Compute overflow weir sizes

4.8.6 Inspection and Maintenance Requirements

Specific maintenance inspections and requirements are contained in Chapter 7 of the Administrative Manual.

4.8.7 Design Form

Design Procedure Form: Sand Filters

	NOTES:
SAND FILTER FEASIBILITY	
1. Is the use of a sand filter appropriate?	
2. Confirm local design criteria and applicability.	
PRELIMINARY HYDROLOGIC CALCULATIONS	
3. Compute, WQ_v water quality 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 (SCS curve number) Adjusted CN (SCS curve number adjusted for 1-inch storm event) Time of concentration	 Pre-developed Post-developed ______ acres ______ acres ______ ______ ______ ______ ______ hours ______ hours
5. Compute WQ_p peak flow	WQ_p = ______ cfs
6. Compute CP_v (channel protection volume) Compute S (maximum retention) Compute 1-yr, 24-hr total rainfall depth Compute q_d (runoff volume for 1-year, 24-hour storm event) Compute CP_v	 S = ______ Rainfall Depth = ______ inches q_d = ______ inches CP_v =__ acre-ft
7. Size flow diversion structure	
8. Compute release rates Compute WQ_v release rate Compute CP_v release rate	 Release Rate = ______ cfs Release Rate = ______ cfs
SAND FILTER DESIGN	
9. Compute sedimentation chamber volume $Vol_{pre} = (0.20)(WQ_v)$	Vol_{pre} = ______ acre-ft
10. Size filtration bed chamber Compute area from Darcy's Law	A_r = ______ft^2 L = ______ft W = ______ft
11. Develop stage-storage and stage-discharge relationships	(see table below)
12. Route Flows through sand filter	
13. Design inlets and underdrain system,	
14. Compute overflow weir sizes Compute overflow – Orifice equation Weir from sedimentation chamber – Weir equation Weir from filtration chamber – Weir equation	 Q =______cfs Length = ______ft Length = ______ft
15. Assess Maintenance Access and Safety Features	

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

Notes

4.8.8 Sand Filter Design Example #1

The following design example is for a sand filter facility designed to control the 1-inch, 6-hour for water quality purposes, 1-year, 24-hour for channel protection purposes, and 10-year 6-hour for flood control purposes following the design procedures given in section 4.8. 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 4.8.6 shows the site plan for the development and base hydrologic data that will be used in the design example.

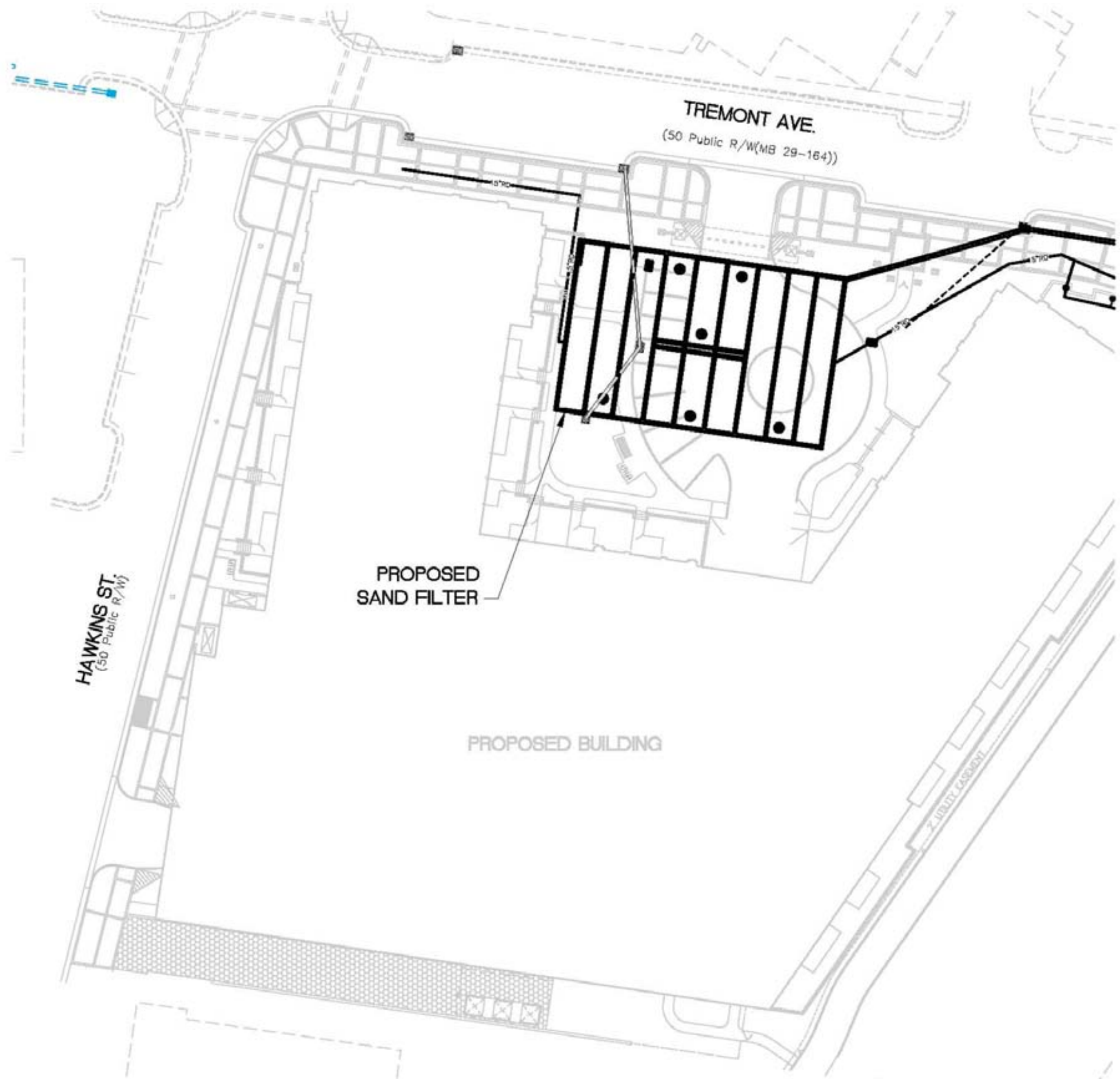

Figure 4.8.6 Example Site Plan for Sand Filter Design

The following steps illustrate how to use the design procedures given in section 4.8 to design a sand filter facility 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 sand filter design 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 Water Quality Volume (WQ_v)

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

  $R_v = 0.05 + 0.009(I) = 0.05 + (79.2)(0.009) = 0.76$

- Compute Water Quality Volume, WQ_v, using Equation 3.2

  $WQ_v = 1.0R_vA/12$ = (1.0 inches)(0.76)(2.93 acre)(1foot/12 inches) = 0.19 ac-ft

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

  $WQ_v = 1.0(R_v) = 1.0(0.76) = 0.76$ inches

Step 4 Compute Site Hydrologic Input Parameters

The site contains 2.93 acres and is proposed to be re-developed to 79.2 percent imperviousness. Using SCS hydrologic procedures, the following data can be determined for the example development site. For pre-developed conditions, an assumption that the site was 50% forest in good hydrologic condition and 50% pasture in good hydrologic condition is required. The site consists of 15% hydrologic type B soils and 85% hydrologic type C soils. The pre-developed topography drains in two directions and includes two sub-basins. The post-developed topography drains in one direction.

The pre-developed weighted curve number is:

$CN_{weighted}$ = (0.5)(0.15)(61) + (0.5)(0.85)(74) + (0.5)(0.15)(55) + (0.5)(0.85)(70)
= 69.9
Use 70

The post-developed weighted curve number is (based on 79 percent impervious from site plan):
$CN_{weighted}$ = (0.21)(0.15)(61) + (0.21)(0.85)(74) + (0.79)(98)
= 92.6
Use 93

The modified post-developed curve number for application with the 1-inch, 6-hour storm event, using Equation 3.4 is:

$CN_{weighted} = 1000/[10 + 5P + 10WQ_v - 10(WQ_v^2 + 1.25\ WQ_vP)^{0.5}]$
$CN_{weighted} = 1000/[10 + 5(1.0) + 10(0.76) - 10\{(0.76^2 + (1.25)(0.76)(1.0)\}^{0.5}]$
= 97.7
Use 98

Table 4.8.2 Hydrologic Input Data

Condition	Area (acres)	CN	CN (adjusted) for 1-inch storm	t_c (hours)[1]
Pre-developed (WS1)	1.1	70	N/A	0.532
Pre-developed (WS2)	1.8	70	N/A	0.532
Post-developed	2.9	93	98	0.083

[1]Based on methods described in the Charlotte-Mecklenburg Storm Water Design Manual

Table 4.8.3 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 (WS1)	0.00	0.38	1.36	1.92	2.39
Pre-developed (WS2)	0.00	0.59	2.12	2.99	3.71
Post-developed	4.61	8.20	17.5	20.70	23.25

Step 5 Compute Water Quality Peak Flow (WQ_p)

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

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 *   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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            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 ABC ENGINEERING
             3           ID       DATE: OCTOBER 2006
                         *  *************************************************************************
                         *
                         *     TIME SPECIFICATION CARD
                         *     TIME DURATION OF 51 HOURS
             4           IT       3       0       0    1020
                         *  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   EAST PRE-DEVELOPED CONDITIONS
          17          KO       5       0       0       0      21
          18          BA   .0018
          19          LS       0    69.9       0
          20          UD   0.319

          21          KK    PRE2
          22          KM   WEST PRE-DEVELOPED CONDITIONS
          23          KO       5       0       0       0      21
          24          BA   .0028
          25          LS       0    69.9       0
          26          UD   0.319

          27          KK   COMB1
          28          KO       5       0       0       0      21
          29          HC       2

          30          KK   POST1
          31          KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          32          KM   ADJUSTED CURVE NUMBER
          33          KO       3       0       0       0      21
          34          BA   .0046
          35          LS       0    97.7       0
          36          UD   0.050
          37          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   10APR08  TIME  10:16:46    *                                                       *           (916) 756-1104            *
 *                                       *                                                       *                                     *
 *****************************************                                                       ***************************************


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


                          HYDROGRAPH AT STATION    POST1

     TOTAL RAINFALL =    1.00, TOTAL LOSS =     .24, TOTAL EXCESS =     .76

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.    5.00          0.          0.          0.        .00

          HYDROGRAPH AT
+                            PRE2        0.    4.95          0.          0.          0.        .00

          2 COMBINED AT
+                           COMB1        0.    5.15          0.          0.          0.        .00

          HYDROGRAPH AT
+                           POST1        5.    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 0.79 inches which is within an acceptable range (0.03 inches deviation from 0.76 inches) of the Schueler method runoff volume results using Equation 3-2.

Step 6 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
  = 1000/93.0 – 10
  = 0.75 inches

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

$Q_d = (P-0.2S)^2/(P+0.8S)$
$= [2.58 – (0.2)(0.75)]^2/[2.58 + (0.8)(0.75)]$
$= 1.86$ inches

Compute watershed runoff

CS_v = (1.86 inches)(2.93 acres)(1 foot/12 inches) = 0.45 acre-feet

- **<u>Estimate Approximate Storage Volume</u>**

The designer has elected to direct all storm events into the sand filter facility. The maximum ponding depth for the 1-inch, 6-hour storm event must be less than 24 inches. The maximum ponding depth for the 1-year, 24-hour and 10-year, 6-hour storm event must be less than 5 feet. In order to achieve the pollutant removal goals of the Post Construction Ordinance, the sand filter must hold the Water Quality Volume for a minimum of 2.0 days above and within the filter media. The design requirements include a filter media thickness of 2.5 feet and an underdrain system thickness of 1.0 feet.

The Channel Protection Volume is required to be held within the sand filter for a minimum of 24 hours beyond the center of the design storm event rainfall. The center of rainfall is at hour twelve, therefore, the time of interest for assessing the Channel Protection Volume is hour thirty-six (24 hours plus 12 hours). The “Static Method” can be used as an initial estimate which sets 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 sand filter facility, the outlet structure for the Water Quality Volume is based on the filter media. The outlet structure for the Channel Protection Volume may be based on a combination of the filter media and an overflow weir and/or orifice structure.

Using the Static Method that sets the storage volume equal to the runoff volume, the sand filter facility requires 0.19 acre-ft storage to hold the Water Quality Volume. The sand filter facility requires 0.45 acre feet storage to hold the total Channel Protection Volume. 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 7 Size Flow Diversion Structure</u>

This design example does not include a flow diversion structure (refer to Section 4.8.9 for example of flow diversion structure design.

<u>Step 8 Compute Release Rates for Water Quality Control and Channel Protection Volume</u>

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

- Compute the release rate for water quality control.

The water quality control volume (WQ_v) is to be released over a 2.0 day period beyond the center of rainfall (48 hours plus 3 hours).

Release rate = (0.19 ac-ft x 43560 ft^2/acre)/(51.0 hrs x 3,600 sec/hr) = 0.045 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 rainfall (24 hours plus 12 hours).

  Release rate = (0.45 ac-ft x 43560 ft^2/acre)/(36 hrs x 3,600 sec/hr) = 0.151 cfs

Step 9 Compute Sedimentation Chamber Volume

The sedimentation chamber storage area above the filter media must be sized to hold 20 percent of the water quality volume in order to remove trash and large sediment particles.

Sediment $Chamber_{vol}$ = (0.19 acre-feet)(43,560sq ft/acre)(0.20) = 1,655 ft^3

For the underground configuration, a six foot depth is effective in providing storage volume for the sedimentation chamber (five feet of headwater storage above the top of sand filter plus one foot below the top of sand filter for sediment and trash storage). A sedimentation chamber 331 ft^2 (1,655 ft^3/5 feet) in area will meet the requirements for pre-treatment. Later routing computations indicate that additional storage is necessary to control the 1-year, 24-hour storm event, so the sedimentation chamber size is increased.

Step 10 Compute Sand Filter Area to Treat Water Quality Volume

Size the sand filter ponding/filter area based on Darcy's equation. Assume that all of the filter media capacity is effective and that no surface area is ineffective due to clogging. A design value of 1.75 inch/hour (3.5 foot/day) for the coefficient of permeability of the filter media is required. The detention time is 2 days beyond the center of rainfall for the 6-hour storm (48 hours plus 3 hours is 51 hours).

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

where:

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

$$Af = \frac{(0.19 \text{ acre-ft})(43560 \text{ sf/ac})(2.5 \text{ ft}))}{(3.5 \text{ ft/day})(0.5\text{ft}+2.5\text{ft})(2.125 \text{ days})}$$
$$= 927.3 \text{ sq ft}$$

Use 30 foot by 30 foot sand filter

Step 11a Develop Sand Filter Storage-Elevation Table

Figure 4.8.6 shows the sand filter location on site, Figure 4.8.7 shows cross-sections and the plan view of the sand filter and Table 4.8.4 shows the storage-elevation data that was developed for this example. Note that the storage volumes presented result from an iterative process of routing three design storm events through the facility; the 1-inch, 6-hour, 1-year, 24-hour, and 10-year, 6-hour storm events. The 50-year storm event is routed through the facility to ensure that the facility and surrounding buildings area not impacted. Also, note that storage volume below the top of the sand filter in the sedimentation chamber is ignored in the routing computations. Runoff does not leave that storage volume with a positive outflow.

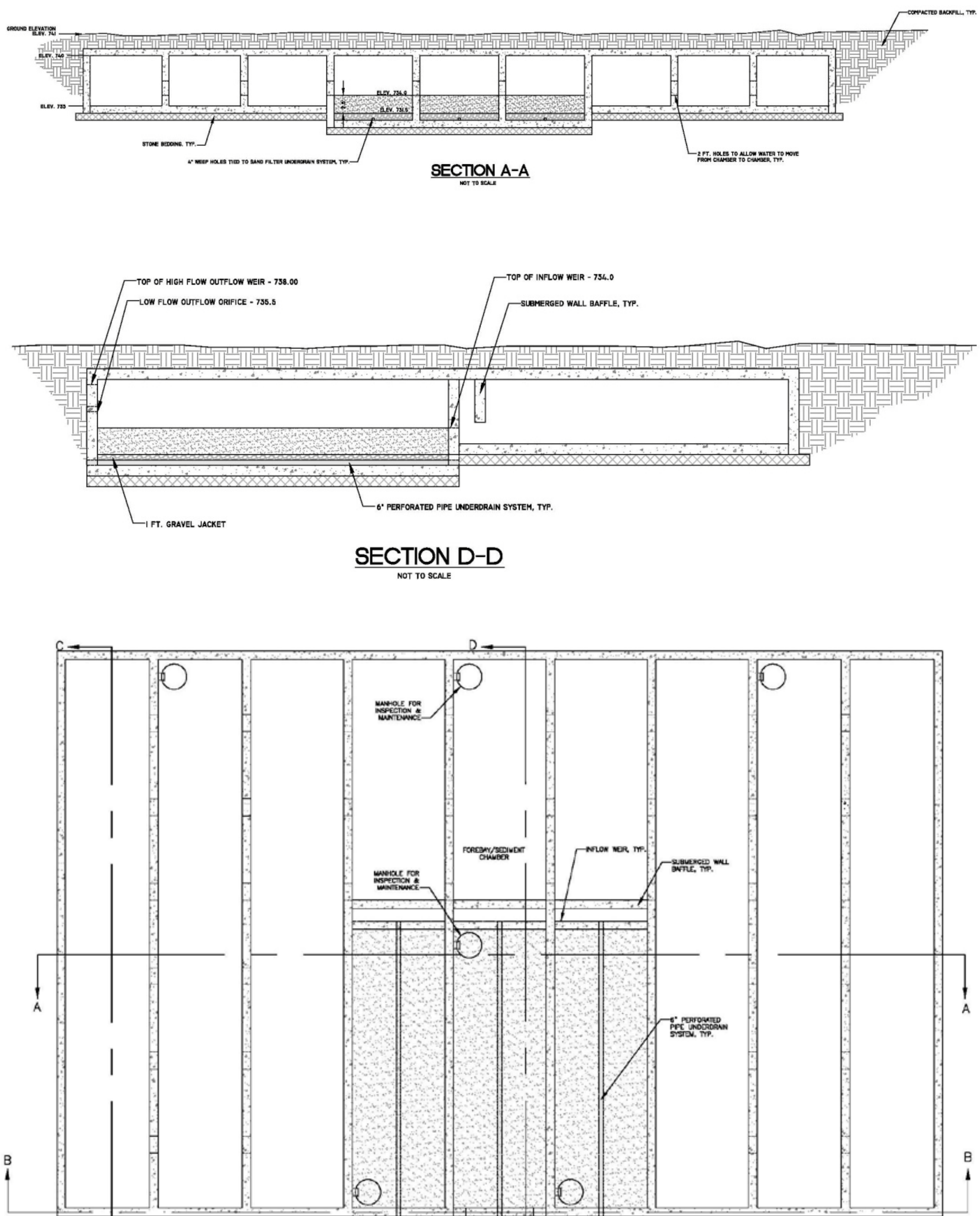

Figure 4.8.7 Plan View of Sand Filter

Table 4.8.4 Sand Filter Storage-Elevation Data

Elevation	Area (sf)	Area (ac)	Avg. Area (ac)	Height (ft)	Inc vol (ac-ft)	Acc vol (ac-ft)
734	5,826	0.134				0.000
735	5,826	0.134	0.134	1.0	0.134	0.134
736	5,826	0.134	0.134	1.0	0.134	0.268
737	5,826	0.134	0.134	1.0	0.134	0.402
738	5,826	0.134	0.134	1.0	0.134	0.536
739	5,826	0.134	0.134	1.0	0.134	0.670

Step 11b Develop Stage-Discharge for Sand 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 below the top of the filter media is ignored and assumed to be zero when the depth of flow is equal to the top of media. The percentage of the filter media that is assumed to be clogged during the surface area computation procedure (0 percent) should be considered when computing the outflow conditions.

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

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

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 739, five feet above the top of filter media

Q_o = $(900ft^2)[(3.5ft/day)(5ft+2.5ft)]/(2.5\ ft)$
= 9,450 cf/day
= 0.109 cfs

At elevation 738, four feet above the top of filter media

Q_o = $(900ft^2)[(3.5ft/day)(4ft+2.5ft)]/(2.5\ ft)$
= 8,190 cf/day
= 0.095 cfs

At elevation 737, three feet above the top of filter media

Q_o = $(900ft^2)[(3.5ft/day)(3ft+2.5ft)]/(2.5\ ft)$
= 6,930 cf/day
= 0.080 cfs

At elevation 736, two feet above the top of filter media

Q_o = $(900ft^2)[(3.5ft/day)(2ft+2.5ft)]/(2.5\ ft)$
= 5,670 cf/day
= 0.066 cfs

At elevation 735, one foot above the top of filter media

Q_o = $(900ft^2)[(3.5ft/day)(1ft+2.5ft)]/(2.5\ ft)$
= 4,410 cf/day
= 0.051 cfs

At elevation 734, top of filter media
Qo = 0.00 cfs

Step 12a Route Runoff Hydrographs through Sand Filter

Route all of the appropriate runoff hydrographs through the sand filter facility with the following goals:

- 1-inch, 6-hour storm event through the filter media with less than 24 inches of ponding depth.
- 1-year, 24-hour; 10-year, 6-hour, and 50-year, 6-hour storm event through the filter media and over flow structure with maximum 5 feet of ponding depth.
- Hold 5 percent of the 1-year, 24-hour storm event within the sand filter storage volume 24 hours after the center of rainfall (48 hours within the City of Charlotte and its ETJ).
- Attenuate the 10-year, 6-hour storm events to pre-development levels. Note that a portion of the site is being diverted, therefore the pre-developed target discharge is based on only the amount of watershed that was flowing in that direction in pre-developed conditions, and additional attenuation and detention storage are required.

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 by 735.29 with the entire 1-inch storm event flowing through the filter media. The peak flow is attenuated from 4.61 cfs to 0.06 cfs. More than five percent (12.8%) of the 1-inch, 6-hour storm event is shown to remain within the sand filter storage volume at 51 hours (2 days after the center of rainfall). An outlet orifice to control the 1-year, 24-hour storm event will be placed above the peak water surface elevation of the 1-inch, 6-hour storm event, 735.29 and is discussed in the next design step.

```
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   10APR08  TIME  10:04:14   *                                          *          (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 ABC ENGINEERING
         3        ID       DATE: OCTOBER 2006
                  *  ****************************************************************************
                  *
                  *     TIME SPECIFICATION CARD
                  *     TIME DURATION OF 51 HOURS
         4        IT       3       0       0    1020
                  *  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   EAST PRE-DEVELOPED CONDITIONS
          17            KO      5       0       0       0      21
          18            BA   .0018
          19            LS      0    69.9       0
          20            UD   0.319

          21            KK    PRE2
          22            KM   WEST PRE-DEVELOPED CONDITIONS
          23            KO      5       0       0       0      21
          24            BA   .0028
          25            LS      0    69.9       0
          26            UD   0.319

          27            KK   COMB1
          28            KO      5       0       0       0      21
          29            HC      2

          30            KK   POST1
          31            KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          32            KM   ADJUSTED CURVE NUMBER
          33            KO      3       0       0       0      21
          34            BA   .0046
          35            LS      0    97.7       0
          36            UD   0.050
1                                                    HEC-1 INPUT                                             PAGE  2

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


          37            KK   WQRTE
          38            KO      3       0       0       0      21
          39            KM   ROUTE HYDROGRAPH THROUGH THE SAND FILTER CHAMBER
          40            KM   TWO ELEVATIONS - 734 FOR SEDIMENTATION CHAMBER, 730.5 FOR BOTTOM OF SAND FILT
          41            KM   THEREFORE GETTING ALL OF SEDIMENTATION CHAMBER EFFECTIVE FOR ATTENUATION
          42            KM   WITH THE EXCEPTION OF 1 FOOT FOR SEDIMENT STORAGE
          43            RS      1    ELEV     734
          44            SV      0    .134    .167    .201    .268    .401    .535    .669
          45            SE    734     735  735.25   735.5     736     737     738     739
          46            SQ      0    .044    .051    .055    .058    .066    .080    .095
          47            SE    734   734.5     735  735.25   735.5     736     737     738
          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   10APR08  TIME  10:04:14   *                                        *          (916) 756-1104             *
 *                                       *                                        *                                     *
 *****************************************                                        ***************************************




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


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

            *************
            *           *
   30 KK    *   POST1   *
            *           *
            *************


                        HYDROGRAPH AT STATION    POST1

     TOTAL RAINFALL =    1.00, TOTAL LOSS =     .24, TOTAL EXCESS =     .76

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.    5.00          0.          0.          0.          .00

          HYDROGRAPH AT
+                            PRE2         0.    4.95          0.          0.          0.          .00

          2 COMBINED AT
+                           COMB1         0.    5.15          0.          0.          0.          .00

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

          ROUTED TO
+                           WQRTE         0.    5.80          0.          0.          0.          .00
+                                                                                                          735.29       6.15


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

The following HEC-1 file provides the results of an iterative process to control the 1-year, 24-hour storm event routing. The iterative process included increasing the storage volume above the sand filter and decreasing the outlet orifice until more than 5 percent of the 1-year, 24-hour storm event runoff is held within the sand filter after 36 hours (24 hours past the center of the rainfall – 12 hours). The iterative process requires the designer to export the hydrograph to a spreadsheet and compute the hydrograph volume before and after the time of interest or setting the total HEC-1 model time to the time of interest and comparing the routed hydrograph volume with the total runoff hydrograph volume.

```
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   10APR08  TIME  10:46:38   *                                                          *           (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.
          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
                      *     TOTAL MODEL DURATION - 36 HOURS
          4           IT       1       0       0    2160
                      *  DIAGRAM
                      *     TIME INTERVAL CARD
                      *     NOTE INPUT INTERVAL SET TO 6 MINUTES FOR 1-YEAR STORM DISTRIBUTION
          5           IN       6       0       0
                      *
                      *     OUTPUT CONTROL CARD
          6           IO       5       0       0
                      *

          7           KK    PRE1
          8           PB    2.58
                      * ****************************************************************************
                      * **************** 1-YEAR, 24-HOUR STORM EVENT *******************************
                      * ********* 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   EAST PRE-DEVELOPED CONDITIONS
         35           KO       5       0       0       0      21
         36           BA   .0018
         37           LS       0    69.9       0
         38           UD   0.319
1                                        HEC-1 INPUT                                                   PAGE  2

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


         39           KK    PRE2
         40           KM   WEST PRE-DEVELOPED CONDITIONS
         41           KO       5       0       0       0      21
```

```
          42           BA   .0028
          43           LS       0    69.9       0
          44           UD   0.319

          45           KK   COMB1
          46           KO       5       0       0       0      21
          47           HC       2

          48           KK   POST
          49           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          50           KO       3       0       0       0      21
          51           BA   .0046
          52           LS       0    92.6       0
          53           UD   0.050

          54           KK   WQRTE
          55           KO       5       0       0       0      21
          56           KM   ROUTE HYDROGRAPH THROUGH THE SAND FILTER CHAMBER
          57           KM   TWO ELEVATIONS - 734 FOR SEDIMENTATION CHAMBER, 730.5 FOR BOTTOM OF SAND FILT
          58           KM   THEREFORE GETTING ALL OF SEDIMENTATION CHAMBER EFFECTIVE FOR ATTENUATION
          59           KM   WITH THE EXCEPTION OF 1 FOOT FOR SEDIMENT STORAGE
          60           KM   5-INCH ORIFICE AT 735.5, 8 FOOT WEIR AT 738
          61           RS       1    ELEV     734
          62           SV       0    .134    .167    .201    .268    .401    .535    .669
          63           SE     734     735  735.25   735.5     736     737     738     739
          64           SQ       0    .044    .051    .055    .058    .420    .826   1.088  37.300
          65           SE     734   734.5     735  735.25   735.5     736     737     738     739
          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   10APR08  TIME  10:46:38  *                                                   *           (916) 756-1104           *
 *                                      *                                                   *                                    *
 ****************************************                                                   **************************************


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


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


             **************
             *            *
   48 KK     *    POST    *
             *            *
             **************

   50 KO          OUTPUT CONTROL VARIABLES

   52 LS          SCS LOSS RATE
                        STRTL          .16  INITIAL ABSTRACTION
                       CRVNBR        92.60  CURVE NUMBER
                        RTIMP          .00  PERCENT IMPERVIOUS AREA

                       HYDROGRAPH AT STATION     POST

     TOTAL RAINFALL =     2.58, TOTAL LOSS =      .76, TOTAL EXCESS =     1.82

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.    12.35          0.          0.          0.        .00

          HYDROGRAPH AT
+                             PRE2          1.    12.35          0.          0.          0.        .00

          2 COMBINED AT
+                            COMB1          1.    12.35          0.          0.          0.        .00

          HYDROGRAPH AT
+                             POST          8.    12.02          1.          0.          0.        .00

          ROUTED TO
+                            WQRTE          0.    13.02          0.          0.          0.        .00
+                                                                                                        736.04      13.15


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

First, note that the runoff volume is computed to be 1.82 inches which is the same runoff volume computed using the standard SCS formulas presented in step 4 of this example. Second, note that the more than 5 percent of the runoff volume is held within the BMP storage volume at 36 hours. A spreadsheet summary indicates that the total runoff volume held within the BMP is 36.6 percent. The peak water surface elevation in the BMP is 736.04. The additional amount held is due to the additional storage volume that is needed to provide peak flow attenuation that is determined in Step 12b.

Step 12b Calculate Q_{10} Release Rate and Water Surface Elevation(s)

The next step of the design process is to design the sand filter to be used to achieve the peak attenuation goals for the 10-year, 6-hour storm event. This process is similar to previous examples in that the design is iterative. A stage-storage-discharge relations is developed assuming an outflow orifice and/or weir and storage area. The storm event is routed through the storage volume, and the outflow peak discharge is compared to the pre-development peak discharge for the 10-year, 6-hour storm event; 1.3 cfs. In addition, the peak stage for the 10-year, 6-hour storm events must be less than 5 feet above the top of the filter media.

The following HEC-1 output files illustrate the results of the iterative process for the 10-year storm event. A 5-inch orifice and an 8-foot weir that are installed at elevations 735.5 and 738.0, respectively attenuate the post-developed discharge to the appropriate value for the 10-year, 6-hour storm event. 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 737.98 which is less than the pre-developed target release rate of 1.36 cfs. Note that the peak stage is 3.98 feet above the top of the sand filter media. The 3.98 feet ponding depth is less than the allowable 5 feet depth. Intermediate steps are not presented.

```
1*****************************************                                          ***************************************
 *                                       *                                          *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                          *  U.S. ARMY CORPS OF ENGINEERS       *
 *             JUN   1998                *                                          *  HYDROLOGIC ENGINEERING CENTER      *
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 *                                       *                                          *     DAVIS, CALIFORNIA 95616         *
 *  RUN DATE   10APR08  TIME  10:57:28   *                                          *         (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
               *     COMPUTATION DURATION SET TO 6 HOURS
   4           IT       1       0       0     360
               *  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   EAST PRE-DEVELOPED CONDITIONS
  17           KO       5       0       0       0      21
  18           BA   .0018
  19           LS       0    69.9       0
  20           UD   0.319

  21           KK    PRE2
  22           KM   WEST PRE-DEVELOPED CONDITIONS
  23           KO       5       0       0       0      21
```

```
          24            BA   .0028
          25            LS       0    69.9       0
          26            UD   0.319

          27            KK   COMB1
          28            KO       5       0       0       0      21
          29            HC       2

          30            KK   POST
          31            KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          32            KO       3       0       0       0      21
          33            BA   .0046
          34            LS       0    92.6       0
          35            UD   0.050
1                                                  HEC-1 INPUT                                              PAGE  2

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


          36            KK   WQRTE
          37            KO       5       0       0       0      21
          38            KM    ROUTE HYDROGRAPH THROUGH THE SAND FILTER CHAMBER
          39            KM   TWO ELEVATIONS - 734 FOR SEDIMENTATION CHAMBER, 730.5 FOR BOTTOM OF SAND FILT
          40            KM   THEREFORE GETTING ALL OF SEDIMENTATION CHAMBER EFFECTIVE FOR ATTENUATION
          41            KM   WITH THE EXCEPTION OF 1 FOOT FOR SEDIMENT STORAGE
          42            KM   5-INCH ORIFICE AT 735.5, 8 FOOT WEIR AT 738
          43            RS       1    ELEV     734
          44            SV       0    .134    .167    .201    .268    .401    .535    .669
          45            SE     734     735  735.25   735.5     736     737     738     739
          46            SQ       0    .044    .051    .055    .058    .420    .826   1.088  37.300
          47            SE     734   734.5     735  735.25   735.5     736     737     738     739
          48            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: 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.    3.52             0.           0.           0.        .00

          HYDROGRAPH AT
+                             PRE2          2.    3.52             0.           0.           0.        .00

          2 COMBINED AT
+                            COMB1          3.    3.52             1.           1.           1.        .00

          HYDROGRAPH AT
+                             POST         17.    3.18             1.           1.           1.        .00

          ROUTED TO
+                            WQRTE          1.    4.15             0.           0.           0.        .00
+                                                                                                               737.98        4.17


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

Step 13 Design Inlets and Underdrain System

Inlet 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.

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 design duration (2.125 days for this example). 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 spaced 3 inches on center, along 4 longitudinal rows 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 sand filter BMP (927 ft^2) the approximate dimensions of the sand filter area is selected to be 30 feet wide by 30 feet in length (approximately 927 ft^2).

The design process uses a trial and error process. 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 51 hours.

Compute minimum drawdown discharge

Water quality volume	=	(0.19 ac-ft)(43,560ft^3/ac ft)	= 8,276 ft^3
Drawdown	=	8,276 ft^3/[(51 hours)(3,600sec/hour)]	
	=	0.045 cfs	

Compute perforation capacity

Since the maximum underdrain spacing is 10 feet on center and the sand filter area is 30 feet wide by 30 feet in length, three parallel underdrain pipes (6-inch diameter PVC) 30 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 fittings.

Number of perforations	=	(3 pipes)(4 rows/ft)(30 – 2) ft/pipe)(4 holes/row)	= 1,344 holes
50 percent of perforations	=	672 holes	
Capacity of one hole	=	$CA(2gh)^{0.5}$	
	=	$(0.6)(3.1416)[(3/8in)(1/24)]^2[(64.4)(5.0ft)]^{0.5}$	
	=	0.0083 cfs	
Total capacity	=	(0.0083 cfs)(672)	= 5.58 cfs

The perforations capacity (5.58 cfs) is greater than the filter media capacity (0.051 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.045 cfs computed in this step). Therefore the design is acceptable.

Note that the headwater depth used to determine the filter media capacity is 1.0 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, 1 feet above the filter media, or 5.0 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
Fifty percent assuming clogging	=	0.20 cfs

The underdrain pipe capacity (0.20 cfs) is greater than the filter media capacity (0.051 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.045 cfs computed in this step). Therefore the design is acceptable.

Step 14 Design Overflow Weir

The final step is to route the 50-year, 6-hour storm event through the sand filter facility to ensure that a minimum of 6-inches of freeboard is provided and that a maximum of 5 feet of depth is over the sand filter media. An eight (8) foot weir at 738.0 is proposed as the emergency overflow. The peak stage is 738.25 which is 4.25 feet above the filter media (less than 5 feet) and therefore meets design standards. 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   10APR08  TIME  11:10:20   *                                                 *         (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
                       *     MODEL DURATION 6 HOURS
           4           IT       1       0       0     360
                       *  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   EAST PRE-DEVELOPED CONDITIONS
          17           KO       5       0       0       0      21
          18           BA   .0018
          19           LS       0    70.0       0
          20           UD   0.319

          21           KK    PRE2
          22           KM   WEST PRE-DEVELOPED CONDITIONS
          23           KO       5       0       0       0      21
          24           BA   .0028
          25           LS       0    70.0       0
          26           UD   0.319

          27           KK   COMB1
          28           KO       5       0       0       0      21
          29           HC       2

          30           KK   POST
          31           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          32           KO       3       0       0       0      21
          33           BA   .0046
          34           LS       0    93.0       0
          35           UD   0.050
1                                         HEC-1 INPUT                                                  PAGE  2

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


          36           KK   WQRTE
          37           KO       5       0       0       0      21
          38           KM    ROUTE HYDROGRAPH THROUGH THE SAND FILTER CHAMBER
          39           KM   TWO ELEVATIONS - 734 FOR SEDIMENTATION CHAMBER, 730.5 FOR BOTTOM OF SAND FILT
          40           KM   THEREFORE GETTING ALL OF SEDIMENTATION CHAMBER EFFECTIVE FOR ATTENUATION
          41           KM   WITH THE EXCEPTION OF 1 FOOT FOR SEDIMENT STORAGE
          42           KM   5-INCH ORIFICE AT 735.5, 8 FOOT WEIR AT 738
          43           RS       1    ELEV     734
          44           SV       0    .134    .167    .201    .268    .401    .535    .669
          45           SE     734     735  735.25   735.5     736     737     738     739
          46           SQ       0    .044    .051    .055    .058    .420    .826   1.088  37.300
          47           SE     734   734.5     735  735.25   735.5     736     737     738     739
          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   10APR08  TIME  11:10:20   *                                                              *          (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.     3.50          0.          0.          0.          .00

          HYDROGRAPH AT
+                           PRE2            4.     3.50          1.          1.          1.          .00

          2 COMBINED AT
+                          COMB1            6.     3.50          1.          1.          1.          .00

          HYDROGRAPH AT
+                           POST           23.     3.18          2.          2.          2.          .00

          ROUTED TO
+                          WQRTE           10.     3.32          1.          1.          1.          .00
+                                                                                                            738.25        3.32


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

Table 4.8.5 Summary of Controls Provided

Control Element	Type/Size of Control	Stor. (ac-ft)	Peak Elev. (MSL)	Disc. (cfs)	Remarks
Water Quality Extended Detention (WQ_{v-ed})	Sand filter media at 734.0	0.176	735.29	0.05	Entire 1-inch, 6-hour storm event is routed through sand filter media
Channel Protection (CP_v)	Sand filter media at 734.0 and 5-inch orifice at 735.5	0.281	736.04	0.43	Portion of the 1-year, 24-hour storm event is routed through the sand filter and a portion is routed through the 5-inch orifice outlet
Flood Protection (Q_{10})	Sand filter media at 734.0 and 5-inch orifice at 735.5	0.542	737.98	1.08	Same orifice control was designed for the 1-year, 24-hour and the 10-year, 6-hour storm events
Emergency Overflow (Q_{50})	Sand filter media at 734.0, 5-inch orifice at 735.5, and 8-foot weir at 738.0	0.717	738.25	10.16	Less than 5 feet of headwater depth on sand filter media.

Step 15 Assess Maintenance Access and Safety Features

The filter media and sedimentation chamber must be accessible from the surface in order to provide regular maintenance without significant access challenges. All areas of both chambers must be within 25 feet of an access location from the surface that is large enough for personnel to enter in order to remove trash, debris, sediment, etc. In addition, the sand filter media must be accessible in order to facilitate complete replacement when the sand filter ponds runoff without filtration.

4.8.9 Sand Filter Design Example #2

The following design example presents a different design approach for the same site presented in Section 4.8.8. Instead of implementing a stand-alone sand filter facility, the different design approach implements a combination of a sand filter facility and above ground extended dry detention basin designed to control the 1-inch, 6-hour for water quality purposes, 1-year, 24-hour for channel protection purposes, and 10-year 6-hour for flood control purposes following the design procedures given in section 4.8. The 1-inch, 6-hour storm event and portions of the 1-year, 24-hour and 10-year, 6-hour storm events are diverted to the sand filter. The additional flow that is not directed to the sand filter of the 1-year, 24-hour and 10-year, 6-hour storm events is diverted to an above-ground extended dry detention basin. 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.

The combination of these two BMP's do not meet the goals of the post-construction ordinance; 85% TSS and 70% TP removal, so they are being presented for illustrative purposes only. For an actual site design case, additional BMPs within the treatment train would be added so that the post-construction goals are met. A grassed swale combined with a bioretention facility would supplement the two BMP presented in the example to meet the post-construction ordinance goals. Methods to compute the pollutant removal of BMPs in series are presented in Section 4.0. Figure 4.8.9 shows the site plan for the development and base hydrologic data that will be used in the design example.

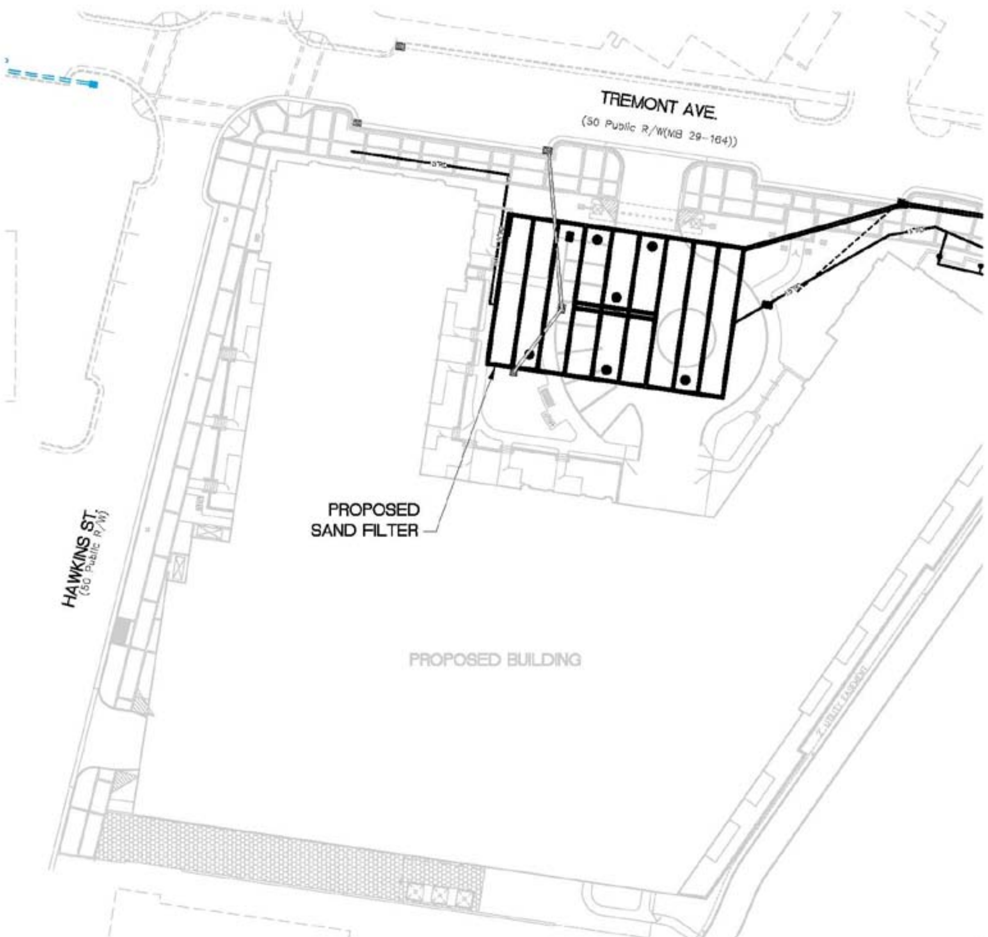

Figure 4.8.9 Example Site Plan for Sand Filter Design

The following steps illustrate how to use the design procedures given in section 4.8 to design a sand filter facility that is acceptable for the design criteria given in this manual.

Step 1 BMP Feasibility

For the purposes of this design example, assume that a sand filter design 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 Water Quality Volume (WQ_v)

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

  $R_v = 0.05 + 0.009(I) = 0.05 + (79.2)(0.009) = 0.76$

- Compute Water Quality Volume, WQ_v, using Equation 3.2

  $WQ_v = 1.0R_vA/12 = (1.0 \text{ inches})(0.76)(2.93 \text{ acre})(1\text{foot}/12 \text{ inches}) = 0.19$ ac-ft

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

  $WQ_v = 1.0(R_v) = 1.0(0.76) = 0.76$ inches

Step 4 Compute Site Hydrologic Input Parameters

The site contains 2.93 acres and is proposed to be re-developed to 79.2 percent imperviousness. Using SCS hydrologic procedures, the following data can be determined for the example development site. For pre-developed conditions, an assumption that the site was 50% forest in good hydrologic condition and 50% pasture in good hydrologic condition is required. The site consists of 15% hydrologic type B soils and 85% hydrologic type C soils. The pre-developed topography drains in two directions and includes two sub-basins. The post-developed topography drains in one direction.

The pre-developed weighted curve number is:

$CN_{weighted} = (0.5)(0.15)(61) + (0.5)(0.85)(74) + (0.5)(0.15)(55) + (0.5)(0.85)(70)$
$= 69.9$
Use 70

The post-developed weighted curve number is (based on 79 percent impervious from site plan):
$CN_{weighted} = (0.21)(0.15)(61) + (0.21)(0.85)(74) + (0.79)(98)$
$= 92.6$
Use 93

The modified post-developed curve number for application with the 1-inch, 6-hour storm event, using Equation 3.4 is:

$CN_{weighted} = 1000/[10 + 5P + 10WQ_v – 10(WQ_v^2 + 1.25\, WQ_vP)^{0.5}]$
$CN_{weighted} = 1000/[10 + 5(1.0) + 10(0.76) – 10\{(0.76^2 + (1.25)(0.76)(1.0)\}^{0.5}]$
$= 97.7$
Use 98

Table 4.8.6 Hydrologic Input Data

Condition	Area (acres)	CN	CN (adjusted) for 1-inch storm	t_c (hours)[1]
Pre-developed (WS1)	1.1	70	N/A	0.532
Pre-developed (WS2)	1.8	70	N/A	0.532
Post-developed	2.9	93	98	0.083

[1]Based on methods described in the Charlotte-Mecklenburg Storm Water Design Manual

Table 4.8.7 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 (WS1)	0.00	0.38	1.36	1.92	2.39
Pre-developed (WS2)	0.00	0.59	2.12	2.99	3.71
Post-developed	5.38	8.20	17.50	20.70	23.25

Step 5 Compute Water Quality Peak Flow (WQ_p)

- 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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 *              JUN   1998              *                              *   HYDROLOGIC ENGINEERING CENTER    *
 *           VERSION 4.1                *                              *        609 SECOND STREET           *
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 *  RUN DATE   10APR08  TIME  10:16:46  *                              *          (916) 756-1104            *
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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
           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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                        *     TIME DURATION OF 51 HOURS
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                        *     TIME INTERVAL CARD
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                        *
                        *     OUTPUT CONTROL CARD
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                        *

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                        * **************** 1-INCH, 6 HOUR STORM EVENT *********************************
                        * **************************************************************************
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          PI    .004    .004    .004    .004    .004    .004    .004    .004    .003    .003
          PI    .003    .003    .003    .000
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          BA   .0018
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          UD   0.319

          KK    PRE2
          KM    WEST PRE-DEVELOPED CONDITIONS
          KO       5       0       0       0      21
          BA   .0028
          LS       0    69.9       0
          UD   0.319

          KK   COMB1
          KO       5       0       0       0      21
          HC       2

          KK   POST1
          KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          KM   ADJUSTED CURVE NUMBER
          KO       3       0       0       0      21
          BA   .0046
          LS       0    97.7       0
          UD   0.050
          ZZ

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 *  RUN DATE    10APR08  TIME  10:16:46  *                        *          (916) 756-1104             *
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                            CHARLOTTE-MECKLENBURG POST CONSTRUCTION DESIGN MANUAL
                            ANALYZED ABC ENGINEERING
                            DATE: OCTOBER 2006

                       HYDROGRAPH AT STATION    POST1

     TOTAL RAINFALL =    1.00, TOTAL LOSS =     .24, TOTAL EXCESS =     .76

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.    5.00            0.           0.           0.         .00

          HYDROGRAPH AT
+                           PRE2         0.    4.95            0.           0.           0.         .00

          2 COMBINED AT
+                          COMB1         0.    5.15            0.           0.           0.         .00

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


 *** NORMAL END OF HEC-1 ***
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Note that the previous HEC-1 model output using the SCS method indicates that the runoff volume is 0.76 inches which agrees with the Schueler method runoff volume results using Equation 3-2.

Step 6 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
  = 1000/93.0 – 10
  = 0.75 inches

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

$Q_d = (P-0.2S)^2/(P+0.8S)$
$= (2.58 - 0.2*0.75)^2/(2.58 + 0.8*0.75)$
$= 1.86$ inches

Compute watershed runoff

CP_v = (1.86 inches)(2.93 acres)(1 foot/12 inches) = 0.45 acre-feet

- **Estimate Approximate Storage Volume**

  The designer has elected to direct the entire Water Quality Volume (WQ_v) into the sand filter. A portion of the channel protection volume (CP_v) and the flood control event; 1-year, 24-hour and 10-year, 6-hour storm events; respectively, will be diverted into the sand filter. The remainder of the channel protection volume and flood control event will be diverted to a downstream extended dry detention basin. For the sand filter, the maximum ponding depth for the 1-inch, 6-hour storm event must be less than 24 inches. For the sand filter, the maximum ponding depth for the 1-year, 24-hour and 10-year, 6-hour storm event must be less than 5 feet. In order to limit the cost of constructing an underground chamber for the sand filter, the standard efficiency sand filter design is selected. The standard efficiency sand filter design requires the Water Quality Volume (WQ_v) to be held for a minimum of 1.0 day above and within the filter media beyond the center of the rainfall design storm event (24 hours plus 3 hours = 27 hours). The design requirements include a filter media thickness of 2.0 feet and an underdrain system thickness of 1.0 feet.

  The Channel Protection Volume (CP_v) is required to be held within the combination of the sand filter and extended dry detention for a minimum of 24 hours beyond the center of the design storm event rainfall. The center of rainfall is at hour twelve, therefore, the time of interest for assessing the Channel Protection Volume (CP_v) is hour thirty-six (24 hours plus 12 hours). The "Static Method" can be used as an initial estimate which sets 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 sand filter facility, 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/or orifice structure.

  Using the Static Method, the sand filter facility requires 0.19 acre-feet to hold the Water Quality Volume (WQ_v). The extended dry detention facility requires approximately 0.26 acre-feet (0.45 – 0.19; Channel Protection Volume (CP_v) less the Water Quality Volume diverted to the sand filter) to meet the goals of controlling 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.

Step 7 Compute Diversion Structure Geometry

All flows less than the peak flow computed for the 1-inch, 6-hour storm event are desired to be diverted into the sand filter facility. Storm events most intense or larger than the 1-inch, 6-hour storm event are desired to be directed away from the sand filter area into the downstream extended dry detention basin. For the development site, the watershed is almost entirely impervious and is drained by closed pipe systems. Therefore, the diversion facility will intercept the contributing watershed in a pipe system structure and divert the low flows into the sand filter through a low flow orifice. A weir wall which overtops for more intense or larger storm events based on the low flow orifice headwater depth directs the additional discharge to the downstream extended dry detention facility. Figure 4.8.10 illustrates the diversion structure geometry.

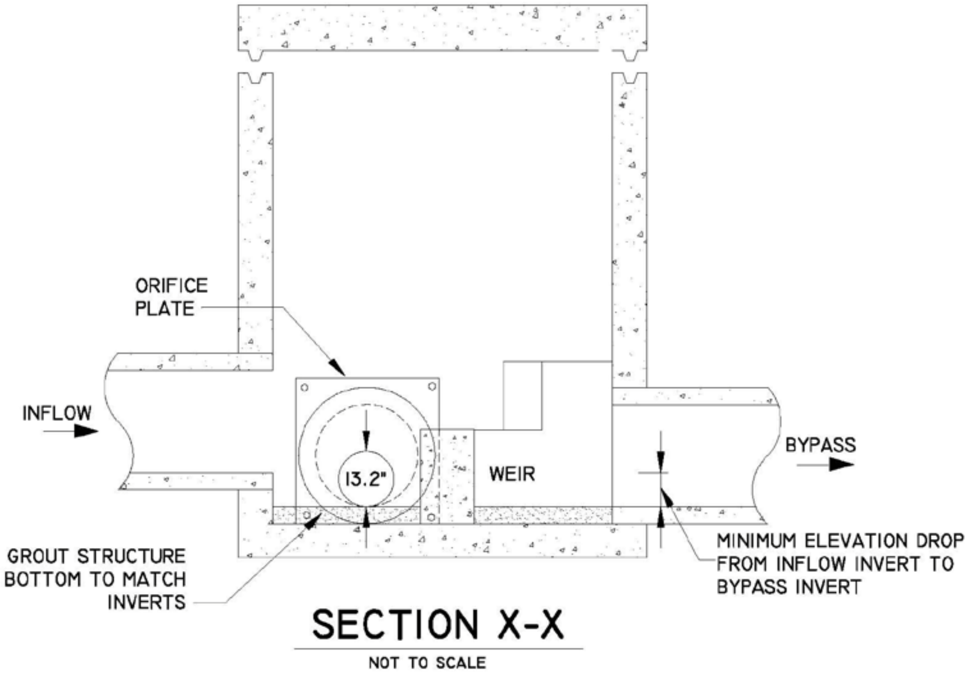

Figure 4.8.10 Diversion Structure Geometry

Based on an assumed weir height of 2 foot and a length of 4 feet, a low flow orifice is sized to direct the peak discharge for the 1-inch, 6-hour storm event with a headwater less than the weir height to the sand filter. Flow that overtops the weir will not enter the sand filter and flow directly to the downstream extended dry detention basin.

- Use orifice equation to compute cross-sectional area and diameter of orifice to divert flow to sand filter.
    - $Q = CA(2gh)^{0.5}$, for Q = 5.38 cfs, h = 2.0 ft – ½ diameter of orifice, and C = discharge coefficient = 0.6
    - Try 13.2 inch orifice
    - Solve for A: $A = 5.38 \text{ cfs} / [0.6((2)(32.2 \text{ ft/s}^2)(2.0-(13.2/24)))^{0.5}] = 0.93 \text{ ft}^2$
    - With $A = \pi d^2/4$, d = 1.09 = 13.0 inches, say OK
    - Use 13.2 inch orifice

Develop stage-discharge relations for a 13.2 inch orifice combined with a 2 foot high weir, 4 feet in length. Invert of the 13.2 inch orifice is 735.0 in a manhole structure upstream from the sand filter with top of filter media elevation of 734.0. Table 4.8.8 illustrates the results of hydraulic computations for the diversion structure

Table 4.8.8 Diversion Structure Hydraulic Results

Elevation	Discharge into sand filter (cfs)	Discharge into extended detention (cfs)	Total flow (cfs)
735.00	0.00	0.00	0.00
735.50	1.54	0.00	1.54
736.00	3.07	0.00	3.07
736.50	4.46	0.00	4.46
737.00	5.51	0.00	5.51

737.50	6.39	3.68	10.07
738.00	7.16	10.40	17.56
738.50	7.86	19.11	26.97
739.00	8.50	29.42	37.92
739.50	9.09	41.11	50.20
740.00	9.65	54.04	63.69

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 may be necessary to ensure that all of the 1-inch, 6-hour storm event is being diverted to the sand filter and that an appropriate amount of the 1-year, 24-hour; 10- and 50-year, 6-hour storm events are being bypassed. For this site, the peak rate and runoff volume for the 1-year, 24-hour storm event is similar to the peak rate and runoff volume for the 1-inch, 6-hour storm event. Therefore, the sand filter will treat all of the 1-inch, 6-hour storm event and the majority of the 1-year, 24-hour storm event, and must provide a safe overflow system for a portion of the larger storm events such as the 10- and 50-year, 6 hour storm events. Table 4.8.9 presents the results of the diversion design which were developed from a detailed HEC-1 output and TAPE21 files. The following HEC-1 output file presents the results of the analysis for the 1-year, 24-hour storm event.

Table 4.8.9 Diversion HEC-1 Model Results

Storm Event	Peak discharge (cfs)	Runoff volume (acre-feet)	Peak discharge into sand filter (cfs)	Runoff volume into sand filter (acre-feet)	Bypassed peak discharge (cfs)	Bypassed runoff volume (acre-feet)
1-inch, 6-hour	5.51	0.19	5.51	0.19	0.00	0.00
1-year, 24-hour	8.33	0.45	6.05	0.43	2.28	0.02
10-year, 6-hour	17.66	0.72	7.17	0.58	10.49	0.14
50-year, 6-hour	23.25	1.01	7.58	0.76	15.66	0.25

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 sand filter for the more severe storm events (10- and 50-year, 6-hour), a high percentage of the runoff volume for those storm events is entering the sand filter. The design of the sand filter must account for the impact of these high runoff volumes.

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                    X     X  X        X     X         X
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          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
                       *     NOTE INPUT INTERVAL SET TO 6 MINUTES FOR 1-YEAR STORM DISTRIBUTION
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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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          18           PI   .0032   .0032   .0032   .0032   .0032   .0032   .0033   .0034   .0036   .0038
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          23           PI   .0038   .0037   .0036   .0035   .0034   .0034   .0033   .0033   .0032   .0031
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          26           PI   .0021   .0020   .0020   .0020   .0019   .0020   .0019   .0019   .0018   .0018
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          40           KM   WEST PRE-DEVELOPED CONDITIONS
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          42           BA   .0028
          43           LS      0    70.0       0
          44           UD   0.319

          45           KK   COMB1
          46           KO      5       0       0       0      21
          47           HC      2

          48           KK   POST
          49           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          50           KO      3       0       0       0      21
          51           BA   .0046
          52           LS      0    93.0       0
          53           UD   0.050

          54           KK     DIV
          55           KO      5       0       0       0      21
          56           DT      SF
          57           DI    0.00    1.54    3.07    4.46    5.51   10.07   17.56   26.97   37.92   50.20
          58           DQ    0.00    1.54    3.07    4.46    5.51    6.39    7.16    7.86    8.50    9.09

          59           KK      SF
          60           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO SAND FILTER
          61           KO      5       0       0       0      21
          62           DR      SF
          63           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   22MAR07  TIME  08:58:39   *                                             *          (916) 756-1104             *
 *                                       *                                             *                                     *
 *****************************************                                             ***************************************

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

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


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

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                *             *
   48 KK        *     POST    *
                *             *
                ***************

     TOTAL RAINFALL =    2.58, TOTAL LOSS =     .73, TOTAL EXCESS =    1.85

                                                                              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.     12.35              0.           0.           0.         .00

              HYDROGRAPH AT
+                                  PRE2              1.     12.35              0.           0.           0.         .00

              2 COMBINED AT
+                                 COMB1              1.     12.35              0.           0.           0.         .00

              HYDROGRAPH AT
+                                  POST              8.     12.02              1.           0.           0.         .00

              DIVERSION TO
+                                    SF              6.     12.02              1.           0.           0.         .00

              HYDROGRAPH AT
+                                   DIV              2.     12.02              0.           0.           0.         .00

              HYDROGRAPH AT
+                                    SF              6.     12.02              1.           0.           0.         .00


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

Step 8 Compute Release Rates for Water Quality Control and Channel Protection Volume

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

- Compute the release rate for water quality control.

  The Water Quality Volume (WQ_v) is to be released over a 1.0 day period beyond the center of rainfall (24 hours plus 3 hours).

  Release rate = (0.19 ac-ft x 43560 ft^2/acre)/(27.0 hrs x 3,600 sec/hr) = 0.085 cfs

- Compute the release rate for Channel Protection Volume (CP_v).

  The Channel Protection Volume (CP_v) is to be released over a 24-hour period beyond the center of rainfall (24 hours plus 12 hours).

  Release rate = (0.26 ac-ft x 43560 ft^2/acre)/(36 hrs x 3,600 sec/hr) = 0.087 cfs

Step 9 Compute Sedimentation Chamber Volume

The sedimentation chamber storage area above the filter media must be sized to hold 20 percent of the Water Quality Volume (WQ_v) in order to remove trash and large sediment particles.

Sediment $Chamber_{vol}$ = (0.19 acre-feet)(43,560sq ft/acre)(0.20) = 1,655 ft^3

For the underground configuration, a three foot depth is effective in providing storage volume for the sedimentation chamber (two feet of headwater storage above the top of sand filter plus one foot below the top of sand filter for sediment and trash storage). A sedimentation chamber 828 ft^2 (1,655 ft^3/2 feet) in area will meet the requirements for pre-treatment. Note that in the previous sand filter example shown in Section 4.8.8. the sedimentation chamber was increased in size in order to control the Channel Protection

Volume (CP_v) and provide attenuation for the 10-year, 6-hour storm event. For this example, the combination of the sand filter and above-ground detention will allow the underground sedimentation chamber size to not be increased as much because the 1-year, 24-hour storm event is controlled with the above-ground extended dry detention facility.

Step 10 Compute Sand Filter Area to Treat Water Quality Volume

Size the sand filter ponding/filter area based on Darcy's equation. Assume that all of the filter media capacity is effective and that no surface area is ineffective due to clogging. A value of 1.75 inch/hour (3.5 ft/day) for the coefficient of permeability of the filter media is required. The detention time is one day beyond the center of rainfall for the 6-hour storm (24 hours plus 3 hours is 27 hours)

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

Where:

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

$$Af = \frac{(0.19 \text{ acre-ft})(43560 \text{ sf/ac})(2.0 \text{ ft})}{[(3.5\text{ft/day})(1.0\text{ft}+2.0\text{ft})(1.13 \text{ days})]}$$

$$= 1{,}395.1 \text{ sq ft}$$

Use 38 foot by 38 foot sand filter

Step 11a Develop Sand Filter Storage-Elevation Table

Figure 4.8.9 shows the sand filter and extended dry detention location on site, Figure 4.8.11 shows the plan view of the sand filter, Figure 4.8.12 shows the plan view of the extended dry detention. Table 4.8.10 shows the storage-elevation data for the sand filter. Table 4.8.11 shows the storage-elevation data for the extended dry detention. Note that the storage volumes presented for the sand filter do not result from an iterative process of routing three design storm events through the facility; the 1-inch, 6-hour, 1-year, 24-hour, and 10-year, 6-hour storm events. The sand filter storage volumes presented are direct results of sedimentation chamber size and filter media foot print size computations because the other design requirements; 10-year, 6-hour storm event peak attenuation is provided by diverting to a downstream BMP facility. A portion of the 50-year storm event is routed through the facility to ensure that the facility and surrounding buildings area not impacted. Also, note that storage volume below the top of the sand filter in the sedimentation chamber is ignored in the routing computations. Storm water runoff does not discharge from that storage volume with a positive outflow.

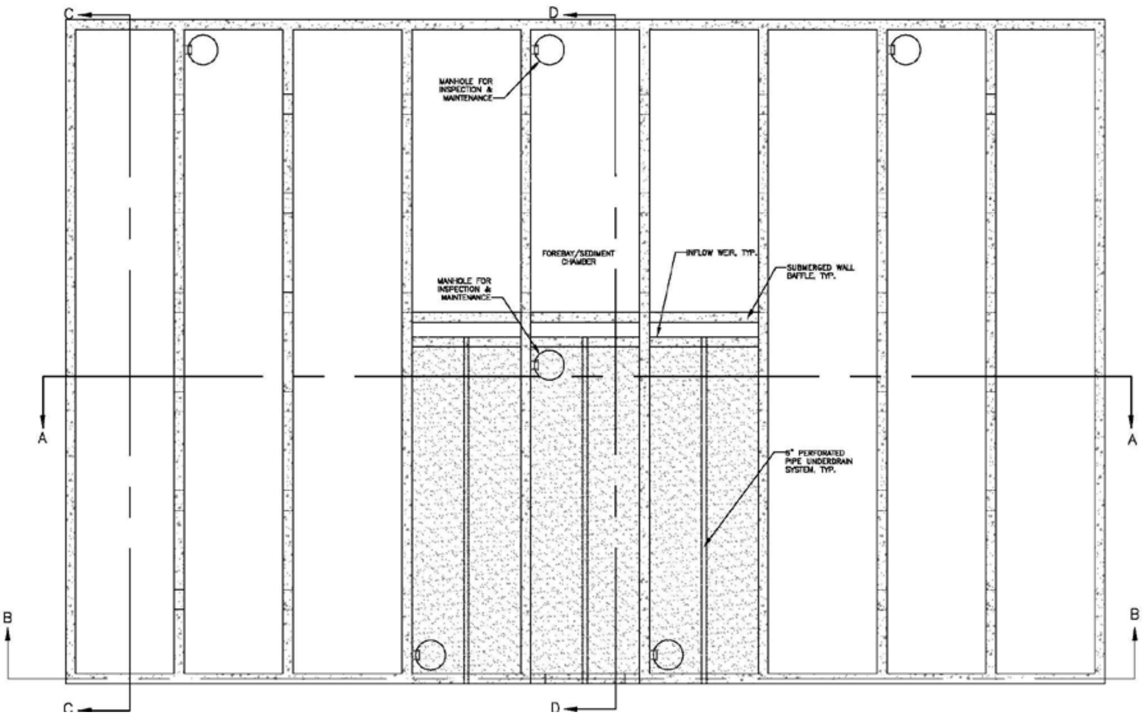
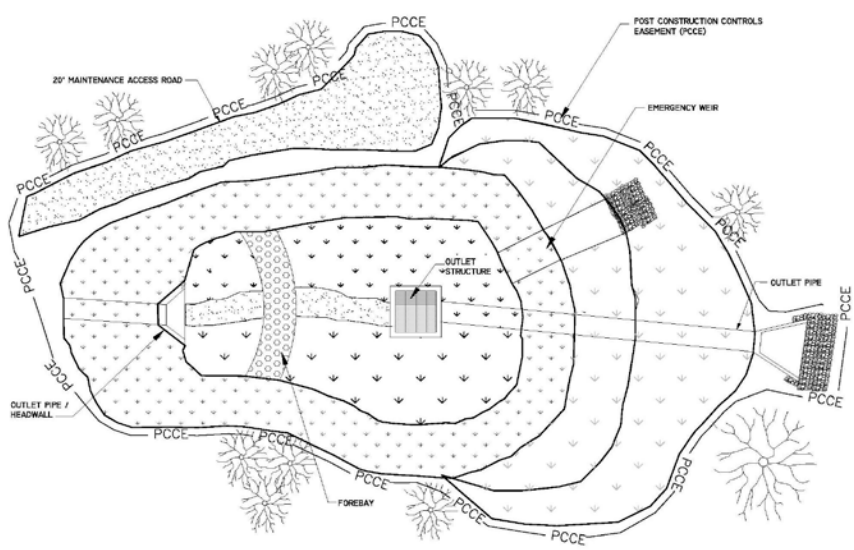


Figure 4.8.11 Plan View of Sand Filter



PLAN VIEW
NOT TO SCALE

Figure 4.8.12 Plan View of Extended Dry Detention

Table 4.8.10 Sand Filter Storage-Elevation Data

Elevation	Area (sf)	Area (ac)	Avg. Area (ac)	Height (ft)	Inc vol (ac-ft)	Acc vol (ac-ft)
734	2,272	0.052				0.000
734.5	2,272	0.052	0.052	0.5	0.026	0.026
735	2,272	0.052	0.052	0.5	0.026	0.052
735.5	2,272	0.052	0.052	0.5	0.026	0.078
736	2,272	0.052	0.052	0.5	0.026	0.104
736.5	2,272	0.052	0.052	0.5	0.026	0.130
737	2,272	0.052	0.052	0.5	0.026	0.156

Table 4.8.11 Extended Dry Detention Storage-Elevation Data

Elevation	Area (sf)	Area (ac)	Avg. Area (ac)	Height (ft)	Inc vol (ac-ft)	Acc vol (ac-ft)
734	3,500	0.080				0.000
735	3,500	0.080	0.080	1.0	0.080	0.080
736	3,500	0.080	0.080	1.0	0.080	0.160
737	3,500	0.080	0.080	1.0	0.080	0.240
738	3,500	0.080	0.080	1.0	0.080	0.320
739	3,500	0.080	0.080	1.0	0.080	0.400

Step 11b Develop Stage-Discharge for Sand Filter Media

The 1-inch, 6-hour storm event and portions of the more severe storm events will flow through the filter media. The filter media flow conditions 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 below the top of the filter media is ignored and assumed to be zero when the depth of flow is equal to the top of media. The percentage of the filter media that is assumed to be clogged during the surface area computation procedure (0 percent) should be considered when computing the outflow conditions.

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

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

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 737, three feet above the top of filter media

Q_o = $(1{,}444ft^2)[(3.5ft/day)(3.0ft+2.0ft)]/(2.0\ ft)$
= 12,635.0 cf/day
= 0.146 cfs

At elevation 736, two feet above the top of filter media

Q_o = $(1{,}444ft^2)[(3.5ft/day)(2.0ft+2.0ft)]/(2.0\ ft)$
= 10.108.0 cf/day
= 0.117 cfs

At elevation 735, one foot above the top of filter media

Q_o = $[(1{,}444 ft^2)][(3.5 ft/day)(1.0 ft+2.0 ft)]/(2.0\ ft)$
 = 7,581 cf/day
 = 0.088 cfs

At elevation 734, top of filter media

Qo = 0.00 cfs

<u>Step 12a Route Runoff Hydrographs through Sand Filter</u>

Route all of the appropriate runoff hydrographs through the sand filter facility with the following goals:

- 1-inch, 6-hour storm event through the filter media with less than 24 inches of ponding depth. Ensure that the 1 day detention time design requirement is being met by holding 5 percent of the 1-inch, 6-hour runoff volume within the storage volume.
- 1-year, 24-hour; 10-year, 6-hour, and 50-year, 6-hour storm event through the filter media and over flow structure with maximum 5 feet of ponding depth.
- Hold 5 percent of the 1-year, 24-hour storm event within the sand filter and/or extended dry detention storage volume 24 hours after the center of rainfall.
- Attenuate the 10-year, 6-hour storm events to pre-development levels. Note that a portion of the site is being diverted, therefore the pre-developed target discharge is based on only the amount of watershed that was flowing in that direction in pre-developed conditions, and additional attenuation and detention storage are required.

The following HEC-1 file provides the results of the first iteration of the 1-inch, 6-hour storm event routing. The peak water surface elevation is shown to by 736.90 with the entire 1-inch storm event flowing through the filter media. The routed peak water surface elevation is 2.90 feet which is greater than the allowable 2.0 feet. The peak flow is attenuated from 5.51 cfs to 0.14 cfs. Three (3.1%) percent of the 1-inch, 6-hour storm event is shown to remain within the sand filter storage volume at 27 hours (1day after the center of rainfall). Therefore, additional iterations are necessary to reduce the peak stage while increasing the attenuation benefits so that the design goal of holding 5% of the runoff volume at 27 hours is met. The revisions that are implemented during the iterations are to increase the storage area by increasing the sedimentation chamber while leaving the outflow through the sand filter at the same value.

```
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   10APR08  TIME  15:22:55   *                                                        *          (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
                       *     TOTAL MODEL DURATION - 27 HOURS
                       *     24 HOURS AFTER CENTER OF 6 HOUR RAINFALL
```

```
           4           IT      1       0       0    1620
                       *  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   EAST SUB-BASIN PRE-DEVELOPED CONDITIONS
          17           KO      5       0       0       0      21
          18           BA   .0018
          19           LS      0    69.9       0
          20           UD   0.319

          21           KK    PRE2
          22           KM   WEST SUB-BASIN PRE-DEVELOPED CONDITIONS
          23           KO      5       0       0       0      21
          24           BA   .0028
          25           LS      0    69.9       0
          26           UD   0.319

          27           KK   COMB1
          28           KO      5       0       0       0      21
          29           HC      2

          30           KK   POST1
          31           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
          32           KO      3       0       0       0      21
          33           BA   .0046
          34           LS      0    97.7       0
          35           UD   0.050
1                                                        HEC-1 INPUT                                           PAGE  2

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


          36           KK     DIV
          37           KO      5       0       0       0      21
          38           DT     SF
          39           DI    0.00    1.54    3.07    4.46    5.51   10.07   17.56   26.97   37.92   50.20
          40           DQ    0.00    1.54    3.07    4.46    5.51    6.39    7.16    7.86    8.50    9.09

          41           KK     SF
          42           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO SAND FILTER
          43           KO      5       0       0       0      21
          44           DR     SF

          45           KK   SFROU
          46           KO      3       0       0       0      21
          47           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE SAND FILTER FACILITY
          48           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
          49           RS      1    ELEV     734
          50           SV      0    .026    .052    .078    .104    .130    .156
          51           SE    734   734.5     735   735.5     736   736.5     737
          52           SQ    0.00   0.073   0.088   0.102   0.117   0.132   0.146
          53           SE    734   734.5     735   735.5     736   736.5     737
          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   10APR08  TIME  15:22:55    *                                                  *          (916) 756-1104            *
 *                                       *                                                  *                                    *
 *****************************************                                                  **************************************



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


                       HYDROGRAPH AT STATION    POST1

    TOTAL RAINFALL =    1.00, TOTAL LOSS =     .24, TOTAL EXCESS =     .76


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.    4.87            0.           0.           0.        .00

          HYDROGRAPH AT
+                            PRE2             0.    5.78            0.           0.           0.        .00

          2 COMBINED AT
+                           COMB1             0.    5.52            0.           0.           0.        .00

          HYDROGRAPH AT
```

```
+                    POST1      5.   3.18        0.        0.        0.       .00

         DIVERSION TO
+                       SF      5.    .00        0.        0.        0.       .00

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

         HYDROGRAPH AT
+                       SF      5.   3.18        0.        0.        0.       .00

         ROUTED TO
+                    SFROU      0.   4.72        0.        0.        0.       .00
+                                                                                      736.90       5.10


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

The following HEC-1 file provides the results of the additional iterations of the 1-inch, 6-hour storm event routing to result in a peak water surface elevation less than 2 feet and to hold more than 5% of the runoff in the BMP at 27 hours. The peak water surface elevation is shown to by 735.94 with the entire 1-inch storm event flowing through the filter media. The peak flow is attenuated from 5.51 cfs to 0.14 cfs. Approximately ten (9.6%) percent of the 1-inch, 6-hour storm event is shown to remain within the sand filter storage volume at 27 hours (1 day after the center of rainfall). The sand filter footprint cannot be reduced because the size must meet the footprint requirements derived by the Darcy equation. Therefore, the sand filter footprint remains as 38 feet by 38 feet. The sedimentation chamber is increased from a footprint area of 828 square feet to 2,070 square feet, an increase of 150 percent. The resulting sedimentation chamber holds 4,140 cubic feet which is 50 percent of the Water Quality Volume (WQ_v), not 20 percent that is required by the design specifications.

```
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   10APR08  TIME  16:26:12  *                                                 *         (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.

            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
                         *     TOTAL MODEL DURATION - 27 HOURS
                         *     24 HOURS AFTER CENTER OF 6 HOUR RAINFALL
             4           IT       1       0       0    1620
                         *  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   EAST SUB-BASIN PRE-DEVELOPED CONDITIONS
         17           KO      5       0       0       0      21
         18           BA   .0018
         19           LS      0    69.9       0
         20           UD   0.319

         21           KK    PRE2
         22           KM   WEST SUB-BASIN PRE-DEVELOPED CONDITIONS
         23           KO      5       0       0       0      21
         24           BA   .0028
         25           LS      0    69.9       0
         26           UD   0.319

         27           KK   COMB1
         28           KO      5       0       0       0      21
         29           HC      2

         30           KK   POST1
         31           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
         32           KO      3       0       0       0      21
         33           BA   .0046
         34           LS      0    97.7       0
         35           UD   0.050
1                                                   HEC-1 INPUT                                        PAGE  2

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


         36           KK     DIV
         37           KO      5       0       0       0      21
         38           DT      SF
         39           DI   0.00    1.54    3.07    4.46    5.51   10.07   17.56   26.97   37.92   50.20
         40           DQ   0.00    1.54    3.07    4.46    5.51    6.39    7.16    7.86    8.50    9.09

         41           KK      SF
         42           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO SAND FILTER
         43           KO      5       0       0       0      21
         44           DR      SF

         45           KK   SFROU
         46           KO      3       0       0       0      21
         47           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE SAND FILTER FACILITY
         48           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
         49           RS      1    ELEV     734
         50           SV      0    .041    .083    .123    .162    .201    .240
         51           SE    734   734.5     735   735.5     736   736.5     737
         52           SQ   0.00   0.073   0.088   0.102   0.117   0.132   0.146
         53           SE    734   734.5     735   735.5     736   736.5     737
         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   10APR08  TIME  16:26:12   *                                               *          (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.    4.87          0.          0.          0.          .00

           HYDROGRAPH AT
+                             PRE2         0.    5.78          0.          0.          0.          .00

           2 COMBINED AT
+                            COMB1         0.    5.52          0.          0.          0.          .00

           HYDROGRAPH AT
+                            POST1         5.    3.18          0.          0.          0.          .00

           DIVERSION TO
+                               SF         5.     .00          0.          0.          0.          .00

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

           HYDROGRAPH AT
+                               SF         5.    3.18          0.          0.          0.          .00

           ROUTED TO
+                            SFROU         0.    5.42          0.          0.          0.          .00
+                                                                                                        735.94       5.73


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

The following HEC-1 file provides the results of an iterative process to control the 1-year, 24-hour storm event routing. The design process is iterative and is performed in concert with the design process for peak flow attenuation for the 10-year, 6-hour storm event. The initial goal is to minimize the storage within the sand filter and maximize the storage within the extended dry detention basin because the relative cost of the underground sand filter is expected to be much greater than the above ground extended dry detention basin. However, some of the first iterations resulted in a conclusion that the flood control attenuation benefits of the extended dry detention basin could be maximized but the overall site flood controls were still not met. In other words, reducing the extended dry detention outflow to near zero would still not meet the pre-development target rates because the sand filter outflow was higher than pre-developed rates. Therefore, additional flood control must be provided by the storage volume above the sand filter to supplement the flood control benefits of the extended dry detention basin.

The iterative process included increasing the storage volume above the sand filter and decreasing the outlet orifice until more than 5 percent of the 1-year, 24-hour storm event runoff is held within the sand filter after 36 hours (24 hours past the center of the rainfall – 12 hours). The iterative process requires the designer to export the hydrograph to a spreadsheet and compute the hydrograph volume before and after the time of interest or setting the total HEC-1 model time to the time of interest and comparing the routed hydrograph volume with the total runoff hydrograph volume.

The design goal to control the 1-year, 24-hour storm event for 24 hours past the center of rainfall is complex because of the two BMPs that are designed to perform as parallel facilities. To assess if the design goal is met, several different checks must be performed. The first design check is straight-forward and is focused on the sand filter facility. The majority of runoff volume for the 1-year, 24-hour storm event is diverted to the sand filter. The diverted hydrograph includes most of the smaller peak flows because higher flows are diverted to the extended dry detention basin. Determining if the 1-year, 24-hour storm event is controlled for the design duration is assessed by comparing the sand filter inflow hydrograph (diverted hydrograph) to the sand filter outflow hydrograph. The entire site 1-year, 24-hour hydrograph should not be used in the comparison. The second check is more complex and requires checking of the combined outflows for the sand filter and extended dry detention basin with the entire site post-development hydrograph.

```
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   11APR08  TIME  10:00:52   *                         *          (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
                     *     TOTAL MODEL DURATION - 27 HOURS
                     *     24 HOURS AFTER CENTER OF 6 HOUR RAINFALL
              4      IT       1       0       0    1620
                     *  DIAGRAM
                     *     NOTE INPUT INTERVAL SET TO 6 MINUTES FOR 1-YEAR STORM DISTRIBUTION
              5      IN       6       0       0
                     *
                     *     OUTPUT CONTROL CARD
              6      IO       5       0       0
```

```
                 *

     7           KK   PRE1
     8           PB   2.58
                 * ******************************************************************************
                 * ***************** 1-YEAR, 24-HOUR STORM EVENT *******************************
                 * ********* 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   EAST SUB-BASIN PRE-DEVELOPED CONDITIONS
    35           KO      5       0       0       0      21
    36           BA   .0018
    37           LS      0    69.9       0
    38           UD   0.319
1                                          HEC-1 INPUT                                              PAGE  2

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


    39           KK   PRE2
    40           KM   WEST SUB-BASIN PRE-DEVELOPED CONDITIONS
    41           KO      5       0       0       0      21
    42           BA   .0028
    43           LS      0    69.9       0
    44           UD   0.319

    45           KK   COMB1
    46           KO      5       0       0       0      21
    47           HC      2

    48           KK   POST1
    49           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
    50           KO      3       0       0       0      21
    51           BA   .0046
    52           LS      0    92.6       0
    53           UD   0.050

    54           KK    DIV
    55           KO      5       0       0       0      21
    56           DT     SF
    57           DI   0.00    1.54    3.07    4.46    5.51   10.07   17.56   26.97   37.92   50.20
    58           DI  63.69
    59           DQ   0.00    1.54    3.07    4.46    5.51    6.39    7.16    7.86    8.50    9.09
    60           DQ   9.65

    61           KK   EDROU
    62           KO      3       0       0       0      21
    63           KM   ROUTE BYPASSED HYDROGRAPH THROUGH THE DOWNSTREAM EXTENDED DRY DETENTION
    64           KM   DESIGN TARGET IS HOLDING COMBINED SAND FILTER AND EXTENDED DRY DETENTION OUTF
    65           KM   FOR 24 HOURS BEYOND THE CENTER OF THE RAINFALL
    66           RS      1    ELEV     730
    67           SV      0    .080    .160    .240    .320
    68           SE    730   730.5     731   731.5     732
    69           SQ   0.00    0.24    0.38    9.68   26.57
    70           SE    730   730.5     731   731.5     732

    71           KK     SF
    72           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO SAND FILTER
    73           KO      5       0       0       0      21
    74           DR     SF

    75           KK   SFROU
    76           KO      3       0       0       0      21
    77           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE SAND FILTER FACILITY
    78           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
    79           RS      1    ELEV     734
    80           SV      0    .041    .083    .123    .162    .201    .240    .282    .323    .364
    81           SV   .391   0.404
    82           SE    734   734.5     735   735.5     736   736.5     737   737.5     738   738.5
    83           SE 738.85     739
    84           SQ   0.00   0.073   0.088   0.102   0.117   0.132   0.146   0.386   0.626   1.107
    85           SQ  1.333   6.706
    86           SE    734   734.5     735   735.5     736   736.5     737   737.5     738   738.5
1                                          HEC-1 INPUT                                              PAGE  3

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

    87           SE 738.85     739

    88           KK   COMBO
    89           KO      3       0       0       0      21
    90           KM   COMBINATION OF SAND FILTER OUTFLOW AND EXTENDED DRY DETENTION OUTFLOW
    91           HC      2
    92           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    11APR08  TIME  10:00:52   *                                                         *          (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.    12.35           0.          0.          0.         .00

          HYDROGRAPH AT
+                            PRE2           1.    12.35           0.          0.          0.         .00

          2 COMBINED AT
+                           COMB1           1.    12.35           0.          0.          0.         .00

          HYDROGRAPH AT
+                           POST1           8.    12.02           1.          0.          0.         .00

          DIVERSION TO
+                              SF           6.    12.02           1.          0.          0.         .00

          HYDROGRAPH AT
+                             DIV           2.    12.02           0.          0.          0.         .00

          ROUTED TO
+                           EDROU           0.    12.13           0.          0.          0.         .00
+                                                                                                          730.13       12.13

          HYDROGRAPH AT
+                              SF           6.    12.02           1.          0.          0.         .00

          ROUTED TO
+                           SFROU           0.    13.85           0.          0.          0.         .00
+                                                                                                          737.31       13.92

          2 COMBINED AT
+                           COMBO           0.    13.65           0.          0.          0.         .00


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

Step 12b Calculate Q_{10} Release Rate and Water Surface Elevation(s)

The next step of the design process is to design the sand filter and extended dry detention to be used to achieve the peak attenuation goals for the 10-year, 6-hour storm event. This process is similar to previous examples in that the design is iterative. A stage-storage-discharge relations is developed assuming an outflow orifice and/or weir and storage area. The storm event is routed through the storage volume, and the outflow peak discharge is compared to the pre-development peak discharge for the 10-year, 6-hour storm event; 3.48 cfs. In addition, the peak stage for the 10-year, 6-hour storm events must be less than 5 feet above the top of the filter media.

The following HEC-1 output files illustrate the results of the iterative process for the 10-year storm event where both the sand filter and extended dry detention basin attenuation benefits are maximize. The sand filter uses a 0.15 foot weir that is installed at elevation 737.0, 3 feet above the sand filter media to attenuate the post-developed discharge to the appropriate value for the 10-year, 6-hour storm event. The extended dry detention basin uses a 4-inch diameter orifice at the invert of the basin. The TAPE21 file indicates that the peak discharge for the 10-year, 6-hour storm event is 1.62 cfs with a peak stage of 738.83 for the sand filter and 730.83 for the extended dry detention basin. Note that the peak stage is 4.83 feet above the top of the sand filter media. The 4.83 feet ponding depth is less than the allowable 5 feet depth. Also note that the peak stage in the extended dry detention basin is only 0.83 feet because of the minimal opportunity for benefit for flood attenuation from the extended dry detention basin because the majority of the hydrograph is diverted into the sand filter. 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   11APR08  TIME  10:07:46 *                                        *        (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
                    *    TOTAL MODEL DURATION - 27 HOURS
                    *    24 HOURS AFTER CENTER OF 6 HOUR RAINFALL
          4         IT      1       0       0    1620
                    *  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   EAST SUB-BASIN PRE-DEVELOPED CONDITIONS
         17         KO      5       0       0       0      21
         18         BA   .0018
         19         LS      0    69.9       0
         20         UD   0.319

         21         KK    PRE2
         22         KM   WEST SUB-BASIN PRE-DEVELOPED CONDITIONS
         23         KO      5       0       0       0      21
         24         BA   .0028
         25         LS      0    69.9       0
         26         UD   0.319

         27         KK   COMB1
         28         KO      5       0       0       0      21
         29         HC      2

         30         KK   POST1
         31         KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
         32         KO      3       0       0       0      21
         33         BA   .0046
         34         LS      0    92.6       0
         35         UD   0.050
1                                       HEC-1 INPUT                                                PAGE  2

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


         36         KK     DIV
         37         KO      5       0       0       0      21
         38         DT     SF
         39         DI    0.00    1.54    3.07    4.46    5.51   10.07   17.56   26.97   37.92   50.20
         40         DI   63.69
         41         DQ    0.00    1.54    3.07    4.46    5.51    6.39    7.16    7.86    8.50    9.09
         42         DQ    9.65

         43         KK   EDROU
         44         KO      3       0       0       0      21
         45         KM   ROUTE BYPASSED HYDROGRAPH THROUGH THE DOWNSTREAM EXTENDED DRY DETENTION
         46         KM   DESIGN TARGET IS HOLDING COMBINED SAND FILTER AND EXTENDED DRY DETENTION OUTF
         47         KM   FOR 24 HOURS BEYOND THE CENTER OF THE RAINFALL
         48         RS      1    ELEV     730
         49         SV      0    .080    .160    .240    .320
         50         SE    730   730.5     731   731.5     732
         51         SQ   0.00    0.24    0.38    9.68   26.57
         52         SE    730   730.5     731   731.5     732

         53         KK      SF
         54         KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO SAND FILTER
```

```
          55           KO       5       0       0       0      21
          56           DR      SF

          57           KK   SFROU
          58           KO       3       0       0       0      21
          59           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE SAND FILTER FACILITY
          60           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
          61           RS       1    ELEV     734
          62           SV       0    .041    .083    .123    .162    .201    .240    .282    .323    .364
          63           SV    .391   0.404
          64           SE     734   734.5     735   735.5     736   736.5     737   737.5     738   738.5
          65           SE  738.85     739
          66           SQ    0.00   0.073   0.088   0.102   0.117   0.132   0.146   0.386   0.626   1.107
          67           SQ   1.333   6.706
          68           SE     734   734.5     735   735.5     736   736.5     737   737.5     738   738.5
          69           SE  738.85     739

          70           KK   COMBO
          71           KO       3       0       0       0      21
          72           KM   COMBINATION OF SAND FILTER OUTFLOW AND EXTENDED DRY DETENTION OUTFLOW
          73           HC       2
          74           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   11APR08  TIME  10:07:46   *                                                   *          (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          1.     3.52           0.          0.          0.          .00

          HYDROGRAPH AT
+                            PRE2          2.     3.52           0.          0.          0.          .00

          2 COMBINED AT
+                           COMB1          3.     3.52           1.          0.          0.          .00

          HYDROGRAPH AT
+                           POST1         17.     3.18           1.          0.          0.          .00

          DIVERSION TO
+                              SF          7.     3.18           1.          0.          0.          .00

          HYDROGRAPH AT
+                             DIV         10.     3.18           0.          0.          0.          .00

          ROUTED TO
+                           EDROU          0.     3.35           0.          0.          0.          .00
+                                                                                                          730.83       3.37

          HYDROGRAPH AT
+                              SF          7.     3.18           1.          0.          0.          .00

          ROUTED TO
+                           SFROU          1.     4.03           1.          0.          0.          .00
+                                                                                                          738.83       4.08

          2 COMBINED AT
+                           COMBO          2.     3.98           1.          0.          0.          .00


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

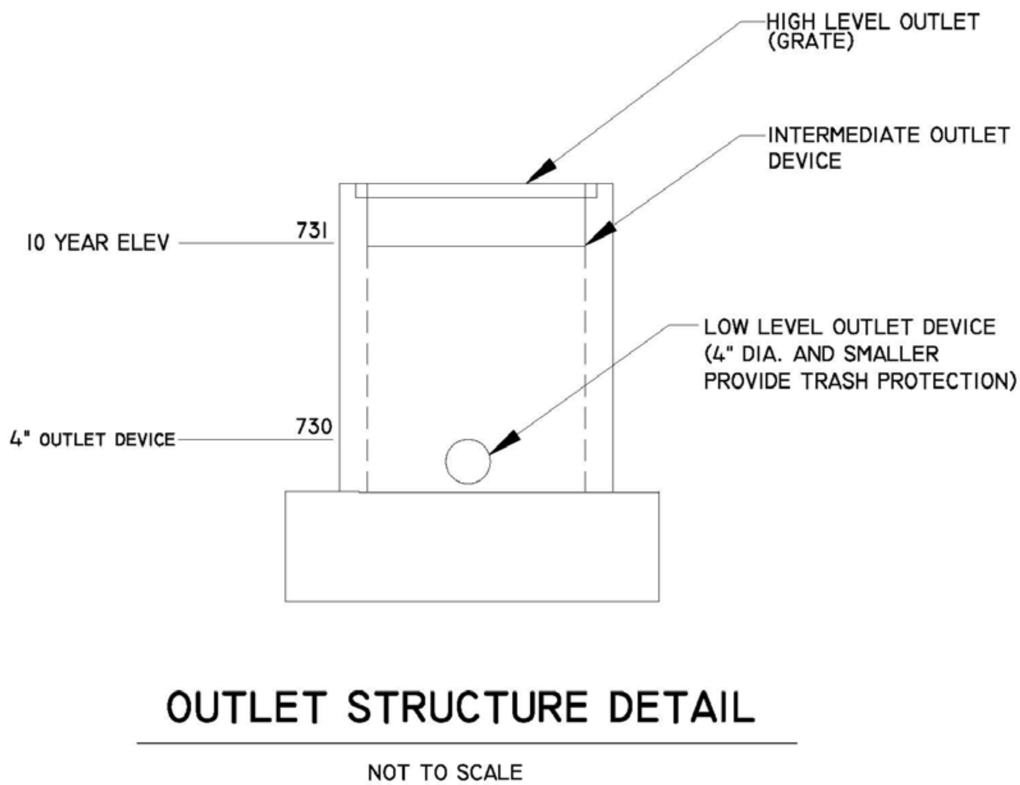

Figure 4.8.13 Schematic of Extended Detention Basin Outlet Structure

Comparison of this example with the previous stand-alone sand filter example indicates that the storage volume required is less for three of the design storm events; 1-inch, 6-hour, 10-year, 6-hour, and 50-year, 6-hour storm events. The storage volume required is slightly larger for this example for the 1-year, 24-hour control requirement. However, some of the storage volume is provided in an above-ground extended dry detention facility which may be more cost-effective to construct relative to an under-ground sand filter.

Step 13 Design Inlets and Underdrain System

Inlet 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.

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 design duration (1.13 days for this example). 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 spaced 3 inches on center, along 4 longitudinal rows 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 sand filter BMP (1,395 ft^2) the approximate dimensions of the sand filter area is selected to be 38 feet wide by 38 feet in length (approximately 1,444 ft^2).

The design process uses a trial and error process. 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 27 hours.

Compute minimum drawdown discharge

Water quality volume	=	(0.19 ac-ft)(43,560ft^3/ac ft)	= 8,276 ft^3
Drawdown	=	8,276 ft^3/[(27 hours)(3,600sec/hour)]	
	=	0.085 cfs	

Compute perforation capacity

Since the maximum underdrain spacing is 10 feet on center and the sand filter area is 38 feet wide by 38 feet in length, three parallel underdrain pipes (6-inch diameter PVC) 38 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 fittings.

Number of perforations	=	(3 pipes)(4 rows/ft)(38-2) ft/pipe)(4 holes/row)	= 1,728 holes
50 percent of perforations	=	864 holes	
Capacity of one hole	=	CA(2gh)$^{0.5}$	
	=	(0.6)(3.1416)[(3/8in)(1/24)]^2[(64.4)(3.0ft)]$^{0.5}$	
	=	0.0064 cfs/hole	
Total capacity	=	(0.0064 cfs/hole)(864 holes)	= 5.53 cfs

The perforations capacity (5.53 cfs) is greater than the filter media capacity (0.088 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.085 cfs computed in this step). Therefore the design is acceptable.

Note that the headwater depth used to determine the filter media capacity is 1.0 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, 1 feet above the filter media, or 3.0 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
Fifty percent assuming clogging	=	0.20 cfs

The pipe capacity (0.20 cfs) is greater than the filter media capacity (0.088 cfs, computed in step 11b) and the minimum drawdown capacity requirement (0.085 cfs computed in this step). Therefore the design is acceptable.

Step 14 Design Overflow Weir

The final step is to route the 50-year, 6-hour storm event through the sand filter and extended dry detention basin facilities to ensure that a minimum of 6-inches of freeboard is provided and that a maximum of 5 feet of depth is over the sand filter media. A thirty (30) foot weir at 738.85 is proposed as the emergency overflow for the sand filter. A ten (10) foot weir at 731.00 is proposed as the emergency overflow for the extended dry detention. 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        *
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* RUN DATE   11APR08  TIME  10:50:36   *                                          *          (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
                      *     TOTAL MODEL DURATION - 27 HOURS
                      *     24 HOURS AFTER CENTER OF 6 HOUR RAINFALL
          4           IT      1       0       0    1620
                      *  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   EAST SUB-BASIN PRE-DEVELOPED CONDITIONS
         17           KO      5       0       0       0      21
         18           BA   .0018
         19           LS      0    69.9       0
         20           UD   0.319

         21           KK    PRE2
         22           KM   WEST SUB-BASIN PRE-DEVELOPED CONDITIONS
         23           KO      5       0       0       0      21
         24           BA   .0028
         25           LS      0    69.9       0
         26           UD   0.319

         27           KK   COMB1
         28           KO      5       0       0       0      21
         29           HC      2

         30           KK   POST1
         31           KM   POST-DEVELOPED CONDITIONS - ENTIRE DRAINAGE AREA
         32           KO      3       0       0       0      21
         33           BA   .0046
         34           LS      0    92.6       0
         35           UD   0.050
1                                         HEC-1 INPUT                                                    PAGE  2

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


         36           KK     DIV
         37           KO       5       0       0       0      21
         38           DT      SF
         39           DI    0.00    1.54    3.07    4.46    5.51   10.07   17.56   26.97   37.92   50.20
         40           DI   63.69
         41           DQ    0.00    1.54    3.07    4.46    5.51    6.39    7.16    7.86    8.50    9.09
         42           DQ    9.65

         43           KK   EDROU
         44           KO      3       0       0       0      21
         45           KM   ROUTE BYPASSED HYDROGRAPH THROUGH THE DOWNSTREAM EXTENDED DRY DETENTION
         46           KM   DESIGN TARGET IS HOLDING COMBINED SAND FILTER AND EXTENDED DRY DETENTION OUTF
         47           KM   FOR 24 HOURS BEYOND THE CENTER OF THE RAINFALL
         48           RS      1    ELEV     730
         49           SV      0    .080    .160    .240    .320
         50           SE    730   730.5     731   731.5     732
         51           SQ   0.00    0.24    0.38    9.68   26.57
         52           SE    730   730.5     731   731.5     732

         53           KK     SF
         54           KM   RECALL HYDROGRAPH THAT WAS DIVERTED TO SAND FILTER
         55           KO      5       0       0       0      21
         56           DR     SF
```

```
57           KK   SFROU
58           KO       3       0       0       0      21
59           KM   ROUTE DIVERTED HYDROGRAPH THROUGH THE SAND FILTER FACILITY
60           KM   NO OVERFLOW STRUCTURE INCLUDED IN STAGE-DISCHARGE; ALL FLOW THROUGH FILTER ME
61           RS       1    ELEV     734
62           SV       0    .041    .083    .123    .162    .201    .240    .282    .323    .364
63           SV    .391   0.404
64           SE     734   734.5     735   735.5     736   736.5     737   737.5     738   738.5
65           SE  738.85     739
66           SQ    0.00   0.073   0.088   0.102   0.117   0.132   0.146   0.386   0.626   1.107
67           SQ   1.333   6.706
68           SE     734   734.5     735   735.5     736   736.5     737   737.5     738   738.5
69           SE  738.85     739

70           KK   COMBO
71           KO       3       0       0       0      21
72           KM   COMBINATION OF SAND FILTER OUTFLOW AND EXTENDED DRY DETENTION OUTFLOW
73           HC       2
74           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   11APR08  TIME  10:50:36    *                                                          *         (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
```

	OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+	HYDROGRAPH AT	PRE1	2.	3.50	0.	0.	0.	.00		
+	HYDROGRAPH AT	PRE2	4.	3.50	1.	0.	0.	.00		
+	2 COMBINED AT	COMB1	6.	3.50	1.	0.	0.	.00		
+	HYDROGRAPH AT	POST1	23.	3.18	2.	1.	0.	.00		
+	DIVERSION TO	SF	8.	3.18	2.	0.	0.	.00		
+	HYDROGRAPH AT	DIV	16.	3.18	1.	0.	0.	.00		
+	ROUTED TO	EDROU	5.	3.30	0.	0.	0.	.00		
+									731.23	3.30
+	HYDROGRAPH AT	SF	8.	3.18	2.	0.	0.	.00		
+	ROUTED TO	SFROU	5.	3.45	1.	0.	0.	.00		
+									738.96	3.45
+	2 COMBINED AT	COMBO	8.	3.42	1.	0.	0.	.00		

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

Table 4.8.12 presents the results of the design. In addition, the table includes the results *(highlighted with italics)* of the previous design example discussed in section 4.8.8. The previous design example used only a sand filter to meet the design goals of the same site.

Table 4.8.12 Summary of Controls Provided

Control Element	Type/Size of Control	Stor. (ac-ft)	Peak Elev. (MSL)	Disc. (cfs)	Remarks
Water Quality Extended Detention ($WQ_{v\text{-}ed}$)	Sand filter media at 734.0	0.154	735.90	0.14 cfs	Entire 1-inch, 6-hour storm event is routed through sand filter media
Water Quality Extended Detention ($WQ_{v\text{-}ed}$)	*Sand filter media at 734.0*	*0.176*	*735.29*	*0.05 cfs*	*Entire 1-inch, 6-hour storm event is routed through sand filter media*
Channel Protection (CP_v)	Sand filter media at 734.0 and 0.15 foot weir at 737.0/extended dry detention 4-inch orifice at 730.0	0.266 + 0.021 = 0.287	737.31 730.13	0.29 0.06	Portion of the 1-year, 24-hour storm event is routed through the sand filter and a portion is routed through the extended dry detention 4-inch orifice outlet
Channel Protection (CP_v)	*Sand filter media at 734.0 and 5-inch orifice at 735.5*	*0.281*	*736.04*	*0.43 cfs*	*Portion of the 1-year, 24-hour storm event is routed through the sand filter and a portion is routed through the 5-inch orifice outlet*
Flood Protection (Q_{10})	Sand filter media at 734.0 and 0.15 foot weir at 737.0/extended dry detention 4-inch orifice at 730.0	0.391 + 0.133 = 0.524	738.83 730.83	1.32 0.33	Same orifice control was designed for the 1-year, 24-hour and the 10-year, 6-hour storm events
Flood Protection (Q_{10})	*Sand filter media at 734.0 and 5-inch orifice at 735.5*	*0.542*	*737.98*	*1.08 cfs*	*Same orifice control was designed for the 1-year, 24-hour and the 10-year, 6-hour storm events*
Emergency Overflow (Q_{50})	Sand filter media at 734.0,0.15 foot weir at 737.0, and 30 foot weir at 738/extended dry detention 4-inch orifice at 730.0 and 10 foot weir at 731.0	0.403 + 0.197 = 0.600	738.96 731.23	5.23 4.75	Less than 5 feet of headwater depth on sand filter media.
Emergency Overflow (Q_{50})	*Sand filter media at 734.0, 5-inch orifice at 735.5, and 8-foot weir at 738.0*	*0.717*	*738.25*	*10.16 cfs*	*Less than 5 feet of headwater depth on sand filter media.*

Step 15 Assess Maintenance Access and Safety Features

The filter media and sedimentation chamber must be accessible from the surface in order to provide regular maintenance without significant access challenges. All areas of both chambers must be within 25 feet of an access location from the surface that is large enough for personnel to enter in order to remove trash, debris, sediment, etc. In addition, the sand filter media must be accessible in order to facilitate complete replacement when the sand filter ponds runoff without filtration.