3.0 SECTION 3: STORMWATER MANAGEMENT CALCULATIONS

3.1 Stormwater Management Objectives

Stormwater quality and quantity control are required by City of Greensboro's Ordinance Sections 30-7 and 27-22. They are required as follows:

1. **Stormwater Quality Control (Sec 30-7 of City Ordinance)**:
   Applicable to high density development within the City's jurisdictional limits. *Required to* provide structural control that removes 85% Total Suspended Solids (TSS) associated with the runoff from the first one (1) inch of rain. In addition, high density projects must discharge the storage volume during the 1 yr 24 hr storm at a peak rate equal to or less than the predevelopment peak discharge. Runoff volume drawdown time shall be a minimum of fourty-eight (48) hours but no more than one hundred twenty (120) hours.

2. **Stormwater Quantity Control (Sec 27-22 of City Ordinance):**
   Applicable to all new development sites within the City that increase the net built-upon area of the site by more than 400 square feet or that result in a change to the predevelopment drainage patterns.
   Required to minimize off-site flooding, drainage and erosion problems.

The stormwater management (SWM) plan must indicate that these minimum control requirements are met, where applicable. An "ideal site SWM Plan" in most cases is one in which the complete pre-developed stormwater runoff characteristics of the site are maintained in the post-developed conditions, including emulation of the pre-developed runoff hydrographs and pollutant runoff characteristics, and is consistent with an approved watershed master plan. Low-impact or no impact developments which incorporate non-structural and/or structural stormwater management practices promote improved urban stormwater management programs and minimize adverse downstream impacts.

3.1.1 Quality Control for High Density Development in Water Supply Watershed Areas and Other Watershed District (Ordinance Section 30-7)

Section 30-7 requires an "engineered" stormwater quality control to improve the quality of stormwater runoff from new high density development sites. Exemptions to these rules can be found on Section 30-7-1.12(C) but only for Development in Other Watershed Districts. The stormwater quality control must be an acceptable structural BMP. The requirements and guidelines for designing these BMPs are presented in the State BMP Manual. Additional design guidelines (beyond the minimum State's Requirements) for BMPs are listed throughout this Manual.
The engineer's certification of stormwater quality control on the appropriate completed form, which is provided in Table 30-7-1-5 of the City's Ordinance, is required for proposed high density developments.

3.1.2 Quantity Control (Ordinance Section 27-22)

Section 27-22 requires a hydrologic and hydraulic engineering analysis to evaluate off-site impacts due to increased stormwater runoff from new development and/or redevelopment sites within city limits. Where impacts are determined, it is the developer's responsibility to provide stormwater improvements to minimize the potential problems.

Site Analysis

1. Evaluate the peak runoff from the property for the pre-development (existing) conditions (Qpre) during a 24-hour rainfall sequence with a recurrence interval of both 2 years and 10 years (where runoff discharges from the property at more than one location, evaluate each location). The 24-hour rainfall sequences for the 2 and 10 year recurrence storms, depth-duration-frequency table, and intensity-duration-frequency table, for the Greensboro area are provided in Appendix C. The rainfall values in the 24-hour rainfall sequence are based on "Type II distribution" (applicable to the Greensboro area, as excerpted from NWS TP-40 and HYDRO-35) of the 24 hour rainfall of 3.38 inches and 4.82 inches for 2- and 10-year recurrence rain storms, respectively.

2. Evaluate the peak runoff from the property for the post-development conditions (Qpost) during a 24-hour rainfall sequence with a recurrence interval of both 2 years and 10 years (where runoff discharges from the property at more than one location, evaluate each location).

3. Compare the peak runoff value(s) for post-development conditions (Qpost) with the pre-development conditions (Qpre) for both the 2-year and 10-year recurrence storms, 24- hour rainfall sequence. If either of the post-development peak flows are greater than the pre-development peak flows, the designer must perform a preliminary and/or detailed hydrologic and hydraulic analysis of the off-site stormwater conveyance system to indicate downstream impacts of any increased stormwater flows to determine if stormwater management improvements are necessary, or provide on-site stormwater control improvements that reduce post-development peak flows of the 2-year and 10-year recurrence storms, 24- hour rainfall sequence to the pre-development peak conditions, or participate in an approved downstream regional SWM facility, if available.

Off-site Analysis

For new development sites where on-site controls are not provided to reduce post-development flows to pre-development flows, an off-site analysis will be required, unless otherwise exempt (in writing) by the City. Where on-site quantity controls are provided to reduce post-development flows to pre-development flows, an off-site analysis may generally not be required, provided that conditions in an approved watershed master plan are satisfied. In some cases, however, it is possible that on-site stormwater controls may exacerbate system-wide drainage problems, and thus the designer should verify that the SWM Plan does not create new problems downstream. Therefore, it is recommended that an off-site analysis be performed prior to sizing a quantity control improvement to reduce post-development rates to pre-development rates as the analysis may indicate that different on-site stormwater controls are needed for the given development (other than those developed based on a site-specific analysis only) or that minimal stormwater control measures are required for the site.

Downstream Limits of Analysis: In determining downstream effects from the proposed site development or redevelopment activity, hydrologic and hydraulic engineering studies shall extend downstream to a point where the proposed site development or redevelopment represents less than ten (10) percent of the total drainage area or watershed. This point is referred to as the "10% point."

For example, a 5-acre site located near the headwaters of a drainage basin is proposed for sustainable development of which 4 acres are proposed to be disturbed (that is, the runoff will increase on 4 acres of the site after it is developed). The 4 acres drain to one location before discharging from the site. The downstream limit of analysis would be where the contributory watershed equals 40 acres. In general, the area of interest for analysis is the property / site itself, the drainage exit point of the property, and each component (channel, pipe, culvert, overland flow etc.) of the downstream system to the 10% point in the watershed, at a minimum.

Design Storm Events for Analysis: The studies shall be based on an analysis of both 2- and 10-year design storm events.

Analysis Criteria: The analysis should examine whether the design storm events of interest cause or increase <u>flooding, drainage, or erosion problems</u> on off-site property. In determining downstream effects from the proposed development, studies shall extend downstream to the 10% point and should include:

a) routing of peak flows to the 10% point within the watershed using accepted hydraulic/hydrologic methods described in Section 4 of the State BMP Manual, and

b) if peak flow calculations indicate that adjacent development(s) or downstream properties might be adversely impacted by the proposed development, then hydraulic step-backwater calculations (Corps of Engineers' computer models HEC-2 or HEC-RAS are recommended where detailed hydraulic analysis is required) shall be performed and flood elevations determined for the areas impacted. *Detailed hydrologic and hydraulic engineering studies can be costly, thus the Guidance Manual recommends detailed studies only where peak flow hydrograph routing analysis indicates that drainage / flooding problems might be present.*

Land Use Conditions: Hydrologic / hydraulic studies should utilize the following land use conditions for analysis:

- use existing conditions for downstream areas of interest

- for development of watershed hydrographs (off-site drainage areas), existing conditions land use is the minimum requirement, but future land use conditions are recommended for a conservative analysis

- the effects of upstream stormwater detention facilities can be considered in the analysis only if such structures (i.e., regional facilities) have been accepted for maintenance by the City or otherwise approved by the City.

<u>Implementation of Stormwater Control Improvements</u>

All high density projects must discharge the storage volume at a peak discharge rate equal or less than the predevelopment peak discharge rate for the <u>1-yr, 24-hr storm</u> to meet water quality requirements.

If it is determined that the proposed development of the site does contribute to flooding, drainage or soil erosion problems at any location between the proposed development site and the 10 percent downstream point, then onsite stormwater quantity control improvements must be implemented. **In addition, if downstream problems are known to exist, the proposed development cannot increase the runoff peak (2-yr and 10-yr storms) and therefore stormwater quantity control improvements must be implemented.** Improvements may consist of:

1. On-site peak reduction – The developer may choose to use nonstructural approaches such as natural or engineered swales, depressions in the land and other natural approaches, or structural approaches such as detention structures, extended detention facilities, and alternative Best Management Practices (BMPs) with provisions for stormwater quantity control. *A combination of nonstructural and structural approaches is encouraged.*

2. Off-site peak reduction – The developer may use a publicly or privately owned off-site facility where: the facility is functional (within 2 years for proposed public facilities); the owner/entity has accepted stormwater runoff from the site; it can be demonstrated that the facility is sized to handle the increased flow; the owner has participated and/or implemented a maintenance agreement for use of the facility; it is demonstrated that there are no quantity problems between the site and the off-site facility.

3. Improvements to the downstream stormwater sewer system – Where it is determined that downstream conveyance consist of a storm sewer system and the best solution is to upgrade the downstream sewer system, this may be done provided that the downstream property owner where the improvements will be made grants a temporary construction easement and the improvement will not cause other problems downstream. The site developer is to coordinate with the City on all proposed downstream improvements.

Design Storm Events: Storage volume must be released at a peak discharge rate equal to or less than the predevelopment peak discharge rate. For the Stormwater study the improvements shall be evaluated based on 1, 2- and 10-year 24-hour design storm events.

Method for Design: The designer should demonstrate that the proposed improvements are adequate to minimize downstream problems. Hydraulic/hydrologic methods presented in Section 3.2.4 of this Manual supplementing Section 3.2 of the State's Manual should be used to evaluate the proposed improvement. An example of an evaluation of a detention facility is provided in Appendix 2.

Land Use Conditions: For site specific design of SWM control structures / facilities, use fully developed land use conditions for the site and existing land use conditions for any upstream areas draining to or through the facility (future land use conditions are recommended, however, for a conservative analysis).

Details of Quantity Control Requirements

The following chart explains in detail the City's requirements of the 10% study. Each explanation reflects the potential requirements that Engineers and Developers must meet to address the Quantity Control Requirements. Cases not specified below will be analyzed on a case by case basis.

CASE 1	10% Study is submitted. The study shows that the existing storm drainage system can handle the 2 & 10 yr pre and post development conditions. The study provides the analysis of swales, pipes, etc. Project will be approved provided that all the required information related to Stormwater Management is submitted
CASE 2	10% Study is submitted. The study shows that the existing storm drainage system can handle the 2 & 10 yr pre development conditions. The study also shows that the downstream system cannot handle postdevelopment conditions. The developer/engineer has two options: option one is to detain the runoff on site and reduce the 2 and 10 yr storms to predevelopment conditions; option two is to upgrade the existing storm drainage system so it can handle the proposed development. If option two is chosen, future conditions (i.e. ultimate buildout conditions within the sub watershed) will have to be studied as well. Developer/engineer will not be responsible for upgrading the existing system to handle future conditions but the City will require that the analysis be submitted so the City can evaluate the option to pay for the incremental upsizing of existing storm drainage system between the proposed development and ultimate buildout. The study must include the analysis of swales, pipes, etc. Project will be approved provided that all the required information is submitted.
CASE 3	10% Study is submitted. The study shows that the existing storm drainage system cannot handle the 2 & 10 yr runoff in either the pre-development conditions or the post-development conditions. If the proposed development drains to an existing system that can not be upgraded (railroad, DOT road, etc) the Developer/engineer must provide a runoff detention facility and submit analyses showing that the proposed quantity control measure will handle the difference in the runoff peak values associated with the proposed development conditions and the existing system's capacity for the 2 and 10 yr storms. In addition, the City may require ultimate buildout conditions analysis. Developer/engineer will not be responsible for upgrading the existing system to future conditions. The study must include the analysis of swales, pipes, etc. Project will be approved provided that all the required information relating Stormwater Management is submitted.

Additional Stormwater Management for Public Benefits

Where the Enforcement Officer determines that additional storage capacity in a stormwater management facility beyond that required for on-site stormwater management is necessary in order to enhance or provide for the public health, safety, and general welfare, to correct undesirable existing drainage or flooding conditions or to provide greater protection for future development, the Enforcement Officer may:

1. require that the applicant grant necessary easements over, through or under the applicant's property to provide access to or drainage for such a facility;

2. require that the applicant attempt to obtain from the owners of property where the proposed stormwater management facility is to be located, any easements necessary for the construction and maintenance of same (and failing the acquisition of such easement(s) the City may, at its option, assist in such matter by purchase, condemnation, dedication or otherwise, and subject to item 3 below, with any cost incurred thereby to be paid by the City); and/or

3. Participate financially in the construction of such facility or improvement to the extent that such facility or improvement exceeds the required on-site stormwater management determined by the Enforcement Officer.

To implement this provision, both the City and owner/developer must be in agreement with the proposed stormwater management facility that includes additional storage capacity and jointly develop a cost sharing plan which is agreeable to all parties involved.

3.1.3 Engineer's Certification of Stormwater Quantity Control

For new development plans within the city limits of Greensboro, one of the following certifications should be made.

1. *The development shown on this plan is consistent with the provisions contained on the preliminary plan/site plan ____(name of plan)______ , which was approved prior to July 1, 1999 and which approval has not lapsed, as specified in Section 30-6-12 of the Greensboro Development Ordinance, and therefore is exempt from compliance with Section 27-22 of the Stormwater Management Ordinance.*

2. *The net increase in built-upon area is less than 400 square feet;, therefore, this development is exempt from subsection (g)(2) "Quantity Control Requirements" of Section 27-22 of the Stormwater Management Ordinance.*

3. *The stormwater management study included with this plan indicates that that to the best of my knowledge, belief and information there will be no downstream flooding, drainage, or erosion problems as a result of the proposed development between the point where the runoff discharges from the property to where the site development area represents less than 10% of the total drainage area. Therefore, no quantity control improvement is proposed.*

4. *The stormwater management study included with this plan indicates that to the best of my knowledge, belief and information,* there *will be downstream flooding, drainage, or erosion problems associated with this development. The proposed stormwater management improvement(s) indicated on this plan is (will be) designed to minimize increased flooding, drainage and erosion problems from occurring between the point where the runoff discharges from the property to where the site development area represents less than 10% of the total drainage area.*

5. *The stormwater control structure(s) shown on this plan is (will be) designed to reduce the peak flow rates in the post-development 2-year 24 hour storm event and the 10-year 24 hour storm event to pre-development peak flow rates.*

6. T*he 10% point is located upstream of the site outlet; therefore no additional quantity control is required.*

3.2 Peak Flow Calculations

3.2.1 Hydraulic/Hydrologic Methods

The following hydraulic/hydrologic methods are accepted by the City for use to address quantity and quality requirements.

<u>Hydrologic Methods (hydrograph formulation and peak flow estimation)</u>

- NRCS (Natural Resources Conservation Service, U.S. Department of Agriculture) hydrologic methods (formerly known as the SCS, Soil Conservation Service) are preferred and acceptable for all applications. NRCS methods include those contained in the TR-55 publication and corresponding computer program.

    - The hydrograph formulation methodology - Tabular Hydrograph method is the preferred method. A summary of this method is given in Appendix 2.

    - Runoff flood peaks for small catchment areas or sub watersheds (approximately 50 acres or less) may be determined using the methodology presented in Chapter 4 of TR-55. However, as pointed out under Limitations in Chapter 4, if a hydrograph is needed or watershed subdivision is required, the Tabular Hydrograph method given in Chapter 5 should be used.

    - The NRCS routines applied within the US Army Corps of Engineers computer models HEC-1 and HEC-HMS are preferred and acceptable for most applications. (The Corps of Engineers HEC-1 / HEC-HMS models are preferred over the NRCS TR-20 model since Corps models are used by the City in watershed modeling and master planning.)

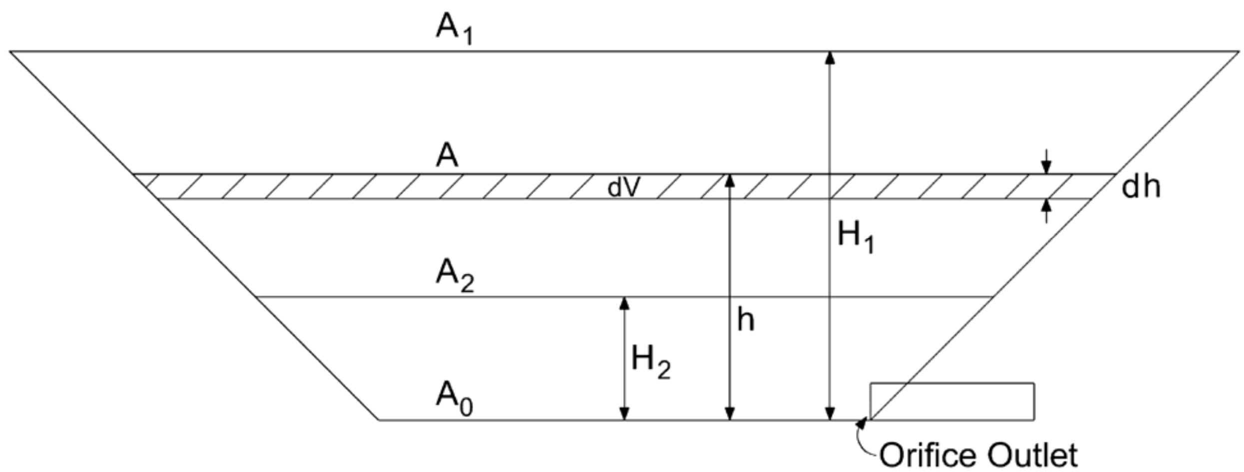
- The formula in the Rational Method, Qp = C I A, is acceptable for determining peak runoff from drainage areas of 200 acres or less.

- The "Small Watershed Method" developed by Dr. H.R. Malcolm, PE, is acceptable for most hydrologic analyses on small watersheds, based on Malcolm's procedures.

- Other hydrologic analysis methods may be allowed if the designer demonstrates that the alternatives are appropriate for the intended purpose subject to the City approval.

3.5.2 Orifice Equation

3.5.2.1 Drawdown Time Calculations for a Pond with an Orifice Outlet



In the above Figure,

A_1 = Area of pond at the beginning of drawdown
A_2 = Area of pond at the end of drawdown
A = Area of pond at time, t during drawdown
A_0 = Area of pond at the orifice outlet elevation
T = Time for water level to fall from H1 to H2
A = Reservoir Area
Cd = Orifice coefficient of discharge
a = Orifice area
g = Acceleration of gravity
H_1 = Maximum head (t=0)
H_2 = Head when t = T ($H_2 = 0$)

Where

$$A = A_0 + \frac{(A_1 - A_0)}{H_1} h$$

$$dV = dt * q = Cd * a * \sqrt{2 * g * h} * dt = -Adh$$

Where:

$dV =$ Change in reservoir volume
$q =$ Outflow rate
$Cd =$ Orifice coefficient of discharge
$a =$ Orifice area
$g =$ Acceleration of gravity
$h =$ Head acting on orifice at time (t)

$$dt = \frac{-1}{Cd * a * \sqrt{2 * g}} * A * h^{-1/2} * dh$$

$$T = \frac{-1}{Cd * a * \sqrt{2 * g}} * \int_{H1}^{H2} A * h^{-1/2} * dh$$

$$T = \frac{-1}{Cd * a * \sqrt{2 * g}} * \int_{H1}^{H2} \left[A_0 + \left(\frac{A_1 - A_0}{H_1} \right) * h \right] * h^{-1/2} dh$$

$$T = \frac{-1}{Cd * a * \sqrt{2 * g}} * \int_{H1}^{H2} \left[A_0 * h^{-1/2} + \left(\frac{A_1 - A_0}{H_1} \right) * h^{-1/2} \right] * dh$$

$$T = \frac{-1}{Cd * a * \sqrt{2 * g}} * \left[2 * A_0 * h^{1/2} + \frac{2}{3} \left(\frac{A_1 - A_0}{H_1} \right) * h^{3/2} \right]_{H_1}^{H_2}$$

$$T = \frac{-1}{Cd * a * \sqrt{2 * g}} * \left[\left(2 * A_0 * H_2^{\ 1/2} + \frac{2}{3} \left(\frac{A_1 - A_0}{H_1} \right) * H_2^{\ 3/2} \right) - \left(2 * A_0 * H_1^{\ 1/2} + \frac{2}{3} \left(\frac{A_1 - A_0}{H_1} \right) * H_1^{\ 3/2} \right) \right]$$

Equation 1

$$T = \frac{1}{Cd * a * \sqrt{2 * g}} * \left[\left(2 * A_0 * H_1^{1/2} + \frac{2}{3}\left(\frac{A_1 - A_0}{H_1}\right) * H_1^{3/2} \right) - \left(2 * A_0 * H_2^{1/2} + \frac{2}{3}\left(\frac{A_1 - A_0}{H_1}\right) * H_2^{3/2} \right) \right]$$

For the specific case where $A_2 = A_0$ and $H_2 = 0$

$$T = \frac{1}{Cd * a * \sqrt{2 * g}} * \left[\left(2 * A_0 * H_1^{1/2} + \frac{2}{3}\left(\frac{A_1 - A_0}{H_1}\right) * H_1^{3/2} \right) \right]$$

Equation 2

$$T = \frac{1}{Cd * a * \sqrt{2 * g}} * \left[\left(\frac{2}{3} A_0 + \frac{1}{3} A_1 \right) * H_1^{1/2} \right]$$

For the case where the area of the pond is nearly constant with respect to depth, Equation 1 reduces to Equation 3 below.

Equation 3

$$T = \frac{2 * A}{Cd * a * \sqrt{2 * g}} * \left[\sqrt{H_1} - \sqrt{H_2} \right]$$

Downstream conditions should be examined to determine the effective head where the orifice is submerged (that is, cases where the tail water is higher than the orifice elevation.

3.6.3 Detention Storage Estimation Methodologies:

- The Storage-Indication (Puls method) is an acceptable method for routing hydrographs through a reservoir of any size. This method is incorporated into the US Army Corps of Engineers HEC-HMS and NRCS TR-20 computer models.

- The “Chainsaw Routing” method developed by Dr. H.R. Malcom, PE, NC State University, Raleigh, NC, is acceptable for most reservoir routing analyses on small reservoirs, as deemed appropriate by the designer based on Malcom’s procedures. The procedure and an example of an application of this method are given on Chapter 3.5 of the State BMP Manual and Appendix B.

- TR-55 as shown in the Storm Sewer Design Manual (page 26) and Dr. H.R. Malcom’s “Preliminary Design” (App. B) present methods to give the designer an approximate estimate of the storage required to provide the desired detention. These methods are good for preliminary design, but are to be followed up with an acceptable reservoir routing method for final design.

- Other reservoir routing analysis methods may be allowed if the designer demonstrates that the alternatives are appropriate for the intended purpose as approved by the City.

3.7.1 Hydraulic Methodologies (Open and closed conveyance analysis):

- Where step-backwater hydraulic computations are required for open stream channels including bridges and culvert roadway crossings, the US Army Corps of Engineers HEC-2 or HEC-RAS models are preferred and recommended for most applications. Where significant closed conduits represent the stormwater conveyance system, EPA's SWMM model is recommended, if a detailed hydraulic analysis is required for development of the SWM Plan.

- For simple hydraulic analyses, where applicable, the Manning's Equation and other hydraulic relationships (e.g., Hydraulic and Energy Grade Line calculations) may be applied where appropriate assumptions for use are satisfied and the results will be conservative.

- Other hydraulic analysis methods may be allowed if the designer demonstrates that the alternatives are appropriate for the intended purpose.

4 SECTION 4: SELECTING THE RIGHT BMP

4.4 Comparison of BMP Treatment Capabilities

Table 4-1 of the State BMP Manual presents the TSS, N, and P removal efficiencies of the various BMPs discussed in the State BMP Manual and in the City's supplement. Fecal coliform reduction is currently regulated as a narrative requirement and as part of the NPDES Phase II permit. After Phase II requirements are adopted by City Ordinance any proposed high density development within North and South Buffalo Creek Watersheds must be designed to drain to a high efficiency device for Fecal Removal Ability to the maximum extent practical.

Table 4-3 Sand filter construction cost is variable depending upon the type; ranges from low to high.