# 3.0 Hydrology

## 3.1 Symbols and Definitions

To provide consistency within this chapter as well as throughout this Manual, the symbols listed in Table 3-1 will be used. These symbols were selected because of their wide use in technical publications. In some cases, the same symbol is used in existing publications for more than one definition. Where this occurs in this section, the symbol will be defined where it occurs in the text or equation.

**Table 3-1 Symbols and Definition**

| Symbol | Definition | Units |
|---|---|---|
| A | Drainage area, cross sectional area | acres, $ft^2$ |
| $B_f$ | Baseflow | ac-ft |
| CN | SCS Curve Number | - |
| $CN_m$ | Modified SCS Curve Number | - |
| $CP_v$ | Channel protection volume | ac-ft |
| E | Evaporation | ft |
| $E_t$ | Evapotranspiration | ft |
| $G_h$ | Hydraulic gradient – pressure head/distance | - |
| I | Percent of impervious cover | % |
| I | Inflow | ac-ft |
| I | Infiltration | ac-ft/day |
| $I_a$ | Initial abstraction | in |
| $K_h$ | Saturated hydraulic conductivity | ft/day |
| P | Rainfall | inches |
| Q, q | Peak inflow or outflow rate, runoff | cfs, in |
| $Q_f$ | Overflow | ft |
| $Q_p$ | Peak rate of discharge | cfs |
| $R_v$ | Volumetric runoff coefficient | - |
| $R_o$ | Runoff | ac-ft |
| S | Potential maximum retention | in |
| $t_c$ | Time of concentration | hours |
| V | Pond volume | ac-ft |
| $V_r$ | Runoff volume | ac-ft |
| $WQ_p$ | Water quality peak discharge | cfs |
| $WQ_v$ | Water quality protection volume | ac-ft, in |

## 3.2 Runoff Volume and Peak Flow

### 3.2.1 Introduction

The following is a discussion of the hydrologic methods needed to calculate the water quality protection volume ($WQ_v$), channel protection volume ($CP_v$), and large flood event peak flows ($Q_{10}$), ($Q_{25}$), ($Q_{50}$), etc. For more details on hydrologic analysis see Chapter 3, Hydrology, in the Charlotte-Mecklenburg Storm Water Design Manual.

BMPs should be designed to treat and/or control the runoff from the 1-inch storm event ($WQ_v$) for water quality, and the 1-year, 24-hour ($CP_v$) for volume control, and 10-year, 6-hour storm event for flood control. More severe storm events may also be required to be analyzed. Table 3-2 summarizes the design storm events for various types of storm drainage systems.

**Table 3-2: Summary of Design Standards**

| Design feature | Design storm |
|---|---|
| BMPs for water quality | 1-inch, 6-hour |
| BMPs for channel protection | 1-year, 24-hour |
| BMPs for flood protection | 10- and 25-year, 6-hour |
| Closed pipe and channels | 10-year, 6-hour |
| Culverts (subdivision streets) | 25-year, 6-hour |
| Culverts (thoroughfare roads) | 50-year, 6-hour |
| Building footprints | 100-year, 6-hour or 100-year, 24-hour on FEMA regulated streams |

Conventional SCS methods have been found to underestimate the volume and rate of runoff for rainfall events less than 2 inches. This discrepancy in estimating runoff and discharge rates can lead to several potential design challenges including undersizing of BMPs, inadequately sized diversion structures, and undersized outlet pipes, channels, etc. Therefore, a modified SCS procedure is required for development for the 1-inch, 6-hour storm event hydrograph.

For accurate runoff volume computational results, the 1-inch storm event runoff volume should be computed using methods developed by Schueler, and the 1-year and larger storm event runoff volumes should be computed using methods developed by SCS. The Schueler methods that are published can be used only to compute total runoff volume and cannot be used to develop a hydrograph including a peak flow. In order to overcome the differences of runoff volume results provided by the two methods, a method is presented to adjust the site curve number so that 1-inch storm event runoff volumes computed by SCS methods match the runoff volumes that are computed by methods developed by Schueler.

### 3.2.2 Water Quality Protection Volume and Peak Flow Calculation

**Water Quality Protection Volume Calculation**

The Water Quality Protection Volume ($WQ_v$) is the runoff volume required to be treated when designing a BMP to meet specific pollutant removal targets. This is achieved by intercepting and treating the runoff from a 1-inch rainfall event. The Water Quality Protection Volume ($WQ_v$) is calculated by method developed by Schueler by multiplying 1.0 inches of rainfall by the volumetric runoff coefficient ($R_v$) and the drainage area. $R_v$ is defined as:

$$\mathbf{R_v = 0.05 + 0.009(I)} \qquad (3.1)$$

Where: I = percent of impervious cover of the drainage basin (%)

Using the 1.0 inches of rainfall, the $WQ_v$ is calculated using the following formula:

$$\mathbf{WQ_v = 1.0R_vA/12} \qquad (3.2)$$

Where: $WQ_v$ = water quality protection volume (acre-feet)
$R_v$ = volumetric runoff coefficient
A = total drainage area (acres)

$WQ_v$ can be expressed in inches (if the designer wants to compare the result to runoff hydrograph volumes): using the following formula.

$$WQ_v = 1.0(R_v) \qquad (3.3)$$

Where: $WQ_v$ = water quality protection volume (inches)

**Peak Flow and Runoff Hydrograph Calculation**

The peak rate of discharge ($Q_p$) and/or runoff hydrograph shape for the Water Quality Protection Volume storm is needed for the sizing of most BMPs such as sand filters, bioretention, infiltration trenches, etc. In addition, the peak rate of discharge ($Q_p$) and/or runoff hydrograph shape is needed if the designer elects to treat only the Water Quality Runoff Volume ($WQ_v$) with one BMP such as bioretention and treat the larger storm events with another BMP such as an extended detention basin.

A balanced 6-hour storm event is chosen for use in Mecklenburg County. The method relies on the water quality protection volume and calculation of a modified Curve Number for use in the standard SCS method. A description of the calculation procedure is presented below.

*Step 1* Using the $WQ_v$, a modified Curve Number (CN) is computed utilizing the following equation:

$$\mathbf{CN_m = 1000/[10 + 5P + 10WQ_v - 10(WQ_v^2 + 1.25WQ_vP)^{0.5}]} \qquad \textbf{(3.4)}$$

Where: P = rainfall, in inches (use 1.0 inches)
$WQ_v$ = Water Quality Volume, in inches ($1.0R_v$)

*Step 2* Once a value for $CN_\mathbf{m}$ is computed, the time of concentration ($t_c$) is computed using the standard procedures contained in Chapter 3, Hydrology, in the Charlotte-Mecklenburg Storm Water Design Manual.

*Step 3* Using the computed $CN_\mathbf{m}$, $t_c$ and drainage area (A), in acres, the peak discharge ($Q_p$) can be calculated using the methods outlined in Chapter 3, Hydrology, in the Charlotte-Mecklenburg Storm Water Design Manual. The rainfall values for the 1-inch, 6-hour storm event using the PH record option for a HEC-1 model are shown in Table 3-3.

**Table 3-3 1-inch, 6-hour – Balanced Storm Event PH Records**

| PH records | | | | | | |
|---|---|---|---|---|---|---|
| Interval | 5 min | 15 min | 60 min | 2 hour | 3 hour | 6 hour |
| Rainfall | 0.188 | 0.371 | 0.640 | 0.769 | 0.855 | 1.0 inch |

PH records should not be used when implementing a HEC-1 model for smaller sites where a computational interval of less than 4 minutes is necessary. The PI records shown in Table 3-4 can be used for models where a computation interval less than 4 minutes is appropriate. Note that the incremental rainfall data is reported on a 5 minute interval, so the user should use an IN record to set the data read into the HEC-1 model as a 5 minute interval.

**Table 3-4 1-inch, 6-hour – Balanced Storm Event PI Records**

| **Time** | Rain | **Time** | Rain | **Time** | Rain | **Time** | Rain | **Time** | Rain | **Time** | Rain |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Min** | Inch | **Min** | Inch | **Min** | Inch | **Min** | Inch | **Min** | Inch | **Min** | Inch |
| **0** | .000 | **65** | .004 | **130** | .009 | **195** | .043 | **260** | .007 | **325** | .004 |
| **5** | .003 | **70** | .004 | **135** | .010 | **200** | .028 | **265** | .007 | **330** | .004 |
| **10** | .003 | **75** | .005 | **140** | .011 | **205** | .023 | **270** | .006 | **335** | .004 |
| **15** | .003 | **80** | .005 | **145** | .012 | **210** | .020 | **275** | .005 | **340** | .003 |
| **20** | .003 | **85** | .005 | **150** | .013 | **215** | .014 | **280** | .005 | **345** | .003 |
| **25** | .003 | **90** | .005 | **155** | .019 | **220** | .012 | **285** | .005 | **350** | .003 |
| **30** | .003 | **95** | .006 | **160** | .022 | **225** | .011 | **290** | .005 | **355** | .003 |
| **35** | .004 | **100** | .007 | **165** | .025 | **230** | .010 | **295** | .005 | **360** | .003 |
| **40** | .004 | **105** | .007 | **170** | .039 | **235** | .009 | **300** | .004 | **365** | .000 |
| **45** | .004 | **110** | .007 | **175** | .050 | **240** | .009 | **305** | .004 | | |
| **50** | .004 | **115** | .008 | **180** | .108 | **245** | .008 | **310** | .004 | | |
| **55** | .004 | **120** | .008 | **185** | .188 | **250** | .008 | **315** | .004 | | |
| **60** | .004 | **125** | .009 | **190** | .075 | **255** | .007 | **320** | .004 | | |

**Example**

Using the following information that was derived for a typical site using the methods described in the Charlotte-Mecklenburg Storm Water Design Manual, calculate the Water Quality Protection Volume ($WQ_v$), water quality peak flow ($Q_p$), and water quality runoff hydrograph.

Area = 50 acres
CN = 72
$t_c$ = 0.34 hours
$t_{lag}$ = 0.20 hours
Total impervious area = 18 acres

Calculate water quality volume ($WQ_v$)

Compute volumetric runoff coefficient, $R_v$ using Equation 3.1:
$R_v = 0.05 + 0.009(I) = 0.05 + (0.009)(18/50 \times 100\%) = 0.37$

Compute water quality volume, $WQ_v$ using Equations 3.2 and 3.3:
$WQ_v = 1.0(R_v)(A)/12 = 1.0(0.37)(50)/12 = 1.54$ acre-feet
$WQ_v = 1.0(R_v) = 1.0(0.37) = 0.37$ inches

Calculate water quality peak flow and runoff hydrograph

Compute modified curve number ($CN_{\mathbf{m}}$) using Equation 3.4:
$CN_{\mathbf{m}} = 1000/[10 + 5P + 10WQ_v - 10(WQ_v^2 + 1.25WQ_vP)^{0.5}]$
$CN_{\mathbf{m}} = 1000/[10 + 5(1.0) + 10(0.37) - 10\{(0.37)^2 + 1.25(0.37)(1.0)\}^{0.5}] = 91.3$

The following HEC-1 model output provides the final results of the peak runoff and runoff hydrograph exercise.

```
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   05MAR07  TIME  17:40:47   *                                                    *           (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       MECKLENBURG COUNTY BMP DESIGN MANUAL
             2           ID       ANALYZED BY ABC ENGINEERING
             3           ID       DATE: OCTOBER 2006
                         *  *************************************************************************
                         *
                         *     TIME SPECIFICATION CARD
             4           IT       1       0       0     360
                         *  DIAGRAM
                         *     TIME INTERVAL CARD
             5           IN       5       0       0
                         *
                         *     OUTPUT CONTROL CARD
             6           IO       1       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   50-ACRE SITE
          17              KO       1       0       0       0      21
          18              BA   .0781
          19              LS       0    91.3       0
          20              UD   0.204
          21              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   05MAR07  TIME  17:40:47   *                                                  *          (916) 756-1104             *
 *                                       *                                                  *                                     *
 *****************************************                                                  ***************************************

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

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

             *************
             *           *
   7 KK      *    PRE1   *
             *           *
             *************
                                                                   *
 ***************************************************************************************************************************

    TOTAL RAINFALL =     .99, TOTAL LOSS =     .63, TOTAL EXCESS =     .37

                                                            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            27.     3.37           3.          3.          3.          .08


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

The peak runoff is computed to be 27 cfs at a time of 3.37 hours. Also note that the runoff excess shown in the HEC-1 output is 0.37 inches, which is the same runoff excess amount that was computed using equations 3.2 and 3.3. The peak runoff, time to peak, hydrograph, etc. shall be used for BMP designs in later sections and chapters.

### 3.2.3 Channel Protection Volume and Peak Flow Calculation

The purpose of controlling the Channel Protection Volume ($CP_v$) is to protect the downstream channel system from the impacts of increased runoff volumes and peak rates due to development. The entire runoff volume from the 1-year, 24-hour storm event must be controlled (captured and released over a specified time duration through a primary outlet structure) in order to meet the requirements of controlling the Channel Protection Volume. An SCS Type II storm event distribution is required. The SCS Type II storm event distribution is slightly different than the balanced storm event which is generated through the use of PH records. Therefore, PH records cannot be used to generate the hydrograph for the 1-year, 24-hour storm event. Table 3-5 presents the 24-hour SCS Type II distribution using a 6-minute time interval. The user must use an IN record to set the data read into the HEC-1 model at a 6-minute interval. The following PI records present only the storm event distribution and accumulate to a total rainfall of 1-inch. The user must include a PB record using the total 1-year, 24-hour rainfall, 2.58 inches. This approach results in the distribution of the total 2.58 inches of rainfall over a 24-hour period using the SCS Type II shape.

The Channel Protection Volume ($CP_v$) can be computed using the standard SCS methods described in

Chapter 3 of the Charlotte-Mecklenburg Storm Water Design Manual. The equation to compute runoff volume is:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \qquad (3.5)$$

Where:

Q = accumulated runoff volume, inches
P = accumulated rainfall (potential maximum runoff), inches
S = potential maximum soil retention, inches = 1000/CN – 10
CN = SCS curve number

Note that the SCS curve number that is used to generate runoff volumes for all storm events other than the 1-inch, 6-hour storm event is the standard curve number and not the modified curve number discussed in Section 3.2.2. The same method as described in Section 3.2.2. to compute the entire runoff hydrograph including the peak discharge should be applied.

**Table 3-5 SCS Type II Storm Event Distribution PI Records**

| **Time Mins** | Rainfall % | **Time Mins** | Rainfall % | **Time Mins** | Rainfall % | **Time Mins** | Rainfall % | **Time Mins** | Rainfall % | **Time Mins** | Rainfall % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 0 | **240** | 0.0014 | **480** | 0.0022 | **720** | 0.0951 | **960** | 0.0023 | **1200** | 0.0013 |
| **6** | 0.001 | **246** | 0.0014 | **486** | 0.0022 | **726** | 0.019 | **966** | 0.0023 | **1206** | 0.0013 |
| **12** | 0.001 | **252** | 0.0014 | **492** | 0.0024 | **732** | 0.0166 | **972** | 0.0022 | **1212** | 0.0013 |
| **18** | 0.001 | **258** | 0.0015 | **498** | 0.0024 | **738** | 0.0144 | **978** | 0.0023 | **1218** | 0.0013 |
| **24** | 0.0011 | **264** | 0.0015 | **504** | 0.0026 | **744** | 0.0122 | **984** | 0.0022 | **1224** | 0.0013 |
| **30** | 0.001 | **270** | 0.0015 | **510** | 0.0026 | **750** | 0.0098 | **990** | 0.0022 | **1230** | 0.0012 |
| **36** | 0.0011 | **276** | 0.0015 | **516** | 0.0028 | **756** | 0.0084 | **996** | 0.0022 | **1236** | 0.0013 |
| **42** | 0.001 | **282** | 0.0015 | **522** | 0.0029 | **762** | 0.008 | **1002** | 0.0021 | **1242** | 0.0013 |
| **48** | 0.0011 | **288** | 0.0015 | **528** | 0.0029 | **768** | 0.0074 | **1008** | 0.0021 | **1248** | 0.0012 |
| **54** | 0.0011 | **294** | 0.0016 | **534** | 0.003 | **774** | 0.0068 | **1014** | 0.0021 | **1254** | 0.0013 |
| **60** | 0.0011 | **300** | 0.0016 | **540** | 0.0032 | **780** | 0.0064 | **1020** | 0.0021 | **1260** | 0.0012 |
| **66** | 0.0011 | **306** | 0.0016 | **546** | 0.0032 | **786** | 0.006 | **1026** | 0.002 | **1266** | 0.0013 |
| **72** | 0.0011 | **312** | 0.0016 | **552** | 0.0032 | **792** | 0.0056 | **1032** | 0.002 | **1272** | 0.0012 |
| **78** | 0.0011 | **318** | 0.0017 | **558** | 0.0032 | **798** | 0.0054 | **1038** | 0.002 | **1278** | 0.0013 |
| **84** | 0.0012 | **324** | 0.0017 | **564** | 0.0032 | **804** | 0.0052 | **1044** | 0.0019 | **1284** | 0.0012 |
| **90** | 0.0011 | **330** | 0.0016 | **570** | 0.0032 | **810** | 0.0048 | **1050** | 0.002 | **1290** | 0.0012 |
| **96** | 0.0012 | **336** | 0.0018 | **576** | 0.0033 | **816** | 0.0046 | **1056** | 0.0019 | **1296** | 0.0013 |
| **102** | 0.0011 | **342** | 0.0017 | **582** | 0.0034 | **822** | 0.0044 | **1062** | 0.0019 | **1302** | 0.0012 |
| **108** | 0.0012 | **348** | 0.0017 | **588** | 0.0036 | **828** | 0.0042 | **1068** | 0.0018 | **1308** | 0.0012 |
| **114** | 0.0012 | **354** | 0.0018 | **594** | 0.0038 | **834** | 0.004 | **1074** | 0.0018 | **1314** | 0.0012 |
| **120** | 0.0012 | **360** | 0.0018 | **600** | 0.0039 | **840** | 0.0038 | **1080** | 0.0018 | **1320** | 0.0012 |
| **126** | 0.0012 | **366** | 0.0018 | **606** | 0.0041 | **846** | 0.0037 | **1086** | 0.0018 | **1326** | 0.0012 |
| **132** | 0.0012 | **372** | 0.0018 | **612** | 0.0044 | **852** | 0.0036 | **1092** | 0.0017 | **1332** | 0.0012 |
| **138** | 0.0013 | **378** | 0.0019 | **618** | 0.0046 | **858** | 0.0035 | **1098** | 0.0018 | **1338** | 0.0012 |
| **144** | 0.0012 | **384** | 0.0019 | **624** | 0.0048 | **864** | 0.0034 | **1104** | 0.0017 | **1344** | 0.0012 |
| **150** | 0.0012 | **390** | 0.0018 | **630** | 0.0051 | **870** | 0.0034 | **1110** | 0.0017 | **1350** | 0.0011 |
| **156** | 0.0013 | **396** | 0.002 | **636** | 0.0054 | **876** | 0.0033 | **1116** | 0.0016 | **1356** | 0.0012 |
| **162** | 0.0012 | **402** | 0.0019 | **642** | 0.0058 | **882** | 0.0033 | **1122** | 0.0017 | **1362** | 0.0012 |
| **168** | 0.0013 | **408** | 0.0019 | **648** | 0.0062 | **888** | 0.0032 | **1128** | 0.0016 | **1368** | 0.0011 |
| **174** | 0.0013 | **414** | 0.002 | **654** | 0.0066 | **894** | 0.0031 | **1134** | 0.0016 | **1374** | 0.0012 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **180** | 0.0013 | **420** | 0.002 | **660** | 0.007 | **900** | 0.003 | **1140** | 0.0015 | **1380** | 0.0011 |
| **186** | 0.0013 | **426** | 0.002 | **666** | 0.0077 | **906** | 0.003 | **1146** | 0.0016 | **1386** | 0.0012 |
| **192** | 0.0013 | **432** | 0.002 | **672** | 0.0086 | **912** | 0.0029 | **1152** | 0.0015 | **1392** | 0.0011 |
| **198** | 0.0013 | **438** | 0.0021 | **678** | 0.0096 | **918** | 0.0028 | **1158** | 0.0015 | **1398** | 0.0012 |
| **204** | 0.0014 | **444** | 0.0021 | **684** | 0.0106 | **924** | 0.0027 | **1164** | 0.0015 | **1404** | 0.0011 |
| **210** | 0.0013 | **450** | 0.0021 | **690** | 0.0115 | **930** | 0.0027 | **1170** | 0.0014 | **1410** | 0.0011 |
| **216** | 0.0014 | **456** | 0.0021 | **696** | 0.0238 | **936** | 0.0026 | **1176** | 0.0014 | **1416** | 0.0012 |
| **222** | 0.0014 | **462** | 0.0021 | **702** | 0.0476 | **942** | 0.0026 | **1182** | 0.0014 | **1422** | 0.0011 |
| **228** | 0.0013 | **468** | 0.0021 | **708** | 0.0764 | **948** | 0.0025 | **1188** | 0.0013 | **1428** | 0.0011 |
| **234** | 0.0014 | **474** | 0.0022 | **714** | 0.1371 | **954** | 0.0024 | **1194** | 0.0014 | **1434** | 0.0011 |
| | | | | | | | | | | **1440** | 0.0011 |

**Example**
Using the following information, calculate the Channel Protection Volume and peak flow.

Area = 50 acres
CN = 72
$t_c$ = 0.34 hours
$t_{lag}$ = 0.20 hours
Total impervious area = 18 acres

Calculate channel protection volume ($CP_v$) using Equation 3.5:

$S = (1000/CN) – 10 = (1000/72) – 10 = 3.89$ inches

$Q = (P – 0.2S)^2 / (P + 0.8S) = (2.58 – 0.2(3.89))^2/ (2.58 + 0.8(3.89)) = 0.57$ inches

Q can be converted to total runoff by applying the runoff to the total watershed and converting to appropriate units.

$CP_v$ = (0.57 inches)(1 foot/12 inches)(50 acres) = 2.38 acre-feet

The same hydrograph generation method can be used to compute the entire runoff hydrograph including the peak discharge. The following HEC-1 output file illustrates the result of the computation.

```
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   05MAR07  TIME  18:11:48 *                               *           (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
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          1           ID       MECKLENBURG COUNTY BMP DESIGN MANUAL
          2           ID       ANALYZED BY ABC ENGINEERING
          3           ID       DATE: OCTOBER 2006
                      *   ***************************************************************************
                      *
                      *     TIME SPECIFICATION CARD
          4           IT       1       0       0   1440
                      *  DIAGRAM
                      *     INPUT PARAMETER CARD
          5           IN       6
                      *     OUTPUT CONTROL CARD
          6           IO       5

          7           KK    PRE1
          8           PB    2.58
                      * *****************************************************************************
                      * ********* 6 MINUTE TIME INCREMENT,24-HOUR STORM EVENT **********************
                      * *****************************************************************************
          9           PI   .0000  .0010  .0010  .0010  .0011  .0010  .0011  .0010  .0011  .0011
         10           PI   .0011  .0011  .0011  .0011  .0012  .0011  .0012  .0011  .0012  .0012
         11           PI   .0012  .0012  .0012  .0013  .0012  .0012  .0013  .0012  .0013  .0013
         12           PI   .0013  .0013  .0013  .0013  .0014  .0013  .0014  .0014  .0013  .0014
         13           PI   .0014  .0014  .0014  .0015  .0015  .0015  .0015  .0015  .0015  .0016
         14           PI   .0016  .0016  .0016  .0017  .0017  .0016  .0018  .0017  .0017  .0018
         15           PI   .0018  .0018  .0018  .0019  .0019  .0018  .0020  .0019  .0019  .0020
         16           PI   .0020  .0020  .0020  .0021  .0021  .0021  .0021  .0021  .0021  .0022
         17           PI   .0022  .0022  .0024  .0024  .0026  .0026  .0028  .0029  .0029  .0030
         18           PI   .0032  .0032  .0032  .0032  .0032  .0032  .0033  .0034  .0036  .0038
         19           PI   .0039  .0041  .0044  .0046  .0048  .0051  .0054  .0058  .0062  .0066
         20           PI   .0070  .0077  .0086  .0096  .0106  .0115  .0238  .0476  .0764  .1371
         21           PI   .0951  .0190  .0166  .0144  .0122  .0098  .0084  .0080  .0074  .0068
         22           PI   .0064  .0060  .0056  .0054  .0052  .0048  .0046  .0044  .0042  .0040
         23           PI   .0038  .0037  .0036  .0035  .0034  .0034  .0033  .0033  .0032  .0031
         24           PI   .0030  .0030  .0029  .0028  .0027  .0027  .0026  .0026  .0025  .0024
         25           PI   .0023  .0023  .0022  .0023  .0022  .0022  .0022  .0021  .0021  .0021
         26           PI   .0021  .0020  .0020  .0020  .0019  .0020  .0019  .0019  .0018  .0018
         27           PI   .0018  .0018  .0017  .0018  .0017  .0017  .0016  .0017  .0016  .0016
         28           PI   .0015  .0016  .0015  .0015  .0015  .0014  .0014  .0014  .0013  .0014
         29           PI   .0013  .0013  .0013  .0013  .0013  .0012  .0013  .0013  .0012  .0013
         30           PI   .0012  .0013  .0012  .0013  .0012  .0012  .0013  .0012  .0012  .0012
         31           PI   .0012  .0012  .0012  .0012  .0012  .0011  .0012  .0012  .0011  .0012
         32           PI   .0011  .0012  .0011  .0012  .0011  .0011  .0012  .0011  .0011  .0011
         33           PI   .0011
         34           KM   50-ACRE SITE
         35           KO      1       0       0       0      21
         36           BA   .0781
         37           LS      0    72.0       0
         38           UD   0.204
         39           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   05MAR07  TIME  18:11:48   *                                          *           (916) 756-1104            *
 *                                       *                                          *                                     *
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                             MECKLENBURG COUNTY BMP DESIGN MANUAL
                             ANALYZED BY ABC ENGINEERING
                             DATE: OCTOBER 2006

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

            *************
            *           *
   7 KK     *     PRE1  *
            *           *
            *************
                                                                    *
 **************************************************************************************************************************************

    TOTAL RAINFALL =    2.58, TOTAL LOSS =    2.01, TOTAL EXCESS =     .57

                                                           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         27.   12.22          4.          1.          1.        .08


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

The peak runoff is computed to be 27 cfs at a time of 12.22 hours. It is a coincidence that the 1-year, 24-hour peak runoff is the same as the 1-inch, 6-hour peak runoff shown in the previous example, but the runoff volumes and time to peak are much different. Also note that the runoff excess shown in the HEC-1 output is 0.57 inches, which is the same runoff excess amount that was computed using equation 3.5. The peak runoff, time to peak, hydrograph, etc. shall be used for BMP designs in later sections and chapters.

## 3.3 Storage Volume Computations

Design of BMPs to treat and control the Water Quality Volume ($WQ_v$) and the Channel Protection Volume ($CP_v$) require level pool routing methods as described in the Charlotte-Mecklenburg Storm Water Design Manual and this Manual. The design process is iterative where a preliminary storage volume and outlet system is assumed, the appropriate design hydrographs are routed through the system, output results are assessed, and refinements to the storage volume and outlet systems are made. This process is continued until all design storm events are properly treated or controlled within the BMP storage volume. The Static Method, described in the following section, can be used to estimate initial conditions so that the number of iterations is reduced.

**Static Method**

The Static Method assumes that all of the runoff volume enters the storage volume instantaneously and therefore, the storage volume is set equal to the runoff volume. The runoff volume exits the storage volume based solely on the outflow system hydraulics and the holding time duration for the selected design condition.

**Example**

Using the following information, calculate an initial estimate of the BMP storage volume and outlet system to hold the Channel Protection Volume for 24 hours beyond the center of rainfall (12 hours).

Area = 50 acres
CN = 72
$t_c$ = 0.34 hours
$t_{lag}$ = 0.20 hours
Total impervious area = 18 acres

The previous example computed the runoff volume to be 2.38 acre-feet. The storage volume is set equal to the runoff volume and units converted to determine the appropriate outlet flow rate.

$$Q_{outlet} = (2.38\text{ acre-feet})(43{,}560\text{ ft}^2/\text{acre})/(36\text{ hours})(3{,}600\text{ sec/hour})$$
$$= 0.80\text{ cfs}$$

It is important to note that within Charlotte and its ETJ, the Channel Protection Volume must be held for 48 hours beyond the center of rainfall. In this example the value of 36 hours would be replaced with 60 hours for sites in the Charlotte area.

Based on the site conditions, the next step is for the designer to fit the 2.38 acre-feet of storage into the site topography. From the site topography, the total and average headwater depth on the outlet structure can be determined. For this example, we assume that the total storage volume depth is 5 feet. The average headwater depth is assumed to be ½ of the maximum depth, or 2.5 feet.

Size the outlet orifice by using the orifice equation to compute cross-sectional area and diameter of outlet.

$Q = CA(2gh)^{0.5}$, for Q = 0.80 cfs, h = 2.50 ft, and C = discharge coefficient = 0.6
Solve for A: $A = 0.80\text{ cfs} / [0.6((2)(32.2\text{ ft/s}^2)(2.50))^{0.5}] = 0.105\text{ ft}^2$
With $A = \pi d^2/4$, d = 0.37 ft = 4.4 inches
Use 4.4 inch orifice plate.

Note that the static method provides an over-estimation of the storage volume needed to hold the runoff volume for the design duration. Detailed routing computations are required to complete the design during which the storage volumes, outlet sizes, etc. are altered during the routing computations. The detailed outlet hydrograph analysis must show that a minimum percentage of the runoff volume is held within the storage volume at the design duration time (see Routing section below).

### Routing

Detailed routing computations are required for the design of all BMPs where storage volume and detention time are key design parameters. Chapter 7 of the Charlotte-Mecklenburg Storm Water Design Manual provides a description of methods required to perform routing. In many cases, the designer will perform the required routing computations using computer models.

The previously described Static Method provides an estimate of the required storage volume to hold the design storm runoff volume for a specific holding duration. Routing computations will be iterative where a preliminary storage volume and outlet system is assumed, the routing computation is performed, and the output is checked to evaluate the success of the BMP meeting the holding duration. In Cornelius, Davidson, Matthews, Mint Hill, Pineville and in areas of Mecklenburg County outside of any planning ETJ's, the detailed outlet hydrograph analysis must show that a minimum of 5 percent of the runoff volume is held within the storage volume at the design duration time (36 hours). In Charlotte and Huntersville, the detailed outlet hydrograph analysis must show that a minimum of 50 percent of the runoff volume is held within the storage volume at 24 hours after the center of the rainfall – 12 hours (total 36 hours) and must show that a portion of the runoff volume is held within the storage volume at the design duration time for those jurisdictions (60 hours).

For example, for the $CP_v$ design, the 1-year, 24-hour storm event must be held for 24 hours (or 48 hours in Charlotte). Therefore, the design should compute the amount of runoff volume that is left within the storage volume at 24 hours after the center of the rainfall (total 36 hours) for all jurisdictions and at 48 hours after the center of the rainfall (total 60 hours) for Huntersville and Charlotte. The remaining volume at 36 hours must be at least 50% of the total runoff volume for Huntersville and Charlotte and at least 5% of the total runoff volume in other jurisdictions. The remaining volume at 60 hours must be at least a portion of the total runoff volume for Huntersville and Charlotte.

## 3.4 Water Balance Calculations

### 3.4.1 Introduction

Water balance calculations are used to determine if a drainage area is large enough, or has the right characteristics, to support a BMP with a permanent pool of water during average conditions. Water balance calculations are required for the design of some BMPs included in this manual independent of contributing watershed size and required for the design of some BMPs included in this manual if the BMPs is proposed to serve a contributing watershed less than a specified threshold. The details of a rigorous water balance are beyond the scope of this manual; however, a simplified procedure is described in this section that will provide an estimate of pool viability and point to the need for more rigorous analysis.

The entire water year should be checked with water balance computations, but the summer season is typically the most critical because high outflows are experienced and are combined with the lowest inflows. Each month must be assessed during the analysis. Two starting conditions should be checked, the water year starting in July and the calendar year starting in January.

### 3.4.1 Basic Equations

Water balance is defined as the change in volume of the permanent pool resulting from the total inflow minus the total outflow (actual or potential).

$$\Delta V = \Sigma I - \Sigma O \qquad (3.6)$$

Where: $\Delta$ = "change in"
V = pond volume (acre-feet)
$\Sigma$ = "sum of"
I = inflows (acre-feet)
O = outflows (acre-feet)

The inflows consist of rainfall, runoff and baseflow into the pond or holding area. The outflows consist of infiltration, evaporation, evapotranspiration, and surface overflow out of the pond or wetland. Equation 3.6 can be changed to reflect these factors.

$$\Delta V = P + R_o + B_f - I - E - E_t - O_f \quad (3.7)$$

Where: P = precipitation (ac-ft)
$R_o$ = runoff (ac-ft)
$B_f$ = baseflow (ac-ft)
I = infiltration (ac-ft)
E = evaporation (ac-ft)
$E_t$ = evapotranspiration (ac-ft)
$O_f$ = overflow (ac-ft)

**Rainfall (P)**
Monthly values are commonly used for calculations of values over a season. Rainfall is the direct amount that falls on the pond surface for the period in question. When multiplied by the pond surface area (in acres) it becomes acre-feet of volume. Table 3-6 shows monthly rainfall values for the Mecklenburg County area.

**Table 3-6 Average Monthly Rainfall Values for Mecklenburg County, North Carolina**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation (in) | 3.72 | 3.84 | 4.44 | 2.64 | 3.84 | 3.36 | 3.96 | 3.72 | 3.48 | 3.36 | 3.24 | 3.48 | 43.08 |

**Runoff ($R_0$)**
Runoff is equivalent to the rainfall for the period multiplied by the "efficiency" of the watershed, which is equal to the ratio of runoff to rainfall. The following method can be used for BMP design in Mecklenburg County. Equation 3.1 gives a ratio of runoff to rainfall volume for a particular storm. If it can be assumed that the average storm that produces runoff has a similar ratio, then the $R_v$ value can serve as the ratio of rainfall to runoff ($R_v$ is defined in section 3.2).

Not all storms produce runoff in an urban setting. Typically initial losses (often called "initial abstractions") are normally estimated to be between 0.1 and 0.2 inches. When compared to the rainfall records in Mecklenburg County, this is equivalent to about a 10% runoff volume loss. Thus a factor of 0.9 should be applied to the calculated $R_v$ value to account for storms that produce no runoff. Equation 3.8 reflects this approach. Total runoff volume (acre-feet) is the product of runoff depth ($0.9PR_v$) times the drainage area.

$$R_o = 0.9PR_vA/12 \quad (3.8)$$

Where: $R_o$ = runoff volume ( acre-feet)
P = precipitation (in)
$R_v$ = volumetric runoff coefficient
A = total drainage area – pond area (acres)

**Baseflow ($B_f$)**
Most storm water ponds and wetlands have little, if any, baseflow, as they are rarely placed across perennial streams. If so placed, baseflow must be estimated from observation or through theoretical

estimates. Review of the USGS Annual Data Report for North Carolina indicates that the watersheds in Mecklenburg County experience a baseflow in the range of 0.2 cfsm (cubic feet per second per square mile of contributing drainage area) for urbanized watersheds and 0.4 cfsm for rural watersheds. The urbanized value 0.2 cfsm should be used for water balance computations when baseflow is present.

**Infiltration (I)**

Infiltration is a very complex subject and cannot be covered in detail here. The amount of infiltration depends on soils, water table depth, rock layers, surface disturbance, the presence or absence of a liner in the pond, and other factors. The infiltration rate is governed by the Darcy equation as:

$$\mathbf{I = Ak_hG_h} \qquad \textbf{(3.9)}$$

Where: I = infiltration (ac-ft/day)

A = cross sectional area through which the water infiltrates (acres)
For the purposes of this analysis, use ponding area at the permanent pool

$k_h$ = saturated hydraulic conductivity or infiltration rate (ft/day)

$G_h$ = hydraulic gradient = pressure head/distance

$G_h$ can be set equal to 1.0 for the typical BMP application in the Mecklenburg County area. Infiltration rates can be established through testing, though not always accurately.

The value of $k_h$ should be based on site specific soil condition testing if available. If site specific soil condition testing is not available, the values shown in Table 3-7 can be used based on the NRCS soil type that is present on site. If the proposed site grading is such that significant cut and fill will occur and therefore displace the NRCS soil type, then the site soil type with the highest $k_h$ value shall be selected for use in the water balance computation.

**Table 3-7 Saturated Hydraulic Conductivity**

| NRCS Soil Type | Hydraulic Conductivity In/hr | Hydraulic Conductivity ft/day |
|---|---|---|
| Appling | 1.3 | 2.6 |
| Cecil | 1.3 | 2.6 |
| Davidson | 1.3 | 2.6 |
| Enon | 0.1 | 0.2 |
| Georgeville | 1.3 | 2.6 |
| Goldston | 4.0 | 8.0 |
| Helena | 0.4 | 0.8 |
| Iredell | 0.1 | 0.2 |
| Lignum | 0.3 | 0.6 |
| Mecklenburg | 0.1 | 0.2 |
| Monacan | 1.3 | 2.6 |
| Pacolet | 1.3 | 2.6 |
| Pits | 0.1 | 0.2 |
| Vance | 0.1 | 0.2 |
| Wilkes | 0.4 | 0.8 |

**Evaporation (E)**

Evaporation is from an open lake water surface. Evaporation rates are dependent on differences in vapor pressure, which, in turn, depend on temperature, wind, atmospheric pressure, water purity, and shape and depth of the pond. It is estimated or measured in a number of ways, which can be found in most hydrology textbooks. Table 3-8 gives evaporation rates for a typical 12-month period based on information from a station in Union, SC. The values in Table 3-8 are converted to volume of evaporation by multiplying by the pond surface area and converting to acre-feet.

**Table 3-8 Monthly Evaporation Rates (inches)**

| Mon | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake | 1.2 | 1.5 | 2.5 | 3.7 | 4.4 | 4.6 | 4.8 | 4.5 | 3.3 | 2.4 | 1.5 | 1.1 | 35.5 |

### Evapotranspiration ($E_t$)

Evapotranspiration consists of the combination of evaporation and transpiration by plants. The estimate of $E_t$ for crops is well documented and has become standard practice. However, for wetlands the estimating methods are not well documented, nor are there consistent studies to assist the designer in estimating the demand wetland plants would put on water volumes. Literature values for various places in the United States vary around the free water surface lake evaporation values. Estimating $E_t$ only becomes important when wetlands are being designed and emergent vegetation covers a significant portion of the pond surface. In these cases conservative estimates of lake evaporation should be compared to crop-based $E_t$ estimates. Crop-based $E_t$ can be obtained from typical hydrology textbooks and from related web sites.

### Overflow ($O_f$)

Overflow is considered as excess runoff and is defined by the volume of water temporarily held in the pond above the "permanent" pool elevation. In the simplified water balance calculations presented in this Manual, all water volume above the permanent pool volume is considered lost at the end of each month (no more than the maximum permanent pool volume is carried forward to the next month).

### Example

A 23 acre site in Mecklenburg County is being developed along with an estimated 0.5 acre surface wet pond. There is no baseflow. The desired pond volume to the overflow point is 2.0 acre-feet at a pond stage of 705.0 feet. The designer must show that the site be able to support the pond volume. From the basic site data it is determined that the site is 40% impervious and has Enon NRCS soil type throughout the entire site.

- From Equation 3.1, $R_v = 0.05 + 0.009(40) = 0.41$. With the correction factor of 0.9 the watershed efficiency is 0.37.
- The annual lake evaporation is 35.5 inches. (Table 3-8)
- For a Enon soil the infiltration rate is I = 0.20 ft/day (Table 3-7)

Table 3-9 shows summary calculations for this site for each month of the year based on a calendar year computation and water year computation.

**Table 3-9 Water Balance Result Summary**

| 1 | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Days/month | 31.0 | 28.0 | 31.0 | 30.0 | 31.0 | 30.0 | 31.0 | 31.0 | 30.0 | 31.0 | 30.0 | 31.0 |
| 3 | Precipitation (inches) | 3.72 | 3.84 | 4.44 | 2.64 | 3.84 | 3.36 | 3.96 | 3.72 | 3.48 | 3.36 | 3.24 | 3.48 |
| 4 | Evaporation (inches) | 1.20 | 1.50 | 2.50 | 3.70 | 4.40 | 4.60 | 4.80 | 4.50 | 3.30 | 2.40 | 1.50 | 1.10 |
| 5 | Runoff (acre-feet) | 2.57 | 2.66 | 3.07 | 1.83 | 2.66 | 2.32 | 2.74 | 2.57 | 2.41 | 2.32 | 2.24 | 2.41 |
| 6 | Pond Precipitation (acre-feet) | 0.16 | 0.16 | 0.19 | 0.11 | 0.16 | 0.14 | 0.17 | 0.16 | 0.15 | 0.14 | 0.14 | 0.15 |
| 7 | Evaporation (acre-feet) | 0.05 | 0.06 | 0.10 | 0.15 | 0.18 | 0.19 | 0.20 | 0.19 | 0.14 | 0.10 | 0.06 | 0.05 |
| 8 | Infiltration (acre-feet) | 3.10 | 2.80 | 3.10 | 3.00 | 3.10 | 3.00 | 3.10 | 3.10 | 3.00 | 3.10 | 3.00 | 3.10 |
| 9 | Monthly Balance (acre-feet) | -0.42 | -0.05 | 0.05 | -1.22 | -0.47 | -0.73 | -0.40 | -0.56 | -0.58 | -0.74 | -0.69 | -0.59 |
| 10 | Running Balance of Retained Pond Volume (acre-feet) | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 11 | Pond water surface elevation (feet) | 699.8 | 699.8 | 700.0 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | Water surface with respect to permanent pool elevation (feet) | -5.2 | -5.2 | -5.0 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 |
| | | | | | | | | | | | | | |
| 1 | | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
| 2 | Days/month | 31.0 | 31.0 | 30.0 | 31.0 | 30.0 | 31.0 | 31.0 | 28.0 | 31.0 | 30.0 | 31.0 | 30.0 |
| 3 | Precipitation (inches) | 3.96 | 3.72 | 3.48 | 3.36 | 3.24 | 3.48 | 3.72 | 3.84 | 4.44 | 2.64 | 3.84 | 3.36 |
| 4 | Evaporation (inches) | 4.80 | 4.50 | 3.30 | 2.40 | 1.50 | 1.10 | 1.20 | 1.50 | 2.50 | 3.70 | 4.40 | 4.60 |
| 5 | Runoff (acre-feet) | 2.74 | 2.57 | 2.41 | 2.32 | 2.24 | 2.41 | 2.57 | 2.66 | 3.07 | 1.83 | 2.66 | 2.32 |
| 6 | Pond Precipitation (acre-feet) | 0.17 | 0.16 | 0.15 | 0.14 | 0.14 | 0.15 | 0.16 | 0.16 | 0.19 | 0.11 | 0.16 | 0.14 |
| 7 | Evaporation (acre-feet) | 0.20 | 0.19 | 0.14 | 0.10 | 0.06 | 0.05 | 0.05 | 0.06 | 0.10 | 0.15 | 0.18 | 0.19 |
| 8 | Infiltration (acre-feet) | 3.10 | 3.10 | 3.00 | 3.10 | 3.00 | 3.10 | 3.10 | 2.80 | 3.10 | 3.00 | 3.10 | 3.00 |
| 9 | Monthly Balance (acre-feet) | -0.40 | -0.56 | -0.58 | -0.74 | -0.69 | -0.59 | -0.42 | -0.05 | 0.05 | -1.22 | -0.47 | -0.73 |
| 10 | Running Balance of Retained Pond Volume (acre-feet) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 |
| 11 | Pond water surface elevation (feet) | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 699.8 | 700.0 | 699.8 | 699.8 | 699.8 |
| 12 | Water surface with respect to permanent pool elevation (feet) | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.2 | -5.0 | -5.2 | -5.2 | -5.2 |

Explanation of Table:

1. Months of the year.
2. Days per month.
3. Monthly precipitation from Table 3-6.
4. Evaporation by month from Table 3-8.
5. Watershed efficiency of 0.37 times the rainfall and converted to acre-feet.
6. Precipitation volume directly into pond equals precipitation depth times pond surface area divided by 12 to convert to acre-feet.
7. Evaporation from line 4 converted to acre-feet.
8. Infiltration converted to acre-feet.
9. Lines 5 and 6 minus lines 7 and 8.
10. Accumulated total from line 9 keeping in mind that all volume above 2 acre-feet overflows and is lost in the trial design.
11. Pond water surface elevation based on stage-storage data for pond.
12. Pond water surface elevation with respect to permanent pool elevation.

For this example the wet pond has the potential to go dry throughout the year. This could be remedied in a number of ways including compacting the pond bottom in areas that are not planned to be planted, placing a liner of clay or geosynthetics, and changing the pond geometry to decrease surface area. Table 3-10 shows revised water balance computations for the same site using an infiltration rate of 0.1 ft/day based on a clay liner.

**Table 3-10 Revised Water Balance Result Summary (Clay Liner)**

| 1 | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Days/month | 31.0 | 28.0 | 31.0 | 30.0 | 31.0 | 30.0 | 31.0 | 31.0 | 30.0 | 31.0 | 30.0 | 31.0 |
| 3 | Precipitation (inches) | 3.72 | 3.84 | 4.44 | 2.64 | 3.84 | 3.36 | 3.96 | 3.72 | 3.48 | 3.36 | 3.24 | 3.48 |
| 4 | Evaporation (inches) | 1.20 | 1.50 | 2.50 | 3.70 | 4.40 | 4.60 | 4.80 | 4.50 | 3.30 | 2.40 | 1.50 | 1.10 |
| 5 | Runoff (acre-feet) | 2.57 | 2.66 | 3.07 | 1.83 | 2.66 | 2.32 | 2.74 | 2.57 | 2.41 | 2.32 | 2.24 | 2.41 |
| 6 | Pond Precipitation (acre-feet) | 0.16 | 0.16 | 0.19 | 0.11 | 0.16 | 0.14 | 0.17 | 0.16 | 0.15 | 0.14 | 0.14 | 0.15 |
| 7 | Evaporation (acre-feet) | 0.05 | 0.06 | 0.10 | 0.15 | 0.18 | 0.19 | 0.20 | 0.19 | 0.14 | 0.10 | 0.06 | 0.05 |
| 8 | Infiltration (acre-feet) | 1.55 | 1.40 | 1.55 | 1.50 | 1.55 | 1.50 | 1.55 | 1.55 | 1.50 | 1.55 | 1.50 | 1.55 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | Monthly Balance (acre-feet) | 1.13 | 1.35 | 1.60 | 0.28 | 1.08 | 0.77 | 1.15 | 0.99 | 0.92 | 0.81 | 0.81 | 0.96 |
| 10 | Running Balance of Retained Pond Volume (acre-feet) | 1.13 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| 11 | Pond water surface elevation (feet) | 703.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 |
| 12 | Water surface with respect to permanent pool elevation (feet) | -2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | | | | | | | |
| 1 | | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
| 2 | Days/month | 31.0 | 31.0 | 30.0 | 31.0 | 30.0 | 31.0 | 31.0 | 28.0 | 31.0 | 30.0 | 31.0 | 30.0 |
| 3 | Precipitation (inches) | 3.96 | 3.72 | 3.48 | 3.36 | 3.24 | 3.48 | 3.72 | 3.84 | 4.44 | 2.64 | 3.84 | 3.36 |
| 4 | Evaporation (inches) | 4.80 | 4.50 | 3.30 | 2.40 | 1.50 | 1.10 | 1.20 | 1.50 | 2.50 | 3.70 | 4.40 | 4.60 |
| 5 | Runoff (acre-feet) | 2.74 | 2.57 | 2.41 | 2.32 | 2.24 | 2.41 | 2.57 | 2.66 | 3.07 | 1.83 | 2.66 | 2.32 |
| 6 | Pond Precipitation (acre-feet) | 0.17 | 0.16 | 0.15 | 0.14 | 0.14 | 0.15 | 0.16 | 0.16 | 0.19 | 0.11 | 0.16 | 0.14 |
| 7 | Evaporation (acre-feet) | 0.20 | 0.19 | 0.14 | 0.10 | 0.06 | 0.05 | 0.05 | 0.06 | 0.10 | 0.15 | 0.18 | 0.19 |
| 8 | Infiltration (acre-feet) | 1.55 | 1.55 | 1.50 | 1.55 | 1.50 | 1.55 | 1.55 | 1.40 | 1.55 | 1.50 | 1.55 | 1.50 |
| 9 | Monthly Balance (acre-feet) | 1.15 | 0.99 | 0.92 | 0.81 | 0.81 | 0.96 | 1.13 | 1.35 | 1.60 | 0.28 | 1.08 | 0.77 |
| 10 | Running Balance of Retained Pond Volume (acre-feet) | 1.15 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| 11 | Pond water surface elevation (feet) | 703.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 | 705.0 |
| 12 | Water surface with respect to permanent pool elevation (feet) | -2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

## 3.5 Downstream Flood Analysis

### 3.5.1 Introduction

The purpose of the flood control detention requirements (10- and 25-year, 6-hour storm event control) is to protect downstream properties from increased flooding due to upstream development. Current standard policies require that 10- and 25-year storms are controlled at the outlet of a site such that post-development peak discharge equals pre-development peak discharge. For commercial developments, some (or all) of the 25-year storm event control requirement can be waived if a downstream analysis indicates that the receiving drainage system meets design standards. For residential developments, some (or all) of the 10- and 25-year storm event control requirement can be waived if a downstream analysis indicates that the receiving drainage system meets design standards. The flood control detention waiver if a project discharges directly to a FEMA floodplain no longer applies. Even though the waiver not longer applies, most developments along the FEMA regulated floodplain will pass the 10 times the site area test described in Section 3.5.3. For example, any project with an area less than 64 acres that discharges directly to the floodway will discharge to a stream system with a drainage area larger than 640 acres and therefore would comply with the 10% rule requirement for downstream analysis at the system outfall.

The portion of the 10- and/or 25-year storm event control requirement that can be waived is based on how well the receiving system meets design standards. The 10- and/or 25-year storm event control cannot be waived, if through the waiver portions of the downstream system do not meet design standards.

Design standards are defined as all storm drainage system requirements described in the Charlotte-Mecklenburg Storm Water Design Manual. These include providing pipe capacity for the 10- and 25-year storm events using Mannings formula and hydraulic gradeline computations, culvert capacity for design storms based on roadway type, and providing protection for first floor flooding for the 100-year storm event. The storms that will need to be analyzed will be based on what features are located within the limits of this study area. Design storms for various features are listed in Table 3-11.

**Table 3-11: Summary of Design Standards for Downstream Analysis**

| Design feature | Design storm for analysis (all 6-hr) |
|---|---|
| Closed pipe/Channel systems/Driveway culverts | 10-year |
| Culverts (subdivision streets) | 25-year |
| Culverts (thoroughfare roads) | 50-year |
| Building footprints | 100-year |

The design storms to be analyzed will depend upon what is downstream from the project site. For example, if there is only a local street crossing within the study area, only the 25-yr 6-hr storm would need to be modeled. The other storms would have to be analyzed as needed.

### 3.5.2. Reasons for Downstream Problems

Many of the sites that are being developed are upstream from existing urbanized areas where the storm drainage infrastructure has been in place for some time. In some cases, this storm drainage infrastructure does not meet current design standards or is showing some signs of failure due to deterioration, poor installation, etc. Design standards for these systems vary based on the potential for flood damage from the 10-year flood event for the pipe and channel systems up to the 100-year flood event for the protection of living space. Current detention requirements require the attenuation of some of these flood events, but not all of the flood events. Therefore, there may be some downstream systems that experience increased discharges due to upstream development for flood events that are not addressed by the current detention requirements. Therefore, the flood damages on these properties may be exacerbated by the upstream development.

### 3.5.3 The Ten-Percent Rule

The "ten-percent" rule is a practical, flexible and effective approach for ensuring all potential impacts of flooding or increased volume from development are assessed. The ten-percent rule recognizes the fact that development and/or a structural BMP control providing detention has a "zone of influence" downstream where its effectiveness can be felt. Beyond this zone of influence the development and/or structural control becomes relatively small and insignificant compared to the runoff from the total drainage area to that point. Based on studies and master planning results, that zone of influence is considered to be the point where the drainage area controlled by the detention facility comprises 10% of the total drainage area (Debo & Reese, 1990). Although the detention exemption along floodplains will no longer be in the ordinance, most developments along the FEMA regulated floodplain will pass the 10 times the site area test. For example, any project with an area less than 64 acres that discharges directly to the floodway will discharge to a stream system with a drainage area larger than 640 acres and therefore would be immediately complying with the 10% rule requirement for downstream analysis.

For example, if the structural BMP control drains 10 acres, the zone of influence ends at the point where the total drainage area is 100 acres or greater.

Typical steps in the application of the ten-percent rule are:

1. Using a topographic map determine the lower limit of the zone of influence (10% point).
2. Using a hydrologic model determine the pre-development peak flows and timing of those peaks at each tributary junction beginning at the pond outlet and ending at the next tributary junction beyond the 10% point. Two watershed land use conditions should be considered when developing the hydrologic model and assessing the potential for downstream impacts, existing and future land use. In addition, the designer should assess other watershed conditions such as sub-basins size, upstream attenuation, etc. so that the results are conservative.

3. Change the land use on the site to post-development and rerun the model.
4. Perform appropriate hydraulic computations for the downstream system to determine if the drainage systems meet or do not meet design standards. Hydraulic computations that may need to be considered include pipe capacity computations, culvert capacity analysis, floodplain backwater computations, channel stability assessment, etc. Storm and flood events that should be assessed include the 10-, 25, 50-, and 100-year events based on the downstream system design standards. For both models, the base survey will need to identify all features that could be affected by flooding to adequately assess impacts. The accuracy of the analysis shall meet current site plan design standards and be sealed by a North Carolina Professional Engineer or Landscape Architect. The field survey shall meet current site plan design standards and be sealed by a North Carolina registered land surveyor.
5. Design the structural BMP control facility such that the pre-developed conditions and post-developed conditions are the same at the downstream site property line and downstream receiving system meets all design standards.

**Example**

Figure 3.5.1 illustrates the concept of the ten-percent rule for two sites in a watershed.

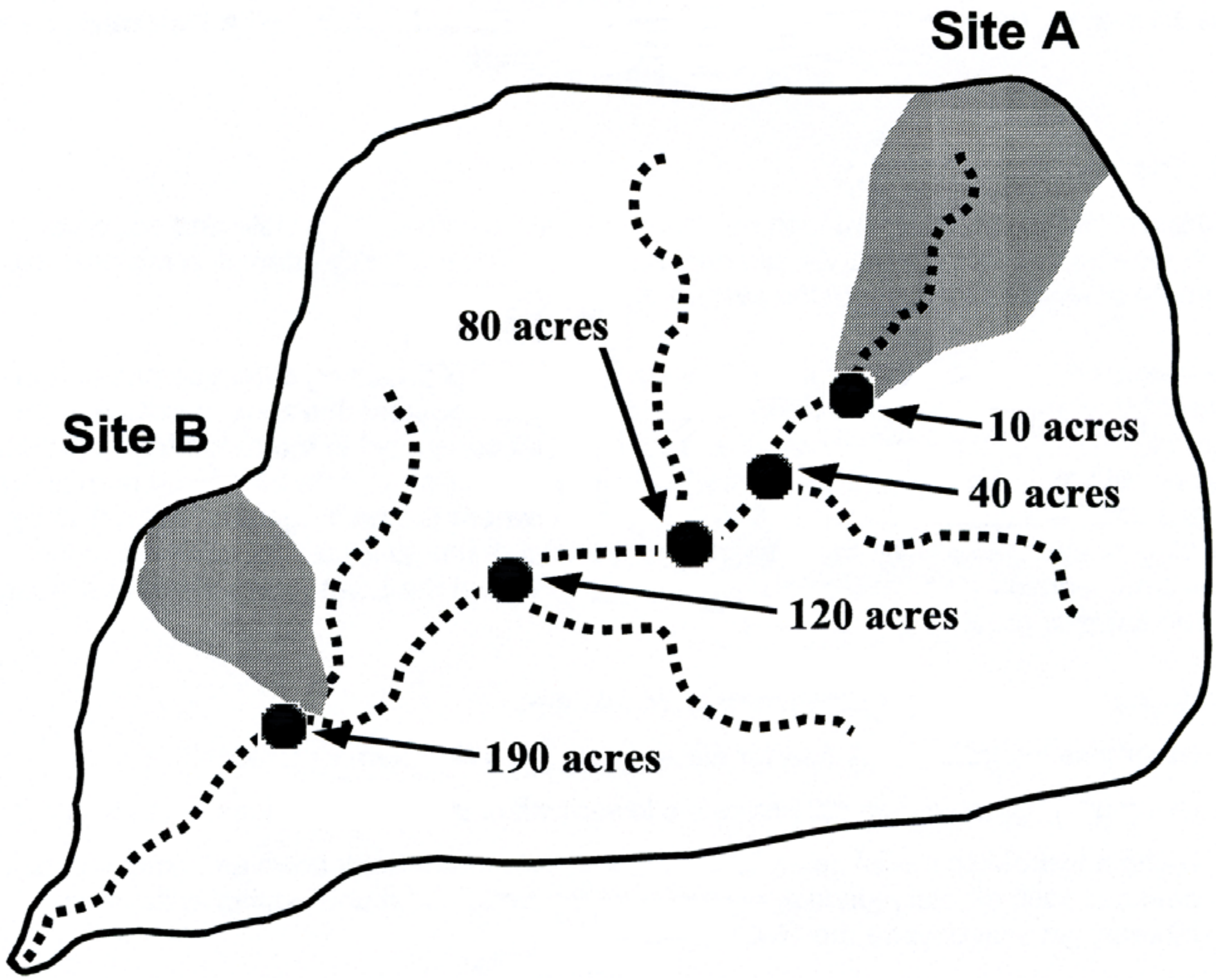


**Figure 3.5.1 Example of the Ten-Percent Rule**

Site A is a commercial development of 10 acres, all draining to a wet pond BMP. The design standards require the post-developed discharges for the 10- and 25-year storm events are controlled to pre-developed conditions at the property line unless a downstream analysis is performed that shows the receiving system can accept additional discharge. The receiving drainage system requires the assessment of the 10-, 25-, 50-, and 100-year storm events down to the ten-percent rule location (see Table 3-11 for appropriate design storms). Looking downstream at each tributary in turn, it is determined that the analysis should end at the tributary marked "120 acres". The 100-acre (10%) point is in between the 80-acre and 120-acre tributary junction points. For simplicity, the analysis can be run down to the 120-acre point, or if the designer wishes, drainage areas can be iteratively drawn to find the exact 100-ac point.

The designer constructs a HEC-1 model, or equivalent, of the 80-acre areas using existing and future land use conditions for each sub-watershed in each tributary. Major attenuation throughout the watershed that could impact the accuracy of the analysis should be included in the model in order to produce conservative results. Hydraulic computations are performed to assess the capacity of the receiving system. The downstream analysis indicates that the entire drainage system meets design standards for all appropriate storm event; 10-, 25-, 50-, and 100-year. Therefore, control of only the 10-year storm event at the outfall of the development site is required. If the downstream analysis showed that downstream system did not meet design standards, then controlling both the appropriate design storms would be required.

Site B is located downstream at the point where the total drainage area is 190 acres. The site itself is only 6 acres. The first tributary junction downstream from the 10-percent point is the junction of the site outlet with the stream. Therefore, the limits of the downstream analysis are the downstream site boundary.

## 3.6 Combined Water Quality ($WQ_v$) and Channel Protection ($CP_v$) Design

### 3.6.1 Introduction

The post-construction ordinance requires treatment of the 1-inch, 6-hour storm event to meet water quality ($WQ_v$) goals and control of the 1-year, 24-hour storm event to meet channel protection ($CP_v$) goals. For some sites (relatively small and high impervious sites) the BMP storage volume needed to meet both of these goals may be similar in size. To facilitate a simpler and more straight-forward design process, a design target has been developed that meets both the water quality treatment ($WQ_v$) and channel protection control ($CP_v$) goals of the post-construction ordinance.

The simpler and most straight-forward design process is called the *Combined Water Quality and Channel Protection Design* and was developed by assessing numerous sites with various watershed sizes and imperviousness intensity. The results of the numerous site assessment indicates that holding the 1-year, 24-hour storm event for 24 hours longer than the detention time for the 1-inch, 6-hour storm event will provide the appropriate water quality treatment. Therefore, a site designer can elect to perform a *Combined Water Quality and Channel Protection Design* for the optimal efficiency wet pond by holding the 1-year, 24-hour storm event for 120 hours (4 days detention time for the optimal efficiency design plus 24 hours) after the center of rainfall (12 hours). Design computations showing that the 1-inch, 6-hour storm event will not needed to be performed.

The *Combined Water Quality and Channel Protection Design* applies to BMPs in this Manual that are designed by routing the design storms through the BMP storage volume which include wet ponds, wetlands, and bioretention. The design is met by controlling the channel protection volume ($CP_v$) for a duration that is 24 hours longer than the design duration for the water quality ($WQ_v$) design. For example, the optimal efficiency for a wet pond is met by controlling the 1-year, 24-hour storm event for 120 hours (4 days plus 24 hours). The standard efficiency for a wet pond is met by controlling the 1-year, 24-hour storm event for 72 hours (2 days plus 24 hours). These design durations are always measured after the center of rainfall.

### 3.6.2 Example

The following design example is a re-design of the wet pond design presented in Section 4.2 using the *Combined Water Quality and Channel Protection Design*. The site data is summarized as follows:

Site Area = Total Drainage Area (A) = 10.0 acre
Impervious Area – 3.4 ac; or I=3.4/10=34.0%
Soils Types: 50% “C”, 50% “B”
Land Use: Residential (1/2 acre lots)

Figure 3.6.1 shows the site plan for the development and base hydrologic data that will be used in the design example.

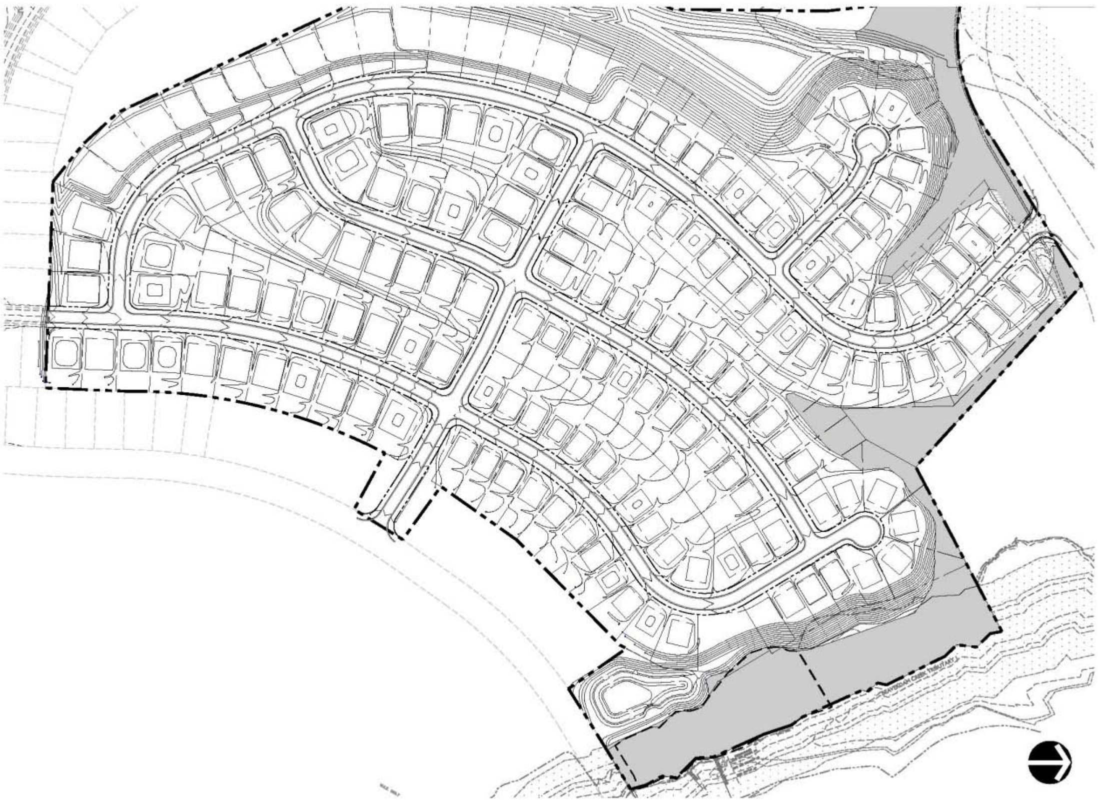

**Figure 3.6.1 Example Site Plan for Combined Water Quality and Channel Protection Design**

## Step 1 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.

$$S = 1000/CN - 10$$
$$= 1000/77.8 - 10$$
$$= 2.85 \text{ inches}$$

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

$$Q_d = (P-0.2S)^2/(P+0.8S)$$
$$= [2.58 - (0.2)(2.85)]^2/(2.58 + 0.8*2.85)$$
$$= 0.83 \text{ inches}$$

Compute watershed runoff

$CP_v$ = (0.83 inches)(10 acres)(1 foot/12 inches) = 0.69 acre-feet

The entire 1-year, 24-hour is required to be held within the wet pond dry storage volume above the permanent pool for a minimum of 120 hours. A design method that is called the "Static Method" sets the storage volume equal to the runoff volume, assumes that the storage volume fills instantaneously and empties through the outlet structure orifices and weirs. Using the Static Method, the facility would require 0.69 acre-feet for 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.

**<u>Step 2 Compute Release Rate for Combined Water Quality and Channel Protection Design</u>**

The following outlet hydraulic computations are performed using the Static Method. Routing computations must be performed to refine the design that show that a minimum of 5 percent of the runoff volume is held within the storage volume at the design duration time after the center of the design storm rainfall (12 hours for 1-year, 24-hour storm event).

- Compute the release rate for the 1-year, 24-hour storm event.

  The 1-year, 24-hour storm event is to be released over a 120 hours beyond the center of rainfall (120 hours plus 12 hours) period.

  Release rate = (0.69 ac-ft x 43560 $ft^2$/acre)/(132 hrs x 3,600 sec/hr) = 0.063 cfs

**<u>Step 3 Compute Site Hydrologic Input Parameters</u>**

Using SCS hydrologic procedures and/or computer models the data shown in Table 3-12 and 3-13 can be determined for the example development site.

**Table 3-12 Hydrologic Input Data**

| Condition | Area (acres) | CN | CN (adjusted) for 1-inch storm | $t_c$ (hours) |
|---|---|---|---|---|
| Pre-developed | 10 | 65 | N/A | 0.631 |
| Post-developed | 10 | 77.8 | 91.0 | 0.202 |

**Table 3-13 Results of Preliminary Hydrologic Calculations**
**(From Computer Model Results Using SCS Hydrologic Procedures)**

| Condition | $Q_{1\text{-year}}$ | $Q_{10\text{-year}}$ | $Q_{25\text{-year}}$ | $Q_{50\text{-year}}$ |
|---|---|---|---|---|
| Runoff | cfs | cfs | cfs | cfs |
| Pre-developed | 1.6 | 7.8 | 11.6 | 14.8 |
| Post-developed | 10.7 | 27.6 | 36.1 | 42.7 |

**<u>Step 4 Develop Storage-Elevation Table and Curve</u>**

Figure 3.6.1 shows the pond location on site, Figure 3.6.2 shows the plan view of the pond grading and Table 3-14 shows the storage-elevation data that was developed for this example.

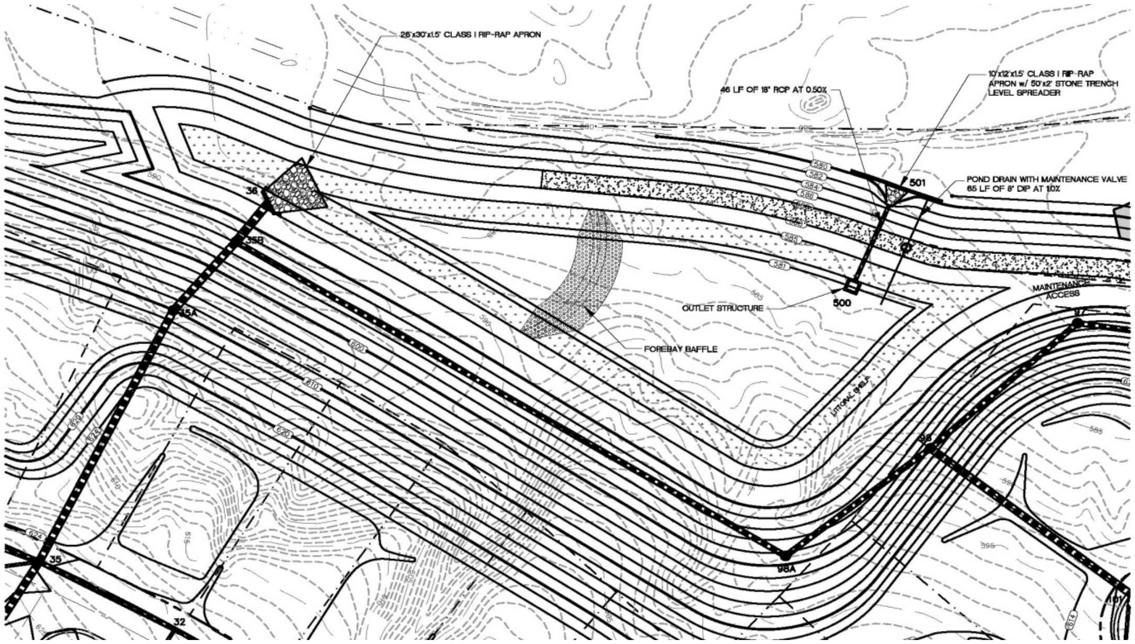


**Figure 3.6.2 Plan View of Pond Grading (Not to Scale)**

**Table 3-14 Storage-Elevation Data**

| Elevation | Area (sf) | Area (ac) | Avg. Area (ac) | Height (ft) | Inc vol (ac-ft) | Acc vol (ac-ft) | Acc vol (ac-ft) |
|---|---|---|---|---|---|---|---|
| 695 | 6400 | 0.147 | | | | 0.000 | |
| 695.5 | 6889 | 0.158 | 0.153 | 0.5 | 0.076 | 0.076 | |
| 696 | 7396 | 0.170 | 0.164 | 0.5 | 0.082 | 0.158 | |
| 696.5 | 7921 | 0.182 | 0.176 | 0.5 | 0.088 | 0.246 | |
| 697.0 | 8464 | 0.194 | 0.188 | 0.5 | 0.094 | 0.340 | |
| 697.5 | 9025 | 0.207 | 0.201 | 0.5 | 0.100 | 0.441 | |
| 698.0 | 9604 | 0.220 | 0.214 | 0.5 | 0.107 | 0.547 | |
| 698.5 | 10201 | 0.234 | 0.227 | 0.5 | 0.114 | 0.661 | |
| 699.0 | 10816 | 0.248 | 0.241 | 0.5 | 0.121 | 0.782 | |
| 699.5 | 11449 | 0.263 | 0.256 | 0.5 | 0.128 | 0.910 | |
| 700.0 | 12100 | 0.278 | 0.270 | 0.5 | 0.135 | 1.045 | 0 |
| 700.5 | 12769 | 0.293 | 0.285 | 0.5 | 0.143 | 1.187 | 0.143 |
| 701.0 | 13456 | 0.309 | 0.301 | 0.5 | 0.151 | 1.338 | 0.293 |
| 701.5 | 14161 | 0.325 | 0.317 | 0.5 | 0.158 | 1.496 | 0.452 |
| 702.0 | 14884 | 0.342 | 0.333 | 0.5 | 0.167 | 1.663 | 0.618 |
| 702.5 | 15265 | 0.350 | 0.346 | 0.5 | 0.173 | 1.836 | 0.791 |
| 703.0 | 16384 | 0.376 | 0.363 | 0.5 | 0.182 | 2.018 | 0.973 |
| 703.5 | 17161 | 0.394 | 0.385 | 0.5 | 0.193 | 2.210 | 1.166 |
| 704.0 | 17956 | 0.412 | 0.403 | 0.5 | 0.202 | 2.412 | 1.367 |
| 704.5 | 18769 | 0.431 | 0.422 | 0.5 | 0.211 | 2.623 | 1.578 |
| 705.0 | 19600 | 0.450 | 0.440 | 0.5 | 0.220 | 2.843 | 1.798 |

## Step 5 Set Basic Elevations for BMP Structure

Set basic elevations for pond structures.

- The pond bottom is set at elevation 695.0.
- Provide gravity flow to allow for pond drain, set riser invert at 694.5.
- Set barrel outlet elevation at 694.0.

Set water surface and other elevations.

- Required permanent pool volume = 1.00 ac-ft. From the elevation-storage table or curve, read the elevation that will have a cumulative volume of 1.00 ac-ft or greater = 100.0. This elevation has a cumulative volume of 1.045 ac-ft which is greater than 1.00 ac-ft to allow for a small safety factor.
- Forebay volume will be provided in two pools, each below the two major inflow location, with an average volume of 0.030 ac-ft in each. This will give the required forebay volume of 0.06 ac-ft.
- The required extended detention volume is the 1-year, 24-hour volume of 0.69 ac-ft held for 120 hours beyond the center of rainfall at 12 hours. From the elevation-storage table or curve (volume above permanent pool), read the elevation that will allow 0.69 ac-ft of storage above the permanent pool at elevation 700. The preliminary elevation to hold the Channel Protection Volume ($CP_v$) is 702.2.

**Step 6 Compute Required Outlet Structure and Stage-Discharge for Combined Water Quality and Channel Protection Volume**

Compute the required combined water quality and channel protection volume orifice diameter to release 0.69 acre-feet over 120 hours beyond 12 hours.

- Required 1-year, 24-hour runoff volume = 0.69 ac-ft
- From the elevation storage table or curve, the elevation at that storage volume = 702.2

Size the combined $WQ_v$ and $CP_v$ design orifice.

- Average extended detention release rate = (0.69 ac-ft)(43,560 $ft^2$/ac)/(132 hr)(3600 sec/hr) = 0.063 cfs
- Average head = (702.2 – 700.0)/2 = 1.10 ft
- Use orifice equation to compute cross-sectional area and diameter of outlet.
    - $Q = CA(2gh)^{0.5}$, for Q = 0.063 cfs, h = 1.15 ft, and C = discharge coefficient = 0.6
    - Solve for A: $A = 0.063 \text{ cfs} / [0.6((2)(32.2 \text{ ft/s}^2)(1.10))^{0.5}] = 0.012 \text{ ft}^2$
    - With $A = \pi d^2/4$, d = 0.125 ft = 1.5 inches
    - Use 1.5 inch orifice plate.

Compute the stage-discharge equation for the 1.5 diameter combined $WQ_v$ and $CP_v$ orifice.

- $Q = CA(2gh)^{0.5} = 0.6(0.012 \text{ ft}^2)[2(32.2 \text{ ft/s}^2)]^{0.5}(h^{0.5})$
  $Q = 0.058h^{0.5}$ Where h = wsel – 700.06
  (Note: Account for one half of the orifice diameter when calculation head).

**Step 7 Calculate $Q_{10}$ and $Q_{25}$ (if required) Release Rate(s) and Water Surface Elevation(s)**

In order to calculate the 10-year and 25-year (if required) release rate(s) and water surface elevation(s), the designer must set up a stage-storage-discharge relationship for the control structure for the low flow release pipes ($WQ_v$ and $CP_v$) plus the 10-year and 25-year (if required) storm(s).

The first step is to route the 1-year, 24-hour storm event through the facility using the orifice and stage-storage developed by the Static Method design. The following HEC-1 output file illustrates the results. Note that the peak stage elevation for the 1-year, 24-hour storm event is 701.99 which is less than 702.2, the peak stage assumed during the Static Method design. In addition, export of the outflow hydrograph through the TAPE21 function indicates that 15% of the runoff volume remains within the basin at the time duration 132 hours, therefore, additional iterations of the 1-year, 24-hour routing are performed. The goal of the additional iterations is to increase the outlet size and reduce the storage volume so that only 5% of the runoff volume remains in the wet pond storage volume at the time duration of 132 hours.

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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        *
 * RUN DATE   14MAR07  TIME  10:46:00    *                                              *          (916) 756-1104             *
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                                                    X     X  X        X                X
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                                                    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
                      *  *************************************************************************
                      *
                      *     TIME SPECIFICATION CARD
                      *     TOTAL COMPUTATIONAL DURATION 132 HOURS
          4           IT      4       0       0    1980
                      *  DIAGRAM
                      *     OUTPUT CONTROL CARD
          5           IO      5       0       0
                      *

          6           KK    PRE1
          7           IN      6
          8           PB    2.58
                      * ****************************************************************************
                      * **************** 1-YEAR, 24-HOUR STORM EVENT ******************************
                      * ********* 6 MINUTE TIME INCREMENT,24-HOUR STORM EVENT **********************
                      * ****************************************************************************
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         12           PI   .0013   .0013   .0013   .0013   .0014   .0013   .0014   .0014   .0013   .0014
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         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   10-ACRE PRE-DEVELOPED CONDITIONS
         35           KO      5       0       0       0      21
         36           BA   .0156
         37           LS      0    65.0       0
         38           UD   0.378
1                                        HEC-1 INPUT                                                  PAGE  2

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


         39           KK   POST1
         40           KM   10-ACRE POST-DEVELOPED CONDITIONS
         41           KO      5       0       0       0      21
         42           BA   .0156
         43           LS      0    77.8       0
         44           UD   0.121
```

```
           45            KK  DETE10
           46            KO      5       0       0       0      21
           47            KM   DETENTION BASIN DESIGN FOR 1-YEAR, 24-HOUR STORM EVENT HELD FOR 132 HOURS
           48            KM   POST-DEVELOPED WITH CONTROLS
           49            KM   1.50 INCH ORIFICE TO ELEVATION 700.0
           50            KM   TOP OF EXTENDED DETENTION STORAGE 702.2
           51            KM   BASED ON STATIC METHOD
           52            RS      1    ELEV     700
           53            SV      0    .143    .293    .452    .618    .690
           54            SE    700   700.5     701   701.5     702   702.2
           55            SQ   0.00   0.039   0.057   0.071   0.082   0.088
           56            ZZ
1*****************************************                                              ***************************************
 *                                       *                                              *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                              *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                              *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                              *         609 SECOND STREET           *
 *                                       *                                              *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   14MAR07  TIME  10:46:00   *                                              *          (916) 756-1104             *
 *                                       *                                              *                                     *
*****************************************                                              ***************************************


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

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

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

          HYDROGRAPH AT
+                              PRE1          1.   12.47            0.           0.           0.      .02

          HYDROGRAPH AT
+                             POST1         10.   12.13            1.           0.           0.      .02

          ROUTED TO
+                            DETE10          0.   22.93            0.           0.           0.      .02
+                                                                                                              701.99       24.27


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

The following HEC-1 output illustrates that result of the additional iterations that were performed to refine the Static Method orifice size. The goal is to increase the outlet size and reduce the storage volume so that only 5% of the runoff volume remained in the basin at the time duration of 132 hours. The orifice size was increased from 1.5 inches to 1.7 inches by performing the additional iterations. The routed peak stage was decreased from 701.99 to 701.93 by the additional iterations. Export of the outflow hydrograph through the TAPE21 function indicates that 7% of the runoff volume remains within the basin at the time duration 132 hours instead of 15% that remained in the wetpond storage volume using the 1.5 inch orifice.

```
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   14MAR07  TIME  10:58:28   *                                              *          (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       MECKLENBURG COUNTY BMP DESIGN MANUAL
            2             ID       ANALYZED BY ABC ENGINEERING
            3             ID       DATE: OCTOBER 2006
                          *  ***************************************************************************
                          *
```

```
                  *     TIME SPECIFICATION CARD
                  *     TOTAL COMPUTATIONAL DURATION 132 HOURS
   4              IT       4       0       0    1980
                  *  DIAGRAM
                  *     OUTPUT CONTROL CARD
   5              IO       5       0       0
                  *

   6              KK    PRE1
   7              IN       6
   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   10-ACRE PRE-DEVELOPED CONDITIONS
  35              KO       5       0       0       0      21
  36              BA   .0156
  37              LS       0    65.0       0
  38              UD   0.378
1                                          HEC-1 INPUT                                             PAGE  2

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


  39              KK   POST1
  40              KM   10-ACRE POST-DEVELOPED CONDITIONS
  41              KO       5       0       0       0      21
  42              BA   .0156
  43              LS       0    77.8       0
  44              UD   0.121

  45              KK  DETE10
  46              KO       5       0       0       0      21
  47              KM   DETENTION BASIN DESIGN FOR 1-YEAR, 24-HOUR STORM EVENT HELD FOR 132 HOURS
  48              KM   POST-DEVELOPED WITH CONTROLS
  49              KM   1.70 INCH ORIFICE TO ELEVATION 700.0
  50              KM   TOP OF EXTENDED DETENTION STORAGE 702.2
  51              KM   BASED ON STATIC METHOD
  52              RS       1    ELEV     700
  53              SV       0    .143    .293    .452    .618    .690
  54              SE     700   700.5     701   701.5     702   702.2
  55              SQ    0.00   0.050   0.073   0.091   0.105   0.111
  56              ZZ
1*****************************************                                            ***************************************
 *                                       *                                            *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                            *   U.S. ARMY CORPS OF ENGINEERS      *
 *            JUN  1998                  *                                            *   HYDROLOGIC ENGINEERING CENTER     *
 *         VERSION 4.1                   *                                            *         609 SECOND STREET           *
 *                                       *                                            *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   14MAR07  TIME  10:58:28   *                                            *           (916) 756-1104            *
 *                                       *                                            *                                     *
 *****************************************                                            ***************************************


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


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

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

          HYDROGRAPH AT
+                           PRE1       1.   12.47          0.          0.           0.        .02

          HYDROGRAPH AT
+                          POST1      10.   12.13          1.          0.           0.        .02

          ROUTED TO
+                         DETE10       0.   23.67          0.          0.           0.        .02
+                                                                                                      701.93      24.27


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

The second and third step is to route the 10- and 25-year, 6-hour storm events through the facility using an iterative process so that the post-development discharge rates are less than the pre-development conditions. The example (the separate $WQ_v$ and $CP_v$ design shown in Chapter 4.2.9) for this site used a 15-inch orifice to control the 10- and 25-year, 6-hour storm events for flood control which is expected to be the approximate required orifice size for this example (*Combined Water Quality and Channel Protection design*).

The following HEC-1 output file illustrates the results of the iterative process for designing the flood control portion of the wet pond. Intermediate steps are not presented. The fourth step is to design the emergency spillway for the 50-year storm event. The elevation of the emergency spillway is set above the peak stage of the routed 25-year storm event. A freeboard of 6 inches above the 50-year peak stage to the top of embankment is required.

```
1****************************************                                                ***************************************
 *                                      *                                                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                                *   U.S. ARMY CORPS OF ENGINEERS      *
 *              JUN   1998              *                                                *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1                *                                                *         609 SECOND STREET           *
 *                                      *                                                *      DAVIS, CALIFORNIA 95616        *
 * RUN DATE   14MAR07  TIME  14:32:30   *                                                *           (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       MECKLENBURG COUNTY BMP DESIGN MANUAL
             2           ID       ANALYZED BY ABC ENGINEERING
             3           ID       DATE: OCTOBER 2006
                         *  ***************************************************************************
                         *
                         *     TIME SPECIFICATION CARD
                         *     TOTAL COMPUTATIONAL DURATION 6 HOURS
             4           IT       1       0       0     365
                         *  DIAGRAM
                         *     DATA INPUT CARD
             5           IN       5
                         *     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   10-ACRE PRE-DEVELOPED CONDITIONS
            17           KO       5       0       0       0      21
            18           BA   .0156
            19           LS       0    65.0       0
            20           UD   0.378

            21           KK   POST1
            22           KM   10-ACRE POST-DEVELOPED CONDITIONS
            23           KO       5       0       0       0      21
            24           BA   .0156
            25           LS       0    77.8       0
            26           UD   0.121

            27           KK  DETE10
            28           KO       5       0       0       0      21
            29           KM   DETENTION BASIN DESIGN FOR 1-YEAR, 24-HOUR STORM EVENT HELD FOR 132 HOURS
            30           KM   POST-DEVELOPED WITH CONTROLS
            31           KM   1.70 INCH ORIFICE TO ELEVATION 700.0
            32           KM   TOP OF EXTENDED DETENTION STORAGE 702
            33           KM   15-INCH ORIFICE ACTIVATES FOR STAGES ABOVE 702
            34           RS       1    ELEV     700
            35           SV       0    .143    .293    .452    .618    .791    .973   1.166   1.367
            36           SE     700   700.5     701   701.5     702   702.5     703   703.5     704
            37           SQ    0.00   0.050   0.073   0.091   0.105   8.091   9.106  10.019  10.855
```

```
         38           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   14MAR07  TIME  14:32:30   *                                                       *          (916) 756-1104             *
 *                                       *                                                       *                                     *
 *****************************************                                                       ***************************************

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

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

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

          HYDROGRAPH AT
+                              PRE1          8.    3.62            1.            1.            1.        .02

          HYDROGRAPH AT
+                             POST1         28.    3.27            3.            3.            3.        .02

          ROUTED TO
+                            DETE10          7.    3.68            1.            1.            1.        .02
+                                                                                                                  702.45        3.68


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

```
1*****************************************                                                       ***************************************
 *                                       *                                                       *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                       *   U.S. ARMY CORPS OF ENGINEERS      *
 *            JUN   1998                 *                                                       *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                       *         609 SECOND STREET           *
 *                                       *                                                       *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   14MAR07  TIME  14:34:59   *                                                       *          (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       MECKLENBURG COUNTY BMP DESIGN MANUAL
            2           ID       ANALYZED BY ABC ENGINEERING
            3           ID       DATE: OCTOBER 2006
                        *  ****************************************************************************
                        *
                        *     TIME SPECIFICATION CARD
                        *     TOTAL COMPUTATIONAL DURATION 6 HOURS
            4           IT       1       0       0     365
                        *  DIAGRAM
                        *     DATA INPUT CARD
            5           IN       5
                        *     OUTPUT CONTROL CARD
            6           IO       5       0       0
                        *

            7           KK    PRE1
                        * ******************************************************************************
                        * **************** 25-YEAR, 6-HOUR STORM EVENT ******************************
                        * ******************************************************************************
            8           PI    .000    .014    .014    .014    .015    .015    .015    .016    .016    .017
            9           PI    .017    .018    .018    .019    .019    .020    .021    .022    .023    .025
           10           PI    .027    .028    .029    .031    .033    .043    .046    .049    .053    .058
           11           PI    .064    .093    .104    .120    .189    .235    .466    .680    .324    .208
           12           PI    .131    .111    .098    .067    .061    .055    .051    .048    .045    .034
           13           PI    .032    .030    .029    .027    .026    .023    .022    .021    .021    .020
           14           PI    .019    .019    .018    .017    .017    .016    .016    .016    .015    .015
           15           PI    .014    .014    .014    .000
           16           KM   10-ACRE PRE-DEVELOPED CONDITIONS
           17           KO       5       0       0       0      21
           18           BA   .0156
           19           LS       0    65.0       0
           20           UD   0.378
```

```
          21           KK   POST1
          22           KM   10-ACRE POST-DEVELOPED CONDITIONS
          23           KO      5       0       0       0      21
          24           BA   .0156
          25           LS      0    77.8       0
          26           UD   0.121

          27           KK  DETE10
          28           KO      5       0       0       0      21
          29           KM   DETENTION BASIN DESIGN FOR 1-YEAR, 24-HOUR STORM EVENT HELD FOR 132 HOURS
          30           KM   POST-DEVELOPED WITH CONTROLS
          31           KM   1.70 INCH ORIFICE TO ELEVATION 700.0
          32           KM   TOP OF EXTENDED DETENTION STORAGE 702
          33           KM   15-INCH ORIFICE ACTIVATES FOR STAGES ABOVE 702
          34           RS      1    ELEV     700
          35           SV      0    .143    .293    .452    .618    .791    .973   1.166   1.367
          36           SE    700   700.5     701   701.5     702   702.5     703   703.5     704
          37           SQ   0.00   0.050   0.073   0.091   0.105   8.091   9.106  10.019  10.855
          38           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   14MAR07  TIME  14:34:59   *                                                      *          (916) 756-1104             *
 *                                       *                                                      *                                     *
 *****************************************                                                      ***************************************

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


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

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

             HYDROGRAPH AT
+                               PRE1      12.    3.60           2.          2.           2.         .02

             HYDROGRAPH AT
+                              POST1      36.    3.27           4.          4.           4.         .02

             ROUTED TO
+                             DETE10       9.    3.68           2.          2.           2.         .02
+                                                                                                            702.97        3.68


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


1*****************************************                                                      ***************************************
 *                                       *                                                      *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                      *   U.S. ARMY CORPS OF ENGINEERS      *
 *             JUN   1998                *                                                      *   HYDROLOGIC ENGINEERING CENTER     *
 *          VERSION 4.1                  *                                                      *         609 SECOND STREET           *
 *                                       *                                                      *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   14MAR07  TIME  14:37:11   *                                                      *          (916) 756-1104             *
 *                                       *                                                      *                                     *
 *****************************************                                                      ***************************************


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



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

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


1                                                    HEC-1 INPUT                                                 PAGE  1

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

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

            7          KK    PRE1
                       * ****************************************************************************
                       * **************** 50-YEAR, 6-HOUR STORM EVENT ******************************
                       * ****************************************************************************
```

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            PI    .000    .016    .016    .016    .017    .017    .018    .018    .019    .019
            PI    .020    .020    .021    .022    .022    .023    .024    .025    .026    .031
            PI    .032    .033    .035    .037    .039    .049    .053    .056    .061    .066
            PI    .073    .103    .116    .133    .209    .260    .513    .749    .356    .231
            PI    .145    .124    .109    .077    .069    .063    .058    .054    .051    .040
            PI    .038    .036    .034    .033    .031    .026    .025    .024    .023    .023
            PI    .022    .021    .021    .020    .019    .019    .018    .018    .017    .017
            PI    .017    .016    .016    .000
            KM   10-ACRE PRE-DEVELOPED CONDITIONS
            KO       5       0       0       0      21
            BA   .0156
            LS       0    65.0       0
            UD   0.378

            KK   POST1
            KM   10-ACRE POST-DEVELOPED CONDITIONS
            KO       5       0       0       0      21
            BA   .0156
            LS       0    77.8       0
            UD   0.121

            KK  DETE10
            KO       5       0       0       0      21
            KM   DETENTION BASIN DESIGN FOR 1-YEAR, 24-HOUR STORM EVENT HELD FOR 132 HOURS
            KM   POST-DEVELOPED WITH CONTROLS
            KM   1.70 INCH ORIFICE TO ELEVATION 700.0
            KM   TOP OF EXTENDED DETENTION STORAGE 702
            KM   15-INCH ORIFICE ACTIVATES FOR STAGES ABOVE 702
            KM   20 FOOT EMERGENCY SPILLWAY SET AT 703.0
            RS       1    ELEV     700
            SV       0    .143    .293    .452    .618    .791    .973   1.166   1.367
            SE     700   700.5     701   701.5     702   702.5     703   703.5     704
            SQ    0.00   0.050   0.073   0.091   0.105   8.091   9.106  28.404  62.855
            ZZ
1*****************************************                                                    ***************************************
 *                                       *                                                    *                                     *
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 *                                       *                                                    *                                     *
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                                  MECKLENBURG COUNTY BMP DESIGN MANUAL
                                  ANALYZED BY ABC ENGINEERING
                                  DATE: OCTOBER 2006

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

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

          HYDROGRAPH AT
+                             PRE1           15.     3.58            3.           3.           3.         .02

          HYDROGRAPH AT
+                            POST1           43.     3.25            4.           4.           4.         .02

          ROUTED TO
+                           DETE10           17.     3.52            3.           3.           3.         .02
+                                                                                                                  703.21        3.52

 *** NORMAL END OF HEC-1 ***
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## Table 3-15 Summary of Controls Provided

| Control Element | Type/Size of Control | Stor. (ac-ft) | Peak Elev. (MSL) | Disc. (cfs) | Remarks |
|---|---|---|---|---|---|
| Permanent Pool | N/A | 1.00 | 700.00 | N/A | 3.33 times 1-inch storm event volume |
| Forebay | Riprap weir wall | 0.06 | 700.00 | N/A | Two forebays, one at each major inflow point |
| Water Quality Extended Detention ($WQ_{v\text{-}ed}$) | 1.7-inch orifice at 700.0 and 2.0-foot tall weir | N/A | N/A | N/A | Not modeled |
| Channel Protection ($CP_v$) | 1.7-inch orifice at 700.0 and 2.0-foot tall weir | 0.60 | 701.93 | 0 | 7% of runoff volume remains in basin at 132 hours (120 hours after center of rainfall) |
| Overbank Flood Protection $Q_{10}$ | 15-inch orifice at 700.0 | 0.77 | 702.45 | 8 | Same orifice control was designed for the 10- and 25-year storm events |
| Overbank Flood Protection $Q_{25}$ | 15-inch orifice at 700.0 | 0.96 | 702.97 | 9 | Same orifice control was designed for the 10- and 25-year storm events |
| Extreme Flood Protection $Q_{50}$ | 20-foot weir at 703.00 | 1.05 | 703.21 | 17 | Top of embankment is set at 704. |

Comparison of the results of the wet pond design using the *Combined Water Quality and Channel Protection* approach with the design of the wet pond using a standard separate Water Quality ($WQ_v$) and Channel Protection ($CP_v$) design approach indicates that the BMP storage volume is very close to the same size. In the case of this example, the additional storage volume needed to comply with the combined design approach was offset by the benefits of routing the design storm events. These differences may be greater for other site types, sizes, imperviousness, etc.

## References


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